COST BENEFIT ANALYSIS OF A HEALTH MANAGEMENT SYSTEM

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OVERVIEW

Born from a need to reduce the cost of maintenance in the face of increasing sophistication in aircraft and aircraft systems, the paper presents methods to assess future maintenance concepts and technologies for airliners of the next generation. The objective is the validation of innovative technologies and techniques, which provide the means to make the maintenance task more efficient and effective. The selection of the most promising ones is applied already within the early stages of the innovation process, in which the main part of the arising product life cycle costs are predefined. This technology appreciation procedure supports the early preselection of maintenance technologies of interest and the subsequent accompanying cost benefit analysis as decisive help in the process of development to the point of the product. It aims to increase the aircraft operability by increasing the operational reliability and the availability as well as by decreasing the maintenance related costs.

1. INTRODUCTION

Due to highly competitive conditions on many markets, and, particularly in the sector of the airline industry, the cost pressure increases, which also has an effect on the aircraft manufactures. On that condition, the management of innovation becomes a strategic imperative for the airline industry. Actual discussions mainly concern aeroplane characteristics such as the number of seats, range, or acquisition cost, but hardly mention the maintenance effort and/or strategies, even though the expenses of the aeroplane maintenance hold a large cost saving-potential as they have a big share in the airline's operational cost with up to 20% [1]. For years, innovative companies have been conducting research in order to identify the indicators which will enable them to estimate the success of planned product innovations in advance. Only companies who understand today the importance of innovation can ensure their future success at the market.

The introduction of future technologies into the aircraft maintenance tasks leads to new maintenance processes. The exact impact of these technologies on the aircraft life cycle cost can hardly be estimated entirely. Thus, a method which supports making decisions is mandatory. In spite of the low degree of available information on future coherences, a realistic trend has to be generated today. To encounter these problems, a cost benefit analysing tool has been developed. The CBA tool generates the outcome by comparing possible future scenarios to the current one. The scenarios are a detailed description of current and future maintenance processes (cf. FIG 1). The key for a successful implementation of cost control is to launch it as early as possible, even during the research phase.

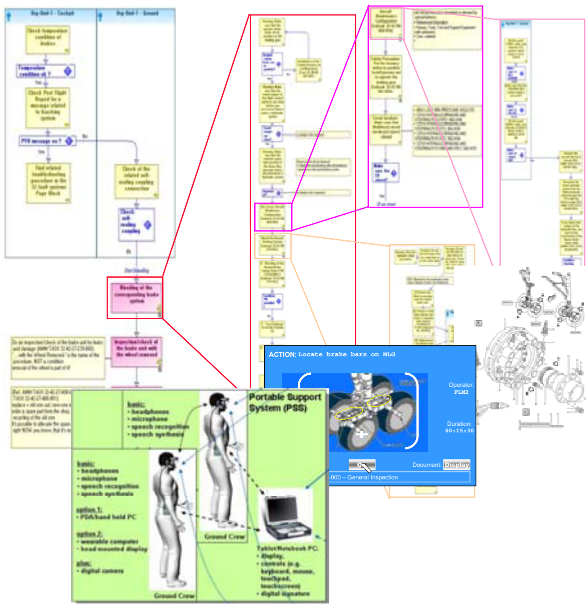

FIG 1. Scenario modelling (excerpt of 'MLG Brake Unit Replacement')

2. FUNDAMENTALS

This chapter describes the basic principles of cost assessment, and provides the basis for explaining the methods of technology assessment discussed later. It shows the link and the importance of these methods to current research in innovation management, beside its undoubtedly practical relevance.

2.1. Cost Assessment of Innovations

The described method is applied in the so called fuzzy-front-end of innovation, those early stages of the innovation process where ideas are generated and evaluated and a first concept of possible future products is developed [2].

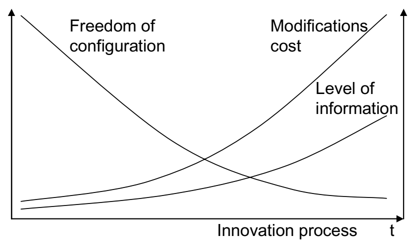

FIG 2. Influence, costs of change and information during the innovation process [3]

The importance of the early stages for the overall success of an innovation project is caused by the fact that essential characteristic features of the future product become fixed, while at the same moment the expenses for changes of the characteristics are relatively low compared to those of the later phases (cf. FIG 2). But the assessment of ideas and concepts is difficult because of the low degree of available information in this stage.

The resources allocation has an outstanding role in the innovation process. The image of an innovation funnel [4] describes the fact that although lots of ideas for new products and processes are generated, only a few of them reach the development stage and even less are introduced to the market. Therefore, for an efficient allocation of resources, the management is forced to evaluate ideas as early as possible. A selection of the most promising projects has to be made early, so that later activities have to focus their effort on the selected projects.

Beside the use of an innovation, its costs have to be considered. Relevant are the total costs for the customer. These exceed the costs for the acquisition of a technology, as the operation of the technology results in additional costs. To calculate the cost/benefit ratio of an innovative technology, the total costs over its whole lifecycle have to be assessed. But the visibility of these additional costs is limited. Blanchard describes this circumstance with an analogy, an iceberg of which the visible top represents the acquisition cost [5]. The much bigger part of the iceberg is not visible under the water surface; it represents the costs for maintenance, distribution, training, etc. To evaluate new technologies during the innovation process the impact of all of these costs have to be considered. But previous research has not yet delivered methods which support the assessment of the costs of an innovation. Thus, new methods for early assessment of technology innovations regarding benefit and total lifecycle costs (LCCs) are to develop. The paper will help to fill this methodical gap by modelling and analysing maintenance-related costs and benefits of future aeronautical technologies in advance to increase the success of future innovations.

