D1.1 Technical Resources and Problem definition

Deliverable 1.1

Pilot3

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Pilot3

A SOFTWARE ENGINE FOR MULTI-CRITERIA DECISION SUPPORT IN FLIGHT MANAGEMENT

This deliverable is part of a project that has received funding from the Clean Sky Joint Undertaking under grant agreement No 863802 under European Union's Horizon 2020 research and innovation programme.

Abstract

This deliverable starts with the proposal of Pilot3 but incorporates the development produced during the first four months of the project: activities on different workpackages, interaction with Topic Manager and Project Officer, and input received during the first Advisory Board meeting.

This deliverable presents the definition of Pilot3 concept and methodology. It includes the high level the requirements of the prototype, preliminary data requirements, preliminary indicators that will be considered and a preliminary definition of case studies.

The deliverable aims at defining the view of the consortium on the project at these early stages, while highlighting the feedback obtained from the Advisory Board and the further activities required to define some of the aspects of the project.

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Executive summary

Pilot3 is a CleanSky2 Innovative Action. This project started in November 2019 and is 27 months long. The Topic Manager is Thales AVS France SAS. Pilot3 aims at providing a software engine model for supporting crew decisions.

The primary objective of Pilot3 is to develop a **software engine model** for supporting crew decisions for civil aircraft. This software will provide the crew with a **set of options** along with information to aid the crew to select the most suitable one considering the **multi-criteria business objectives** of the airline, including the **impact on the network** of flights of the airline of those decisions.

This deliverable presents the definition of the problem with the concept and methodology that will be followed during the project. It also includes the high level the requirements of the prototype, data requirements, indicators that will be considered and a preliminary definition of case studies. The deliverable starts with the proposal of Pilot3 but incorporates the development produced during the first four months of the project: activities on different workpackages, interaction with Topic Manager and Project Officer, and very relevantly, the input received during the first Advisory Board meeting.

The deliverable aims at defining the view of the consortium on the project at these early stages, while highlighting the feedback obtained from the Advisory Board and the further activities required to define some of the aspects of the project.

Pilot3 comprises five sub-systems:

- **Alternatives Generator**, which will compute the different alternatives to be considered by the pilot; fed by the two independent sub-systems:
    - **Performance Indicators Estimator**, which provides the Alternatives Generator with information on how to estimate the impact of each solution for the different performance indicators (PIs);
    - **Operational ATM Estimator**, which provides the Alternative Generator with information on how to estimate some operational aspects such as tactical route amendments, expected arrival procedure, holding time in terminal airspace, distance flown (or flight time spent) in terminal airspace due to arrival sequencing and merging operations, or taxi-in time;
- **Performance Assessment Module**, which, considering the expected results for each alternative on the different KPIs, is able to filter and rank the alternatives considering airlines and pilots preferences, and to show them to the pilot; and
- **Human Machine Interface**, which will present these alternatives to the pilot and allow them to interact with the system.

The use of Pilot3 will require two phases: a configuration phase, performed prior the flight; and an execution phase, carried out during the flight. The configuration phase is performed prior the flight and helps to define how the indicators and the operational ATM parameters should be estimated, and to configure Pilot3 to reflect the airline flight policy. The execution phase consists on the tactical usage of Pilot3 by the crew and consists of three steps: generation of alternatives, ranking of these

considering the airline's policies, and selection and interaction with them from the pilot. Note that the pilot can introduce constraints which might trigger the generation of new alternatives.

Pilot3 will help the pilot to better understand the impact of the different alternatives on the key indicators that are relevant for the airlines: on-time performance and cost.

High-level requirements for the prototype have been identified. Three type of datasets are also preliminary defined including: data required as input in the project, data required for training the predictive models and data that will be used for the validation of the prototype.

The case studies which will be modelled in Pilot3 will be finally described in D5.1 - Verification and validation plan, however, key parameters to be considered have already been identified. Two main type of scenarios will be considered: scenarios focused on short/medium haul flight and scenarios defined for long haul flights.

1 Introduction

Pilot3 is a CleanSky2 Innovative Action. This project started in November 2019 and is 27 months long. The Topic Manager is Thales AVS France SAS. Pilot3 aims at providing a software engine model for supporting crew decisions.

1.1 Pilot3 objectives

The primary objective of Pilot3 is to develop a **software engine model** for supporting crew decisions for civil aircraft. This software will provide the crew with a **set of options** along with information to aid the crew to select the most suitable one considering the **multi-criteria business objectives** of the airline, including the **impact on the network** of flights of the airline of those decisions. In particular Pilot3 will:

- Gain understanding on the **types of performance** that airlines are seeking in order to translate these into high level objectives that can be formulated in **measurable parameters** which are relevant for airlines.
- Understand different **airlines policies and flight management policies** in order to identify the best **multi-criteria decision making technique** to provide the crew with the different options and their trade-offs.
- Provide a tool which allows airlines define their preferences, **enriching their flight policies**.
- Develop an enhanced system to **estimate the different indicators** for the different trajectories alternatives. From using only available airborne information to the use of advanced machine learning trained ground predictors.
- Incorporate flexibility to **select which approach to use to estimate the indicators**, trading accuracy and complexity with efficiency, and considering the costs associated to develop enhanced indicators predictors by the airline and to operate the required data-links.
- Estimate the **overall impact of each trajectory option** not only for the current flight, but considering follow-up rotations of the same aircraft and the complex **network effects** which are critical when dealing with **passengers' itineraries**
- Create a **software engine model** which can be used by crews to produce alternatives and that can be assessed in a fast time simulator environment.
- Provide the **design of a possible HMI** for such a tool and a software interface for the system.

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When a flight is disrupted, the crew faces different options and, nowadays, it could be difficult to understand their impact on the overall airline business policy. This is since there are different parameters that should be considered at the same time, which can represent trade-offs such as total operating cost, adherence to a given flight schedule or the environmental impact of the flight. Moreover, understanding the full value of these indicators can be challenging as their overall value does not depend solely on the disrupted flight but on the whole network. For example, connecting passengers missing their connections might have a significant impact on the overall cost of a given flight, but these potential missed connections depend on the performance of other flights (e.g., if outbound connecting flights are delayed on their own); or uncertainty in the system means that suboptimal decisions can be selected, for example, speeding up a flight to encounter congestion at arrival airport. Pilot3 will mitigate some of these problems by allowing the estimation of the performances of each alternative, not only based on the information available within a particular flight, but considering trained machine learning predictors.

One of the main objectives of Pilot3 is therefore, to **provide a comprehensive selection of options** with their associated trade-offs, considering the airline's business objectives, and to **maximise the likelihood that estimated values of those parameters are accurate**.

1.2 Deliverable purpose and intended reader

The purpose of this deliverable is to present the definition of the problem which is considered by Pilot3. It presents the concept and methodology that will be followed during the project.

This deliverable captures at a high level the requirements of the prototype, data requirements, indicators that will be considered and a preliminary definition of case studies. The deliverable starts with the proposal of Pilot3 but incorporates the development produced during the first 4 month of the project: activities on different workpackages, interaction with Topic Manager and Project Officer, and very relevantly, the input received during the first Advisory Board meeting.

The deliverable aims at defining the view of the consortium on the project at these early stages, while highlighting the feedback obtained from the Advisory Board and the further activities required to define some of the aspects of the project.

The intended reader of the deliverable is the Topic Manager and Project Officer in order to validate that the concept and approach defined are adequate; and broader audience with interest in the topic. This deliverable aims at improving the dissemination of the project objectives, approach and activities.

1.3 Deliverable structure

The deliverable is structured in 7 sections:

- Section 2 presents the problem definition and scope formulation. This section includes the Pilot3 concept and methodology that will be used to develop the prototype. Note that some of the methodologies will be further developed as part of WP2 - Multi-criteria decision making techniques (reported in D2.1. Trade-off report on multi-criteria decision making techniques); the model details will be further considered in the model development (WP4 - Model development); and the validation approach will be captured by the activities of WP5 - Model verification and validation.

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- Section 3 describes the high-level prototype requirements. The detailed requirements of the modules that form Pilot3 will be part of WP4 - Model development, and the requirements on the design of the HMI will be captured in WP2 as part of the interaction with the multi-criteria methodology.
- Section 4 includes the preliminary data requirements considering three different applications for the data: input for the model, training of predictive models, and validation activities. Note that the acquisition of the data and their further definition will be performed in WP3.
- Section 5 contains preliminary performance and operational indicators which could be modelled in Pilot3. These already capture the feedback obtained from the Advisory Board.
- Section 6 defines the preliminary case studies considered in Pilot3. Further consultation with the Advisory Board will be used to select and prioritise these. The final case studies will be designed as part of WP5 - Model verification and validation.
- Section 7 is the next steps and look ahead which is very relevant for this deliverable.

The document closes with references and acronyms.

2 Problem definition and scope

In the current concept of operations, without a support tool such as Pilot3, and as generally understood, strategically, the airline considers its business objectives in order to identify key performance areas (KPAs) that are of interest, and how they will be monitored with individual key performance indicators (KPIs). The airline may define different targets that it wants to achieve, considering its business priorities. This information is shared with the crew[1] and translated into individual flight policies that can be used when disruption appears during the operations. This process might not be present on some airlines and in some cases the decision could be driven by dispatchers using a more ad-hoc process. However, in some cases, specific flight policies might be defined for different types of flights, considering the expected impact of the disruptions on the flight and network operations. For example, for short flights between two secondary airports, the airline could establish to not recover delay lower than a given amount of minutes, or use a maximum percentage of extra fuel for a given delay recovery strategy, as the knock-on effect on its network's operations is small; while for a long haul flight it might consider to recover more delay (as more delay can generally be recovered in a longer flight without requiring a too aggressive approach); or even a more aggressive delay recovery approach could be established for short and medium haul flights which are feeding large number of connecting passengers to the hub. The airline is strategically assessing which performance areas are important and defining trade-offs in what could be considered an implicit a priori multi-objective preference definition.

During the operations, as depicted in in Figure 1, when a disruption arises, the pilot should consider the airline's set targets and policies, and using a trajectory optimisation or prediction system, estimates the different trajectory options. Note that currently this might not be enforced. Potentially, this tool could be integrated within the flight management system (FMS), however a more realistic approach is to keep it independent of the FMS and embed it into the pilot's Electronic Flight Bag (EFB). The different options will have an impact on the expected duration of the flight (time) and/or on the amount of fuel consumed (kg), which are typically the main outcomes of these trajectory optimisation/prediction systems. The pilot, then, considers this information and other data available (such as the list of connecting passengers who are on board, or previous experience on expected delay at arrival for that particular route) and has to estimate the existing trade-offs to decide if it is worth it to recover a given amount of time using a certain amount of extra fuel. During this analysis and selection exercise, the crew might discard options, which they don't accept as valid (e.g., changing flight level to a level where the pilot knows turbulence is experienced), and mentally ranks the different possibilities to select the one that is considered best. The pilot is doing a manual iterative analysis of alternatives.

[1] Note that we use crew and pilot in the text interchangeably.

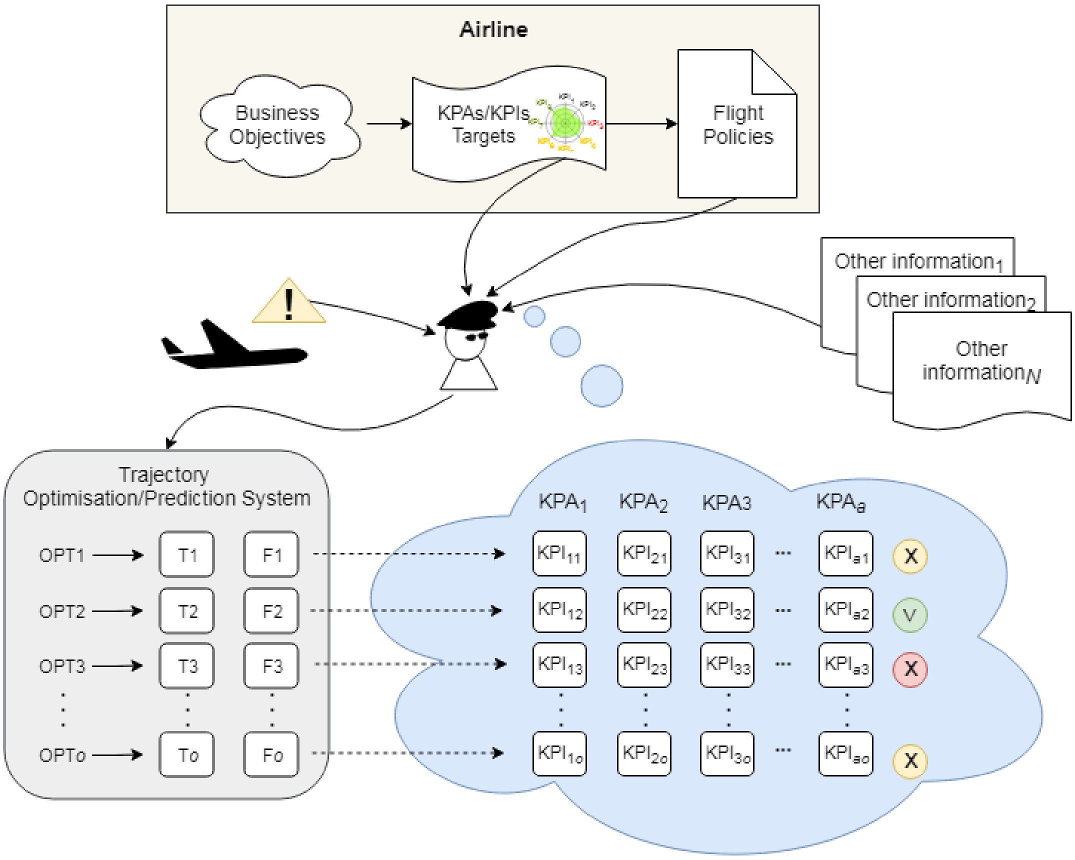

Figure 1. Flight crew decision-making process: current concept of operations

The aircraft crew does not have an explicit view of the trade-offs nor an automatic computation of the possible options that consider the overall airline objectives and flight policies. **Pilot3 will provide the capability to explicitly estimate the impact of each alternative with respect to the airline's performance targets**. When an action is required by the pilot, Pilot3 will compute the different alternatives available and then, the pilot will be able to do this analysis of alternatives by interacting with the tool (e.g., adding constraints or rejecting solutions).

Note on current operations from Advisory Board consultation

Different airlines might have different policies in place, but one common approach to managing disruption is to estimate the alternatives from the ground (e.g., monitoring the operation of flights by dispatchers) and indicate to the pilot how they should operate (e.g., which Cost Index to select). However, in some instances, for example, small variations, or when considering tactical operational issues (e.g., where to perform the top of descent), pilots still maintain some autonomy. Moreover, pilots might still make decisions based on their own interpretation of priorities, which might vary from flight to flight.

Pilot3 will help to support pilots on their understanding on the trade-offs between different tactical alternatives that are available.

