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ReMAP

Real-time Condition-based Maintenance for
Adaptive Aircraft Maintenance Planning

Deliverable D8.1

Integration, Verification and Validation (IVV) strategy definition

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Document History

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1. Introduction

1.1. Project summary

ReMAP “Real-time Condition-based Maintenance for adaptive Aircraft Maintenance Planning” (hereinafter also referred as “ReMAP” or “the project”), is a European project started on the 1st of June 2018 and has a duration of four years. The project addresses the specific challenge to take a step forward into the adoption of Condition-Based Maintenance in the aviation sector. To achieve this, a data driven approach will be implemented, based on hybrid machine learning & physics-based algorithms for systems, and data driven probabilistic algorithms for systems and structures. A similar approach will be followed to develop a maintenance management optimization solution, capable of adapting to real-time health conditions of the aircraft fleet. These algorithms will run on an open-source IT platform, for adaptive fleet maintenance management. The proposed Condition-Based Maintenance solution will be evaluated according to a safety risk assessment, ensuring its reliable implementation and promoting an informed discussion on regulatory challenges and concrete actions towards the certification of Condition-Based Maintenance.

1.2. Work Package Context

The Work Package 8 (WP8) concerns the development and execution of a systematic Integration, Verification and Validation (IVV) strategy of the ReMAP solution. A demonstration test will be performed in this Work Package (WP). This test will revolve around the use of three scenarios: Scenario 0 comprising the current state-of-practice; Scenario 1 comprising the implementation of the ReMAP solution as a decision support tool at KLM for 6 months and the structural test in representative structural composite sub-components; and Scenario 2 involving the simulation of the implementation of the ReMAP solution in a context of purely CBM driven maintenance planning.

For the demonstration test, we will distinguish two relevant failure types. The first category contains failures that have an adverse impact on operations, economics or safety. The impact of these failures is mitigated towards a pre-defined accepted target by periodic maintenance tasks. An example of a safety critical failure is the (partial) loss of structural integrity. These failures are prevented by (amongst others) periodic inspections. The second category contains failures that do not have a significant impact on operations, economics or safety. However, they do cause a cost to the operator by means of high repair costs, delays & cancellations. These costs could have been avoided if the condition of the subsystem had been known a-priori. In current state practices, these failures are restored after the failure has occurred. An example of a non-safety critical failure is the partial loss of functionality in one of the cooling units for the food galleys.

Condition-based Maintenance (CBM) is a concept that eliminates the downsides of both categories of failures, by introducing technologies that estimate the current and future condition of aircraft structures and systems. In addition, CBM provides an optimal planning and scheduling solution such that the operator is able to exploit the benefits of condition monitoring.

For all stakeholders in the maintenance chain, estimating realistic benefits of CBM is crucial for investment decision-making. An assessment is needed on what is realistic in terms of technology performance, and what benefits are to be expected. This is the main goal of this WP. Potential benefits of CBM need to be compared against a relevant benchmark. This benchmark will be established by conducting a state-of-practice study (Scenario 0). Realistic technology performance levels and operational implementability for existing aircraft fleet and current regulations are obtained by conducting a 6-months operational demonstration (Scenario 1). Benefits from CBM for future aircraft fleet and maintenance programs are addressed by simulating various CBM scenario’s (Scenario 2). This deliverable describes how we will address these tasks in more detail.

1.3. Purpose of this document

The main intent of the present document is to report on the deliverable D8.1 'Integration, Verification, & Validation (IVV) Strategy and Plan', as introduced in the consortium grant agreement. The aim of this document is to define the strategy and an actionable plan to ensure proper alignment and execution of ReMAP's laboratory and demonstration tests.

Figure 1 shows a timeline for this WP. In summary, the WP has four tasks as listed below.

- Integrate and implement the technologies developed under the various WPs
- Analyze current-state maintenance practice (Scenario 0)
- Demonstrate CBM technology in real-life operations (Scenario 1)
- Assess value of CBM for European Aviation (Scenario 2)

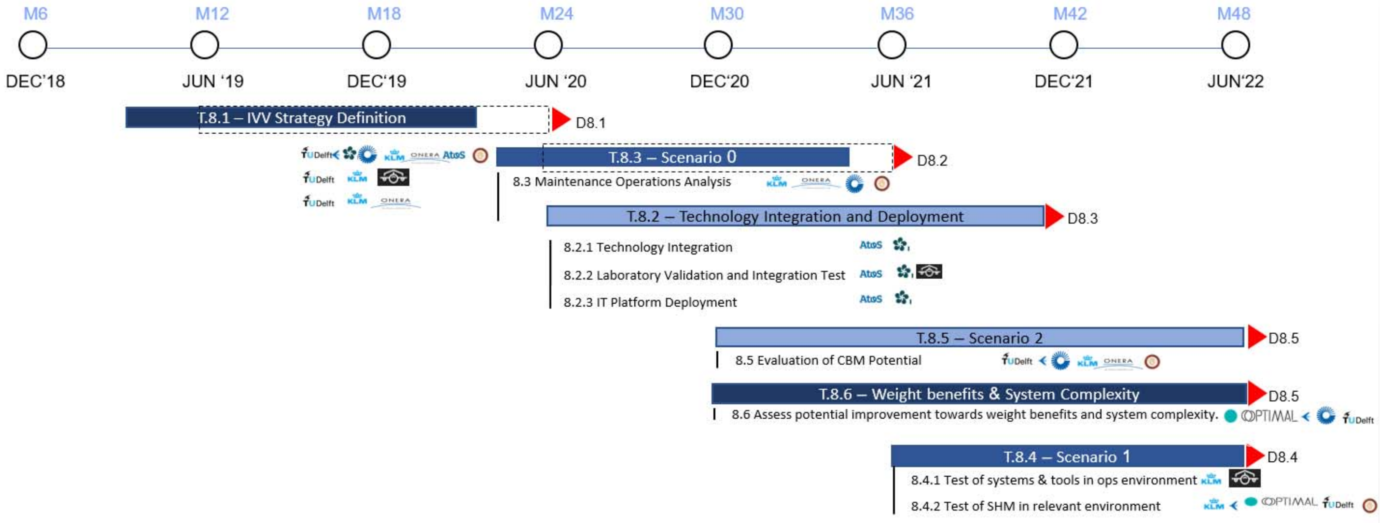

Figure 1: WP8 8 Timeline and partners involvement

The present document is a result of the activities in the first task (8.1) and prepares the activities for the remaining tasks.

1.4. Document structure

In Section 2, the Key Performance Indicators (KPIs) for operational benefit and technology performance are presented. Section 3 discusses the strategy for the Integration, Verification and Validation of the technologies to be tested in the three scenarios, followed by Section 4 in which the Integration, Verification and Validation plan is explained. Finally, conclusions are discussed in Section 5.

2. Maintenance Key Performance Indicators

This section discusses the KPIs that are planned to be used during the Integration, Verification and Validation exercise. The KPIs will be divided in two sets: operator benefit and technology performance.

For the first set (operator benefits), we took learnings from earlier work in academic literature [1-3], and made a top-down deconstruction of total (life-cycle) maintenance costs, into its component parts relevant for CBM. Total cost was split into '*maintenance cost'* and '*opportunity cost*'. The former cost type is further split up into *direct* -and *indirect* cost of maintaining a commercial airline fleet. The latter are costs incurred by the unavailability of the aircraft due to maintenance-related activities. The result of this exercise is provided in Figure 2.