2.2. Aviation Maintenance

The major task of aircraft maintenance is to ensure that, the aircraft fleet is available in due time and the aircrafts airworthiness is guaranteed. Further, the passenger's as well as the personnel's security should be guaranteed at any time. The objectives of aircraft maintenance can be divided into three major tasks, which are reliability maximisation, maintenance costs minimisation and down-time costs minimisation.

The maximisation of the aircraft leads to an increased use of the plane and therefore to an increase of benefits. The aircraft availability is defined as the ratio of deviation from the flight schedule compared to the sum of the departures. The overall costs for maintaining an airplane exceed the purchase value after a few years. Therefore, reducing the maintenance costs to a minimum level is the goal to be achieved [6]. The down-time related interruptions of the time schedule have an impact on the connecting flights. Frequent delays and cancellations are likely to damage the image of the airline and cause additional costs. Therefore, stagnation of the air traffic has to be avoided. The main duties of aircraft maintenance are Maintenance, Overhaul, and Inspection.

Maintenance comprises methods to keep the condition of the aircraft in order to avoid cancellations. Overhaul includes the re-establishing of the airplane's target state after breakdowns and malfunctions. Inspections are activities which include the examination of the components of an aircraft. In this process, the actual state of the airplane is identified and the necessary maintenance activities are defined [7]. Maintenance tasks are defined in accordance to the system components of an aircraft. The aircraft can be divided in the following main chapters:

- Structure
- Engine
- Hydraulics
- Instruments
- Electrical systems
- Avionics
- Cabin

Furthermore, maintenance actions can be categorized as scheduled or unscheduled. Depending on the particular component of the aircraft, a maintenance schedule which defines at which time the component has to be checked or exchanged is set. Unscheduled events are malfunctions which are unpredictable (FIG 3) [6].

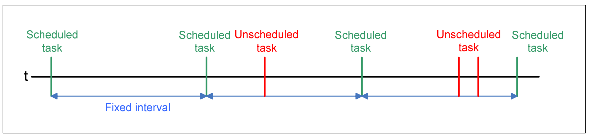

FIG 3. Maintenance interval

The intervals between the singular maintenance activities are expressed in several units, i.e. flight hours (FH), days (DY), months (MO), years (YR) or the number of flight cycles (FC) [8].

Over the years, a standardised method for maintaining aircrafts has been developed. In 1980, the Maintenance Steering Group (MSG) elaborated a method called MSG-3. This method sets up guidelines for aircraft maintenance which describe the procedure and scheduling of maintenance activities. In the following, this method is explained. The resulting Reliability Centred Maintenance (RCM) differentiates between aircraft maintenance activities being near or distant to flight operations. The difference depends on the frequency and complexity of activities. Frequently occurring activities are integrated into the flight schedule. The more complex and infrequent activities take place in special hangars. For optimizing the integration of the activities into the flight schedule, it is important to plan in advance where the more complex maintenance activities will be executed. [9].

An example for activities being near to flight operation is Line Maintenance (LM). This includes regular maintenance, pre- and post flight repair and activities at night. Before taking off, the Trip Check has to be proceeded. The daily proceeded R-Check and the weekly proceeded S-Check happen additionally. The activities reserved to flight operations are called Base Maintenance and are divided into A-, B-, C- and D-Checks. A-, B- and C-Checks are part of the Periodic Maintenance. These events include the following activities:

- Scheduled maintenance
- Exchange of components
- Cleaning
- Modifications

On the D-Check, which is the most complex and time-consuming check, the entire structure of the airplane is inspected to detect possible damages. This implies the disassembling of large parts of the airplane's interior, which enables the personnel to inspect the inner structure of an aircraft. The D-Check includes the following activities:

- Scheduled inspection of the structural components
- Testing of the component's functioning and exchange when defects occur
- Scheduled exchange of components
- General overhaul of the entire cabin

For analysing the major tasks of maintenance, this inspection system is a meaningful basis. For the approval of an aircraft, it is necessary to generate a Maintenance Review Board (MRB), which is part of the mandatory documents required by the concerned authorities. The MRB describes the mandatory approach for aircraft maintenance [6].

2.3. Health Management Technologies

Today, Health Management Technologies (HMT) exists for different ranges of application. The structure and the engines of aircrafts are an important application area for HMT. This technology collects data from aircraft components and systems. For this purpose, sensors have to be placed at the components. The installing of this technology assures a continuous recording of data. At first, the component's behaviour is recorded under nominal conditions. The derived pattern from this recording serves as the reference value, which can be compared to irregularities that might occur later on. Consequently, sources of occurring irregularities and differences can be identified.

HMT are composed of sensors and specific software. The sensors record data like oscillation, temperature, rotational speed, and pressure. The software analyzes the data and generates significant information on the particular component. Through the use of HMT, three major tasks can be realised:

- Diagnosis
- Troubleshooting
- Prognosis

The diagnosis comprises the continuous acquisition of data. Based on the recorded data, troubleshooting is possible. On the basis of the recognised fault, the maintenance personnel can classify its attributes. By analysing the data of a component over a period of time, the personnel are able to forecast the lifetime expectancy [10]. Depending on the material type, crack propagation, fatigue and wear cause different damage levels. The trend of component lifetime expectancy measured according to changing data is a useful feature of HMT. The possible areas of applying HMT are multifaceted, which will be exemplarily demonstrated in the following.