2.1 Pilot3 concept

2.1.1 Pilot3 architecture

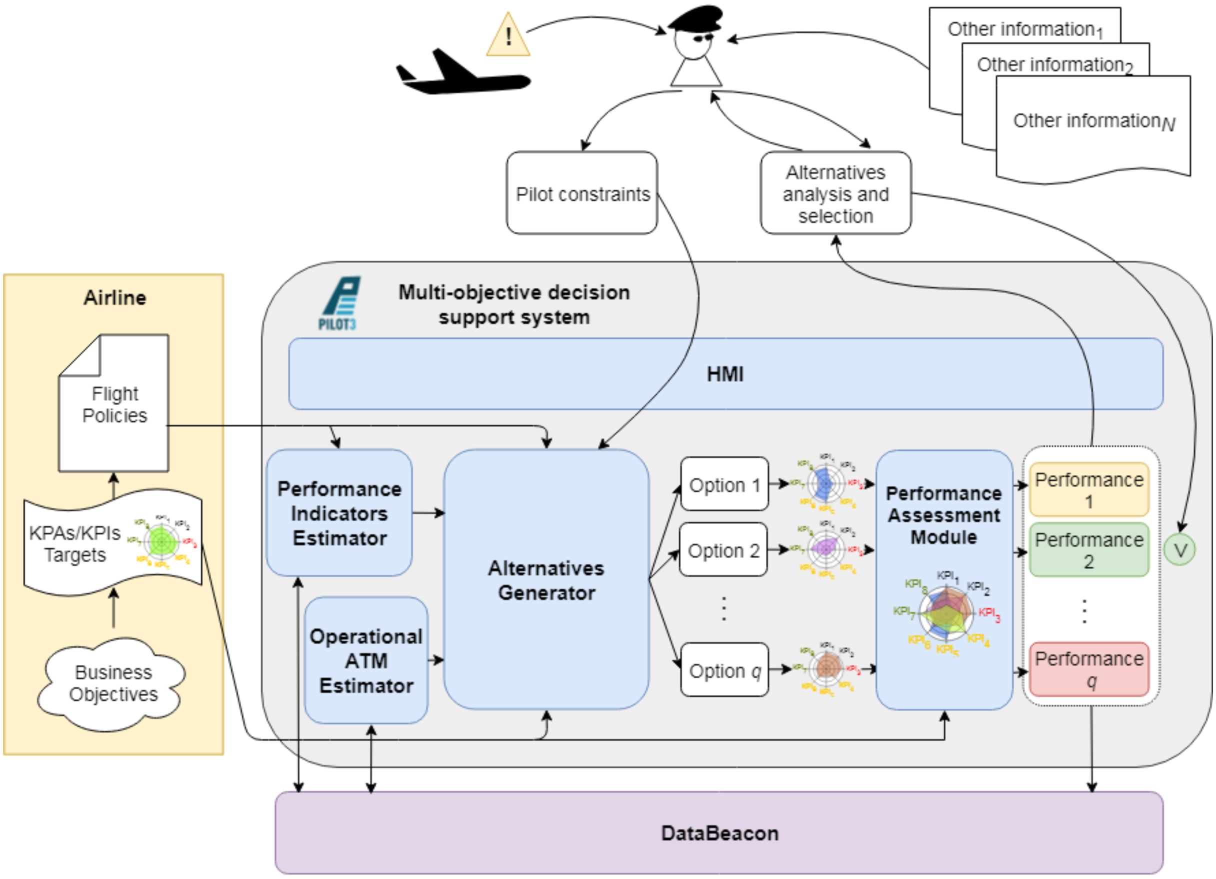

Figure 2. Pilot3 architecture concept diagram

Pilot3 comprises five sub-systems (as shown in **Figure 2**), namely the:

- **Alternatives Generator**, which will compute the different alternatives to be considered by the pilot; fed by the two independent sub-systems:
  - **Performance Indicators Estimator**, which provides the Alternatives Generator with information on how to estimate the impact of each solution for the different performance indicators (PIs);
  - **Operational ATM Estimator**, which provides the Alternative Generator with information on how to estimate some operational aspects such as tactical route amendments, expected arrival procedure, holding time in terminal airspace, distance flown (or flight time spent) in terminal airspace due to arrival sequencing and merging operations, or taxi-in time;

- **Performance Assessment Module**, which, considering the expected results for each alternative on the different KPIs, is able to filter and rank the alternatives considering airlines and pilots preferences, and to show them to the pilot; and
- **Human Machine Interface**, which will present these alternatives to the pilot and allow them to interact with the system.

The first four sub-systems will be developed during the duration of Pilot3 project. A possible Human Machine Interface will be designed and the minimum implementation for the validation of the multi-criteria decision system implemented. The systems software interfaces will be defined to ensure their interoperability.

Variation with respect to proposal after Advisory Board consultation

A new module has been included: **Operational ATM estimator**.

Most of the indicators are evaluated considering the delay experienced by the flight at their arrival at gate (actual in-block time (AIBT)) and not at landing. This means that some ATM operational indicators need to be considered, notably:

- ATM factors affecting the time required to reach the gate:
    - Estimated taxi-in time (which could depend for example on the gate assigned, runway at landing)
- ATM factors affecting the time required from arriving to the TMA (terminal manoeuvring area) to the actual landing:
    - Expected STAR (standard terminal arrival route) or transition to be used at arrival
    - Estimated distance flown (or flight time spent) in TMA due to arrival sequencing and merging operations
    - Estimated holding time in TMA
- ATM factors affecting the flight time before arriving to the TMA:
    - Conditional route granted (in line with the flexible use of airspace - FUA).
    - Estimated en-route or departure shortcuts given by ATC.

In the proposal, it was assumed that the impact of operational uncertainty would be captured by the indicators estimator, for example, the cost of delay for passengers could be a function of the landing time which incorporates (implicitly) the expected taxi-in time. However, at this stage in the project, we consider that it is beneficial to explicitly estimate these parameters within this dedicated new module. These operational parameters can be complex to estimate and different techniques, such as in the case for the Indicators Estimator, could be considered.

2.1.2 Pilot3 general overview

There are two phases where Pilot3 will be used:

- Configuration phase: performed prior the flight.
- Execution phase: carried out during the flight.

2.1.2.1 Configuration phase

The configuration phase will be performed by the airline prior to the flight. This could be done strategically, or some parameters could be selected at dispatching level on a flight-by-flight basis. The objectives of this phase are to select how the indicators and the operational ATM parameters should be estimated, and to configure Pilot3 to reflect the airline flight policy. For example, indicating if a heuristic or an advanced model should be used to estimate a given parameter with air or ground information, which thresholds should be used when comparing solutions, in case of equivalent impact on different indicators which ones should be prioritised, etc.

The exact number of parameters and how these will be provided will be defined as part of the project. See Section 2.2.1 and Section 0 for more information on the possibilities to configure the Indicators Estimator and the Operational ATM Estimator; and Section 2.2.3 and 2.2.4 for information on the usage of airline optimisation and flight policies for the generation and ranking of alternatives.

2.1.2.2 Pilot3 execution logic

When analysing and selecting alternatives, the pilot may be performing a **multi-criteria trade-off** analysis. This will be driven by different factors: the airline's business objectives and flight policies, and operational aspects considered by the pilot. The process can be seen as an exploration of alternatives which consists on optimisation, filtering of solutions and addition/modification of operational constraints. Pilot3 will help the pilot to explicitly understand the impact of those alternatives on the airline's performances.

Insight on optimisation objectives from Advisory Board consultation

From the consultation with the Advisory Board, it has been preliminary established that the main high objectives that are relevant for an airline are cost and on-time performance (understood as a binary variable of achieving on-time performance (i.e., arrival delay≤15 minutes or not). Cost is in its turn a complex indicator build from the aggregation of many different sub-indicators, see Section 5 for information on the preliminary indicators that are considered in Pilot3. However, from an optimisation point of view, it could be considered that only two objectives (cost and on-time performance) could be considered. This, along with the relationship between the two objectives, will be further explored in WP2 - Multi-criteria decision making techniques.

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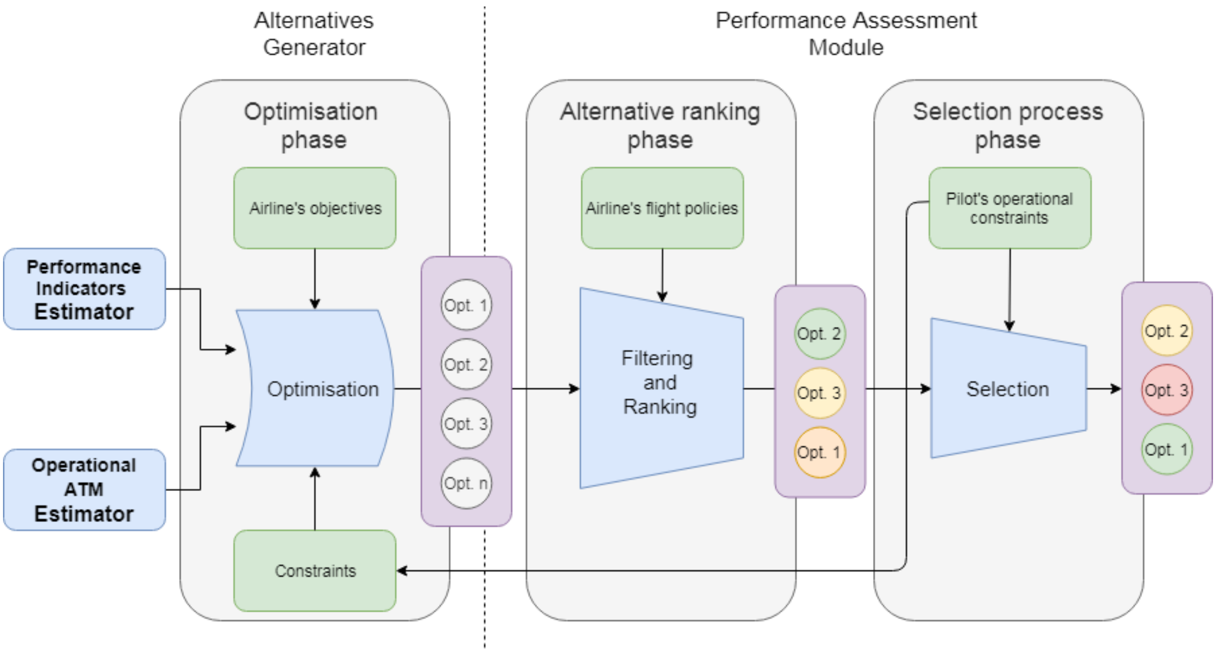

Figure 3. Example of execution of Pilot3 diagram

Disclaimer on the execution phase
The full identification of the process to generate and select the alternatives will be defined as part of WP2 - Multi-criteria decision making techniques and could still be slightly modified from this preliminary version.

Figure 3 presents the execution logic of Pilot3. When Pilot3 is triggered, the **Alternatives Generator** uses a trajectory generation engine to create a set of alternatives. This will be done considering:

- the performance targets and flight policies set by the airline for the key performance indicators (KPIs);
- constraints: operational (e.g., airways) and ad hoc defined by the pilot (e.g., 'do not provide solutions which imply an altitude change'); and,
- the information from the Indicators Estimator and the Operational ATM Estimator on how to estimate these indicators and operational parameters.

When a trajectory is modified, the expected flight duration (i.e., expected arrival time) and the fuel consumption might be changed. The Alternatives Generator will use information from the **Operational ATM Estimator** to consider aspects which affect the total fuel consumption (e.g., holdings and path stretching at TMA) and time at arrival at gate (e.g., taxi-in time). With this, the optimiser will be able to use the estimators provided by the **Performance Indicators Estimator** to transform the total expected fuel and arrival delay into the different indicators which are relevant to the airline.

Note that the performance indicators might not be known until the arrival of the flight, or even until the end of the operational day (e.g., total amount of reactionary delay), and may have to be estimated. These estimations will be made based on the information available at the moment of making the decision. This is the main objective of the **Performance Indicators Estimator** module: to indicate how to estimate the performance indicators from the trajectory parameters.

Once this set of alternatives has been generated, there is a process of ranking and selection which will be performed by the **Performance Assessment Module** with interaction with the **Human Machine Interface**. The ranking of alternatives might be required as a function of the number of alternatives provided by the Alternatives Generator. The objective of this process is to filter and rank the alternatives consider the airlines' policies with respect to the different KPIs. For example, two solutions might provide the same cost but trading fuel cost and passenger cost (e.g., from compensation due to Reg. 261), in this case, even if the total expected cost for both alternatives is equivalent, the airline might define that passengers should be prioritised. Note that this ranking is produced with the information defined in the configuration phase of Pilot3 and if more than one alternative is produced by the Alternatives Generator.

The final step consists in considering pilot operational related aspects. The pilot must have a mechanism allowing to compare and rank the solutions. For example, some solutions might be dismissed, as not deemed adequate from an operational perspective. Others, if acceptable, might not be their preferred solution as, for example, the required workload might be too high (e.g., they require a high interaction with the ATC). These operational aspects could be captured by tactical operational indicators which could be considered as part of the optimisation (e.g., minimise number of flight level changes). However, after the interaction with the Advisory Board, we consider that this might be too difficult to capture, as it is embedded with pilot preferences, knowledge, operational awareness, etc. For this reason, an iterative approach where the pilot can prioritise the alternatives and add constraints could be considered. This might trigger another optimisation of trajectories with these new constraints. Note that the newly generated trajectories could still be compared by the pilot with the previous ones which were considered adequate. It is paramount to present to the pilot not only the high-level indication of the KPIs of the alternatives but also the impact on different components of those indicators (see Section 5), so that they have a full understanding of the alternatives. Pilot3 will store the information on both the 'accepted' and the 'rejected' trajectories which could be used to gain understanding on the drivers of these decisions.

2.2 Methodology for the development of the modules

This section presents the methodology proposed to develop the different components.

2.2.1 Performance Indicators Estimator

When the trajectory of an aircraft is modified, the pilot is usually trading time (delay) and/or fuel (extra fuel burned or saved). Based on those two indicators, the others can be derived or approximated. In the general case, the accuracy and precision of the estimation will depend on the type of data available which, unless the system was designed to capture the required data, might not be available.

Making predictions requires the use of statistical approximations either by using analytical, heuristic or data mining techniques, such as machine learning or deep neural networks. The final value will not be known by the airline until the arrival of the flight or even until the end of the operational day. While heuristic models are developed with preconceived assumptions about the system made by experts or by analysis of post-operational data, data mining relies only on data to learn and discover the most likely scenarios.

