Development of an End to End Maintenance Evaluation Strategy for new Technologies in the Context of IVHM

Hendrik Meyer
Deutsches Zentrum für Luft- und Raumfahrt
Researcher
Blohmstr. 20, 21079 Hamburg, Germany
hendrik.meyer@dlr.de

Nicolas Bontikous
M2P Consulting
Consultant
Bockenheimer Landstraße 94-96, 60323 Frankfurt/Main, Germany

Alexander Plagemann
Airbus
CS2 ADVANCE Project Coordinator
Airbus-Allee 1, 28199 Bremen, Germany

ABSTRACT

Abstract: In the Clean Sky II Platform 3 Large Passenger Aircraft (LPA) the work package 3.6 (WP3.6) ”Maintenance” new technologies are developed for an integrated End to End (E2E) Maintenance Service Architecture. The technologies that will be developed are based on Integrated Vehicle Health Management Technologies supported by maintenance execution enhancement solutions. Inside WP3.6 three different projects are placed under the head of a leading partner consortium ADVANCE. The three Projects which are included in the WP3.6 are DEMETER, PACMAN and AIRMES. To evaluate the overall impact of the developed technologies, an E2E Evaluation Strategy for all technologies across the different projects is needed. The technologies in the different projects reach from structural health management, system health management, data analytics over virtual and augmented reality to mobile applications. Overall more than 20 improvements are identified that will be verified and validated through different scenarios, use cases and prototype demonstrations. To identify the global impact of the combination of these technologies on airline as well as European level an Evaluation strategy needs to be developed under the constraints of several partners in different projects and the influence of the scenarios and use cases. The paper describes the E2E Evaluation Strategy and shows the integration of different technologies and partner inputs. These include the impact identification process, the MRO (Maintenance, Repair and Overhaul) value chain analysis, the simulation on airline level and the global value chain impact. Also the participating process, the risk handling and the detailed processes for the different parts of the E2E Evaluation approach will be shown.

KEYWORDS: *Evaluation, Technology, Integrated Vehicle Health Management, E2E, IVHM*

NOMENCLATURE

IVHM - “Integrated Vehicle Health Management (IVHM) or Integrated System Health Management (ISHM) is the unified capability of systems to assess the current or future state of the member system health and integrate that picture of system health within a framework of available resources and operational demand.” [1]

Stakeholder - The Stakeholder are according the DLR IVHM Stakeholder Model [1] defined. One party can reflect several stakeholders. As an example the airline can be the owner, operator and fleet manager at once. Based on [2], the main stakeholders of IVHM could be categorized from requirements perspective in the following manner:

- Owner (e.g. airline, lease company)

- Maintenance personnel and management (e.g. airline, MRO personnel)
- Original Equipment Manufacturer (OEM, e.g. Internal integrated engineering teams developing the product)
- Health Management (HM) system integrator (e.g. third party IVHM provider)
- Operator (e.g. airline)
- Fleet manager (e.g. mission commander)
- Regulatory authorities (e.g. airworthiness, certification)
- General public (e.g. employees)

It is necessary to mention that there are many other stakeholders with lower impact as shown in Figure 1:

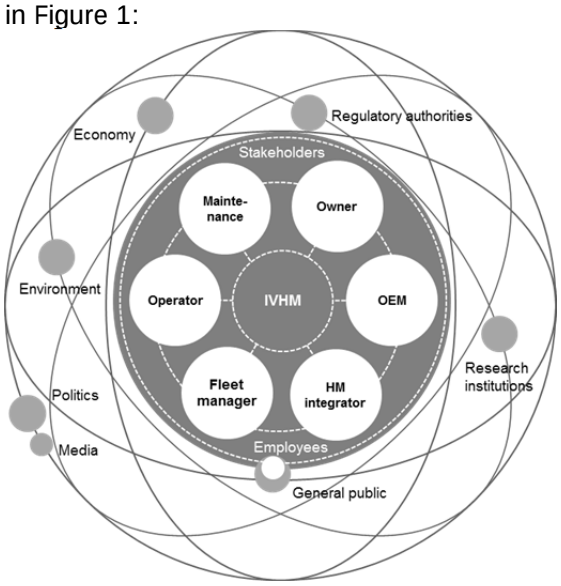

Figure 1: IVHM Stakeholder [1]