The second set of KPIs (those assessing the technology performance) can be further distinguished into KPIs for diagnostics & prognostics, and KPIs for maintenance scheduling. A description of both is provided below:

1. KPIs for diagnostics & prognostics
    - Accuracy, Precision and Robustness-based metrics [4]
    - Trajectory of former metrics over its prediction horizon [4]
    - Level and accuracy of diagnostics
2. KPIs for maintenance scheduling:
    - Computational Time
    - Solution Feasibility
    - Solution Stability
    - Solution Readability.

At this stage, it is not possible to define safety related performance indicators. For non safety-critical failures for systems, a CBM technology would not make the system safer, because the failure itself does not affect safety. One could argue that because of prognostics, the mean time between maintenance for the system with prognostics is shorter than without prognostics. This means that on an aircraft life-cycle scale, more maintenance is performed with CBM. This affects the risk of a human error during a maintenance intervention. However, this is currently out of scope for this WP. For safety-critical failures that are mitigated by a preventive task, we must assume that the CBM technology that substitute the task provides the same (or better) safety target as the preventive task. The safety risk analysis of the ReMAP solution will be developed in Work Package 7 of the ReMAP project.

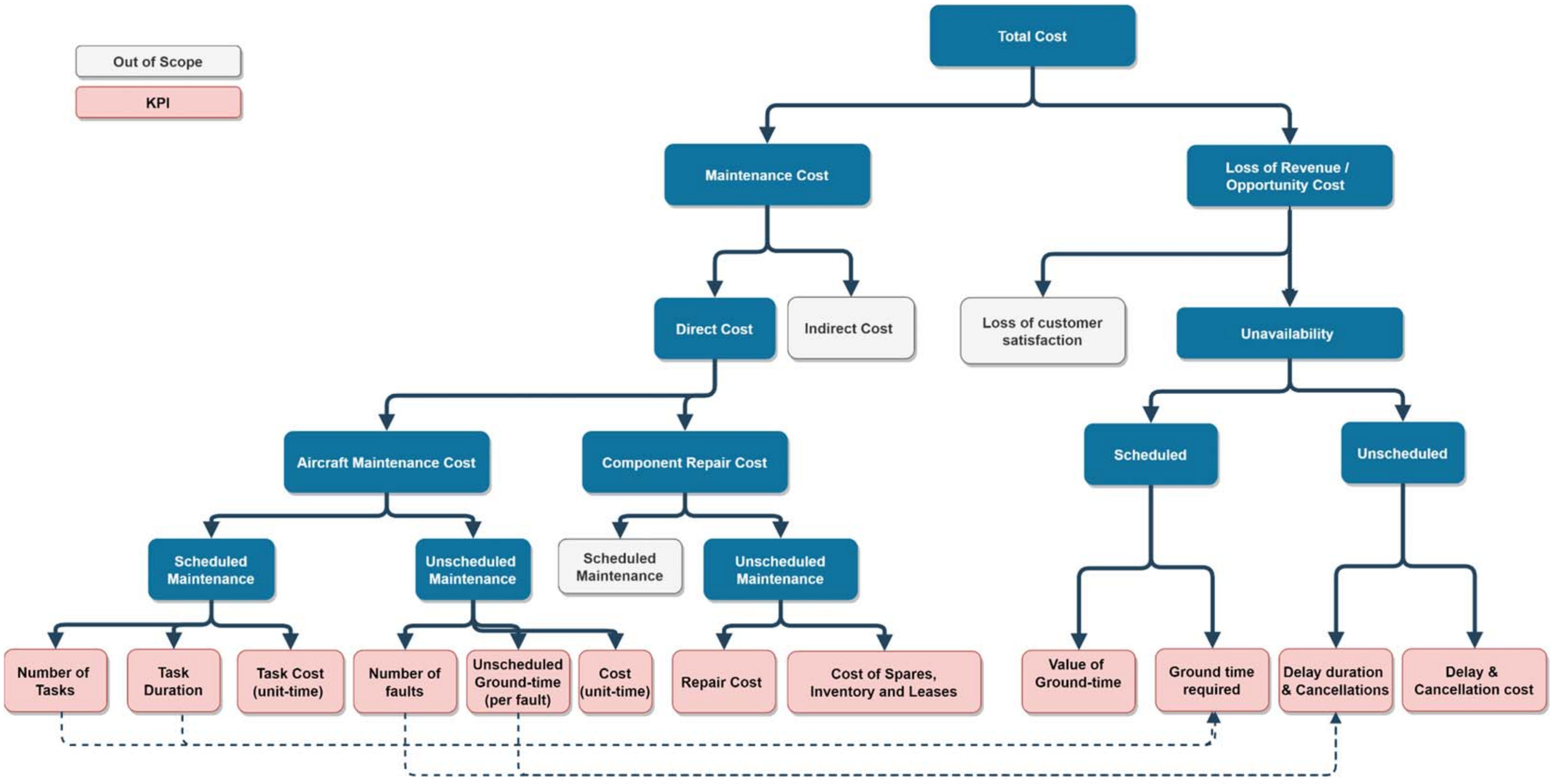

Figure 2: Breakdown of total maintenance cost

3. Integration, Verification and Validation Strategy

The strategy for the Integration, Verification and Validation (IVV) of this WP will be defined for the three different WP Scenarios. Each of the Scenarios capture two or more Operational Scenarios (Figure 3). With the exception of the Current-State Practice, each Operational Scenario can be seen as an element of the CBM technology. The operational Scenarios are summarized in the figure below.

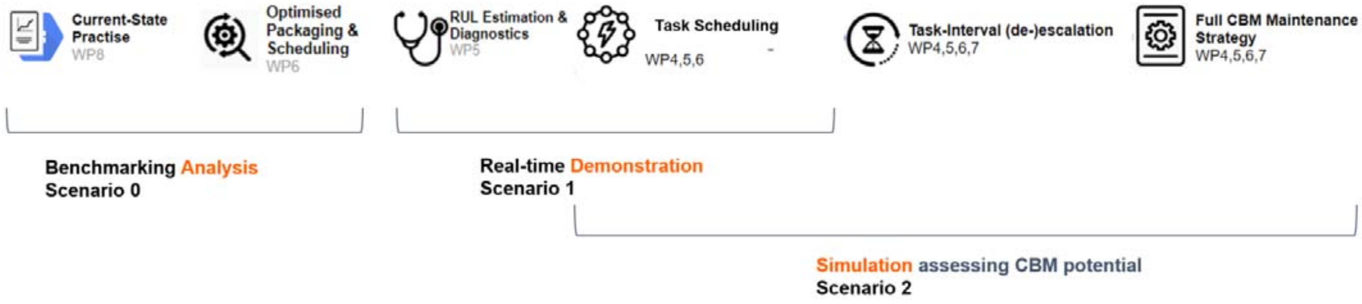

Figure 3: Operational Scenarios for the Integration, Verification and Validation strategy

This chapter will describe the strategy for each Scenario (0,1,2) separately.