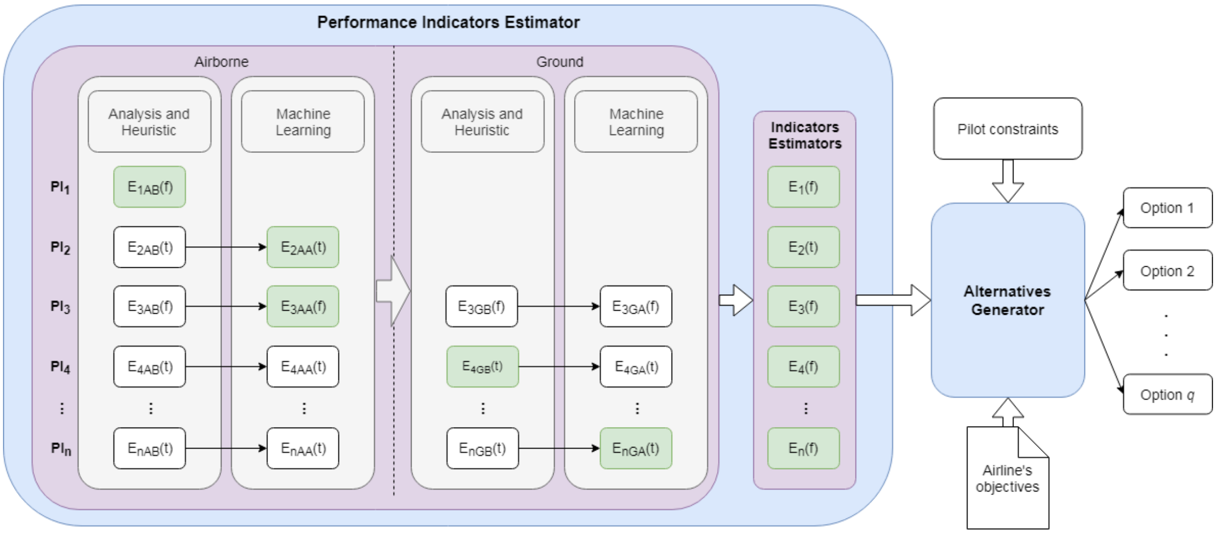

Figure 4. Performance Indicators Estimator diagram

As shown in **Figure 4**, **different types of data sources can be used when estimating the indicators**. Notably one could use the information available:

1. in the aircraft (**airborne data**). This has the advantage that no data-link is required with the airline operating centre (AOC) reducing the communications costs. However, it has the drawback that some relevant information might not be considered when estimating a given parameter; or
2. at the AOC (**ground data**). In this case, a full picture of the status of the airline network for flights and passengers can be used, improving significantly, the estimation of some indicators. This comes with the cost of the communication link and the ground infrastructure required.

Then for each of these two data sources, **two data analysis approaches are considered for the estimation of the indicators**, based on the:

1. analysis of available data and heuristics (**analysis and heuristics approach**)
2. use of historical data analysis with machine learning techniques (**machine learning approach**)

Section 5 presents the information on the preliminary performance indicators which are considered in Pilot3. Note that in many cases, these indicators are not based on the expected delay at landing but on the delay at arrival at gate. For each indicator, the **data required for its estimation** will be identified and an assessment will be done on how using different levels of complexity can lead to better predictions. For example, PI_1 can be estimated by the Alternatives Generator considering only basic available airborne data or estimators. This could be the case of the expected cost of fuel, once the fuel is estimated, its cost can be directly computed. PI_2, could benefit from some advanced heuristic that could come from some machine learning training done offline, but which relies only on airborne data. The other PIs could be enhanced by considering ground data or advanced ground models which forecast the impact of that indicator at the end of the operational day. For the indicators that will benefit from a machine learning approach, Pilot3 will identify the **data required for their training**.

In Pilot3, it will be possible for each indicator to **select dynamically (as a function of time) which estimator should be used and for each particular flight** this is relevant as ground data communications with data links, ground infrastructure, etc. need to be established and this can have a cost. In order to benefit from the machine learning approach, an airline will require to maintain updated and trained models. This is a very powerful approach as it allows to consider post-operational performances to enhance the decision making process. However, this might be costly for a given airline or only possible for some specific indicators and/or in a subset of flights. Pilot3 allows this flexibility for different airlines to operate differently but even for the same **airline to decide flight-by-flight** how to estimate the indicators. This will be done as part of the **configuration phase** of the system allowing AOCs, for example, to restrict the computation to airborne analysis and heuristic approach for short flights operating between secondary airports, but maybe, consider ground data in a complex machine learning predictor for long-haul flights with large number of connecting passengers. This results in overall operational costs savings. The increase in the complexity of the computation of the estimator, e.g., using data available on-ground and advanced machine learning algorithms, should revert into more accurate predictions. Pilot3 infrastructure should allow experts to assess the degree of improvement of these predictions as more data and complex algorithms are considered. A full analysis of this trade-off is out-of-scope of this project, but dedicated case studies will be defined in WP5 to illustrate these effects.

Note that some indicators could be computed as a composition of others. For example, the cost of delay could consider the amount of estimated reactionary delay (knock-on delay in the network).

2.2.1.1 Heuristic models

Heuristic models are any techniques to problem solving that to not pursue a complete solution, e.g., a solution that works even in worst case scenarios. Heuristics are used when partial solutions are enough to satisfy the requirements or when there are no perfect methods available. Most heuristic methods are built upon hypothesis.

In Pilot3, the indicator is estimated using the (limited) available data to explicitly analyse its value, and, when required, pre-computed heuristics could be applied. This would include, for example, estimation on the reactionary delay by comparing the estimated in-block time with the scheduled off-block time of the next rotation of the aircraft considering an estimated minimum turnaround time. However, if one wants to estimate how this reactionary delay will propagate through the day of operations, heuristics could be used.

2.2.1.2 Predictive modelling

Modern **predictive analytics** [20] use Machine Learning algorithms to uncover **statistically relevant patte**rns in data sets (training data). In order to make valid predictions it needs to be assumed that those patterns might repeat in the future, e.g., the stochastic process of which the training data was extracted is stationary. If that is the case, a set of **features**, e.g., linear or non-linear combinations of the training data, are created and their influence on the variable to predict (target variable) is measured empirically using a statistically optimal estimator. Such features are often combinations that escape human direct observation or even intuition due to the complexity of the relations on the data. In this context, predictive analytics and machine learning can be used not only for making predictions but also for analysing precursors, e.g., features on the training data set that are relevant for a particular event.

The standard methodology in predictive modelling requires [1,11,23]:

- **identifying of a set of scenarios** that can be described with the data available,
- **translating the case study to a supervised machine learning problem** (e.g., classification for predicting a discrete variable or regression for predicting a continuous variable);

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- **extracting of a set of features** in which the variable to predict is described;
- **selecting** a supervised machine learning algorithm appropriate for the problem;
- **tuning** and **assembling** algorithms as needed;
- the **training of the machine learning model** and test the performance with new (previously unseen) samples.

The most important part of the predictive modelling process is cleaning, processing, merging data from different sources to create a unified dataset, that then needs to be correctly labelled with the target variable. Not addressing this pipeline can be a major drawback for the project due to the **lack of a good training dataset**. In order to provide the analytics team with the **storage and computing power** necessary to build these data pipelines accordingly, Pilot3 will be supported by **DataBeacon**, a cloud-based data processing platform (see Section 2.3.2 for a description of the platform).

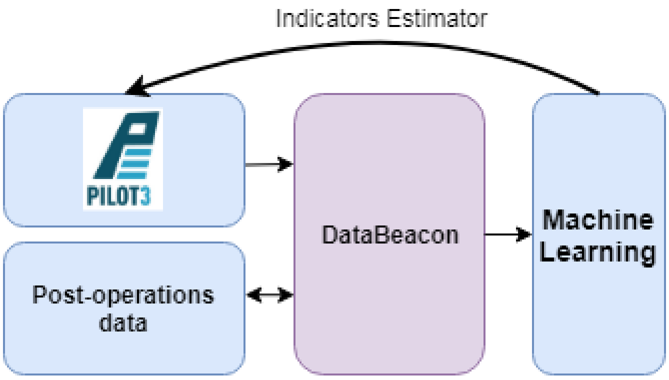

Figure 5. Machine learning from post-analysis of operations

Furthermore, in order to continuously improve machine learning estimators, the training datasets need to be updated with new unseen data. **Figure 5** presents how the use of DataBeacon (see Section 2.3.2) allows a data processing pipeline to accomplish this. Additionally, the Pilot3 system will store each alternative computed with their estimated outcomes in DataBeacon's datalake.

This is a continuous enhancement process, the most data available, i.e., the longer the system is used, the more accurate the indicators can be estimated. This machine learning feedback is out of the scope of Pilot3, but the integration with the DataBeacon infrastructure in Pilot3 allows for the first step of data acquisition needed for this continuous training to be put in place paving the way for its future operational development.

Additionally, Pilot3 will also select a subset of indicators that can be modelled with predictive techniques trained using synthetic data. The development in Pilot3 for the machine-learning estimators will be a proof of concept of this powerful approach, which will set out the infrastructure required for its exploitation.

2.2.2 Operational ATM Estimator

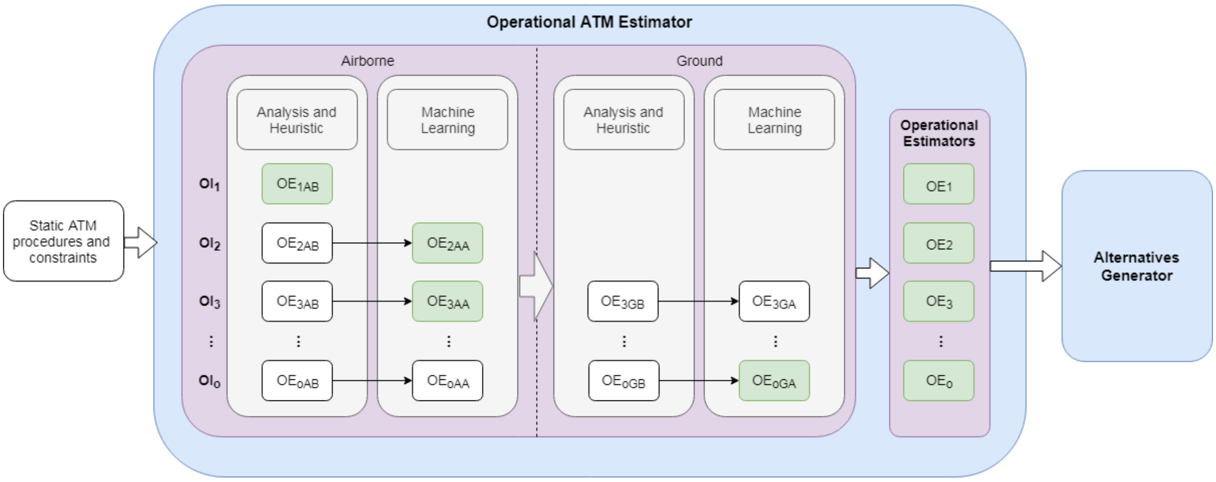

Figure 6. Operational ATM Estimator diagram

In order to estimate the arrival delay at gate and the total expected fuel consumption, some operational parameters need to be considered. Note that as Pilot3 is operated tactically most of these uncertainties will be linked to the operations in the TMA and on-ground at arrival, but en-route parameters, such as potential shortcuts could also be considered.

In particular, the operations in the TMA and on-ground can produce large uncertainty. For example, for some flights it might not even be possible to know which STAR will be used on arrival, some airports might be more prone to holding delays, and taxi times might vary depending on which runway and gate are assigned. These operational parameters will be estimated by the Operational ATM Estimator module. Section 5 presents a preliminary list of operational indicators to be modelled.

As presented in **Figure 6**, a similar architecture to the Performance Indicators Estimators is proposed. For each operational parameter, different alternatives on how to estimate it could be considered. These can be estimated with information which is available on board or considering information available on ground. Some of these parameters are particularly suitable for the application of machine learning techniques. For example, trying to predict the amount of delay that will be experienced at arrival.

Using a similar pipeline as the one described for the Performance Indicators, DataBeacon can store in the datalake the operational and post-operational data. Merging the airline data with real trajectory data (e.g., ADS-B) and other data sources, a training dataset can be generated and maintained for the estimation of these indicators that would introduce uncertainty on the operations (e.g., holding time, taxi time). Note that not only the expected value might need to be estimated but also the variance of these parameters. As the flight progresses, some parameters might become more accurate to predict reducing the uncertainty.

2.2.3 Alternatives Generator

The Alternatives Generator proposed in Pilot3 is composed by a core trajectory generation engine, capable to creating realistic (optimal) aircraft 4D trajectories, embedded into a multi-objective optimisation framework.

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A key functionality of the decision support system proposed in Pilot3 is **the transformation of the original complex and large multi-criteria optimisation problem to a concise and meaningful set of alternatives for the aircraft crew**. The overall architecture proposed by this component is depicted in **Figure 7** and detailed as follows.

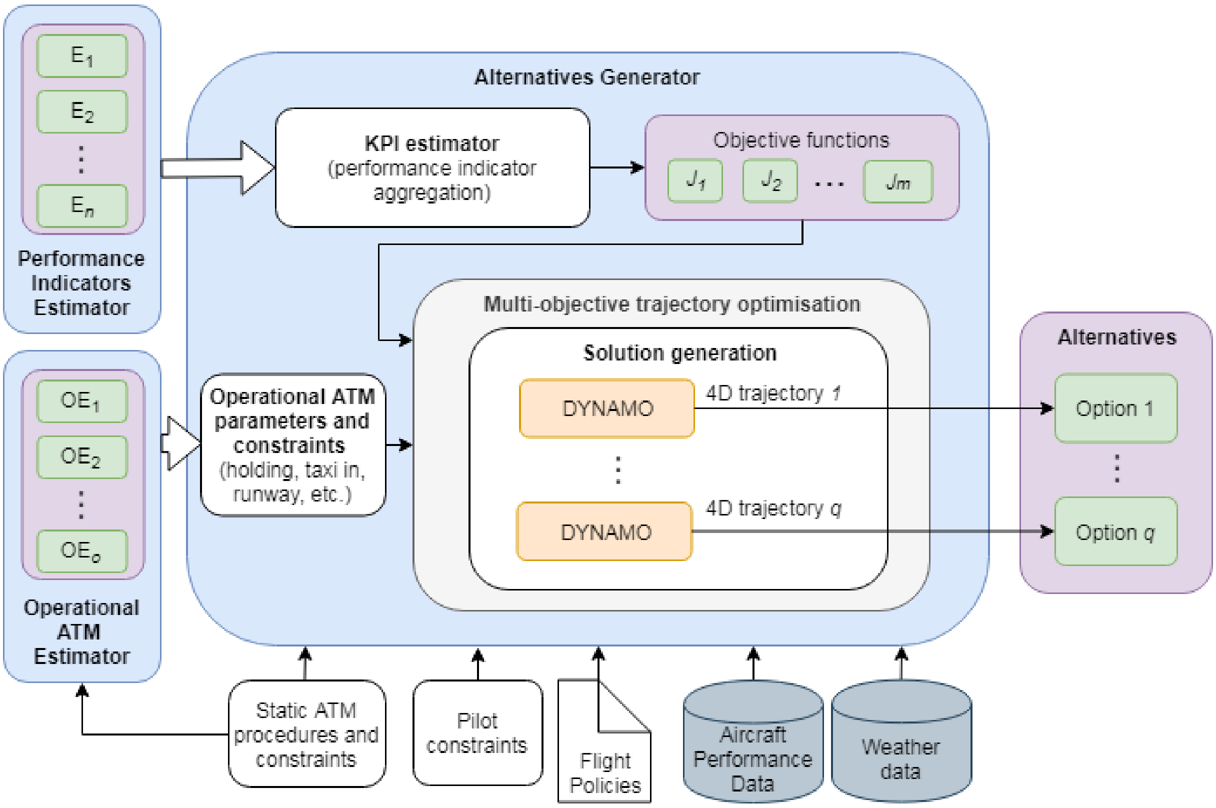

Figure 7. Alternative Generator diagram

2.2.3.1 DYNAMO: Aircraft 4D trajectory generation

The core 4D trajectory generation module is DYNAMO, an aircraft trajectory prediction and optimisation engine capable to rapidly compute trajectories using realistic and accurate weather and aircraft performance data. DYNAMO is based on an aircraft point-mass model (3 degree of freedom) and its design enables it to be used on real-time applications and/or when a large set of trajectories needs to be rapidly generated for simulation or benchmarking purposes. Moreover, DYNAMO is highly flexible and configurable, and allows the user to easily specify a great variety of constraints and objective functions.