End-to-End (E2E) Maintenance - Extend terminology of the term maintenance to precise its application in an operational context and product life cycle context as shown in Figure 2:

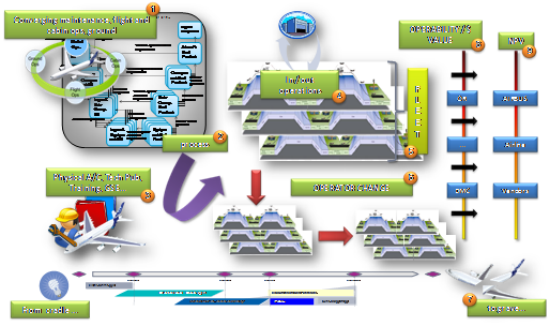

Figure 2: E2E Maintenance Context [3]

E2E Maintenance in the Operational Context - Holistic description of the operational maintenance processes, activities (incl. resources and actors) and product characteristics covering the operational flight cycle from flight preparation to flight closure and the full maintenance scope from scheduled to unscheduled events.

E2E Maintenance in the Product Life Cycle Context - Holistic description of maintenance performance enabling design and support activities along the product life cycle:

- From future projects to customer support
- From product conception to product disposal (Cradle to Grave)

SOA (State of the art) Technology – Includes all technologies, improvements and processes which are considered inside of the projects in WP3.6 and basis for further developments.

1 PROJECT DESCRIPTION

Within WP3.6 ADVANCE (related to maintenance) of IADP Large Passenger Aircraft – Platform 3, the H2020 (Horizon 2020) challenges on seamless air mobility, industrial leadership and competitiveness will be addressed by enhanced reliability and affordability of the air transport system through less operational disruptions and higher maintenance economics efficiency. These challenges are addressed on the basis of a multidisciplinary integration of aircraft and ground based health monitoring and management and maintenance supporting technologies into a service-oriented, airline operational focused, collaborative environment.
In this context, validation for a global End-to-End maintenance service architecture and demonstration of the technical and operational maturity of the enabling technologies integrated at higher level into the global architecture will be provided to support the accomplishment of the following objectives:

- Reduction of operational disruption caused by unplanned maintenance for the European legacy fleet and short term derivatives

- Maximization of airline and maintenance asset utilization (aircrafts, maintenance resources and infrastructure)
- Improvement of the value chain through services for the main actors (Airlines, MROs, OEMs, Supplier)
- Exploration of the impact of new services on the way of working for maintenance actors
- Improvement of maintenance economics with focus on early opportunities for the legacy fleet and short term product derivatives

The demonstration of the achievements of the project objectives are based on further development and adaption of component level technologies with a minimum of TRL3 and their integration into a higher level architecture providing an increase from TRL3 to TRL6 on that level.
The multidisciplinary development of a service-oriented End-to-End (E2E) Architecture and the selection and integration of the enabling technologies requires an iterative approach to ensure the consistency between all elements. Furthermore the technical and project management dependencies of the different activities need to be fully understood and considered. Figure 3 illustrates key inputs and outputs between the architecture related WP's and the WPs providing the enabling technology bricks as well as the intermediate integration.