3.1. Scenario 0 – Current state-of-practice

The main objective for Scenario 0 is to set a benchmark for evaluating current and future CBM technologies, and to find in what areas of maintenance most benefit is expected. We aim to achieve this goal by evaluating relevant aspects of the maintenance operations at KLM. This assessment is done in two steps.

In the first step, we will provide a high-level overview of how current maintenance practices are embedded in the aviation sector. This overview includes a summary of maintenance policies originating from maintenance policy stakeholders such as the Maintenance Review Board, Industry Steering Committees and Maintenance Working Groups. The former policies are implemented at operator level by roles and responsibilities defined by aviation authorities, which will be described. Thereafter, a low-level description of the maintenance practices at an airline and Maintenance Repair and Overhaul (MRO) organization will be presented (see Figure 4, obtained from WP 7). Finally, this first step ends with KLM's current processes that touch upon estimation of the aircraft current and future state (initial attempts towards CBM, for example by Boeing Aircraft Health Management tool or by KLM's Prognos). The final result of this first step is to present the framework under which current maintenance realizations have to be put in perspective.

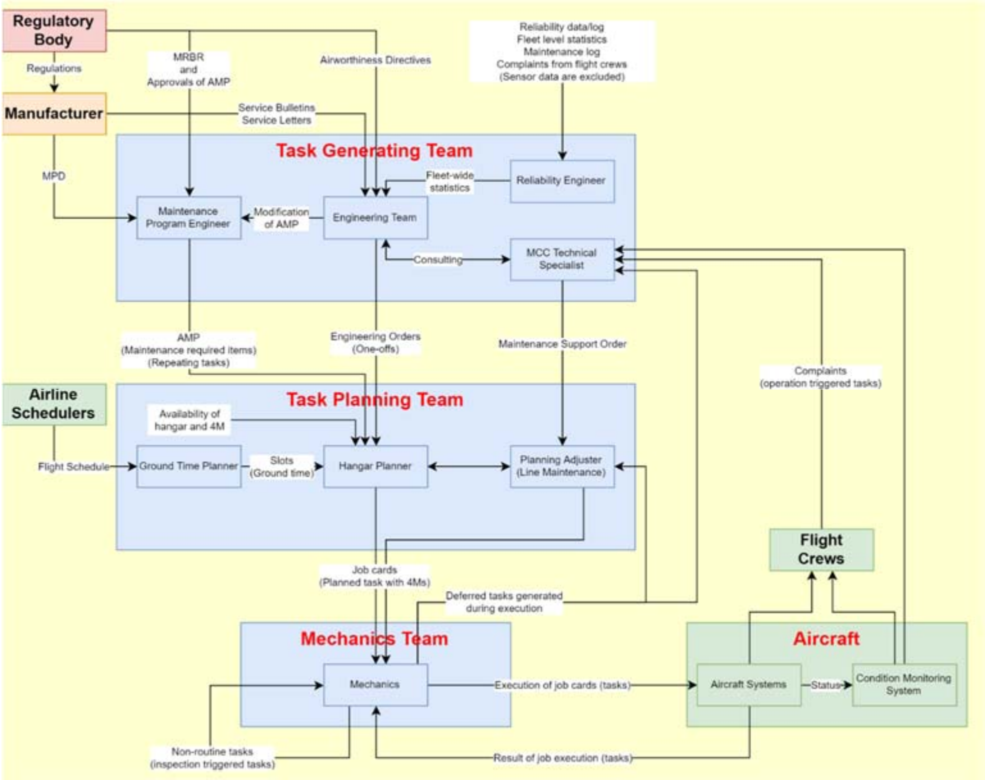

Figure 4: A low-level description of the maintenance practices at an airline and Maintenance Repair and Overhaul (MRO) organization (created with WP7)

Secondly, historical data from KLM will be used to measure previously defined KPIs for the current-state maintenance operations. The considered time-period will be long enough to capture various task-types that are needed throughout the aircraft's life cycle. Consequently, for some KPIs we will look at the Boeing 777 because KLM's Boeings 787 (ReMAP's scope for wide-body aircraft) fleet is too young to cover all aspects of maintenance (e.g. late structural tasks). The same yields for KLM Cityhopper's (KLC) fleet.

As described in Chapter 2 we distinguish two high-level KPIs:

- Direct maintenance related cost
- Opportunity cost

For both high-level KPIs, the main cost drivers and the analysis to be performed are described below.

3.1.1. Maintenance related cost

The maintenance related cost can be divided into direct and indirect costs. The direct costs are incurred by scheduled or unscheduled maintenance and are calculated by the product of the following three factors:

1. Number of maintenance events
    - Scheduled Maintenance:
        - Driver 1 Number and frequency of each task from the Aircraft Maintenance Program (AMP)

        - Driver 2 Interval Utilization of each task from the AMP
        - Driver 3 Package Efficiency of each package containing the tasks from the AMP
    - Unscheduled Maintenance
        - Driver 4 Number of faults and corrective actions
2. Duration of maintenance events
    - Scheduled Maintenance
        - Driver 5 Cumulative (life-time) duration of all tasks from the AMP
    - Unscheduled Maintenance
        - Driver 6 Cumulative (life-time) duration of corrective actions due to faults and non-routines
3. Cost of maintenance events
    - Scheduled Maintenance
        - Driver 7 Estimation of unit time-cost and per task material cost of scheduled maintenance
    - Unscheduled Maintenance
        - Driver 8 Estimation of unit time-cost of unscheduled maintenance
        - Driver 9 Estimation of total repair cost for selected systems

The analysis of these factors is not yet indicative for benchmarking current-state practices against CBM practices yet. This is because the numbers following from this analysis (e.g. unit-cost per task) may not be altered after CBM is introduced. For this reason (and for reasons of confidentiality) the results of the analysis will not be disclosed. However, the outcome of the analysis described above will be used to provide a base understanding of where CBM can have most impact. This base understanding will consist of the following 5 items:

1. Understanding of what are the most demanding type of maintenance requirements, categorized by:
    - Systems or structures tasks
    - Task types (Discard, Restore, Inspect, etc.)
    - Check types (A- or C-checks)
    - Scheduled or unscheduled tasks

   For example if scheduled maintenance tasks show to have a much larger maintenance demand than unscheduled tasks, than it makes sense for CBM to first focus on scheduled tasks.

2. Understanding the size of tasks that could theoretically be eliminated if the aircraft condition was known a-priori. In particular the number/duration/cost of tasks for which:
    a. Aircraft condition was not altered by the execution of the task
    b. No non-routine tasks were identified

   For example, it may be concluded that about a third of all tasks are inspection tasks, of which the majority does not lead to a follow-up task. If CBM had been implemented, these tasks would not have to be executed, thereby eliminating a need for ground-time.

3. Understanding of tasks that could have been eliminated or optimized if better diagnostics were available:
    - Number/duration/cost of tasks for which
        - No faults where found
        - Direct fault at aircraft after maintenance

    - Component shows repeated faults (at various aircraft)
    - Tasks take longer than expected due to longer troubleshooting, wait for material, etc.

For example, if a certain component is removed during an unscheduled task but the shop finds no fault, then CBM could have provided better diagnostics that would not have ended up in the removal. Better diagnostics can also help in the preparation phase of a task execution (e.g. sourcing of material, work preparation, or troubleshooting).