DYNAMO decouples the generation of the lateral and vertical profiles. The lateral trajectory (route) prediction/optimisation module is in charge of generating the sequence of waypoints from origin to destination (i.e., the route), starting from some guess altitude and speed profiles. Subsequently, the vertical profile prediction/optimisation module is launched assuming a fixed and known route. This process is iterated several times until an acceptable (optimal) trajectory is found. For the lateral optimisation, DYNAMO uses an A* algorithm, a well-known method to find the optimal path in a graph.

For the vertical optimisation, an optimal control problem is formulated and can be solved with two different methods: discretising the problem and solving it by using commercial-off-the-shelf nonlinear programming (NLP) solvers; or using pre-computed look-up tables, which can be generated with DYNAMO as well or taken from an external source. The former approach allows more flexibility to define complex optimisation constraints, but might present algorithm stability issues due to the problem non-linearities. In this context, the latter approach is much more stable and robust, allowing as well to speed-up the computation time, making it appealing for on-board real-time applications. However, defining constraints might be complex. Depending on the application, DYNAMO can be configured to use one method or the other, or even a hybrid approach. The exact modelling approach used in DYNAMO will be decided as part of the activities of WP4.

The required inputs for DYNAMO are grouped and summarised as follows:

- **Aircraft performance data**: DYNAMO can accept different aircraft performance models, such those developed by EUROCONTROL in the BADA v3.x or BADA v4.x models; data derived by performance tools provided by aircraft manufacturers (such as Airbus PEP or Boeing BCOP); or data directly coming from flight tests. In this context, a virtue of DYNAMO is that it accepts performance data in tabular form and it automatically and transparently handles these data to generate numerically friendly continuous and differentiable functions (using splines), which are required by most NLP solvers.

- **Weather data**: DYNAMO can predict/optimise aircraft trajectories using weather models of various complexity, from the International Standard Atmosphere (ISA) or Hellmann wind power-law models, useful for initial assessments or benchmarking, to real weather data provided in GRIdded Binary (GRIB) format, which is also handled automatically to generate continuous and differentiable functions for the NLP solvers.

- **Airline or pilot parameters/constraints**: including basic parameters such as the cost index, payload or flight plan restrictions/preferences; or more complex structures such as a user-defined objective function.

- **Operational ATM parameters and constraints**, specifying how the route and the vertical trajectory can be generated, intimately linked with the ATM concept of operations in place. These can be of different nature, from static constraints such as structure route networks, free route areas, flight level allocation and orientation schemes, route or altitude availability/constraints, terminal airspace procedures, etc.; to more dynamic constraints that could materialise in-flight, such as air holding, tactical path stretching by ATC etc.

For more details on DYNAMO see [3], and the references therein.

2.2.3.2 KPI estimator

Considering the airline definition of their performance indicators, the KPI estimator will combine the individual estimators provided by the Indicators Estimator in order to generate the performance indicators that should be considered by the optimisation engine. For instance, a KPI of passenger cost due to delay could be composed of the addition of two indicators: one capturing hard costs and one estimating soft costs. Hence, the airline policy mix, the list of available PIs plus their estimated confidence/accuracy levels provided by the Indicators Estimation module. The detail of the interface between the estimators and the optimiser will be defined as part of WP4. The estimators should be fast enough to allow the optimiser to evaluate the trajectories.

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2.2.3.3 Operational ATM parameters

As presented before, some of the indicators will be based on the total arrival delay and fuel consumption. Therefore, it is paramount to consider ATM operational parameters such as expected holding time or taxi-in time. This is also required to avoid solutions where, for example, fuel is saved by slowing down and then delay is introduced by unplanned holding time. The Operational ATM parameters will use the information provided by the Operational ATM Estimator to generate these required parameters, that will be modelled as trajectory constraints in Dynamo.

2.2.3.4 Multi-objective trajectory optimisation

In a multi-objective optimisation problem, one might have a set of Pareto optimal solutions (i.e., solutions equally acceptable from a mathematical point of view) and manually assessing all trade-offs arising from various KPAs might be a complex and time consuming task that the pilot cannot afford during flight. A **first automatic selection of candidate solutions** to be presented later to the aircraft crew is thus interesting to reduce pilot workload.

As described earlier (see Section 2.1.2.2), the total number of objectives that will be considered in Pilot3 might be small. This analysis is part of the activities carried out in WP2. One possibility is to consider the optimisation of one criteria (cost) with and without forcing the achievement of the second objective (on-time performance).

When optimising the trajectories, different optimisation alternatives might be available (a simple example of two trajectories which provide equivalent outcome is the avoidance of a region by the left or the right, assuming the effect of the wind is the same). This means that the trajectory optimisation will have to produce a set of alternatives. Note that in some cases, if thresholds or rounding in the indicators are introduced (consider the fuel consumption at a resolution of ten kilograms, or arrival delay at a resolution of one minute, for instance), the number of potential trajectories which are equivalent might increase. Mathematically speaking, this first automatic decision-making process can be interpreted as an a priori selection of a subset of Pareto optimal solutions.

Finally, Pilot3 is considering the modelling of uncertainties (see Section 2.3.1). These uncertainties impact the trajectories (e.g., time required to reach the arrival destination, or total fuel that will be consumed) and also the outcome of those trajectories on the airlines' indicators. With these considerations, different alternatives could be considered statistically equivalent increasing the pool of alternatives to be considered for their presentation to the pilot.

Another option to increase the number of alternatives to display to the pilot is to force the trajectory optimiser to produce a minimum number of distinct trajectories, even if they cannot be considered equivalent from an optimisation point of view. This will allow the exploration of more alternatives by the pilot, but the avoidance of bias on the generation of these alternatives might difficult.

2.2.4 Performance Assessment Module

Once the subset of alternatives has been generated by the Alternatives Generator module, the Performance Assessment will rank them and perform the selection process of a solution.

2.2.4.1 Alternatives ranking

If different alternatives generated by the Alternatives Generator can be considered equivalent, flight policies might be taken into account in order to rank and filter them. This first post-processing is performed in order to pre-compute how the alternatives will be presented to the pilot. One possibility is that the Alternatives Generator creates a large set of solutions but only a subset of sufficiently different alternatives is presented; if alternatives are dismissed by the pilot, then follow-up alternatives can be shown.

2.2.4.2 Selection process

The information on the trajectories and their impact on the different indicators which are relevant for the airlines will be presented to the pilot via the Human Machine Interface system. Then, the pilot will be able to interact with the Performance Assessment, rejecting solutions or, based on the information provided, adding new constraints and requesting a re-evaluation of the alternatives.

This overall process can be seen as a **second multi-criteria decision making problem**, this time however, allowing an interactive assessment of the solutions by the aircraft crew. Different multi-criteria optimisation methods could be considered for this phase, as this exploration of the alternatives can be considered as a discrete multi-criteria optimisation problem. WP2 will present the analysis of the available optimisation methods and indicate which one is selected for this particular problem.

One of the requirements that will be guaranteed is that the info**rmation provided to the crew should be simple** and, as much as possible predictable in its presentation, so that the pilot can easily understand the different trade-offs and make an informed decision.

Insight from Advisory Board consultation
It was deemed important that the pilot should maintain some freedom to select the alternatives and to add constraints/preferences during this process.

2.2.5 Human Machine Interface and system interfaces

Pilot3 will design an HMI to the prototype so that the pilot could interact with the system. The final definition of the interface will be dependent on the feedback and requirements obtained from the interaction with the airlines and from the requirements on the multi-criteria decision making techniques selected in WP2.

The first suggestion of Pilot3 is to present a small set of alternatives to the pilot. An indication will be given on how close they are with respect to the airlines business objectives (airline policies) so that the pilot can understand the trade-offs existing among them.

Insight from Advisory Board consultation
It is indicated as significantly desirable to present to the pilot information on the expected impact of the alternatives on cost indicators such as the ones due to passengers' disruptions.

Whilst the human interface is only designed in Pilot3, depending on this design a set of software interfaces will be specified and implemented. These interfaces will allow each of the modules of Pilot3, or the whole decision making software engine, to be integrated on different architectures. Pilot3 will provide an Application Programming Interface (API) to facilitate this integration or rely on serialised file exchange like (B)JSON or YAML, all of them supported by Pilot3 platform, namely DataBeacon (see Section 2.3.2).

2.3 Other methodological issues

2.3.1 Considering uncertainty

There are different levels of uncertainty that should be considered in Pilot3:

- **Uncertainty on the trajectories**: this uncertainty is driven by the environment in which the flight operates (e.g., weather, holding times, taxi in times). Some of these parameters will reduce their uncertainty as the flight progresses (e.g., which STAR and runway in use will be communicated by ATC at some point during the flight, a new weather forecast update might be available in-flight). Pilot3 will consider some of these uncertainties thanks to the introduction of the Operational ATM Estimator. As discussed, even if much of this uncertainty is linked with the operations in the arrival TMA, the Operational ATM Estimator does not limit its scope to this phase but to all operational changes which might affect the trajectory in terms of flown distance or extra time (e.g., holdings).

- **Uncertainty on the performance indicators**: as described, the actual value of some indicators is unknown until the end of the day of operations (e.g., if the final flight of the day will be affected by a curfew). Therefore, there is uncertainty on the expected performance that will be achieved with different trajectories.

The consideration of these two levels of **uncertainty is an addition to the proposal that is considered relevant at this stage of the project**. The uncertainty will potentially increase the number of alternatives which are equivalent from a Pareto point of view (e.g., achieving equivalent costs from different sub-indicators, such as passengers or fuel). The modelling of the uncertainty also introduces new considerations such as robust optimisation and risk aversion, which could be explored. This could lead to the emergence of new multi objective optimisation trade-offs where not only the (expected value of) KPI is considered, but also its statistical variance, or the probability to fall above a certain (unacceptable) threshold, etc.

2.3.2 Data and computing infrastructure: DataBeacon

Pilot3 will use DataBeacon as a data and computing infrastructure. DataBeacon is a multi-sided data platform (MSP) for aviation data and data-driven applications. It matches among aviation stakeholders, research institutions and industry interests and facilitates the exchange of information, thereby enabling value creation for all participants.

Different data owners and consumers of analytic services interact through DataBeacon and, using secure common exploitation of data, improve their performance among various aspects of their business. Private environments hold the data but are not accessible by applications or analysts directly.

Instead, data is consumed by the Secure Data Fusion (SDF) technology. One of the major advantages of the SDF technology is being able to merge private data from different sources using secure cryptographic techniques. This enriches each isolated data set by combining multiple sources of data, while also respecting the privacy of the data owners.

The DataBeacon platform provides analysts a fully featured, hassle-free, updated and secured set of tools to develop **data driven applications right out of the box**. The front-end application of DataBeacon for analysts consists of an on-demand cluster of distributed instances that contains an updated repository of data science tools, adapted over the popular Anaconda, and an easily accessible datalake that enables big data storage. Despite the complexity of the platform, it can be accessed with a secure SSL connection on any compatible internet browser with zero set-up time.

In order to maximise cost-effectiveness, DataBeacon is deployed using the state-of-the-art solutions in the cloud. The flexibility of the cloud allows the platform to adapt dynamically to the demand, without having to commit to purchase any hardware, which is the core of current business models in the industry. Also, the cloud services comply with the highest standards on security, both physical and virtual, which also allows DataBeacon to comply with regulations.

Pilot3 will use DataBeacon as a mean of storing and sharing information between Pilot3 and the AOC. This will allow in the future, to exploit those datasets to enhance the machine learning predictors. Some of the datasets available in DataBeacon for Pilot3 include meteorological data, airspace sectorisation, navaids, airport data and ADS-B (see Section 4 for more information on identified preliminary datasets).

2.3.3 Stakeholders interaction

Pilot3 relies on continuous interaction with airlines. An Advisory Board has been established with airlines (Norwegian, SWISS, Vueling, AirBaltic), experts, EUROCONTROL and industry (A3 Aviation Consulting and Salient), which will be consulted on the project evolution. The Advisory Board is open to incorporate new members, particularly at the start of the project.

A first Advisory Board meeting has already taken place (February 7th, 2020) to gather information on flight policies and to discuss the definition of preferences between performance indicators. Further consultation is already planned to validate the selected approach and to help us identifying the case studies that will be modelled.

If required, site visits are planned to discuss technical details on the implementation of the prototype.

Validation activities will be carried out presenting the prototype to airlines in a one-to-one interaction but also as part of a workshop (in order to include the view of airlines and stakeholders, e.g., pilots, which are not part of the Advisory Board), once the first prototype is created.

2.3.4 Verification and validation

Two types of verification and validation activities will be carried out during the duration of Pilot3: internal and external. The internal activities involve the members of the consortium and the Topic Manager. They will be performed during the development of the prototype. Once a first version is available, external validation of the tool will be done with the input from airlines from the Advisory Board and in a dedicated workshop.

Pilot3 will be validated in with a dedicated set of activities involving **external experts**, mainly from airlines. Moreover, some of the functionalities of Pilot3 could be incorporated to a **fast time simulator** (FTS) in order to assess the performance of the system under different case studies, the extend of this will be defined as part of WP5. This activity will, however, not be prioritised since the main objective of Pilot3 is to develop a prototype that can be validated with human interaction. For this reason, the definition of representative case studies is paramount, see Section 6 for the preliminary definition of these case studies.

Pilot3 could be incorporated in a fast time simulator in order to assess its performances. The project could rely on **Mercury**. Mercury is a pre-tactical/tactical mobility model which considers flights and passengers itineraries. It has been developed by Innaxis and the University of Westminster in successful projects (POEM, ComplexityCosts, Vista and Domino). In its current version it is developed as an agent-based system which incorporates the activities of AOCs. The modularity of Mercury and its agent-based approach could allow us to incorporate Pilot3 as a mechanism to be used by the AOC and the flight agents. This has two advantages:

- Pilot3 incorporated in Mercury could allow human in the loop simulations where the AOC has information on passenger itineraries and connections, and
- it allows fast time simulations to assess the performance of the system, i.e., how the indicators improve thanks to the use of Pilot3.