Structural Health Monitoring

Modern aircraft structures are made up of metal or composites. Damages caused by different force effects and environmental conditions during the flight as well as on the ground are inevitable. Interacting strains cause the overstress of the material, this then leads to cracking (fine cracks) in the structure [11]. Avoiding a high crack propagation rate is important for the security and functionality of the structural components. To be able to react, the structure has to be inspected regularly. Manual inspection is a time and personnel-consuming method. Besides, the overlooking of cracks has occurred frequently, particularly when the crack's length ranged from 50 to 150 mm [9]. Therefore, the Structural Health Monitoring has been developed aiming to optimise the outcome of the inspection. A continuous diagnosis is possible by using built-in sensors. The recorded data is stored and evaluated with the Data Acquisition Unit.

Based on the recording of sound waves inside the material, the diagnosis tool analyses the sound spectrum. A crack causes sound waves results of stressing the damaged part of the structure. The spectrum differs from engine and air stream caused vibrations. Today, several methods exist, but they all work with the same principle. As an example, the passive acoustic emission method is illustrated in the following. Passive means that only occurring sound waves are recorded. Active systems on the other hand stimulate the structure with sensor produced vibrations. A possible arrangement of sensors is shown in FIG 4.

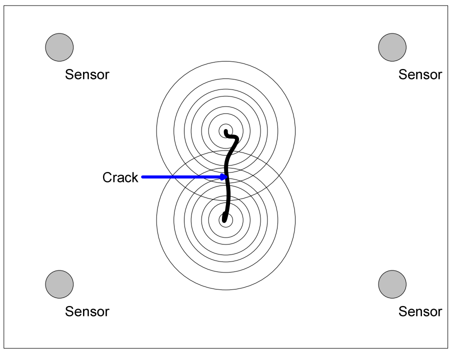

FIG 4. Acoustic emission

The sensors record the sound waves caused by the crack. The appurtenant software differentiates the regular sound spectrum from crack caused vibrations. Depending on the position in the aircraft, the sensors are placed in different distances to each other. Hence, the difference between a sensor and a crack can be calculated. For detecting the position of a crack, the time between producing vibrations and their recognition is measured. By using a lot of different positioned sensors, the location of the crack can be defined exactly [11].

Engine Health Monitoring

Engines are complex components of an aircraft and are composed of highly stressed elements. Avoiding overstress and damage requires the continuous monitoring of the operating characteristic. Engine Health Monitoring (EHM) systems are developed to serve this purpose. The material is stressed by high temperature and high rotational frequency combined with high pressure. This inevitably leads to abrasion. Resulting kinds of damage are fatigue, deformation and wear. In addition to strains occurring in regular use, there are other elements which have an impact on the durability of an engine. Mistakes while producing or mounting parts of the engine result in malfunction. Exceeding the construction related maximum power level reduces lifetime expectancy [12]. Reasons for using an EHM are the increase of operational safety, the increase of working life, and the collection of data for new generations of construction.

Monitoring operational characteristic of an engine implies several different positioned sensors. The recorded data includes the following values [13]:

- Rotating frequency
- Compressing pressure
- Functionality
- Temperature
- Humidity
- Electromagnetic compatibility
- Vibrations

An EHM system is composed of three separate positioned units. The engine data are recorded by the in-flight system. Broadcasting from aircraft to ground station is realized by the data-transfer system. The ground based system receives the data stream. While developing EHM, several methods were constructed and inserted. Therefore, recording and evaluating on board is possible. Other systems only record data. The evaluation takes place on the ground. To generate meaningful outcome, the data streams must be prepared to recognize distinctive features. For example, crack propagation or increasing mechanical wear might cause unusual rise in temperature and concurrent vibrations [10].

To be able to evaluate data it is necessary to record the operational characteristics over a period of time. Comparing operational characteristics makes pointing out of occurring unusual values possible. Termination for examination of items is no longer depending on fixed intervals. Inspection can be planned, when EHM signalizes unusual behaviour of the engine components. The current operation characteristics can be recalled at any time.

Actuator monitoring

An aircraft consists of different kinds of actuators executing different functions. The monitoring of actuators is a mean to analyse the accuracy and steadiness of its operational behaviour. In the literature, an actuator is defined as an element controlled electrically whose outputs are mechanical movement or power (cf. FIG 5). In most of the cases, the actuator runs a mechanical movement [14].

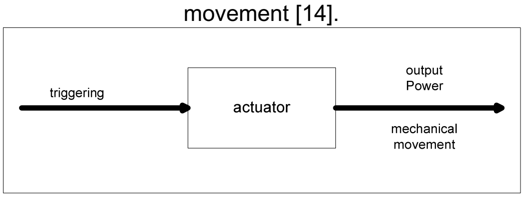

FIG 5. Actuator work principle [14]

Current tests verify functionality only. If a failure occurs, the test equipment records this. An identification of the fault is not possible yet. The actuator is sent to the manufacturer or gets maintained. This meets the safety requirements, but a troubleshooting feature affords more options. If troubleshooting is possible, it is only necessary to demount an actuator when a failure exists. This must be repaired off-aircraft. A comprehensive diagnosis is the basis for better planning of maintenance periods. Increasing security is an additional advantage [15].

To realise a more specific diagnosis, the recorded data must be evaluated with special software. Using a stable trouble detection algorithm enables to make an exact diagnosis possible. This algorithm transfers the recorded data into a term. This term allows generating a forecast for lifetime expectancy. Locating the failure is an important additional feature [16].