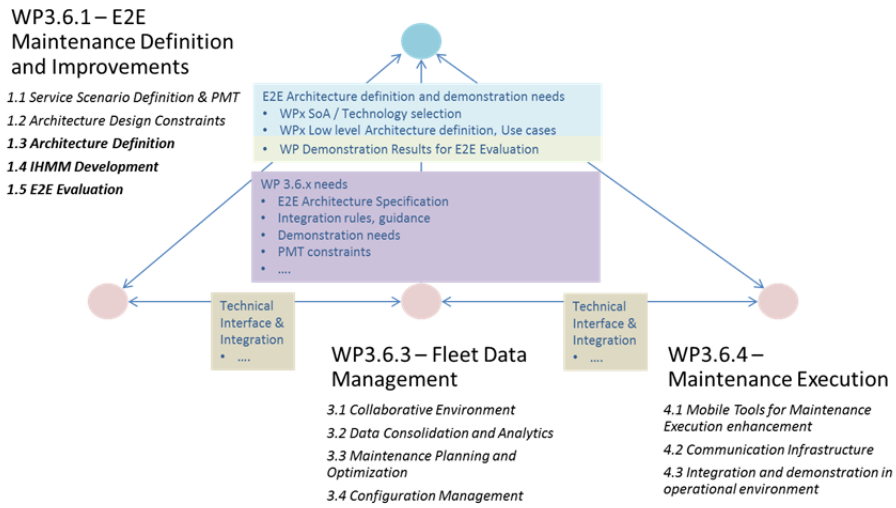

Figure 3: Relationship between CS2 WP

The overall architecture leading work packages is WP3.6.1. It will provide service scenarios, business and operational scenarios and the whole architecture including IHMM relevant technical, performance and integration requirements to the enabling WPs. Furthermore the overall process, methods, tools and KPIs will be provided. The development of the Architecture and its requirements will be based on state of the art analysis, technology feasibility studies and selections conducted by the enabling WP3.6.2 to WP3.6.4 and delivered as input to WP3.6.1. To ensure the overall demonstration of the End-to-End architecture WP3.6.1 will provides the global demonstration strategy and requirements taking into account the demonstration capabilities on lower and intermediate level as provided by the enabling WPs.
ADVANCE WP3.6 includes different projects: AIRMES (Airline Maintenance Operations implementation of an E2E Maintenance Service Architecture and its enablers), DEMETER (Development of E2E Maintenance architecture process and methods enabling a reliable and economic air transport system) and PACMAN (Prognostics And Computer Aided Maintenance). The three projects are independently from each other, but several deliverables contribute as an input for the other projects. Especially for the E2E Evaluation each partner, that delivers results of an improvement needs to interact with the other projects.
The involved Partners at the project AIRMES are Transportes Aereos Portugueses SA (TAP), Aerospace International Services Limited (AIS), Atos Origin Integration SAS (ATOS), Cranfield University (Cranfield), Instituto de Soldadura e Qualidade (ISQ), L-Up SAS (LUP), Meggitt SA (Meggitt), M2P Consulting GmbH (M2P), Office national d'etudes et de recherches aerospatiales (ONERA), Parametric Technology SA (PTC), Technische Universiteit Delft (TU Delft), Tecnologias de

Informacao SA (TEKEVER). The DEMETER Project includes the Deutsches Zentrum für Luft- und Raumfahrt E.V. (DLR) and Stichting Nationaal lucht- en Ruimtevaartlaboratorium (NLR). The PACMAN consortia is built by Honeywell International SRO and Vysoka Skola Banska – Technicka Univerzita Ostrava. [4]

Table 1 describes the E2E architecture relevant SOA-Technologies split for each project. Several of the technologies are already matured, but not in the context of an overall platform integration. That is one of the main goals of the projects.

Table 1: Technologies list

	DEMETER	PACMAN	AIRMES
SOA-Technology	▪ Indirect Structural Health Monitoring ▪ Direct Structural Health Monitoring	▪ APU Prognostic Solution ▪ Prognostic Architecture ▪ Augmented Reality Tools for Maintenance Execution enhancement	▪ Integrated Health Monitoring and Management (IHMM); ▪ Prognostic Solutions; ▪ Collaborative Environment and Data Analytics; ▪ Maintenance Planning and Performance Optimization Tool; ▪ Augmented Reality Prototype; ▪ Contextualized Documentation Tool ▪ Defects Reporting Tool ▪ Configuration Management Capturing ▪ Maintenance Elapse Time Control Tool ▪ Knowledge Database ▪ Dispatch Assessment Tool ▪ Workspace (Portable Service Tools) ▪ Software Infrastructure for Communication