The mobility model of Mercury, however, has limitations as, in order to be able to model a whole day of operations in Europe with flights and passengers, many design assumptions and simplifications are necessarily considered. This is not an issue when the overall performance of the system is to be assessed but could be problematic when specific flights are simulated.

As presented, we consider the inclusion of Pilot3 within Mercury not a priority for the project and focus will be given to estimate operational metrics from the solutions generated ton increase the acceptability and validation of the tool with interaction with experts and the Advisory Board. Mercury could, on the other hand, be used to generate synthetic data which could be used as part of the training of machine learning models for the estimation of performance indicators.

2.4 Considerations on Pilot3 and the ATM operational concept

The ATM operational environment where Pilot3 will be integrated should be considered. As described, Pilot3 is a decision support tool for pilots, which focuses on the flight phase. Activities prior departure are out of the scope of this project. The performance indicators consider operations until the arrival at the gate, but the trajectory optimiser focuses on the trajectory until landing.

2.4.1 Current ATM system

The capabilities and limitations of the current ATM system are captured in Pilot3 from the interaction with stakeholders. Moreover, operational constraints will be incorporated to ensure the feasibility of the different trajectories that are generated. One key feature that is currently not enforced are the Controlled Time Over/Controlled Time of Arrival (CTO/CTA); this allows some flexibility to the operations but might result on suboptimal decisions and larger uncertainties (e.g., flying faster to arrive to a holding in the TMA). This highlight the relevance of the inclusion of the Operational ATM Estimator.

The operational context within-Europe is relevant but limiting the potential usage of a tool such as Pilot3 (e.g., relatively short flights on rigid structured airspace). Pilot3 might benefit from operational context where more flexibility is available (e.g., free route airspace in northern Europe, oceanic airspace).

2.4.2 Future ATM system – Pilot3 and ATM modernisation programmes

Insight from Advisory Board consultation

The Advisory Board highlighted the need to analyse how a tool such as Pilot3 could be incorporated in the next operational concepts as defined for SESAR and NextGen.

2.4.2.1 New concepts of ATM programme worldwide

According to ICAO [12], aviation transport directly and indirectly supports the employment of 58.1 million people, contributes over $2.4 trillion to global Gross Domestic Product (GDP), and carries over 3.3 billion passengers and $6.4 trillion worth of cargo annually. Despite economic crisis and other turmoil, the global air traffic has doubled in size every 15 years since 1977 on global level and this trend is likely to continue in the future. To accommodate the sustainable air traffic growth, modernisation of Air Traffic Control (ATC) system worldwide is of vital importance and aims at enhancing safety, increasing Air Traffic Management (ATM) capacity and efficiency, reducing fuel consumption and other environmental impact per flight and eventually, reducing ATM costs to users.

The Europe's Single European Sky ATM Research (SESAR) and the United States' Next Generation Air Transportation System (NextGen) are among the first developed and implemented programmes that conceptualise the recent advances in ATM and advances in avionics technology. Both programmes share the common goals built on the notion of trajectory-based operations (in contrast to current airspace centric paradigm), dynamically managing flights on an end-to-end time basis and enabling airspace users to fly their preferred flight trajectories [8]. In order to achieve this ambitious goal, the ATM system will face the digital transformation of the underlying infrastructure system requiring the satellite-based navigation and specific level of automation and connectivity between stakeholders.

The countries of Asia-Pacific have also launched various initiatives in order to be in a line with major participants in ATM modernisation programme – the U.S. Federal Aviation Administration and the Single European Sky ATM Research Joint Undertaking (SESAR JU). The Japan Civil Aviation Bureau (JCAB) proposed its solution to future ATM challenges in its Collaborative Action for Renovation of Air Traffic Systems (CARATS), whereas Australia developed OneSKY programme to effectively derive the benefits from new Civil Military Air Traffic Management System (CMATS). In China, the corresponding action is the ATMB Strategic Development Programme.

a. SESAR Joint Undertaking programme

The core of SESAR programme resides in Trajectory Based Operations providing "high predictability and accuracy of the trajectory, which allows a seamless process from planning to execution and a seamless process from gate-to-gate based on information sharing, with airborne and ground actors sharing consistent information throughout the Business Trajectory lifecycle."[17]. In this way, airspace users will be enabled to design its trajectory based on company policy and business models, for example using the User Driven Prioritisation Process (UDPP).

In order to effectively bridge the gap between airspace users' requirements in terms of preferred trajectories and ATM capabilities, SESAR launched the Optimised Airspace User Operations project

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(PJ07 – OAUO) as a part of industrial research and validation project. The aim of PJ.07-01 ("Airspace user processes for trajectory definition") is "to fully integrate the Flight Operations Centre (FOC) into the ATM network process through improved interaction tools, which will deliver improved collaborative decision making throughout the trajectory lifecycle. This includes defining and validating an iterative trajectory planning process for each flight covering the creation of the trajectory, update, negotiation, and agreement." [19]. The further development of the mentioned processes will be realised in the second wave of SESAR industrial research projects that have been initiated at the beginning of 2020 [18]. Although all these processes refer to the pre-tactical level of flight planning (i.e., dispatch), their aim is to provide more flexibility to airspace users (AUs) to incorporate specific policy and priorities into the requested trajectory, without compromising the performance of the overall ATM system.

b. Trajectory definition

The SESAR ConOps [17] distinguishes three different types of trajectories for the planning stage of the flight and engagement of the stakeholders in the system (see **Figure 8**):

1. Business Development Trajectory (BDT) – BDT exists during Business Development processes and is internal to the user,
2. Shared Business Trajectory (SBT) – SBT is the trajectory published by the Airspace User that is available for collaborative ATM planning purposes. The refinement of the SBT is an iterative process. The final form of the SBT becomes the Reference Business or Mission Trajectory (RBT) and is part of the filed flight plan,
3. The Reference Business Trajectory (RBT) – RBT is created from the last version of the SBT. **It is the trajectory that the Airspace User agrees to fly and that the ANSP and Airport agree to facilitate**. It is associated to the filed flight plan and includes both air and ground segments. It consists of 2D routes (based on published way points and/or pseudo waypoints computed by air or ground tools to build the lateral transitions and vertical profiles); altitude and time constraints where and when required; altitude, time and speed estimates at waypoints, etc.

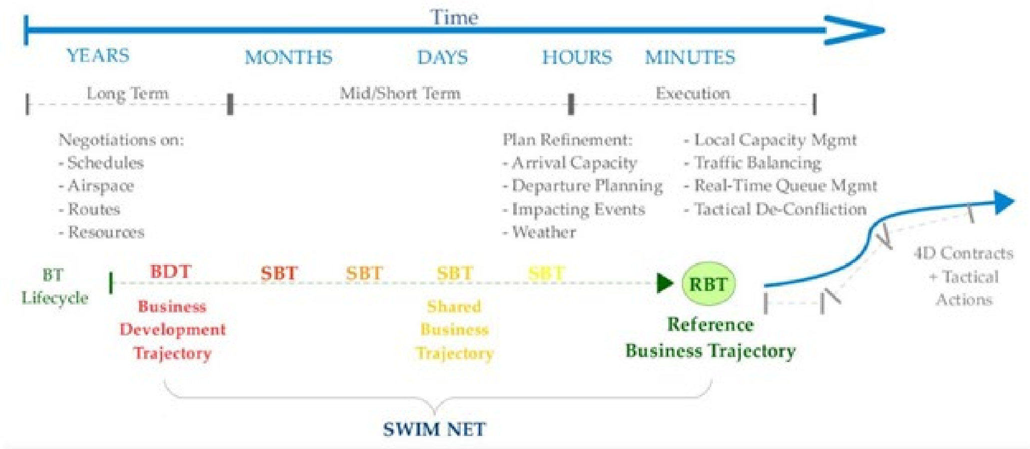

Figure 8. Business Trajectory Life-Cycle (Source: [16])

In order to better understand the RBT revision process it is important to identify the four sub-clusters within RBT:

- **The Cleared Trajectory Data**: the route/pre-defined points and altitude/speed/4D constraints (constraints refer to parameters that the flight has to comply with during the execution phase, such as speed and altitude constraints during Standard Instrument Departure (SID), Standard Terminal Arrival Route (STAR), Controlled Time Over (CTO)/Controlled Time of Arrival (CTA)); these data correspond to the inputs to the on-board navigation system and represent the trajectory that is anticipated to be executed by the flight. Unless for safety reason (at Air Traffic Control Officer (ATCO) or Flight Crew initiative only), **any modification of these data have to be made through RBT revision process** (preferably through Collaborative Decision Making (CDM) encompassing the acknowledgement of the relevant Clearance or Instruction by the Flight Crew.

- **The Supporting Data: all other trajectory data including**

    - Consolidated time estimates and flight levels at waypoints as well as at air or ground computed points, which are predicted by onboard avionics or by ground tools

    - the 4D targets and their tolerance window (merely at constrained points/hotspots) as identified during the planning phase and updated/revised during the execution phase, as well as those that may be created during the execution phase.

- **The Temporary Supporting Data**: Such data, of a temporary nature, are created and are used by the ground systems when the trajectory has already been modified and agreed amongst the ground actors, but does not yet have been communicated to and approved by the Flight Crew. Such data may be used by the downstream Air Navigation Services Providers (ANSPs). These are anticipated to amend the “cleared trajectory data” as well as, when relevant, related “supporting data” once the revision process is finalised.

- **Airport Milestones at the Aerodrome of Departure (ADEP) & Aerodrome of Destination (ADES)**: The ground routing is expected to remain local, unshared; however, the milestones will be shared and timely updated in function of the situation at the airport (e.g., ground routing and delays).

c. RBT revision process

In the context of Pilot3, it is important to understand the possible set of actions which can be performed by the pilot during the execution phase of flight in the light of possible RBT revision.

As mentioned above, **the first instantiation of the RBT flight profile** contains in particular the 3D trajectory respecting the planning constraints (and Target Start-up Approval Time (TSAT)/ Target Take-Off Time (TTOT) with related tolerance windows at the ADEP).

The Flight Crew is made aware of specific conditions leading to the selection of the agreed trajectory.

When airborne the Flight Crew will respect, as per ICAO, the [3D + the speed] profile as "filed and revised". In function of the circumstances, the Flight Crew may either opt for:

- "Fly as filed" or
- adjust the flight parameters (if need be) in order to remain within the current and active target window[2].

The RBT revision process is described in detail in the RBT Revision Process of the SESAR ConOps [17]. As stated, the revision of the RBT is a process "to address a need or request for change in specific elements of the RBT data currently shared in the System Wide Information Management (SWIM) environment. This process is associated to a need for a decision to be made by two or more stakeholders". When time permits and specific conditions are met, the RBT revision request is processed through CDM "addressing a new proposal, its related impact assessment, negotiation, leading to an agreement and its implementation".

In the context of revision process, SESAR ConOps [17] identifies the triggers that initiate the RBT revision process during the execution of the flight and are as follows:

- A significant deviation or predicted deviation of the flown trajectory from the RBT (out of tolerances).
- A constraint affecting the RBT or triggering the need for new target window or a modification of an existing target window.
- **A request to change the RBT for optimisation reasons**.
- The need to modify the cleared trajectory for reasons such as weather or other urgent operational reasons (e.g., diversion or critical event), as well as the need to provide separation, organise a queue for a constrained resource (e.g., runway), or due to a new operational constraint (e.g., airspace segregation or runway change).
- A need for NMF intervention, e.g., Short Term Air Traffic Flow and Capacity Management (ATFCM) Measure (STAM).

The following events can serve as examples that trigger an RBT revision process and are listed below, starting with a proposal for change:

1. **When the Flight Crew cannot maintain the cleared trajectory, (e.g., due to a change in weather conditions)**.
2. When ATC cannot facilitate the cleared trajectory as described in the RBT, (e.g., due to reasons relating to flight safety).

[2] **A flight Crew should initiate a trajectory revision** for this adjustment, **unless the change stays within the ICAO limitations** (e.g., changing the speed by less than 5%)) [16].

3. When ATC detect a deviation from the aircraft position/flight prediction with the "Cleared Trajectory Data" of the RBT.

4. After consistency check, for the resolution of a discrepancy between airborne and ground data by the relevant Air Traffic Services Unit (ATSU).

5. When a new constraint is being created or is being modified (the originator of the constraint in the Network Management Function (NMF) triggers the revision).

6. **When change of AU business needs or in order to benefit from new opportunities in case of removed constraints have a significant impact on the trajectory.**

7. After determining that a target tolerance has not been, or will not be met, the NMF performs a workload assessment on the network impact; suitable mitigation is determined which may include RBT revision if necessary (and may affect multiple flights). Alternative measures may be possible, e.g., sector splitting or STAM which may themselves lead to trajectory revision.

An RBT revision process ends when the final decision is made and, in case of modification of related Cleared Trajectory data, when the Flight Crew acknowledge the trajectory change.

Based on the events that trigger the RBT revision process, it is likely that Pilot3 can play a significant role in the future ATM environment by supporting the pilot with a possible set of actions to mitigate the unexpected deviation from the RBT trajectory. Pilot3 can be particularly useful in the future ATM concept in the case of an unexpected event and/or meteorological conditions by providing the pilot a set of alternative routes to mitigate the deviation from the RBT trajectory.

d. Controlled Time Over/Controlled Time of Arrival (CTO/CTA)

The Controlled Times (CTO/CTA) is described in detail in the SESAR ConOps [17]. Controlled Times (CTO/CTA) are "ATM-imposed time constraints which can be imposed during the flight in order to manage airspace access, to sequence for positioning over intersecting points over approach metering fixes in TMAs. As these constraints can be achieved by the flight with high accuracy (i.e., a few seconds) they enable performant metering and precise sequencing. The Trajectory Management of merging traffic flows at metering points supports new terminal airspace designs and optimises multiple airport arrival and departure services."

2.4.2.2 North Atlantic Tracks (NAT)

The link between Europe and North America is perceived as the most mature and busiest oceanic space in the world. Additionally, the passenger flow to/from North America and Europe are ranked in fourth place with 579 billion RPK realised in 2018 [2]. According to ICAO, approximately 730,000 flights crossed the North Atlantic in 2017 (ref NAT SPG/54 – WP/08 - OUTCOMES OF NAT EFFG/33 AND NAT EFFG/34) [14]. The ATS surveillance and Director Controller Pilot Communication are unavailable in the most part of the airspace of North Atlantic and thus the highest standards of horizontal and vertical separation must be ensured.

Nowadays, much of the North Atlantic (NAT) air traffic is the part of two major alternating flows: a westbound flow departing Europe in the morning (between 1130 UTC and 1900 UTC), and an eastbound flow departing North America in the evening (0100 UTC and 0800 UTC). This pattern flow results from passenger demand, time zone differences and airport noise restrictions [1413]. The similar flows exist between Asia and the west coast of North America organised in the Pacific Organised Track System (PACOTS).

The large horizontal separation constraints combined with limited economical band of flight levels (FL 310-FL 400) available to the airspace users cause the airspace congestion during the peak hours. Therefore, organised track structures (NAT-OTS), one for eastbound traffic and one for westbound traffic are established as an appropriate solution to effectively manage the airspace congestion. A large portion of the airspace of the NAT is designated as the NAT High Level Airspace (NAT HLA) between FL 285 and 420 inclusive and NAT separation of 60 NM (see **Figure 9**).