Brake monitoring

Brakes are security-relevant components. If the brake pads are worn, the functioning of the brakes can not be guaranteed. For this reason, the brake pad's reserve capacity has to be checked frequently to ensure that worn brake pads are exchanged in time. Currently, brakes are inspected manually. Brake wear is examined by measuring the length of the brake wear pin (cf. FIG 6). These pins are made of metal and serve as an indicator which shows when the pads have to be exchanged: The more the brake pads are worn the shorter the pin gets [17].

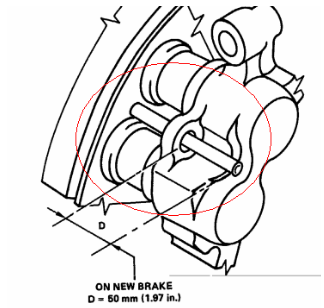

FIG 6. Brake wear pin [8]

The diagnosis of wear by using sensors is not yet applied in aircraft maintenance [8]. However, the automotive industry uses automatic wear measuring. The implemented system detects wear with a special kind of sensor. A compressing spring, placed in a guide bushing, pushes a rod on the brake pad. In the course of the wearing process, the rod changes its position. The extent of this movement is measured by the sensor, and the flashing of a warning light indicates that the brake pads have to be exchanged. Periodic maintenance is no longer necessary [18].

Pump monitoring

Like all equipment in use, components of pumps wear, too. In addition to wear caused by fretting, cavitation occurs. In order to locate, and differentiate between, the various reasons leading to malfunctions, a profile of each particular pump's operating behaviour has to be generated. On the base of comparing characteristics, failures can be detected and located. Causally determined data generates a decision tree. According to the pump, sequences of up to 1000 if-then-queries are the result. This procedure permits an exact failure diagnosis and is defined as automatic learning. A few sensors are sufficient to monitor a multitude of possible failures, which makes this diagnosis very cost-efficient. A vibration-energy measuring sensor is a usual used element. The combination of sensor and catalogue allows collecting a lot of different attributes [19]. Using the example of an axial submersible motor-driven pump, Huhn defines the particular steps of diagnosing the actual condition as follows: Monitoring the actual condition, Generating attributes, and Categorisation of actual condition. The finding of the actual condition is realized by using two accelerometers. In this case, one sensor is placed at the impeller-cage. The second one is mounted at the spindle-cage. To generate attributes it is necessary to know the rounding frequency. Applying the method which is explained in literature, calculating of meaningful attributes is realized. This requires a high capacity computer. The categorization of the actual condition is executed by a mathematical approach. Therefore the condition of a mounted impeller can be detected [20]. Removing of the impeller for inspection is not necessary anymore.

Bearing vibration diagnosis

Manual inspections of bearings cause idleness and mount the effort. An automatically diagnosis of operating characteristic affords continuous detecting and recognizing of upcoming malfunction. Bearings are constructed for reducing friction on rotating components. Recognising an occurring damage is only shortly before malfunction possible. Preventive maintenance is time consuming and often without success. To save time, automatic diagnosis of bearings was developed. The applied method is diagnosis by monitoring the vibration spectra. Depending on vibration intensity, evaluating the condition can be progressed [21]. Three possibilities are given for occurring bearing damage:

- Damage of the roller race
- Damage of the rolling elements
- Damage of the bearing cage

Generally, the changing of vibration spectra is an indicator for changing condition of equipment. For bearings this is a significant indicator. Vibration monitoring means to record and identify changing operational characteristics. This is an important basic to monitor rounding components. There are different sensors for monitoring: Accelerometer, Sensor for measuring unbalance, Vibration detection. The sensors are placed next to the bearing case or on the rounding elements. The first step is to record the measured values. The following step includes splitting up the frequency spectra into separate frequencies. The calculation of the fragmentation is realized by applying the Fourier analysis. The Fourier analysis includes the fragmentation of a signal into a sum of harmonic functions [22]. The outcome value is generated as a Fourier progression. The subsequent presentation is realized by special software. To calculate manually is impossible, because of the immense volume of data stream. To allocate one frequency to an element is the advantage of this approach [23]. This enables allocating vibrations to separate components.

Humane Machine Interface Health Management Technology

For carrying out the aircraft maintenance activities, the maintenance personnel need a manual. Each particular procedure is exactly defined. The digital manuals are stored on personal computers in the maintenance areas. Before starting maintenance activities, the work instructions have to be printed. The maintenance personnel have to execute the procedure strictly according to the manual. Thus, the working process is step by step Simultaneous reading and mounting complicates the maintenance activities significantly.

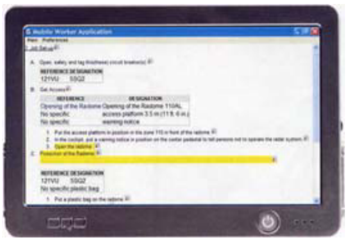

FIG 7. PDA [24]

In order to generate a better workflow without interruptions, existing technologies have been combined. The result provides the maintenance personnel with an interactive manual. The additional feature is downloading of different kinds of information and data. The technology enables communication with specialists without leaving the working environment [24]. FIG 7 shows a transportable PDA with digital view. This construction is like a minimized personal computer with fewer features. In addition to the PDA, special glasses were developed. The picture is projected onto the glasses (cf. FIG 8).

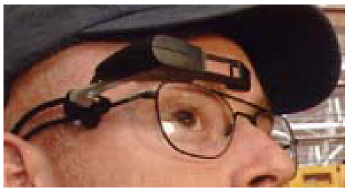

FIG 8. Multi-function-glasses [24]

The advantage is that the mechanics can use both hands for working. Relevant information is always visible, but can be suppressed if necessary. For the useful menu navigation, three various methods exist [24]. One method is the gesture association. Static gestures navigate from one application to the next. To adjust the calibration, a camera records the gesture. This enables the computer to relate gestures to commands.