2 E2E EVALUATION STRATEGY

Evaluation means proper and appropriate examination and assessment of a process or technology. [6] The complexity of the evaluation system for IVHM technologies is driven by two factors. On one side the connectivity that includes the type and number of connections in the system. On the other side the variety driven by the number and types of the involved system elements. [7] The goal is to integrate different demonstration results with different granularity into a global E2E Evaluation Simulation to determine the global impact on a virtual airline with different aircrafts (AC's), routes and business cases. Therefore, all developed SOA-Technologies need to be identified. Also the business scenarios and use cases are necessary inputs for the development of a comprehensive E2E Evaluation strategy. Figure 4 describes the workshare and deliverables (results) between the DEMETER and AIRMES project within the Evaluation. On DEMETER side the DLR is responsible for the E2E Evaluation. On the AIRMES side M2P is in charge of the Evaluation. This figure describes the interaction of M2P with DLR and the needed flow of results. The E2E evaluation is furthermore supported by TAP as the airline representative and Thales and Airbus as OEM representatives.

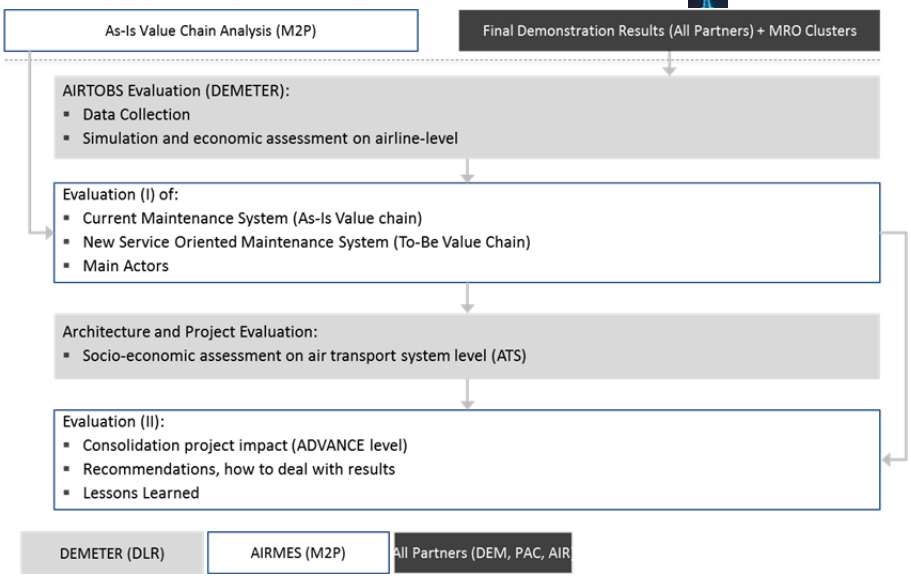

Figure 4: Approach for an E2E Evaluation (simplified)

Figure 5 delivers the IVV-structure from ADVANCE Level. As seen, the different prototype results will be integrated in the E2E Architecture and serve as a basis for the final E2E Evaluation. This includes further a virtual airline model. The virtual airline model deliver necessary input for the global value chain analysis. The figure describes further the dependencies between AIRMES, DEMETER and PACMAN. Therefore a participating evaluation strategy with transparent processes and responsibilities must be implemented.