For the purpose of optimising airspace users' trajectories, the track structures are published on daily basis as they consider the daily variation of NAT weather conditions, locations of pressure systems and jet streams. In this way, airspace users flying specific NAT can benefit from substantially reduction in fuel cost and other operating costs. However, the airspace users that use a NAT are obliged to meet minimum equipment capabilities and certifications (Reduced Vertical Separation Minimum (RVSM) certification and with Minimum Navigation Performance Specification (MNPS) capability). The airspace users are obliged to fly the NAT that has been assigned to them by ATC, although in some cases, these NAT can be different from the NAT initially filed by airspace users [22].

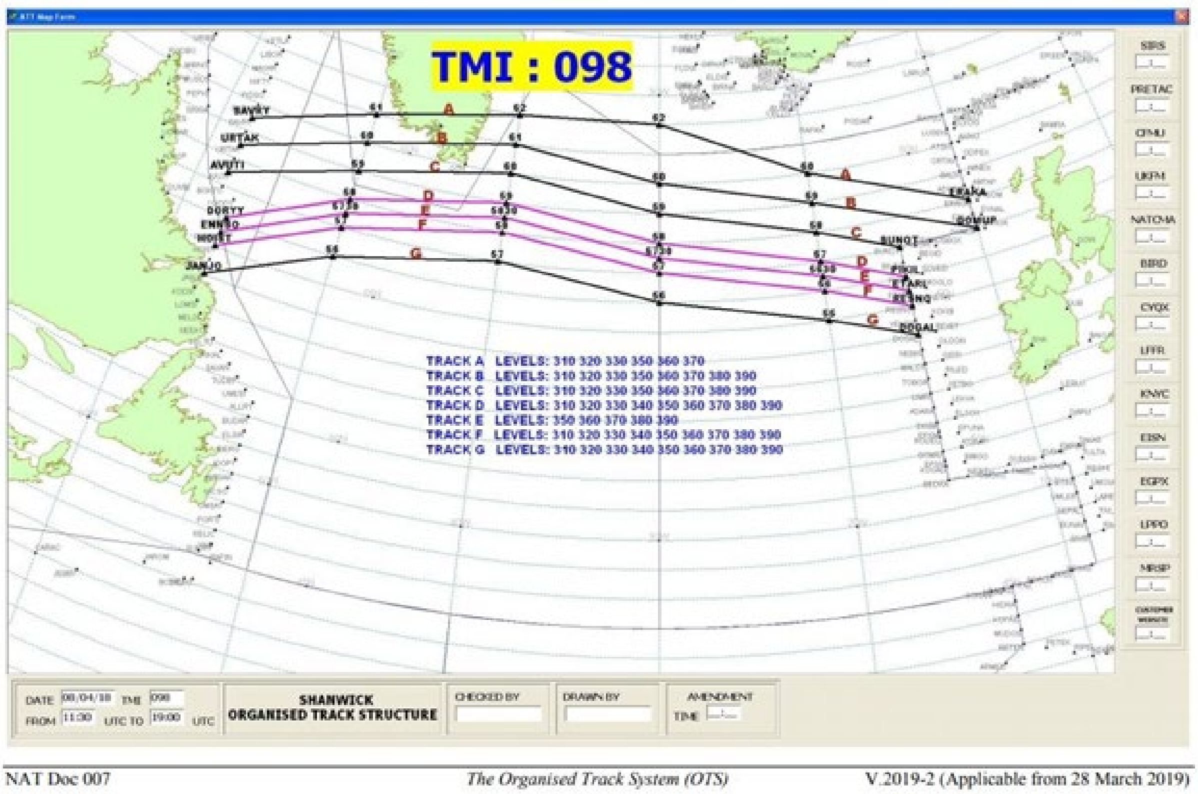

Figure 9. Example of Day-Time Westbound NAT Organised Track System (Source:[14])

a. Modernisation of NAT-OTS

It is worth mentioning that "NAT HLA" is a re-designation of the airspace formerly known as the "North Atlantic Minimum Navigational Performance Specifications Airspace (NAT MNPSA), it represents one third of the milestones of the “MNPS to Performance Based Navigation (PBN) Transition Plan” for the North Atlantic region and it has been effective from February 2016 (ICAO, 2019). In the light of ongoing NAT transformation and modernisation, Reduced Lateral Separation Minimum (RLatSM) is introduced on the trial basis that aims at reducing the lateral separation between the core tracks from 60 NM to 25 NM, which will substantially increase the NAT capacity.

These inserted “half-tracks” are currently available at flight levels FL 350 to FL 390, as opposed to the regular tracks that are available from FL 290 to FL 420. In addition to RLatSM implementation, the capacity of current NAT can also benefit from the introduction of Reduced Longitudinal Separation (RLong) programme that reduces the longitudinal separation between planes on the same track based on time. As of March 2018, ICAO combined the RLatSM and RLong into Performance Based Communication and Surveillance (PBCS) that requires the airplane to be equipped with additional Automatic Dependent Surveillance-Broadcast (ADS-B) system. Once the PBCS NAT comes fully into the effect, the NAT airspace will be very similar to a radar-controlled environment.

It is worth emphasising that the on-going enhancement in NAT HLA airspace could potentially open the broader space for using Pilot3 in the oceanic airspace. Transforming the NAT HLA airspace into more radar-controlled like environment will provide the opportunity for pilots to have more flexibility in changing altitude/speed profile during flight execution phase. Thus, Pilot3 could be a particularly useful tool in selecting an alternative route in the case of unexpected events or in the case of absorbing flight delay occurred at the departure airport, for instance.

2.4.2.3 Aviation CO_2 emission and market-based measures

Concern of policy makers regarding aviation's environmental impact has increased over the last decade. In order to promote the sustainable and green transport sector and combat the climate change, the European Union included the aviation sector in the European Union Trading Scheme (EU-ETS), from 1st January 2012 with the Directive 101/2008/EC [4]. According to the European Aviation Environmental Report “in 2016, aviation was accountable for **3.6% of the total EU28 greenhouse gas emissions and for 13.4% of the emissions from transport**, making aviation the second most important source of transport GHG emissions after road traffic. Greenhouse gas emissions from aviation in the EU have more than doubled since 1990, when it accounted for 1.4% of total emissions. As emissions from non-transport sources decline, the emissions from aviation become increasingly significant. **European aviation represented 20% of global aviation’s CO_2 emissions in 2015**.” However, achieving the substantial reduction of CO_2 in aviation sector is very difficult to sustain due to the relatively large aircraft lifespan of 25 years and the constantly increase in air travel demand.

According to the Directive 101/2008/EC, all flights arriving at and departing from an airport located within the European Economic Area (EEA) must be covered by the EU-ETS, regardless of the airline nationality [4]. The Directive has raised unfavourable reactions among non-European airlines, aviation lobbies and some European policy makers. The non-European airlines were concerned about an unlevel playing field, as they were subject to the Directive that caused additional costs whereas the European airlines were exempted from additional emission charges in their respective countries outside the EU. Consequently, the European Union suspended the Directive 2008/101/EC by introducing the set of actions (the “stop the clock” derogation of 2013 (Decision 2013/337/EU) [6] and the Regulation 2014/421) [15].

In order to offer a single global market-based measure by 2020, “in October 2016, the 39th General Assembly of ICAO Contracting States **reconfirmed the 2013 objective of stabilising CO_2 emissions from**

international aviation at 2020 levels. In addition, the States adopted Resolution A39-3, aiming to introduce a global market based measure, namely the 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA) [13], to offset international aviation's CO_2 emissions above 2020 levels through international credits [13]." The CORSIA will be applicable to "all aeroplane operators with international flights producing annual CO_2 emissions greater than 10,000 tonnes from aeroplanes with a maximum take-off mass greater than 5,700 kg, regardless of whether their administering State is participating or not in the offsetting phases, will be required to monitor, verify and report their CO_2 emissions during 2019 and 2020. **The average yearly CO_2 emissions reported during that period will represent the baseline for carbon neutral growth from 2020. Beyond 2020, the aviation sector will be required to offset its international CO_2 emissions above this level**." [9].

In 2008, global stakeholder associations of the aviation industry (Airports Council International, Civil Air Navigation Services Organization, International Air Transport Association and International Coordinating Council of Aerospace Industries Associations), agreed that reductions in CO_2 can be achieved through a four-pillar strategy:

- Improved technology, including the deployment of sustainable low-carbon fuels;
- **More efficient aircraft operations**;
- Infrastructure improvements, including modernised air traffic management systems; and
- A single global market-based measure, to fill the remaining emissions gap.

It is worth mentioning that additional 5.8% gate-to-gate CO_2 emissions was recorded at the European level in 2017 as the result of the deviation of actual gate-to-gate trajectories from their respective unimpeded trajectories[3]. According to the European Aviation Environmental Report [9], the average excess CO_2 emissions has remained stable over the last 6 years, even though traffic has increased. Bearing in mind the importance of reduction in excess CO_2, the Single European Sky (SES) Performance Scheme introduced two key performance indicators (KPIs) that measure flight horizontal flight efficiency, by comparing (essentially) the great circle (shortest) distance against the:

- trajectory in the last-filed flight plan (key performance environment indicator based on last-filed flight plan - KEP), and;
- actual trajectory flown (key performance environment indicator based on actual trajectory - KEA)

The SES Performance Scheme sets KEP and KEA binding targets at the EU level at 4.27% and 2.69% respectively. As observed from **Figure 10**, KEA has slightly worsened up to 2.83% in 2018 from 2.81% recorded in 2017, the increase probably stem from increased airspace restrictions, airspace user preferences and that constraints in capacity resulted in longer routes being offered and flown [21].

[3] Unimpeded trajectories are defined by SESAR as: zero additional taxi-out time, no level-off during climb (full CCO), no sub-optimal cruise level, en route actual distance equal to great circle distance, no level-off during descent (full CDO), no additional time in the Arrival Sequencing and Metering Area (ASMA), zero additional taxi-in time [9].

However, it is worth mentioning that KEP will be dropped as a KPI in Reference Period 3 (RP3), but retained as a Performance Indicator (PI) and obviously without binding targets required to be set up [10].

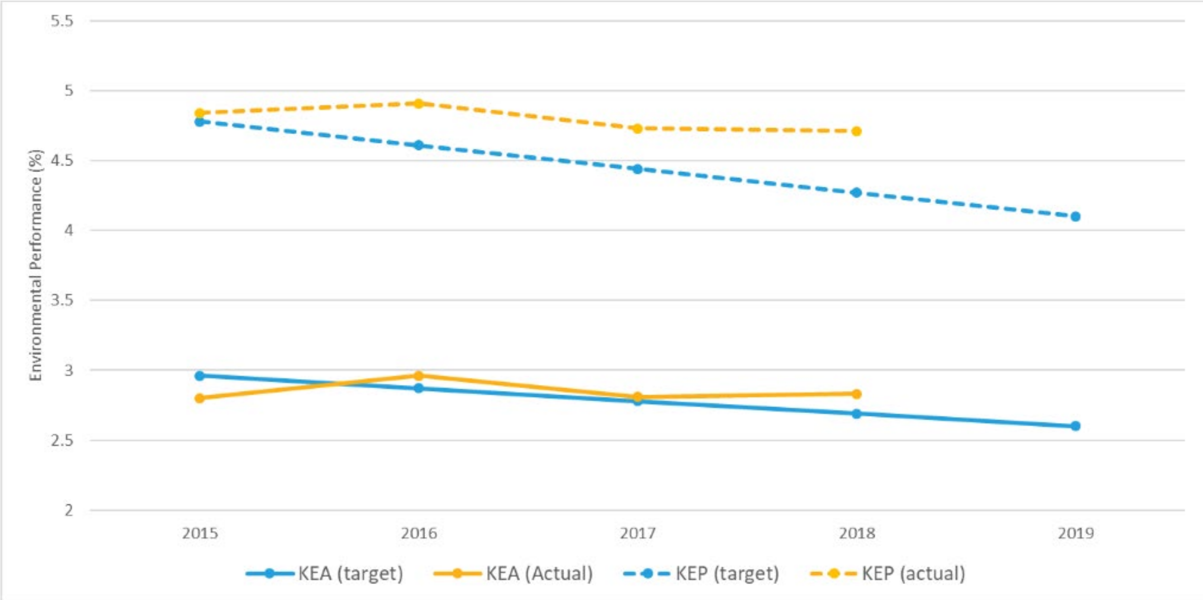

Figure 10. Actual (KEA) and planned (KEP) horizontal flight efficienciesagainst respective the second Reference Period reference values, highlighting the worsening performance from 2017 to 2018 (Source: [21])

European ATM Master Plan - 2020 edition (2019) ambition is to continue **reducing the additional gate-to-gate flight time per flight**[4] and **gate-to-gate CO_2 emissions** to reach maximum **relative improvements by 55% and 10% respectively by 2035 in comparison to baseline scenario (2012)**.

The introduction of the EU-ETS did not realise its full potential, as it lacks straightforward allowances allocation, effective implementation processes and complex monitoring, reporting and verification mechanism [5]. The overall impact of the EU-ETS on aeroplane operators within the EU remained limited in magnitude by contributing to 0.3% in total operating costs in 2017 and, as such, is unlikely to affect the airline operators towards more carbon-neutral operations. However, with ICAO's CORSIA set up as a single global market-based scheme based on the offsetting mechanism, the operators will be required to purchase offset credits in order to compensate for emissions exceeding the 2019-2020 baseline.

Bearing in mind the ongoing regulations towards a more carbon-neutral aviation, it is reasonable to expect that the reduction of carbon emissions will receive greater focus from operators in the future. This could be an important input for the Pilot3 project, as carbon emissions targets could be included as an additional constraint when generating alternative routes. As already discussed, the SESAR JU's ambition of reducing gate-to-gate CO2 emissions may have further implications on the constraints that

[4] "Additional" here means the average flight time extension caused by ATM inefficiencies [8].

should be considered in Pilot3. In this context, the deviation of the actual trajectory from its respective unimpeded trajectory may impose additional constraints on operations in the future.

3 High-level prototype requirements

This section comprises the high-level prototype requirements for Pilot3. Note that the detailed requirements for the different modules will be developed and captured as part of the activities performed in WP4 - Model development; Human Machine Interface requirements will be captured as part of WP2 - Multi-criteria decision making techniques, where Task 2.2: Interface requirements is devoted to this in order to ensure the input and feedback from the methodology used to perform the multi-criteria optimisation; and validation requirements will be captured in WP5 - Model verification and validation.

The section includes information on the structure of the requirements (Section 3.1), functional requirements (Section 3.2), no-functional requirements (Section 3.3) and domain requirements (Section 3.4).

3.1 Requirements structure

All requirements of Pilot3 prototype will be documented according to the format defined in Table 1.