4. Understanding of number/duration/cost ‘wasted’ when a task had been scheduled more optimally, on life-cycle bases
    a. Number/Duration/Cost ‘wasted’ when scheduling a task, by
    b. Sub-optimal packaging
    c. Sub-optimal interval utilization

For example, a long task that occurs at a high frequency results in a large life-cycle waste if not scheduled close to its due-date.

5. Understanding of number of faults that are identified at an inconvenient maintenance opportunity
    - Number of faults that are:
        - Deferred
        - Cause Unscheduled Ground-Time

For example, tasks that are often deferred could have benefited if CBM had enabled a preventive task in a more convenient maintenance opportunity (making unplanned maintenance planned).

3.1.2. Opportunity Cost

In this WP, opportunity cost is defined by the cost of utilizing ground-time that could potentially have been used to serve the airline’s network. Ground time required for both scheduled and unscheduled maintenance is part of opportunity cost, but also the required use of spare aircraft and the cost of cancelling a flight must be seen as opportunity cost. The true opportunity cost is network-dependent. For example, ground time used at night-periods during which flights are not allowed by local authorities carry almost no opportunity cost, whereas ground-time during the day will carry a much higher opportunity cost. Disruptions for demanding networks with many sequential flights per aircraft and few spare aircraft have a higher risk of delays and cancellations than networks that have long turn-around-times and plenty of spare aircraft. In Scenario 0, we will estimate required ground time for both unscheduled and scheduled maintenance per flight-hour and flight-cycle, and use a flat-rate to obtain opportunity cost for those slots. Knowing the size of these maintenance slots is also useful for estimating how many maintenance opportunities a network should plan for. This estimation will be useful for WP6 and Scenario 2, where CBM and non-CBM tasks will have to be assigned to existing available maintenance opportunities.

3.2. Scenario 1

Scenario 1 concerns the real-life, 6 months operational demonstration conducted at KLM. The Operational Scenarios here include i) Prognostics & Diagnostics and ii) Task Scheduling. Referring back to the two different failure categories that CBM addresses (i.e., with or without impact to safety/operations/economics), we distinguish three actions where CBM can ultimately lead to value:

- Failures with no significant impact to safety/operations/economics
    Action 1: A **failure** is **avoided** by preventive measures during a convenient maintenance opportunity
- Failures with signification impact on safety/operations/economics
    Action 2: A **task** is **substituted** and removed from a work-package
    Action 3: A **task** is **postponed** and planned in a future convenient maintenance opportunity

These different actions (*Functional Use-Cases)*, combined with necessary steps to introduce CBM technologies to an airline (*Enabling Use-Cases*) are combined into use cases described below.

3.2.1. Functional Use Cases

A failure to be avoided is either triggered by a binary alarm indicating there is a certain probability of a fault in the next *x* days, or a nearing fault is estimated by an indication of the expected Remaining Useful Life (RUL) of the component, also accompanied with probability indicators. In both cases, the nearing fault is prevented during the most optimal maintenance opportunity, as calculated by the decision support tool or *task scheduler*.

For tasks, CBM can be used to either directly substitute an inspection or provide a health indication that justifies postponement of a non-inspection task. Task substitution is relevant when the inspection on-ground is equivalent to an on-board monitoring system in terms of its capability of detecting the relevant failure mode. When a task is substituted, it is removed from the work-package and no further scheduling is required. Note that if this happens on a large scale, less ground-time will be required as the maintenance demand is lowered. Health indication for task escalation is relevant when the conditioning monitoring system indicates that the component's health is in such a state that a task for improving or keeping its condition is not necessary yet. In this case, a suitable *next* maintenance opportunity must be selected. This opportunity will take place when the condition of the component is in such a state that the restoring task is not actually needed. Instead, (re)scheduling the restoring task based on prognostics is required. Note that also in this case, the total ground-time required can be lowered, as less maintenance tasks are to be performed on an aircraft life-cycle basis.

Because of a difference in sensor availability, systems and structures are as separate use-cases in Scenario 1.

Systems

Given the availability of data to train models with in WP5, and because of the fact that postponing and substituting a task is currently not permitted by aviation regulators, Scenario 1 will be limited to failure avoidance and the hypothetical case of inspection substitution (Figure 5).

Structures

Note that the aircraft considered in ReMAP currently have no sensors placed at structures. Hence, the use-case of Structural Health Monitoring (SHM) will not be part of the 6-months live demonstration at KLM.

The lack of real-life data from sensorized flying structures necessitates the need to develop the required SHM data in lab testing in *relevant* environment instead of a *real* environment. A subcomponent of the wing box has been described as the Level 3 test article in D4.1 after a lot of useful input from Embraer. Originally, we plan to test three demonstrator test articles (one level 3 and two level 2) in fatigue loading. One of the two L2 shall be manufactured lighter in an attempt to research into the direction of utilizing SHM to design lighter structures. The ambition is to shed light in a series of critical issues regarding the condition-based maintenance of critical structures and answer questions such as the following:

1. Are the methodologies for damage detection (diagnostics) developed at lower hierarchical structures (generic elements and flat panels) applicable and successful in subcomponent level?
2. Are the methodologies for the Remaining Useful Life (prognostics) developed at lower hierarchical structures (generic elements and flat panels) applicable and successful in subcomponent level?

Accordingly, in WP8 (subtask 8.4.2) fatigue tests are planned for the demonstrators where a critical check of the applicability of the sensor data acquisition and sensor data processing as well as the diagnostic and prognostic methodologies developed in WP3 and WP4. During the tests, estimates of damage with various approaches (strain based or acoustic/ultrasound based) as well as estimates of the Remaining Useful Life of the subcomponent will be acquired based on mathematical models trained with data from lower level testing. This activity is considered high risk as the associated uncertainties are quite large, however a successful achievement even in a subset of the objectives set will be a milestone towards implementation of CBM for critical aircraft structures.

In summary, the functional use-cases in Scenario 1 for the demonstration are defined as follows:

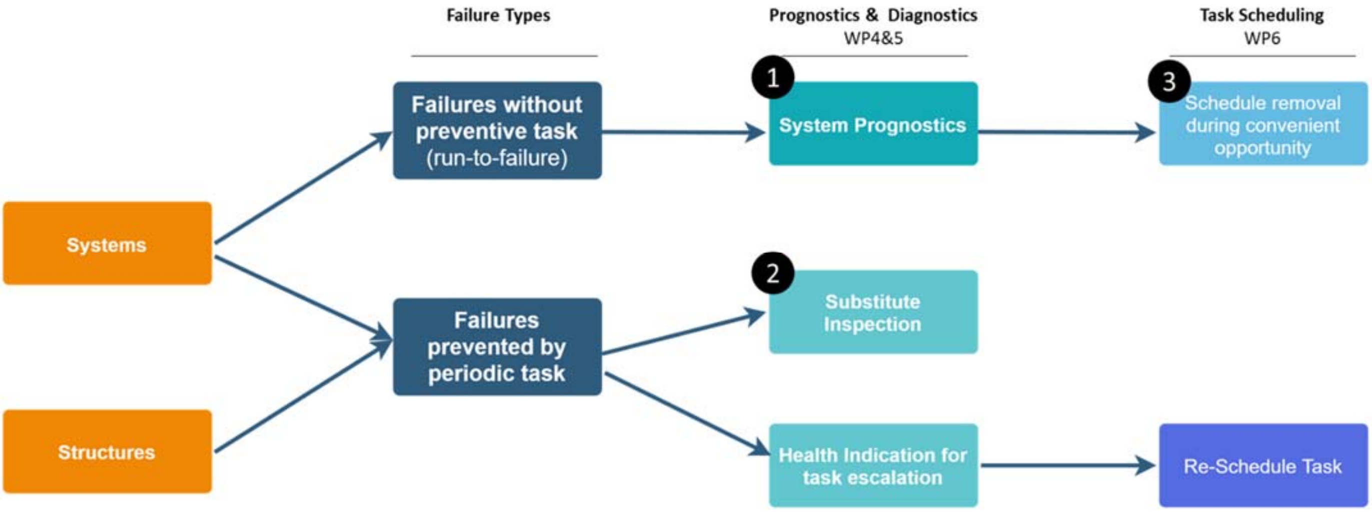

Figure 5 Overview of the three use-cases in Scenario 1

Note that the bottom blocks from Figure 5 is disregarded in the real-life demonstration due to the lack of episodes to support health prognostics. A more detailed description of the use cases during the 6-months operational demonstration for system prognostics is provided below.

Table 1 Use-cases for Prognostics & Diagnostics

Prognostics & Diagnostics						
#	Use case	Attributes	Follow-up action	KPI	Interface	Risk
1	System prognostics by classification (fault/no-fault nearing) or RUL	- Prognostic Performance metrics - Failure Mode	Creation of replacement task	- Maximum cost saved - Fault Confirmed	WP6	- Low performance of the prognostic models - Low frequency of fault occurrence during the six month demonstration
2	Substitution of inspection by sensor	- Task to be substituted - Rationale behind substitution	Remove task from work-package	Life-cycle cost saving	WP6 (WP7)	- Low number of candidates tasks for task substitution - Low value for simple (short duration) tasks

As can be seen from Table 1, there are a few attributes that these use-cases must contain. For example in use-case 1, the prognostic technology needs to provide a trigger (either as a failure class or as RUL) with a measure of uncertainty and prediction horizon in order to select an optimal opportunity (see technology KPIs in Chapter 2). Furthermore, a task for a preventive removal must result in an actionable task that can be scheduled. Finally, the monetary benefits of these use-cases depend on the availability of a convenient maintenance opportunity prior to failure. This is why the KPI only captures the maximum possible benefit, which is the case when a cheap maintenance opportunity is present just before failure.

A detailed description of the use-case for scheduling a preventive action to avoid a failure is provided below

Table 2 Use cases for maintenance task scheduling

Task Scheduling						
#	Use case	Attributes	Follow-up action	KPI	Interface	Risk
3	Schedule a removal based on prognostic input	- Selected maintenance slot from the existing maintenance opportunities	-	Actual cost saving realized on life-cycle based (including RUL wasted, lower repair cost, fewer disruptions, etc).	-	Scoping – it can either be a very simplistic problem if only health monitored-based tasks are considered or a very large problem if all tasks from all aircraft in the fleet are considered when scheduling maintenance tasks

In this use-case, the scheduling technology selects the most optimal maintenance opportunity for the preventive task (e.g. a removal). At this point (after scheduling), a more realistic estimation of the benefit of the CBM technology can be obtained. Note that the scheduling task can be very trivial if only already planned future hangar visits are considered as maintenance opportunities. Likewise, it can be very complex if the addition of the single prognostic task is reconsidering the fleet-level maintenance plan to accommodate a new optimal schedule.

Means of demonstration of functional use-cases

There are three options for demonstrating the technologies, depending on the Technology Readiness Level (TRL) of the technologies developed in WP5 and WP6, and the expected impact on KLM's operations:

- Option 1: Developed models will run in the background, isolated from actual operations.
- Option 2: ReMAP contributors will actively monitor the models, and advise the planner and technical specialist to take action.
- Option 3: Models are used by the planner and the technical specialist.

From the perspective of the project, the third option is preferred. However at this point, given the risks of models with insufficient prognostic performance, it is not possible to guarantee that the demonstration of the ReMAP technologies will be fully integrated in the maintenance process. The developed tools must have direct value for the operations in order to convince planners and technical specialist to use these tools in addition to (or instead of) the tools they already use. It is proposed to have a final decision on how to execute Scenario 1 before December 2020, because it is expected that by this time, WP leaders have a good understanding of the performance of the developed methodologies.

3.2.2. Enabling use-cases

The REMAP project, as part of the work of WP2, will provide an IT platform that supports the ecosystem of cloud services for CBM. The IT platform is the integrator of the results of the other work packages and enables the processing of the data, from the data acquisition to the model execution. The IT platform can be seen as the tool to conduct the functional use-cases described above.

For validating and demonstrating that the platform achieves all the requirements identified in WP2 and gives support to the functional use cases described previously, four user stories have been identified in the scope of WP8. In this context, user *stories* are used to define a higher level goal that one or more actors want to achieve. User-stories can be refined into lower-level actions (use-cases). These use *cases* are described in more technical terms than user-stories. A use-case can belong to multiple user-stories.

User stories

Each use case listed represents an action that must be achieved through the platform by the actors. Other user stories have been identified in the scope of WP2, but the four listed below are the ones identified as a minimum for validation.

The user stories are defined by 3 fields:

- User story: the name of the user story, short sentence to identify it.
- Description: Brief description of the purpose of the user story

- Actions: actions that the actors will deploy during the execution of the user story.

Table 3 Platform user stories

User Stories			
#	User story	Description	Actions
1	Airline node deployment	A new airline deploys a ReMAP node inside its systems.	•The airline admin registers in the ReMAP core. • The airline IT staff gets the node code from GitLab, configures node parameters, and runs the compose command. • Finally, the airline admin federates the node within the core
2	Integrate new data source	The airline IT staff adds a new data source to integrate data in his/her node.	• Before starting the new data integration, the airline's IT staff registers the airline fleet including the components and parameters setup. • The IT staff configures the SFTP connection in the node and define the folder where the data files will be uploaded. • The metadata keeper will define the metadata and link the source and the metadata.
3	Execute a new RUL model	The airline data scientist gets the RUL (if available) of a component by executing a new model available in the core.	• Model developers upload a model to the platform • The data scientist looks in the models' catalogue for a model that fits his/her needs and downloads it to the airline node • The data scientist defines a data set for the model and runs the model
4	Execute new Health Management model	The maintenance planner gets a planning proposal from a new solution available in the platform.	• Upload DSS (Decision Support System) to platform • Open DSS from the platform • Get dataset (including WP5 data) • Execute DSS • Save maintenance solution in the core

Actors

According to the deliverable D2.1 Platform requirements[1], "*an actor is a person or system that have an interaction with the software system under development, with the intention of executing an action*."

Below, a subset of actors from this deliverable are listed that will be involved in the user stories and use cases for the platform.