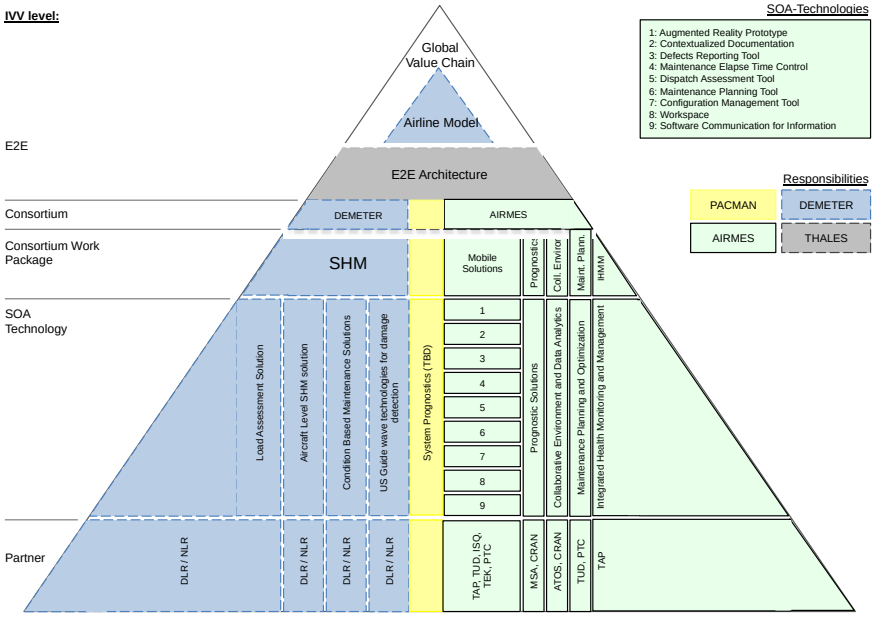

Figure 5: IVV-Structure from ADVANCE level, including relevant E2E aspects

3 EVALUATION PROCESS

The E2E Evaluation process is composed of four different steps:

1. The impact identification
2. The as-is Analysis
3. The tool development
4. The evaluation

The next paragraphs describe the four steps. Within WP3.6 step 1 and 2 are completed. Steps 3 is under progress by all involved partners. The evaluation itself will be performed by using the first demonstrator results at the second half of 2018.

3.1 Impact Identification

The Impact identification will be done by M2P and DLR. The value chain analysis of M2P includes already the estimated impacts of the different SOA-Technologies on the MRO processes. The DLR will add additional impacts based on expert knowledge inside of the DLR for the different technologies. The number of impacts per technology will be limited to ten, to limit the selection process to a reduced complexity. At the end of process a list with the indicator will be given to the next process step: the Indicator Selection. The overall selection and wheiting process will be done by a participative multi-criteria synthesis and analysis process as described in Figure 6.

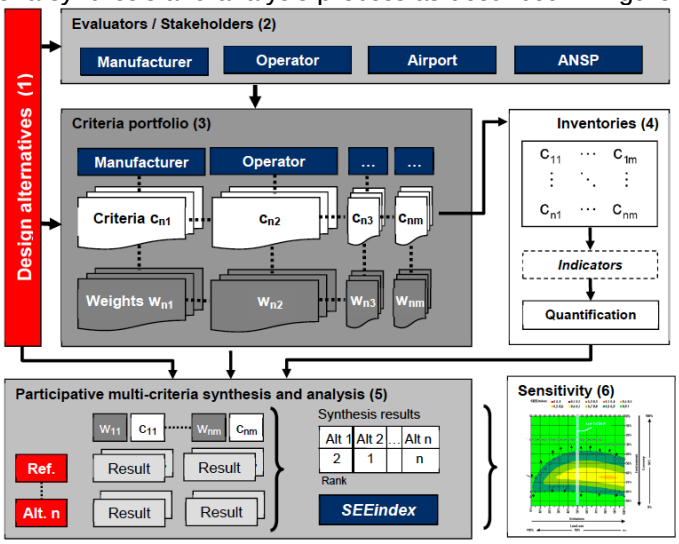

Figure 6: Participative Indicator Selection Process [4]