Table 1. Format of requirements

Identifier	Version	<x.y>	SW release	<a.b>	Priority	{1,2,3,4,5}
Description	<text>					
Rationale	<text>					
Validation	<text>					
Origin	<text>					

- Identifier: P3-{FR,NFR,DR}-{SYS,IE,OE,AG,PA,HMI,INT}-nnn
    - P3: Pilot3 (fixed tag)
    - FR: Functional Requirement - NFR: Non-functional requirement - DR: Domain requirement
    - SYS: High level system - IE: Indicators estimator - OE: Operational ATM Estimator - AG: Alternatives Generator - PA: Performance Assessment - HMI: Human Machine Interface - INT: integration
    - nnn: 3-digit number initially increasing in steps of 10
- Version: identifies the version number of the requirement.
- SW release: identifies the software (SW) version of the release in which the requirements should be implemented.

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- Priority: 1 for highest priority, 5 for lowest priority for not-binding provisions.
- Description: usage of "shall" for mandatory requirements and "may" for not-binding provisions.

Note as the validation activities will be defined in WP5, the validation information is not provided for these preliminary requirements.

3.2 Functional requirements

Table 2. P3-FR-SYS-010

P3-FR-SYS-010	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** be manually configured by a human user (airline operator).					
Rationale	The user will be able to specify different static parameters and/or rules to configure the Pilot3 prototype according to the airline policies. This configuration would take place before the flight departs the gate and would be done by an expert operator from the airline (a dispatcher or similar).					
Origin	D1.1					

Table 3. P3-FR-SYS-020

P3-FR-SYS-020	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** be manually triggered by a human user (pilot).					
Rationale	This user would be a member of the flight deck crew who would launch the Pilot3 application in flight.					
Origin	D1.1					

Table 4. P3-FR-SYS-030

P3-FR-SYS-030	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** be triggered at any moment of flight from FL100 in climb down to FL100 in descent.					
Rationale	It is considered that below FL100 (either for departures/arrivals) the aircraft crew workload does not permit the usage of Pilot3. Moreover, once below FL100 in an arrival, there is not much flexibility left to modify the remaining trajectory and get significant changes in the performance indicators.					
Origin	D1.1					

Table 5. P3-FR-SYS-040

P3-FR-SYS-040	Version 1.0	SW release 1.0	Priority -
Description	When triggered, Pilot3 prototype **shall** automatically provide a set of alternative 4D trajectories down to the runway threshold.		
Rationale	Although not all the trajectory might be subject of optimisation, the trajectories delivered by the prototype will be described by a succession of 4D samples (longitude, latitude, pressure altitude and time) down to the runway threshold of the destination airport.		
Origin	D1.1		

Table 6. P3-FR-SYS-050

P3-FR-SYS-050	Version 1.0	SW release 1.0	Priority -
Description	The Pilot3 prototype **shall** rank the set of trajectory alternatives according to the airline policies.		
Rationale	If more than one trajectory is available, Pilot3 shall consider the airline's policy to rank them according to the stated airline's objectives.		
Origin	D1.1		

Table 7. P3-FR-SYS-060

P3-FR-SYS-060	Version 1.0	SW release 1.0	Priority -
Description	The Pilot3 prototype **shall** interact with the pilot to select among the alternatives generated.		
Rationale	The pilot shall be able to select, reject and impose constraints on the presented solutions.		
Origin	D1.1		

Table 8. P3-FR-SYS-070

P3-FR-SYS-070	Version 1.0	SW release 1.0	Priority -
Description	For each 4D trajectory provided by Pilot3, the prototype **shall** quantify its impact on airline performance goals by means of several PIs (performance indicators).		
Rationale	PIs might be divided in sub-PIs and aggregated to high-level PIs. A taxonomy of these indicators will be provided.		
Origin	D1.1		

Table 9. P3-FR-SYS-080

P3-FR-SYS-080	Version 1.0 SW release 1.0 Priority -
Description	The Pilot3 prototype **shall** be able to produce up to four different estimators for the same PI: • Airborne analytic: by manipulating data that is available on-board and/or using heuristics with some of these data. • AOC analytic: by manipulating data that is available by the airline operating centre (AOC) and/or using heuristics with some of these data. • Airborne ML: by using machine learning techniques with the on-board available data. • AOC ML: by using machine learning techniques with the AOC available data.
Rationale	The use of different information will affect the precision and quality of the estimation of the different indicators. However, relaying on communication with AOC might be costly and hence a full airborne solution could be preferred. Also, in some instances advanced machine learning estimators might not be available (or required). For this reason, Pilot3 shall allow the airspace users to configure the estimators individually.
Origin	D1.1

Table 10. P3-FR-SYS-090

P3-FR-SYS-090	Version 1.0	SW release 1.0	Priority -
Description	The Pilot3 prototype **shall** allow the user (airline operator) to specify which estimator(s) should be used as a function, for instance, of some (or all) of the following items: • the moment/phase of the flight; • the flight number; • the weather conditions; • the status of the fleet; • the operational context; • the cost of data-link if AOC estimations are done; and • the nature of the disruption or triggering event.		
Rationale	This will be part of the configuration of the tool done before the departure (see requirement P3-FR-SYS-10). For each indicator a possible set of estimators shall be provided so that the user can select which one to use.		
Origin	D1.1		

Table 11. P3-FR-SYS-100

P3-FR-SYS-100	Version 1.0	SW release 1.0	Priority 2
Description	The Pilot3 prototype **may** produce an estimated accuracy/confidence level for each PI estimator.		
Rationale	Considering the stochasticity of the estimation process (data uncertainty, inaccuracies of the model, etc.).		
Origin	D1.1		

Table 12. P3-FR-SYS-110

Identifier	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** consider the influence of the wind when computing the alternative trajectories					
Rationale	The wind field has a significant impact in aircraft trajectories (and fuel consumption). Neglecting the influence of the wind would result in non-realistic (or too simple) trajectories. Moreover, discrepancies between forecast and actual wind, or wind forecast updates along the flight could trigger the use of Pilot3 by the pilot.					
Origin	D1.1					

Table 13. P3-FR-SYS-120

P3-FR-SYS-120	Version	1.0	SW release	1.0	Priority	3
Description	The Pilot3 prototype **may** consider real temperature and/or pressure atmospheric conditions when computing the alternative trajectories.					
Rationale	Atmospheric temperature and pressure along the flight have also an impact in aircraft trajectories, but to a lesser extent if compared with wind. If realistic temperature/pressure profiles are not finally considered in Pilot3, the international standard atmosphere (ISA) profiles will be used instead. ISA plus/minus a delta temperature and/or a delta pressure could potentially be implemented.					
Origin	D1.1					

Table 14. P3-FR-SYS-130

P3-FR-SYS-130	Version	1.0	SW release	1.0	Priority	3
Description	The Pilot3 prototype **may** consider uncertainties related to weather forecasts.					
Rationale	Weather forecast might present different levels of uncertainties. Pilot3 may use information from probabilistic forecast (e.g., using weather ensembles) to estimate the uncertainty on the trajectory due to these weather uncertainties.					
Origin	D1.1					

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Table 15. P3-FR-SYS-140

P3-FR-SYS-140	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** implement solutions for an Airbus A320.					
Rationale	This aircraft is representative for short-haul flights, which could be considered in the validation of Pilot3. EUROCONTORL's Base of Aircraft Data (BADA) will be used to model aircraft performance, flight envelope and reference weights.					
Origin	D1.1					

Table 16. P3-FR-SYS-150

P3-FR-SYS-150	Version	1.0	SW release	1.0	Priority	-
Description	The Pilot3 prototype **shall** implement solutions for a Boeing B777.					
Rationale	This aircraft is representative for long-haul flights, which could be considered in the validation of Pilot3. EUROCONTORL's Base of Aircraft Data (BADA) will be used to model aircraft performance, flight envelope and reference weights.					
Origin	D1.1					

Table 17. P3-FR-SYS-160

P3-FR-SYS-160	Version	1.0	SW release	1.0	Priority	4
Description	The Pilot3 prototype **may** be able to implement other turbojet aircraft (different from an A320 and a B777).					
Rationale	This aircraft is representative for long-haul flights, which could be considered in the validation of Pilot3. EUROCONTORL's Base of Aircraft Data (BADA) will be used to model aircraft performance, flight envelope and reference weights					
Origin	D1.1					

Table 18. P3-FR-SYS-170

P3-FR-SYS-170	Version	1.0	SW release	1.0	Priority	5
Description	The Pilot3 prototype **may** be able to implement turboprop aircraft.					
Rationale	To assess the sensitivity of the solutions to this particular type of aircraft and to address the type of missions typically carried out by turboprops.					
Origin	D1.1					

Table 19. P3-FR-SYS-180

P3-FR-SYS-180	Version	1.0	SW release	1.0	Priority	-
Description	When computing trajectories, the Pilot3 prototype **shall** consider constraints of the following nature: • Aircraft operation (flight envelope): such as min/max speeds, max thrust, ceiling, etc. • Constraints set by the pilot: such as avoiding altitude changes, min/max speeds, etc. • Airline specific policies: such as bounds in total fuel consumption, target arrival times, etc. • Static ATM related constraints: such as FL orientation/allocation schemes, en-route procedures (airways), terminal procedures (departures, arrivals, ...), altitude/speed constraints in certain segments, etc.					
Rationale	The first two sets of constraints will ensure the trajectory is operationally sound (i.e., flyable), while allowing some interaction with the pilot to consider external events such as turbulence, ATC not conceding certain clearances, etc. The third set may be needed to implement a decision making support process, to explore trade-offs between different solutions, etc. Finally, the fourth set will ensure the trajectory is compliant with ATM regulations.					
Origin	D1.1					

Table 20. P3-FR-SYS-190

P3-FR-SYS-190	Version 1.0	SW release 1.0	Priority 1
Description	The Pilot3 prototype **may** estimate ATC tactical interventions in the trajectory, including at least: • Extra flown distance in en-route (not considering conflict resolution interventions // considering for ex: conditional route availability, tactical rerouting (shortcuts, weather avoidance...). • Extra flown distance in terminal airspace (i.e., shortcuts, sequencing and merging operations in arrival, etc.) • Air holding in published holding patterns. • Taxi-in time.		
Rationale	ATC tactical interventions can significantly change the trip distance and time (impacting in fuel consumption and other PIs). Pilot3 will be probably triggered when an ATC intervention deviates the aircraft from its original (4D) trajectory. Nevertheless, estimating possible ATC interventions ahead of the flight will be of added value when computing alternative trajectories by Pilot3. It should be noted that most of the PIs considered by the airlines will be likely "gate-to-gate". Therefore, although the descent below FL100 and taxi-in operations are not subject to optimisation by Pilot3, ATC intervention in these flight phases can introduce a significant amount of delay impacting the final indicators. Note that no connection between the ATC and Pilot3 is envisaged. Available current information will be used to predict the impact of potential variations in the trajectory based on the analysis of historical datasets. This available information could include ATM data. How these data could be incorporated may be described.		
Origin	D1.1		

Table 21. P3-FR-SYS-200

P3-FR-SYS-200	Version 1.0	SW release 1.0	Priority -
Description	All alternatives along with the metadata related to their generation (e.g., characteristics of the flight) and the interaction with the pilot **shall** be stored in a dedicated data infrastructure (DataBeacon).		
Rationale	All trajectories generated by Pilot3 along with the data and metadata used to generate them shall be stored. This will allow the use of machine learning techniques on these datasets to for example, compute the accuracy of the predictions of the estimators, or to understand the characteristics of trajectories rejected by the pilots, so that the system can identify their features to improve which ones are filtered.		
Origin	D1.1		

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3.3 Non-functional requirements

Table 22. P3-NFR-SYS-010

P3-NFR-SYS-010	Version	1.0	SW release	1.0	Priority	-
Description	Pilot3 prototype **shall** be a standalone software.					
Rationale	Although this prototype will be a joint development by Pilot3 consortium partners and some of its building blocks are brought as background, a final integrated software will be produced.					
Origin	D1.1					

Table 23. P3-NFR-SYS-020

P3-NFR-SYS-020	Version	1.0	SW release	1.0	Priority	-
Description	Pilot3 prototype **shall** run in a conventional PC platform under Linux.					
Rationale	The software shall be integrated into a single PC platform with Linux as operating system. Data access might require connections to remote datasets (e.g., in DataBeacon).					
Origin	D1.1					

Table 24. P3-NFR-SYS-030

P3-NFR-SYS-030	Version	1.0	SW release	1.0	Priority	2
Description	Pilot3 prototype **may** run in DataBeacon.					
Rationale	DataBeacon cloud platform not only allows data storage and management, but applications can also run using on-demand processing services that can be called using an API REST, a web-application or remotely via SSH.					
Origin	D1.1					

Table 25. P3-NFR-SYS-040

P3-NFR-SYS-040	Version	1.0	SW release	1.0	Priority	-
Description	Pilot3 prototype **shall** store all input and output files in the DataBeacon platform.					
Rationale	Besides being a centralised and safe repository to store all data required to run Pilot3 validation exercises, this data will also enable the Machine Learning algorithms that will be needed in the estimation of some PIs.					
Origin	D1.1					

Table 26. P3-NFR-SYS-050

P3-NFR-SYS-050	Version	1.0	SW release	1.0	Priority	5
Description	Pilot3 prototype **may** run in a conventional PC platform under Windows 10.					
Rationale	The software may be integrated into a single PC platform with Windows 10 as operating system. Data access might require connections to remote datasets (e.g., in DataBeacon).					
Origin	D1.1					

Table 27. P3-NFR-SYS-060

P3-NFR-SYS-060	Version	1.0	SW release	1.0	Priority	4
Description	Pilot3 prototype **may** be deployed using a container with Docker.					
Rationale	The software may be deployed using a container with Docker to make it platform agnostic.					
Origin	D1.1					

3.4 Domain requirements

Table 28. P3-DR-SYS-010

P3-DR-SYS-010	Version	1.0	SW release	1.0	Priority	-
Description	Pilot3 prototype **shall** model European Commission (EC) Regulation 261/2004 in the estimation of the appropriate indicators.					
Rationale	EC Regulation 261/2004 defines the conditions and obligations for airlines to compensate passengers in case of flight delay or cancellations.					
Origin	D1.1					

Table 29. P3-DR-SYS-020

P3-DR-SYS-020	Version	1.0	SW release	1.0	Priority	-
Description	Pilot3 prototype **shall** take into consideration the SESAR 2020 Transition ConOps [8]					
Rationale	The SESAR 2020 Transition ConOps defines, among others, the trajectory based operations (TBO) and performance based operations (PBO) concepts, along with the expected interactions and information sharing among the different aviation stakeholders in a future new paradigm for ATM. In particular, Pilot3 will take into consideration the SESAR view on the negotiation and update processes of the reference business trajectory (RBT).					
Origin	D1.1					

4 Preliminary data requirements

The following section contains a description on the selected data sets to support Pilot3, including a brief description summarising the main properties, the structure and size, the data items descriptions for each parameter contained within the data set, data availability and the limitations. The range of available data (temporal and spatial) will be case study dependent. Note that this is a preliminary identification of datasets as they will be fully identified and acquired as part of the activities of WP3 - Data collection and management from AOCs.