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[1] ReMAP WP2 Deliverable: 769288_Deliverable_4_(IT platform requirements)

Table 4 Platform actors

Actors	
Name	**Description**
ReMAP IT Staff	This actor represents the technical staff from ReMAP, that is responsible for the internal configuration and management of the IT Platform and for providing the necessary support to the other actors. This actor must have the needed knowledge (or access to documentation) to configure and manage the communications within the ReMAP platform. It should also configure and manage the access and permission details of the other actors.
Automatic Job Scheduler	This is an automated actor, responsible for the automatic triggering of tasks in the ReMAP platform. The tasks to be triggered are configured and scheduled by the Airline IT Staff actor.
Model Builder	This actor represents the engineers, physicists or data scientists that develop data-based, physics-based and hybrid models to be used in the ReMAP platform. This actor should ideally have expertise in techniques to build models and knowledge of the aeronautics domain (behavior of the aircraft structures and systems, aircraft maintenance operations, etc.). This knowledge might be obtained from a cooperation with aircraft engineers (this is a procedural issue external to the ReMAP platform). A Model Builder will not have direct access to the full raw data, just to metrics and calculated values about the data, such as the mean, maximum and minimum value of a sensor reading. Samples of data may be made available under contractual obligations or non-disclosure agreements. The Model Builder will also have access to the configuration of datasets to be used in the development and validation of the models.
Airline IT Staff	This actor represents the technical staff (generic IT staff) from the airline, which configures and manages the ReMAP platform within the scope of the airline. This actor must have the needed knowledge (or access to documentation) at the level of the IT infrastructure, to configure the communications and interactions between the airline's systems and personnel and the ReMAP platform. Regarding the airline, this actor must know details about the data sources of the airline (for example, how to communicate with them) and details about the personnel that interacts with the ReMAP platform (for example, who can access it and what permissions should be assigned to each user). Regarding the ReMAP platform, this actor must know details about the configuration operations to be performed in the platform, such as setting up the communications with data sources and automatic tasks.
Metadata Keeper	This actor represents a user that configures the linkage between the data from the airline and the data model of the ReMAP platform, including the needed data transformations. This actor must have knowledge of the domain of the airline (such as what data the airline has available, its meaning, formats, etc.) and knowledge regarding the data model provided by the ReMAP platform (its data structures, formats, types, etc.). Although this actor has knowledge about the data model of the ReMAP platform, it resides in the scope of the airline. This is because this actor is the one with knowledge regarding the data model in use in the airline it belongs to.
Aircraft Engineer	This actor represents domain specialists, such as System Engineers, Structures Engineers, Big Data Engineers, Avionics Engineers, Maintenance Program Engineer, among others.

	This actor uses the platform to approve models (data-based, physics-based and hybrid models), enabling its usage by an airline. This is only an internal approval of the models, by the airline.
Technical Specialist	This actor represents a Technical Specialist from the airline. The Technical Specialist has a specific set of aircraft assigned to handle and has specific knowledge of the aircraft structures and systems. This actor uses the platform to obtain diagnostics and RUL estimations of aircraft structures and systems and must have knowledge to interpret this information.
Maintenance Planner	This actor represents a Maintenance Planner from the airline, who is responsible for its maintenance planning. The Maintenance Planner has a fleet of aircraft under its responsibility.. This actor uses the platform to obtain recommendations of maintenance tasks and of when and where they can be performed. It is its responsibility to apply or discard these recommendations.

Use cases

The user stories described above are refined in more detailed use cases and described in this section. The use cases represent a specific action for one or more actors. These actions may be executed once or several times during the demonstration time, some of them may be executed in parallel many times a day.

The picture below represents the actors related to the use cases.

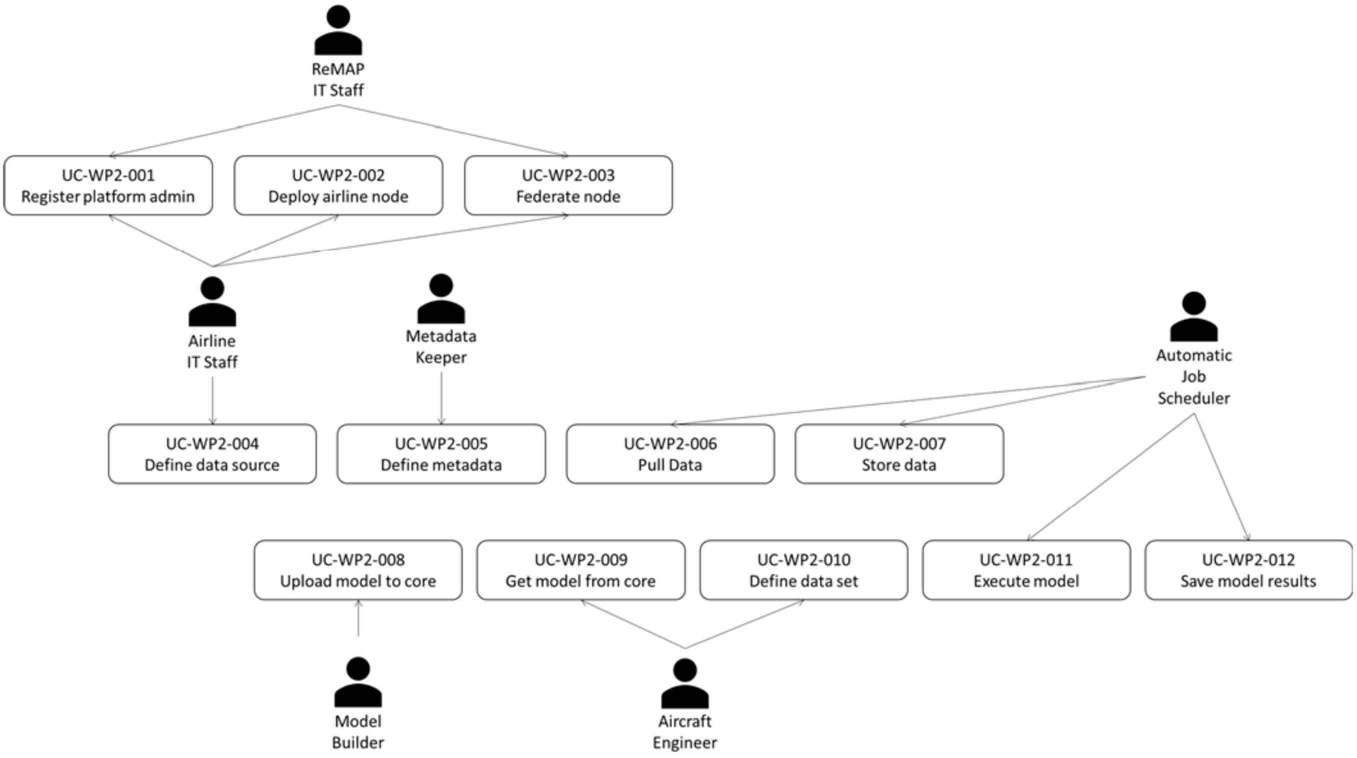

Figure 6 Platform use cases and actors

The next table list the use cases with 4 characteristics:

- Use case: name or identifier of the use case
- Description: the purpose of the use case, action to be deployed by the actors.
- Actors: actors involved in the use case
- Pre-conditions: condition supposed to be true and needed to the correct execution of the actions of the use case.