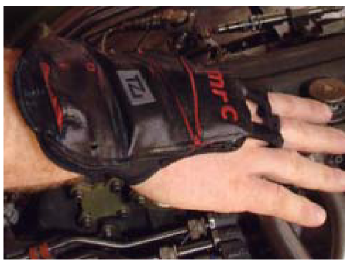

FIG 9. Special gloves [24]

In addition, navigation can be executed by using a specially prepared glove (FIG 9). To detect moving from the left to the right and backwards, accelerometers are inserted. Depending on the intensity of the movement, the position of the cursor is changing. Two pushbuttons are placed for input acknowledgement or additive features.

The third option is voice-control. Comparing voice inputs with stored samples by the computer allows menu navigation. The worn Head set can be used for communication between mechanics. Storing of additional comments or information per micro is an interesting option. The computer converts the voice into words. The used PDA gets the required data per WLAN or downloaded from the workstation [24]. Complicated searching for information and annoyed turning the pages is a thing of the past.

3. ASSESSMENT OF HEALTH MANAGMENT CONCEPTS

This chapter describes how health management concepts can be evaluated. The procedure of a cost benefit analysis is demonstrated. It shall become clear how the comparing of scenarios generates the basis for evaluation. In the following, the required structure for calculating maintenance costs is explained. The combination of scenarios, maintenance costs and the cost benefit analysis led to the development of the CBA tool, which is presented afterwards.

3.1. Approach of the Cost Benefit Analysis

Within this process, the methodology on how to approach the cost benefit analysis is developed as a means for decision support. For a capital investment decision the classical cost benefit analysis (CBA) compares additional costs of an investment with its expanded benefit. To measure the cost and benefit of a new technology it is useful to compare one future use case against a reference, the current use case. FIG 10 drafts the process steps or tasks between a conjoint initial and final state of the current scenario and the future one. To ensure that the future scenario is more profitable than the current one, the applied resources (e.g. man-hours, material, etc.), process steps or the occurrence should be less than in the current scenario.

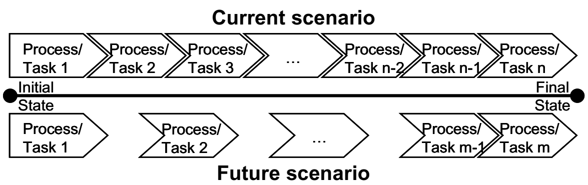

FIG 10. Comparison of future against current scenario (schematised)

By implementing innovative technologies, the current maintenance concept changes to the future one. Thus, the CBA tool does not value future technologies directly; it assesses them indirectly by evaluation of different maintenance scenarios in which the future technologies are applied. A scenario includes all (maintenance) tasks from an initial unknown failure status to a final known repair status.

The different maintenance scenarios, which should be assessed, are the basis for the CBA model. These can be divided a first instance into aircraft in-service mission scenarios, scheduled maintenance on aircraft scenarios and shop maintenance scenarios. Each of these scenarios consists of different use cases in which the future technology can be applied. To measure its impact on the future use case, both the current and the future parameters for each process step are mandatory. These are stored in a database and serve as input for the CBA tool (cf. FIG 11). By using the different models described in the following chapter, the designated output is generated.

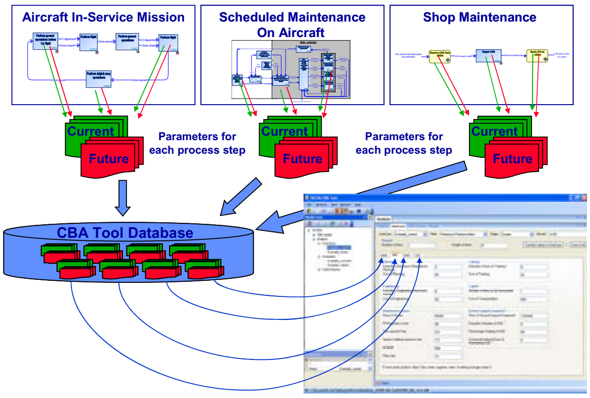

FIG 11. Assessing of maintenance scenarios

The overall process of cost benefit analysis consists of the CBA model and the calculating tool using input from the use case descriptions as well as the reference aircraft and airline profiles (cf. FIG 12).

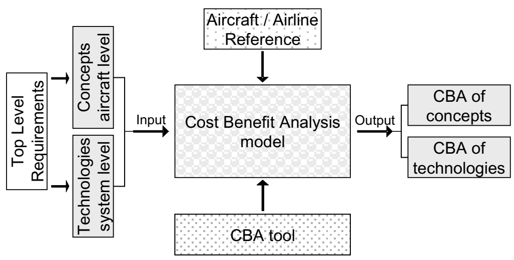

FIG 12. Input parameter

3.2. Maintenance related Cost Model

The study focuses on the assessment of future maintenance technologies within use cases. Therefore, it evaluates those cost elements of the operator's "cost of ownership", which are affected by maintenance actions, especially when maintenance actions change. These cost elements are defined as maintenance-related cost in the following.
Airline total operating costs are divided into Direct Operating Costs (DOC) and Indirect Operating Costs (IOC). DOC are cost that can be allocated to the aircraft whereas IOC are caused more generally by running the airlines business.