Each Stakeholder will be asked, for each technology he is involved, to rate the five most important indicators. The results of each stakeholder will be summarized in a list of the five most named indicators. The indicator weighting will be done for each technology and the relevant stakeholder. Each Indicator will be weighed against each other. The scale reaches from minus nine (-9) to nine (9). The result will be a weighted list of indicator. This list will be used to identify and measure the importance of the integration into the evaluation model. Inside these projects every partner will be asked to estimate the impact for all technologies regarding pre-developed scenarios and use cases. This will be used for a rectification of the importance of the integration of the single values. The results serve as a basis to estimate the impacts on ecologic and social level. This will be only integrated in a qualitative way in the overall E2E Evaluation. The Results for the economic impacts are the baseline for the evaluation tool development. The estimation should include the unit of estimated impact. E.g.: 5% or 3 minutes. Outside of the project it is planned to ask several aviation experts to give an estimation on the technology impacts in a specific context. This is planned by:

- Poster on Conferences
- Internal Questioner at the project partner at experts which are not involved into the project
- Dissemination activities
- Homepage.

It is planned to split the survey according to the DLR IVHM stakeholder model (ref. to Figure 1). This will enable later an analysis by the leading stakeholder for each technology. E.g. impact on maintenance estimated by an MRO, Impact on flight operation by airline. The Result will be used as a benchmark for the project results and a definition of a possible “to Be”.

3.2 As-is Value Chain Analysis

In general, a value chain is described as a set of activities that a firm operating in a specific industry performs to deliver a valuable product or service for the market. Within the MRO-context, a value chain describes the sequence of necessary and involved process steps (planning, execution, reporting) to generate value and fulfills requirements (keep on airworthiness).

One major part of the tool development is the as-is analysis of the MRO market, existing services and MRO functions. To get detailed and all-embracing overview of the MRO demander, it is helpful to characterize airlines according to the following three models:

- Business Model
- Operational Model
- MRO Model

In general, a business model describes the ratio of how an organization creates, delivers, and captures value, in economic, social, and cultural and other contexts [7]. Further, the process of business model construction is part of the business strategy. Within the airline context, the business model can be described by analyzing the following factors:

1. Network Structure
2. Product type
3. Fleet size
4. Fleet structure
5. Fleet age
6. Leasing A/C split
7. Alliance membership
8. Fleet trends

Based on the business model analysis three different relevant airline clusters are identified. The large hub and spoke operator (L-H&S) describes an airline with more than 100 aircraft operating with hub and spoke concept. The small hub and spoke operator (S-H&S) has less than 100 aircraft. The point to point operator (P2P) has no dedicated home base for the whole fleet. In addition to the segmentation above, the three defined airline clusters specified with operational characteristics. For the maintenance aspect, relevant operational factors analyzed:

1. Average sector length
2. Average Turnaround Time (TAT)
3. On time performance (OTP)
4. Number of Hubs and Bases
5. Number of Destinations
6. Average Legs per day and A/C

The three defined and specified clusters (L-H&S, S-H&S and P2P) are furthermore detailed with relevant MRO characteristics. The relevant factors are:

1. Maintenance Regime
2. Number of Maintenance Bases

Table 2 lists the as-is analysis results. For presentation purpose the table is shorted on some relevant factors.

Table 2: As is analysis results

	L-H&S	**S-H&S**	**P2P**
Product Type [8]	Full Service	Full Service	Low Cost or Leisure
Avg. Fleet Size [10]	200	50	104
# Narrow-Body [10]	130	38	100
# Wide-body [10]	70	12	4
Avg. Fleet age [10]	11,3 years	12,4 years	8,9 years
Airline Alliance [10]	Member	Member	No Member
TAT (Short, middle)	50-90 minutes	45-80 minutes	30-60 minutes
TAT (Long)	200 minutes	180 minutes	150 minutes
# Legs (Short, Middle) [12]	5-6	6	7-8
# Legs (Long) [12]	2	2	2
MRO Regime [12]	In-House Airline 3rd Party Provider	In-House Airline 3rd Party Provider Independent 3rd Party Provider	Airline 3rd Party Provider Independent 3rd Party Provider