Table 5 Platform use cases

Use cases					
#	User Story	Use case	Description	Actors	Pre-conditions
1	1	Register platform admin	A new platform admin registers in the ReMAP core.	airline IT staff, remap IT staff	The ReMAP core is fully deployed and the airline has requested to join the platform.
2	1	Deploy a new airline node	The airline IT staff deploy a new airline node from the public images in the ReMAP repository.	airline IT staff	The airline systems are compliant with the ReMAP IT requirements.
3	1	Federate a node	The airline IT staff and the remap IT staff federates the new airline node within the platform core	airline IT staff, remap IT staff	The core and the node are fully deployed and they can communicate each other.
4	2	Define a data source	The airline IT staff configures a new SFTP connection a defines the folder where the data will be available.	airline IT staff	The SFTP server is accessible from the node network and the user has read access to it.
5	2	Define metadata	The metadata keeper defines the metadata need to parse the aircraft data and transform it into the ReMAP format.	metadata keeper	The metadata keeper knows the files format; the fleet has been defined in the node.
6	2	Pull data from SFTP server	The node pulls the information from the airline server automatically and invokes the data transformation.	automatic job scheduler	Both data sources and metadata has been defined; there is new files in the server folder
7	2	Store data in the local data storage	The platform stores the data from the aircraft like readings in the node data base.	automatic job scheduler	
8	3 & 4	Upload a model	The model builder uploads a model to the platform core and defines the model requirements to be executed successfully.	model builder	The model has been trained, tested and validate offline and it is a valid model for some system available through the platform, the model must be a python code compliant with the spark requirements and use the ReMAP SDK to get the data set.

9	3 & 4	Get a model from the platform catalogue	The airline staff finds a model in the catalogue which fits their requirements, then downloads it to the node	aircraft engineer	There is at least one model available in the platform core, the aircraft engineer has knowledge about the parameters available in the node.
10	3 & 4	Define a data set	The airline staff defines a data set for a specific aircraft including the parameters required by the model and the time slot.	aircraft engineer	The fleet and the metadata are defined; the airline staff has knowledge about the model requirements.
11	3 & 4	Execute a model	The job scheduler builds and launch a container which executes a model within a data set.	automatic job scheduler	The model is downloaded in the node, the data set is defined according to the model requirements, both are correctly linked by the airline staff
12	3 & 4	Save models' results	The models' output is stored in the local data repository to be used for other solution or as a final result.	automatic job scheduler	The model output is compliant with the data model specified.

3.3. Scenario 2

Scenario 2 will assess the potential life-cycle cost-benefits in a scenario where technologies and regulations are in place to support CBM for both structures and systems. An initial literature review has identified two gaps in academic research:

- Fleet level assessment of CBM benefits for scheduled and unscheduled maintenance as a function of:
  - Prognostic performance
  - Maintenance policies (e.g. Minimum Equipment List and operator specific policies)
  - Availability of maintenance opportunities in fleet network
- Implementation of exhaustive operator and MRO cost benefits, including
  - Opportunity cost
  - Repair and overhaul cost
  - Inventory and supply-chain cost

These gaps will form the requirements for an operational discrete event simulator to assess various CBM use-cases. The simulator will be validated with actual reliability data (corrected for biased (censored) data due to young fleet), cost and operational data. Again, we distinguish the two different failure types (those that are non-critical and accepted, and those that are prevented by maintenance tasks).

For non-critical failures, representative prognostic performance parameters are obtained from Scenario 1 and WP 5. For various systems, the effect of the prognostic performance on cost benefits will be estimated based on a damage escalation model, under various scenarios for maintenance policies like Minimum Equipment List (MEL) and fleet networks.

For critical failures, we have to assume prognostic that is at least as effective as the original (classical) task. At this point, we do not possess performance (safety) targets for each classical task as this is proprietary data of the Original Equipment Manufacturer

(OEM). Hence, for task substitution and task postponement (escalation), rough estimates for the amount of tasks to be postponed and substituted will be used.

The simulator enables a full assessment of CBM benefits, under various scenarios, for various aircraft and fleet types, and various operator profiles. It will contribute to the Roadmap towards CBM, by identifying the areas in maintenance where the largest benefits are to be expected. It will also help identifying optimal maintenance policies for exploiting CBM technologies. For example, it will give insight in how maintenance opportunities should be organized to leverage CBM, and how decision threshold should be defined to make an optimal trade-off between RUL utilization and risk of high repair cost and operational disturbances.

3.4. Processes, Methods, Tools (PMT)

The goal of the PMT subtask is to define a standardized way of working and delivering output throughout the project to ensure smooth implementation for the demonstration phase. In particular, issues regarding different terminologies, different model interpretations, different metrics and – perhaps most important of all – incompatible technologies can be prevented through 1) a systematic survey of the processes, methodologies, technologies and tools that partners intend to use in the project; 2) a consolidated proposal towards the consortium to mandate the use of selected PMT. The PMT subtask is an ongoing activity, in that it does not just occur at the beginning at the project but is a recurring activity throughout the execution of ReMAP. In this report, the initial findings from two rounds of information gathering are presented:

1) **PMT questionnaire (June 2019):** to survey the intentions of all consortium partners towards the use of Processes, Methods and Tools (PMT) in the execution of ReMAP, a questionnaire was compiled and distributed in June 2019. For the original questionnaire, see Appendix A. Out of all technical partners (i.e., excluding partners that have no role in technology development), 5 responded to this questionnaire (for of a total of 11), leading to a response rate of 45%. The results were compiled and briefly presented to the partners in September 2019, but as the results pointed towards alignment within the consortium or were inconclusive (see below), no further actions were deemed necessary at that point in time.
2) **PMT follow-up (March 2020):** in March 2020, with ongoing discussions in WP2 and WP5 in particular regarding the technologies and integration efforts to be adopted, it was decided to follow up with the partners to obtain further understanding of three aspects:
    a. Data: there is a need to determine and possibly fix a (set of) common formats. This has been a focus issue for follow-up, as this discussion is only partially covered by ongoing WP2 and WP5 activities.
    b. Technology: WP2, WP4 and WP5 are focusing a major effort on aligning their approaches in terms of common development platforms and programming languages (e.g. SPARK, Python). The outcomes of this discussion will inform subsequent decisions on PMT, but are not further followed up in the PMT efforts to avoid duplication.
    c. Representation: one aspect which has not been covered in detail yet is how to represent models, algorithms and tools (e.g. to ensure consistent User Interface (UI) guidelines). This is another focus issue for PMT follow-up, as the discussion is not covered yet by ongoing WP2 and WP5 activities, and the earlier PMT questionnaire output was inconclusive.

The results of the PMT questionnaire round are briefly summarized below.

- **Input:** in terms of required inputs, partners mention sensor data (as (quasi-)continuous time series with numeric and textual entries), maintenance data (in numeric and textual format), as well as resource information (e.g. available manpower, skill codes, machines, tools, etc.). Most partners expect to work with .csv, .parquet, .dat, and .json file formats.
- **Models / algorithms:** partners expect to develop diagnostic algorithms with several possible directions, such as an alerting function (a yes/no indication over a specific time horizon), an indication of degradation level in %, or a health indicator. Furthermore, prognostic algorithms that yield Remaining Useful Life (RUL) and associated confidence intervals are expected. Optimized planning output is expected for different time horizons. Models and/or algorithms are expected to be visualized and explained using logic diagrams and process representations, such as IDEF, grey box models with associated pseudo-code, and mock-ups to end users. As by the date of the questionnaire, partners were developing using the Python programming language (v3), e.g. using Anaconda or Jupyter Notebooks, with a view to containerize applications in Dockers. In terms of data modelling, views were inconclusive, though some efforts had been made towards setting up a data template for flight data, with future plans for a protocol for constraints and resources for plan management.
- **Outputs:** the expected output from WP5 and WP6 in particular were RUL (primarily expected to be expressed in flight hours and/or flight cycles) and associated confidence intervals, plus optimized maintenance plans (incorporating task allocation and probability of concretization).