Direct operating costs are a result of flight operations such as fuel, crew, maintenance, insurance, and depreciation costs. Indirect Operating Costs are those costs not considered to be DOC but contributing to the overall operating costs of the aircraft, including such costs as general administration and finance, passenger service, marketing, and aircraft and passenger handling services [25]. The IOC cannot be accurately approximated because they vary widely with each purchaser of the aircraft.

Maintenance Costs as part of the DOC are made up by Indirect Maintenance Costs (IMC, also known as burden maintenance) and Direct Maintenance Costs (DMC). Indirect maintenance costs are the maintenance labour and material costs not considered to be DMC but which contribute to the overall maintenance program costs through overhead operation, administration, engineering, record keeping, supervision, tooling, test equipment, facilities, etc. Direct maintenance costs are the maintenance labour and material costs directly expended in performing maintenance on an item or aircraft [25]. To cover the different origins DMC is split into two categories: On-Aircraft and Off-Aircraft DMC. So the origin of DMC is the labour and material costs caused by aircraft systems, engines and structures on a scheduled and unscheduled basis to keep the aircraft in an operational state.

Due to the complexity of the cost of ownership, the CBA does not include the whole cost of ownership elements but considers the “Maintenance-related Cost” (MrC) elements only in order to evaluate the global impact of the proposed use cases on aircraft maintenance. The scope of the CBA is to focus on those costs elements, which can change as a result of modified maintenance actions due to new technologies.

In order to get operational concepts-driven parameters into the model, reference aircraft and airline profiles are defined which will support and permit the conduct of the cost benefit analysis. Therefore, a representative set of reference aircraft and airline profiles for short and long range aircraft and various types of airlines/operators (e.g. premium, low-budget, charter, cargo etc.) are identified, captured and modelled, e.g.

- Aircraft data for Short & Long Range (A320, 737, A340, 747, …)
- Fleet data (MMEL, Delay duration, # of Flight sectors, …)
- Maintenance data (Line/Base/Shop Labour rate, Unit repair TAT, …)
- Economic data (Depreciation period, Tax rate, Insurance, IP-Level, …)
- Equipment cost factors (Cost of Spare, MTBF, MTBUR, NFF, …)
- No. seats, MTOW, range, annual utilisation, sector length, …

Besides the aviation life cycle cost breakdown and the airline and aircraft profiles, other components are to be considered to enable a comparative cost benefit analysis (cf. FIG 13). According to ATA the aircraft system is broken down into different chapters, e.g. Landing gear, air-condition or electrical power. Basis for the analysis of is the maintenance activity. One can distinguish between the maintenance program planned for the whole life cycle of the aircraft and between the specific maintenance event. The events are a suite of different maintenance processes and steps. The technologies for a health managed aircraft being introduced can have an influence on the aircraft system breakdown, the maintenance activities and on the LCC.

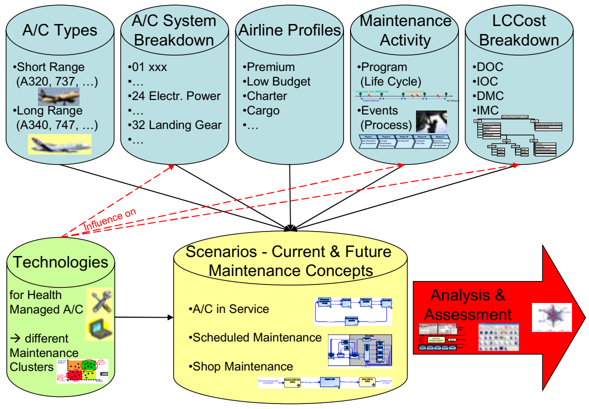

FIG 13. Influencing factors on maintenance concepts

All these factors are modelling/describing the scenarios which have to be evaluated. Having different parameters for current and future factors, there is the possibility to analyse and assess the effect and the consequence of an innovative technology being used for aircraft maintenance. The final outcome is considered of high quality and accuracy (depending on the sources used)

3.3. CBA Tool

This chapter shows how the cost benefit tool works. The requirements to the analysis tool are defined introductorily. Further, the structure and the features are explained.

3.3.1. Requirements

The tool shall support the cost benefit analysis model. The requirements determine the demands placed on the CBA tool. They form the basis for the CBA tool selection process. For the definition of the tool requirements following topics are investigated:

- the requirements capturing from different partners and their activities related to the cost benefit analysis
- the definition of global objectives (cost reduction, usability, reliability improvement etc.) of the cost benefit analysis derived from the global project goals and current and future maintenance scenarios
- the investigation of existing cost benefit models, tools and approaches

The investigation results in a list of requirements, which can be divided as follows:

- Top level requirements which are linked to global project objective, process, etc.
  - Support of the entire CBA process
  - Appropriateness for the needed tasks
  - The tool shall contain the models and algorithms to support the concept and methodology for assessment
- Functional requirements which are linked to the main CBA functions
  - Data import possibilities of different maintenance

concepts, aircraft, airline, economic parameters, etc.
- Calculation of maintenance related cost by using sensitivity analysis, statistical and probabilistic methods as well as mathematical algorithms
- Saving of analysis results
- Capability to export the results of the CBA analysis into different formats

- Interface requirements
- Technical requirements
- Costs requirements

3.3.2. Design

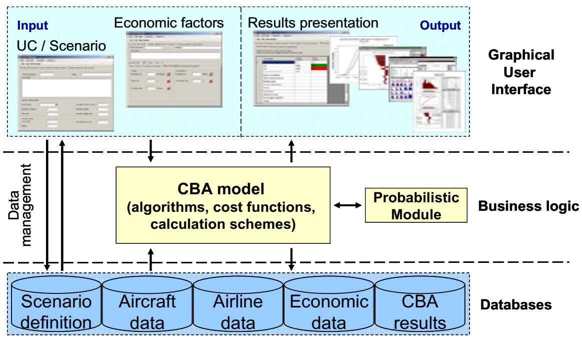

FIG 14. CBA tool prototype architecture

FIG 14 illustrates the technical design of the CBA tool. The multilayer architecture is realised through the data storage, the business logic for the calculations and the user interface for modelling, data input and results presentation. Input model is the scenario data as well as aircraft, airline, and economic data stored in a database. Further, the model is linked to a probabilistic module. The uncertainties and distributions are modelled with a software system which incorporates methods for analysing risk intensive situations, @Risk. The input and output is processed via a GUI and can be analysed upon different aims. Some GUI screenshots of the beta version are given in FIG 15.