3.3 Tool Development

For the E2E Evaluation two different tools will be used. For the Evaluation on Airline level the DLR AirTobs (Aircraft Technology & Operations Benchmark System) will be modified to integrate all improvements with transfer functions. The second tool will be E2E Evaluation System, developed by M2P. Each SOA-Technology will be integrated step-by-step into AirTobs. Therefore transfer functions will be developed. A transfer function can be a mathematical algorithm, a table manipulation, a single value manipulation or, a new program.
The main changes are estimated in the Maintenance Schedule Builder as shown in Figure 7. It is also estimated, that the improvements will have a large impact on the task data base and the cost data base. For the verification of the tool, the results will be analysed, for each implemented impact about the logical estimated result. For the validation, the results will be analysed according the expected results, estimated by experts outside of the project and literature values, by other projects or developments which are comparable.

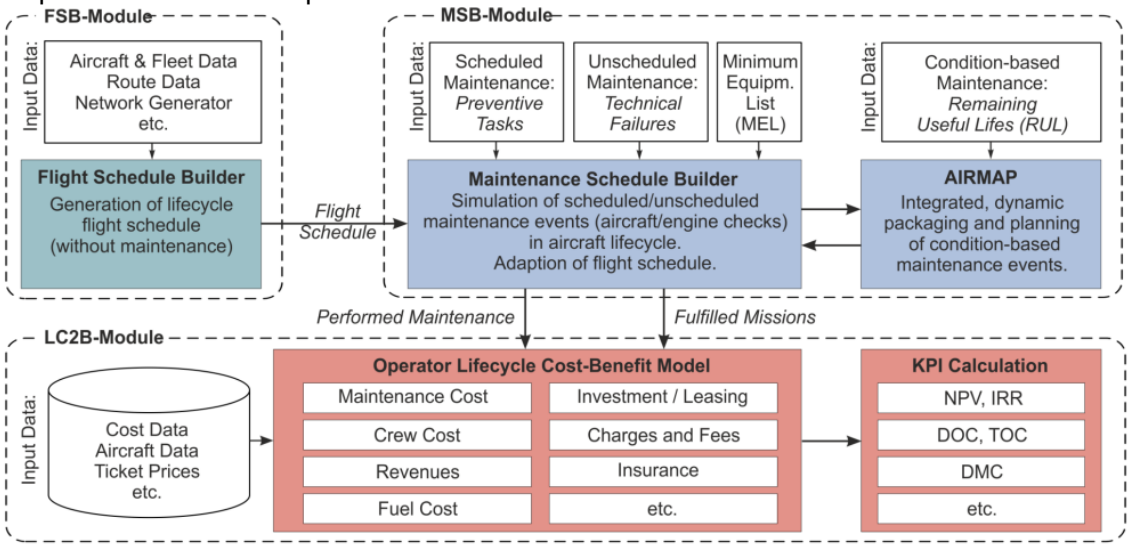

Figure 7: AirTobs Architecture [15]

For each technology and improvement DLR will starts a single technology evaluation. The single technology evaluation will be based on first results of the technology owner. The result of the E2E Evaluation on single technology will be the baseline for adjustments and validation of the expectations for each single technology. With all technologies and improvements integrated into the DLR tool, the overall E2E Evaluation on airline level will be performed. It is planned to perform this analysis for three different airline clusters to reflect the complex airline structure within the European aviation network. The results will be the baseline for the E2E Evaluation on European Network Level. The results of the analysis on airline level will be extrapolated to the European Network Level to analyse the impact on the European Aviation Sector.
The E2E Evaluation System is the second tool which will be used. The AirTobs simulation results are necessary inputs to execute the E2E Evaluation System. Besides the AirTobs input, the as-is insights, especially the three defined airline clusters (L-H&S, S-H&S, P2P) flow into the E2E Evaluation System. Furthermore, necessary data and insights out of the MRO Business Analysis Report will be integrated. Therefore, the extrapolation for each airline cluster can be made with the number of airlines in that cluster. As a next step the scale effect for Europe is be done by the sum of the different airline clusters. At this project stadium, it is planned to have the opportunity of retracing the impacts back to the single KPI's for each improvement.