The PMT follow-up will be formally reported on in the next Deliverable. It focuses on the following issues and associated proposals:

- **Data formats and models:** partners are currently working with .csv, .parquet, .dat, and .json file formats, facilitated by Spark. WP2 is coordinating data model development in conjunction with WP5 and WP6.
- **Output representation:**
    - Data mapping: the data models being developed cover main model classes and attributes. Work is progressing on dataset specification. As more aircraft (systems) are entering into WP5 efforts towards model development, verification and validation, it is expected that subsequent iterations will reveal further parameters, data sources, metadata, etc. These parameters must be carefully mapped and tracked to ensure consistent sharing, representation and traceability across WP technology contributions, enabling as smooth of an integration effort in WP8 as possible. The PMT effort may be used to identify one or more processes to ensure this mapping and tracking effort.
    - UI guidelines: for the purposes of the demonstration, the models and algorithms developed in WP4, WP5 and WP6 in particular will require user interactions. To enable this, it is imperative that one or more User Interface(s) (UI) are developed. To increase consistency in use and reliability of demonstration results, the UI(s) should be developed according to shared ReMAP guidelines. Determination of the exact content of these guidelines is an activity that has only recently started, but these will likely cover at least the following aspects: visual formatting, style, language, process representations, and use of visual indicators.

4. Integration, Verification, and Validation Plan

The goal of this chapter is to translate the strategy from the previous chapter into an actionable plan for integration, verification and validation activities along the project timeline. At the time of writing, a sub-selection of eligible systems and structure candidates cannot be made, as there is no insight in what systems and structures provide the highest feasibility and benefit. Hence, the action plan includes exploratory scoping work on a remainder of the 12 selected systems, which must be finished prior to integration of the platform.

The plan along the project's timeline can be found in the figure below. For activities that are dependent on prior activities, a high-level critical path is provided.

Note on COVID-19 Impact

At the moment of writing, the COVID-19 pandemic is having an unprecedented impact on the aviation industry. The consequences to the ReMAP project are currently uncertain. In this document, we are assuming that all actions are continued as originally planned. However, it is possible that when the situation persists or worsens, available (IT) resources to support the demonstration may become scarce. Contrarily, if the industry recovers, overdue projects are competing for the same IT resources at once, which could have an effect on ReMAP. Uncertainty in the developments of COVID-19 force us to work with a planning that is as flexible as reasonably practical.

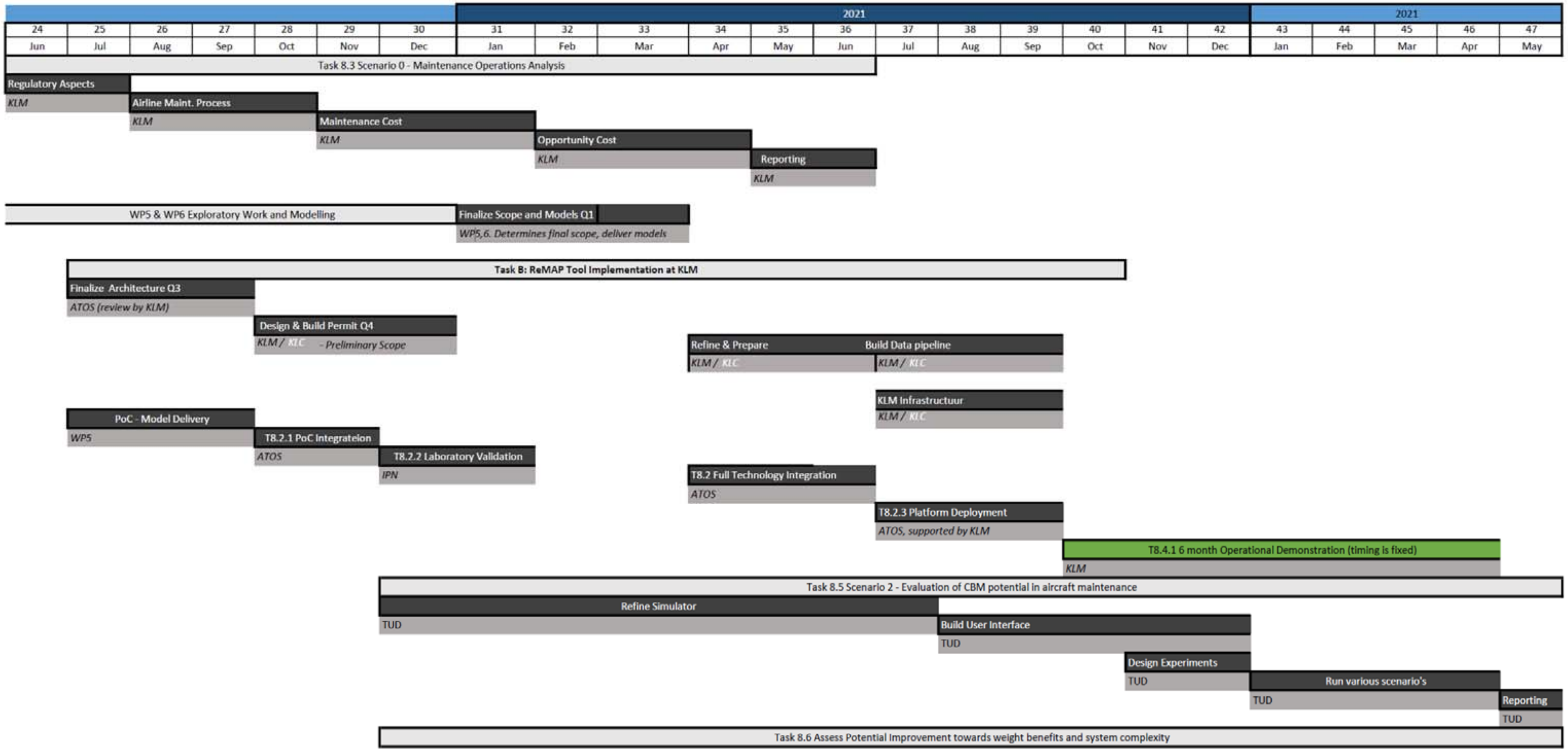

Figure 7: Planning of WP8 activities

5. Conclusion

This document described ReMAP's Integration, Validation & Verification Strategies and Plans. Throughout the work package, maintenance cost and network opportunity cost will be used as the main performance indicator for CBM technologies. Scenario 0 will highlight current-state practices that will be affected the most when CBM is introduced. Scenario 1 shall provide insights into CBM implementation into an airline and demonstrate a selection of prognostic and planning models that can be used in airline maintenance today. Scenario 2 will provide a more extensive insight into future value of CBM, by simulating CBM concepts for new aircraft types, new maintenance policies and new prognostic technologies. These scenarios together with improvements towards weight & system complexity for future aircraft will give an insight in benefits of CBM on the medium and long term.

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