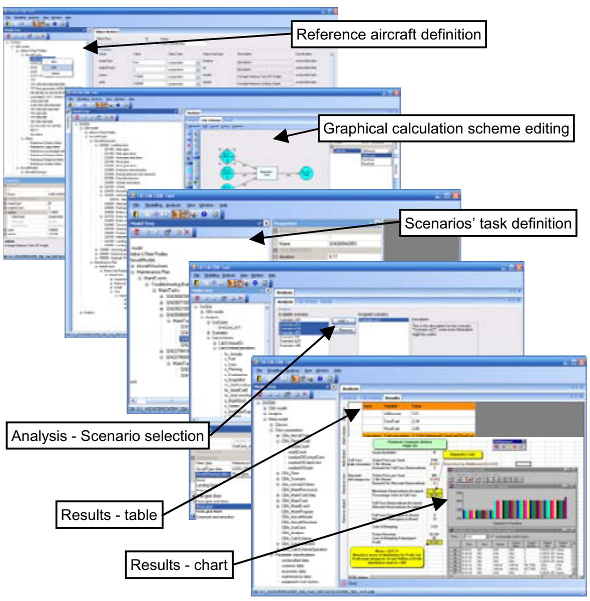

FIG 15. CBA Tool GUIs

Calculation with uncertain data is possible by using distributions instead of scalars. There is a probabilistic module to deal with uncertainties, i.e. the tool gives the possibility to translate uncertain information into distribution, e.g. triangular estimates, to process distributions and to simply choose the corresponding distribution. Furthermore, a Monte Carlo simulation of the cost can be applied to have a more exact view of the real cost. Additionally, the tool is featured with for example:

- Graphical editing of calculation schemes, i.e. dynamical modification of the calculation rules for the single cost chapters
- Different access levels based on user rights
- Explicit display of the meta-model. Editing possible for administrative users
- Trend estimation (→;↑;↓) processing capability is envisaged, if even estimated data unavailable

4. APPLICATION

In the following, the evaluation of technology related impact is shown. One of the presented technologies generates a future maintenance scenario. This technology is the process supporting combination, based on PDA and multifunction-glasses.

4.1. Example of a Health Management approach

Before explaining the modified scenario, the current maintenance process will be demonstrated using an example of aircraft maintenance.

Current process

The process starts by an illuminating warning lamp. The control display of the Electronic Centralized Monitoring indicates an overheated brake related to the right main gear. The scheduled maintenance action has been performed recently (cf. FIG 16).

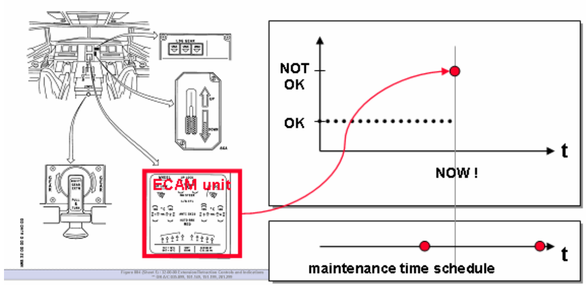

FIG 16. Start event process

In order to identify the source which has caused the increase in temperature, a troubleshooting is executed. Troubleshooting is a clearly defined process based on excludability. A questionnaire guides through the maintenance process. This results in detecting the failure. The maintenance instructions are defined by the Aircraft Maintenance Manual (AMM) and the Trouble Shooting Manual (TSM). Depending on the kind of warning notice, the AMM/TSM points out where to start troubleshooting. Before starting the work, the manuals have to be printed. Some parts of the maintenance activity are shown exemplarily in FIG 17. In order to locate the failure, singular states are checked in every step of troubleshooting. Guided in this way, the workflow stops when the failure is identified. In the example, the brake has to be replaced. After demounting, a damage at the drive blocks is detected. The mechanic has to hold the paper based manual in his hands while he is working. This is necessary to follow the steps and get information about the process. Permanent browsing through the manual pages is inevitable to follow the working steps.

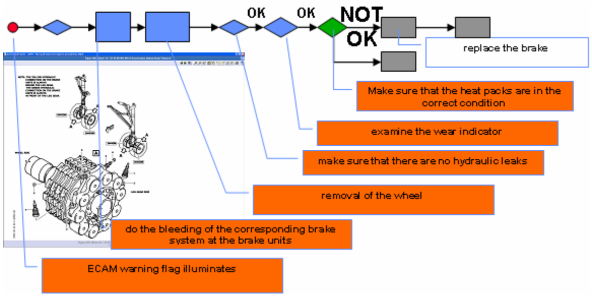

FIG 17. Process steps

Future process

In the future process, the same warning light illuminates. That causes the same troubleshooting process. When using a personal digital assistant (PDA) as a data storage, printing of manuals is not necessary anymore. The required information is copied onto the portable PDA directly. Following the approach, the troubleshooting is executed. The Mechanic is able to add comments or get information for every step. Animated visualisations support the mounting. The components are shown in mounting sequence. In addition, a general view of the components is also possible. Equipped with a head set, the mechanic is able to communicate with other persons.