3.4 Evaluation

The evaluation will follow the process described in Figure 8. It consist of six parts were different project partners are involved.

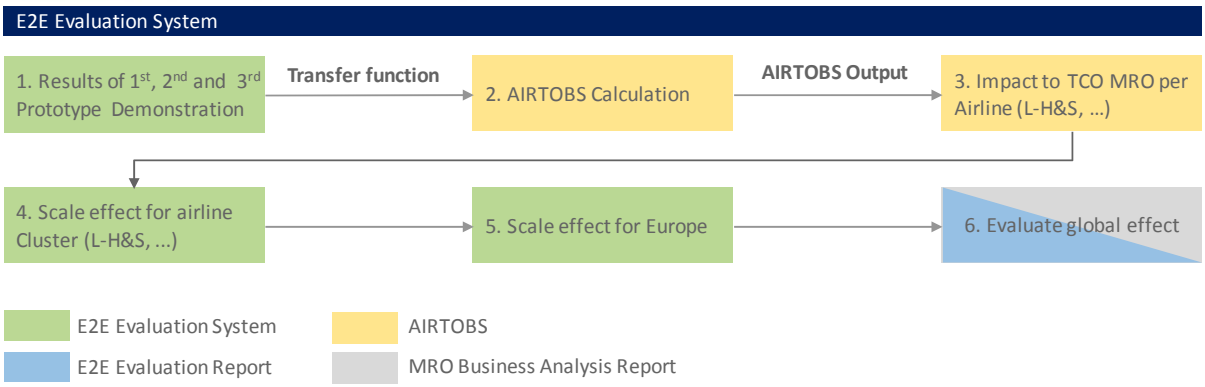

Figure 8: Simplified approach for an E2E Evaluation System [14]

The prototype demonstration will be performed by the technology and improvement owner accordingly to the validation and verification strategy of ADVANCE as well as the demonstration roadmap. The results of the demonstration activities will be transferred to the DLR. The demonstration team is responsible to assure that the results are valid and verified.
In the second step the AirTobs calculation will take place. The results of the demonstrations will be integrated via transfer functions into the E2E Evaluation System. The calculation will perform a life cycle cost benefit analysis of a fleet of aircraft in the context of three different airline clusters. As the fourth step the scale effect per airline cluster will be done. Therefore, the results of the single airlines will be integrated into the tool and multiplied by the number of airlines, considering the size of the different operators (number of bases, number of routes, maintenance regime) and regarding fleet size. These results will be integrated into the last step of the tool that calculates the scale effect for Europe about the impact of the different technologies on the main drivers in airline operations. The last step is a report about the E2E Evaluation concerning the impacts. Also, the MRO Business Analysis Report is derivate from that results, to show the business opportunities for the different stakeholder on the field of IVHM. The results of the evaluation will be compared with the as-is results from the business analysis, to show the benefits of the technology implementation. Additionally, the results will also be compared with the expectations.

4 CONCLUSION

This paper shows the principal approach for the E2E Evaluation inside the WP3.6 for the projects AIRMES, DEMETER and PACMAN within CleanSky II. The considered SOA-Technologies in the projects will be improved, changed or digitalized and contribute to an overall IVHM E2E architecture. To evaluate the impact of these SOA-Technologies on European level an E2E evaluation process needs to be developed. The complexity is given by the number and types of SOA-Technologies, partners, projects and connections between the different workpackages. To reduce this complexity a participating process for the impact factors has been performed. Additionally the as-is analysis delivers the inputs for suitable business and operational models and results into a scalable European aviation sector. Based on this preprocesses the tool development started. To ensure a comprehensive E2E evaluation process through the projects, a sufficient cooperation between the projects and the partners is established. Also the tools for the evaluation will be developed by different partners and end up in one E2E evaluation over all SOA-Technologies.

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