4.2. Assessment

An EADS based survey concluded that 50% of working time in aircraft maintenance is spent on the search and exchange of information. For 85% of his/her activities, the mechanic needs both hands [24]. Optimising information flow will decrease time consumption. The implementation of digital media offers several advantages compared to the current approach. With free hands, the mechanic is able to work in an unrestricted manner. Information is available at any time. Performing maintenance tasks is eased by viewing digital mounting sequences. This speeds time consuming tasks.

In TAB 1 the benefits of working more effectively are exemplary depicted. These values are based on estimates. The process steps comply with the real process. The comparison of current with future scenarios is the main feature of the CBA tool. This allows the comparison of costs related to the current process and variances. To realise a calculation of maintenance-related costs, all parameters are linked into formulas.

Maintask	Subtask1	Time (HRs) before	Time (HRs) after
32-42-00-870-052 **Bleed the Normal Braking System**		0,18	0,14
32-42-00-710-056-A: **Test**		0,28	0,2
32-42-00-210-057 check level of green hydraulic system (Ref. AMM TASK 12-12-29-611-001)		0,05	0,03
32-42-00-860-053 **Aircraft Maintenance Configuration**			
	Depressurize the Green and Yellow hydraulic system (Ref. AMM TASK 29-23-00-864-001)	0,05	0,03
	De-energize the aircraft electrical circuits (Ref. AMM TASK 24-41-00-862-002)	0,06	0,03
	32-42-00-942-053 Removal of Equipment	0,17	0,1
	do an inspection/check of the brake unit for leaks and damage. AMM TASK 32-42-27-210-006	0,17	0,11
32-42-27-941-064 **Safety Precautions**		0,25	0,2
32-42-27-860-063 **Aircraft Maintenance Configuration**			
	Remove the wheel of the brake that you must examine (Ref. AMM TASK 32-41-11-000-006)	0,22	0,18
	32-41-11-210-064 Wheel Assembly Check (to be accomplished prior to wheel removal) Check wheel assembly for missing, broken or loose tie-bolts	0,08	0,05
	total time:	**1,51**	**1,07**

TAB 1. Time benefits in future process

An exemplary calculation is shown in the following. Relevant cost units are listed as an extract. The approach of the tool is shown using on-aircraft unscheduled costs for DMC and training costs for IMC. The training costs are a result of training the personnel in using the new technology. The adopted values for the analysed use case are highlighted in TAB 2.

DMC/ On aircraft unscheduled maintenance			
	before	after	
Number of Items	1	1	
Manhours	1,51	1,07	Hrs
Labour line rate	25	25	$/h
Labour efficiency	65	95	%
Material Cost	35.000	35.000	$
Lifetime aircraft	25	25	yr
Annual utilization	4000	4000	FH/yr
MTBUR	1250	1250	FH/yr

FH = flight hours — user input
yr = year — tool input

TAB 2. DMC Values

To generate meaningful results, the resulting costs have to be compared. I.e., the costs from the current and the future scenario have to be calculated and evaluated. The calculation of on-aircraft unscheduled costs with the CBA tool is based on the following formula (1):

(1)
$$on\,aircraft\,unscheduled\,costs = \left(Number\,of\,Items * \left(\left(Manhours * \left(100 * \frac{Labour\,line\,rate}{Labour\,efficiency} \right) + Material\,cost \right) * Lifetime * \frac{Annual\,utilization}{MTBUR} \right) \right)$$

The results are listed in TAB 3. A reduction of effort leads to increasing costs.

DMC/OAUM	Costs p.a.	Costs p. lifetime
before	$26.821,30	$670.532,50
after	$26.650,40	$666.260,00
savings	$170,90	$4.272,50

TAB 3. DMC costs

For a complementary example, the training costs are calculated in the following (cf. TAB 4).

IMC/ Training			
	before	after	
Extra hours of training	0	10	h
Training costs	62	62	$/h

user input
tool input

TAB 4. Training values

The training costs of the new technology are calculated by the following formula (2):

(2) $$Total\ training\ costs = Extra\ hours\ of\ training * Training\ costs$$

The resulting costs for training are shown in TAB 5.

IMC/training	Costs p.a.	Costs p. lifetime
before	$0,00	$0,00
after	$620,00	$620,00
savings	-$620,00	-$620,00

TAB 5. Training costs

The expenditure per mechanic is a one-time fee. Instructed once, the technology can be used without further training sessions. Evaluating both cost units shows that savings can be generated. Depending on the fleet size, the benefit accumulates. Comparing the investment for the technology with the generated benefits supports the decision to use the introduced technology.

4.3. Results

Using the CBA tool provides a lot of additional features for calculating maintenance-related costs. The complex structure of maintenance costs is integrated into the cost calculation by the CBA tool. The analysis depicted above makes up only a small part of the entire evaluation. All cost units mentioned in chapter 3.2 are integrated in the tool. Getting significant results is realised by assessing all maintenance-related costs. Comparing several scenarios is a good basis to evaluate changes within the process. Benefits may be assessed before the development of the new technology. To optimize the CBA tool, the experience with use case modelling will be considered. The tool will be upgraded with an additional module. This module processes qualitative input data and makes meaningful trend estimates possible. Once the tool is designed in a more complete manner, it will be a suitable solution to evaluate changes and related costs.

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