We identify three different type of data types based on their usage in the Pilot3 project:

- input data for the model needed to execute Pilot3 prototype;
- data required for predictive models, which will be used to train the machine learning algorithms considered for some indicators of the Performance Indicators Estimator and the Operational ATM Estimator; and
- data required for the validation of the model.

Finally, note that Pilot3 will in its turn generate data. This will be defined as part of WP4 - Model development and considered by WP3 to ensure its adequate storage.

4.1 Input data for the model

Data used as input to the Pilot 3 system. Feeds the Performance Indicators Estimator, the Operational ATM Estimator and the Alternatives Generator. The data availability needs to be sufficient to cover the proposed case studies, offering enough variety. The data will be accessible using a real-time API that interfaces DataBeacon with the Pilot3 system. The data that can be presented as the input of the Pilot3 systems is presented in **Table *28***.

Table 30. Preliminary data requirements for input

Data items and properties	Datasets	Parameters	Availability	Limitations
Flight policies	Definition files	Configuration file for Pilot3 to define heuristics and estimators.	Flight policies will be processed by the Innaxis team and stored in DataBeacon, in where they can be retrieved in xml or JSON.	Data needs to be manually defined. File formatting is required.

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Data items and properties	Datasets	Parameters	Availability	Limitations
Operational airspace information	AIXM or DDR2 (PRISME) and AIPs and Route Availability Document (RAD)	En-route and TMA procedures (airways, SIDs, STARs, ...) Waypoints Radionavigation facilities Operational constraints (i.e., airspace "graphs").	AIXM data available in DataBeacon. AIPs to be defined in the case studies. Route Availability Document (RAD) available from DDR2. DDR data needs to be requested to EUROCONTROL and access may not be granted.	AIPs are normally in PDF format. Hard to code into a readable tabular format. Some Pilot3 partners have already some DDR2 files corresponding to a limited set of AIRACs. This could have an impact on the validation case studies.
ATM ConOps	Free Route Airspace Flight level allocation and orientation schemes.	Defined ad-hoc for the validation exercises.	Defined ad-hoc for the validation exercises.	Modelling of futuristic operations.
Weather measures and forecast	NOAA GFS or ECMFW EUMETSA	Wind, temperature and pressure gridded. Convective weather and storms.	Public datasets. Retrieved, processed and available at DataBeacon.	Grib data needs to be processed and filtered for certain meteorological conditions and a given trajectory.
Aircraft performance	BADA	Thrust, drag and fuel flow models. Operational variables for different aircraft types.	Provided by EUROCONTROL, stored in DataBeacon.	License needs to be requested for each partner accessing the data.

4.2 Data required for predictive models

For estimating some indicators Pilot3 considers historical data analysis with machine learning techniques. A data pipeline will clean each dataset, merge all the data required and label the indicators accordingly. This final dataset will be used for cross-validation of the machine learning estimators, i.e., random split of the dataset to train and test the model will help in assessing how it will generalise to a previously unseen independent dataset.

Some of the data sources that are going to be considered for the training of the machine learning estimators within the scope of Pilot3 are presented in the **Table *29***. The table below is a general overview of the data sets that can be explored for its usage in such predictive models. The given list is not exhaustive and will be updated as the project progresses, and the requirements change.

Table 31. Preliminary data requirements for predictive models

Data items and properties	Datasets	Parameters	Availability	Limitations
Traffic information and regulations	ADS-B DDR	Sector counts. Traffic characteristics at TMA (ac-types, expected arrivals departures, ...) Regulations	ADS-B data available at DataBeacon. DDR data needs to be requested to EUROCONTROL and access may not be granted.	DDR data can be very large if the model is at EU level.
Flight information and flown trajectory	Flight plans ADS-B	Holding time, taxi time, ETA, ATA ...	Flight plans could be provided by airlines from the advisory board. ADS-B data available at DataBeacon.	Some de-identification might be required (callsign, date, etc..)

Data items and properties	Datasets	Parameters	Availability	Limitations
Passenger and flight data	Synthetic data	E-AMAN arrival queue sequencing ATFM delays; reactionary delays Executed flight data: fuel, velocity, time parameters (AOBT, SOBT, EOBT, etc.), delay cause and cost, flight plan, etc. Passenger itineraries: travel class, fare, passenger delays, passenger costs (duty of care, compensation), re-scheduling UDPP mechanism: slot swapping and respective cost models	Synthetic data can be generated by Mercury, simulating historical days of operations under various traffic conditions (varying delay levels etc.).	Synthetic data might introduce bias to predictive models. This approach needs to be assessed and tested carefully

4.3 Data required for validation

Besides the other datasets identified, specific data will be used in the validation of the built models. Although we can synthesise these data to reproduce realistic scenarios, it would be more desirable to use datasets describing real operations. Some of the datasets to be considered are presented in the **Table *30***.

Table 32. Predictive data requirements for validation

Data items and properties	Datasets	Parameters	Availability	Limitations
Flight information and flown trajectory	Flight plans ADS-B Synthetic data generated by Pilot3	Waypoint sequences of the nominal planned flight. Speed and altitude schedules (or intents) and/or Cost Index.	Flight plans could be provided by airlines from the advisory board. ADS-B data available at DataBeacon.	Some de-identification might be required (callsign, date, etc..).

Data items and properties	Datasets	Parameters	Availability	Limitations
Flight characteristics	Airline flight data	Payload, number of passengers, fuel-on board, passengers' itineraries.		Some de-identification might be required (callsign, date, etc..).
ATM ConOps	Free Route Airspace Flight level allocation and orientation schemes.	Defined ad-hoc for the validation exercises.	Defined ad-hoc for the validation exercises.	Modelling of futuristic operations.

5 Preliminary performance and operational indicators

As presented in Section 2, Pilot3 has two distinct modules which focus on the estimation of indicators: Performance Indicators Estimator and Operational ATM Estimator. The objective of the Performance Indicators Estimator is to estimate the outcome of a given trajectory on the different indicators which are relevant for stakeholders. The goal of the Operational ATM Estimator is to estimate parameters which affect the operations of the flight which are linked to ATM uncertainties.

This section identifies a preliminary set of indicators to be considered and modelled in Pilot3.

5.1 Performance indicators

From the feedback obtained from the Advisory Board focus should be given to identify two indicators: cost and on-time performance. Detail on the Advisory Board meeting and the detailed feedback obtained will be reported in D3.1 - Airlines data collection report.

On-time performance is a binary indicator which states if a flight has an actual in-block time no later than 15 minutes with respect to their scheduled in-block time. This indicator is relevant as it is used as a proxy for different aspects which are considered by airlines (such as reputation, operational costs, or reliability).

Cost is the second indicator which is monitored and relevant for airlines. This is however a complex indicator composed of several sub-indicators. Therefore, we consider adequate to create a taxonomy:

- Cost
- Fuel cost
- Passenger costs (IROPS)
- Other costs
    - Curfew
    - Crew and maintenance delay cost
    - Other
- Reactionary cost

Note that some of these indicators can be easily estimated from the trajectory (e.g., expected cost of fuel) while others might require complex estimations (e.g., cost of curfew, as if the flight might incur into a curfew at the end of the day might need to be estimated in its turn; or reactionary cost, which can be composed of sub-costs).

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5.2 Operational ATM indicators

Indicators that need to be considered by the Alternatives Generator in order to estimate the performance indicators derived from the operational environment will be modelled by the Operational ATM Estimator. As presented in the previous section, the airline focuses on on-time performance and cost. On-time performance is measured with respect to the arrival at the destination gate; and most cost that will be incurred tactically (i.e., once the flight is on operation) are with respect the arrival to the gate time. Therefore, capturing not only the time required to reach a point in the TMA (e.g., the IAF) but the time to reach the arrival gate should be considered.

Insight from Advisory Board consultation

For pilots is difficult to decide if they should operate a faster trajectory as even if 'on time' unexpected delays at arrival (e.g., due to holding) might lead to arrival delays at the gate.

Most of the parameters which add uncertainty on the total distance flown (and hence the fuel required) and the time are contained in the TMA and due to the sequencing and merging procedures. However, en-route variations might also occur (such as variations of flight distance due to a direct).

Some preliminary operational ATM indicators which have been identified are:

- arrival procedure that will be used
- holding time in terminal airspace
- distance flown in terminal airspace due to arrival sequencing and merging operations
- taxi-in time

As with the performance indicators, these parameters can be estimated using different techniques and, in some cases, a set of factors which affect their prediction could also be defined. For example, the taxi-in time might depend on the arrival runway used, the gate assigned and the congestion at the airport. The Operational ATM Estimator will be developed in WP4 - Model development and these indicators will be further defined.

6 Preliminary case studies definition

The different scenarios that will be modelled in Pilot3 are developed considering airlines and flights characteristics, and the different event which trigger usage of Pilot3 tool.

Some of the flight characteristics considered include:

- Aircraft size
- Length of flight
- Type of operations (with low number of connecting passengers, or a feeder flight)
- Time of the day
- Flights with curfew at the end of the day or not

Some of the airlines' characteristics are:

- Type of airline (full-service carrier, low cost carrier)
- Relative importance of indicators on their flight policy

Some of the characteristics of the event which triggers the usage of Pilto3 are:

- Type of even (e.g., delay, early operation, weather ahead)
- Flight stage when the event takes place

As presented in Section 2.3.4, the validation of Pilot3 will be mainly based on interaction with stakeholders. Therefore, for each scenario different case studies will be defined and evaluated. There are some case studies parameters which will be applicable across all the scenarios, namely:

- The consideration of a major disruption in network or operation on nominal conditions.
- The usage of different weather conditions (such as the use days with different levels of uncertainty on the forecast)
- The consideration of different levels and sources of uncertainty

In addition to these, for short and medium haul flights other characteristics such as if the flight is a feeder with connecting passengers or not and if a curfew is expected at the end of the day could also be included.

Specific origin and destination routes will be selected on the modelling. Operational parameters such as the type of approach procedures used at arrival, or the type of airspace, which is used during the cruise, will be considered on this decision.

A specific consultation with the Advisory Board will be carried out to help us identify the case studies which are more relevant for them. Note that specific case studies to be presented to individual members of the Advisory Board could be developed as part of the validation. For example, operations of a low-cost carrier to an airport which has a curfew might be relevant for some members of the Advisory Board while other users might be more interested on disrupted operations of a feeder into the hub. This will be detailed in D5.1 - Verification and validation plan.

Finally, Pilot3 framework could allow us to evaluate the impact of different operational context, for example, the introduction of free route or different degrees of flexibility to change tracks on oceanic routes.

Table 31 and **Table 32** present a preliminary identification of scenarios considered for short and medium haul flights (modelled considering an Airbus A320) and for long haul flights (modelled considering a Boeing B777).

Table 33. Short and medium haul flights scenarios (modelled with Airbus A320)

Scenario ID	Name	Short description	Other considerations
SH-CLB-010	Late take-off for short haul.	The actual take-off is done minutes after the nominal schedule. In the initial climb (FL100) the aircraft crew queries Pilot3.	This is expected to be a frequent scenario.
SH-CLB-020	Early take-off for short haul.	The actual take-off is done minutes before the nominal schedule. In the initial climb (FL100) the aircraft crew queries Pilot3.	This is expected to be a frequent scenario.
SH-CRZ-010	Late TOC for short haul.	The aircraft reaches the cruise altitude (top of climb - TOC) later than planned. The aircraft crew queries Pilot3.	A weather forecast update could be considered.
SH-CRZ-020	Early TOC for short haul.	The aircraft reaches the cruise altitude (top of climb - TOC) early than planned. The aircraft crew queries Pilot3.	A weather forecast update could be considered.
SH-CRZ-030	Late en-route estimates for short haul.	After x NM flying at cruise altitude the time estimates are wrong, and the flight is late. The aircraft crew queries Pilot3.	Similar to SH-CRZ-010 but considering different cruise location where Pilot3 is triggered. It could include or not a weather forecast update.

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Scenario ID	Name	Short description	Other considerations
SH-CRZ-040	Early en-route estimates for short haul.	After x NM flying at cruise altitude the time estimates are wrong, and the flight is early. The aircraft crew queries Pilot3.	Similar to SH-CRZ-020 but considering different cruise location where Pilot3 is triggered. It could include or not a weather forecast update.
SH-CRZ-050	Weather ahead for short haul.	"No-go" weather zones (i.e., convective weather, severe turbulence, ...) appear ahead in the cruise phase. The crew needs to modify the trajectory and queries Pilot3	Different cruise location where Pilot3 is triggered could be considered. Different location of the weather zones to avoid could be considered.
SH-CRZ-060	Turbulence in current FL for short haul.	Turbulence experienced in current FL. The aircraft crew queries Pilot3 to explore other possible FLs (and/or routes).	Different cruise location where Pilot3 is triggered could be considered. Different size of turbulence layer could be considered.
SH-CRZ-070	Conditional route given for short haul.	Conditional route crossing MIL space granted by ATC shortening flight distance.	Similar to being granted a direct. Different location in the cruise could be considered.
SH-CRZ-080	Delay at destination TMA for short haul known in cruise.	Delay expected in the arrival flow (holding stacks, speed reduction...) while the aircraft is still in cruise.	Different values of the expected arrival delay could be considered.
SH-DES-010	Early descent for short haul.	The ATC instructs to descent earlier than planned in the FMS.	Descent speed could be adjusted.
SH-DES-020	Delay at destination TMA for short haul known in descent.	Delay expected in the arrival flow (holding stacks, speed reduction...) while the aircraft has initiated the descent (and above FL100).	In this case flight might be fully controlled by ATC and Pilot3 might not be able to be triggered.

Table 34. Long haul flights scenarios (modelled with Boeing B777)

Scenario ID	Name	Short description	Other considerations
LH-CLB-010	Late take-off for long haul.	The actual take-off is done minutes after the nominal schedule. In the initial climb (FL100) the aircraft crew queries Pilot3.	This is expected to be a frequent scenario
LH-CLB-020	Early take-off for long haul.	The actual take-off is done minutes before the nominal schedule. In the initial climb (FL100) the aircraft crew queries Pilot3.	This is expected to be a frequent scenario
LH-CRZ-010	Late TOC for long haul	The aircraft reaches the cruise altitude (top of climb - TOC) later than planned. The aircraft crew queries Pilot3.	A weather forecast update could be considered.
LH-CRZ-020	Early TOC for long haul	The aircraft reaches the cruise altitude (top of climb - TOC) early than planned. The aircraft crew queries Pilot3.	A weather forecast update could be considered.
LH-CRZ-030	Late en-route estimates for long haul	After x NM flying at cruise altitude the time estimates are wrong, and the flight is late. The aircraft crew queries Pilot3.	Similar to LH-CRZ-010 but considering different cruise location where Pilot3 is triggered. It could include or not a weather forecast update.
LH-CRZ-040	Early en-route estimates for long haul	After x NM flying at cruise altitude the time estimates are wrong, and the flight is early. The aircraft crew queries Pilot3.	Similar to LH-CRZ-020 but considering different cruise location where Pilot3 is triggered. It could include or not a weather forecast update.
LH-CRZ-050	Weather ahead for long haul	"No-go" weather zones (i.e., convective weather, severe turbulence, ...) appear ahead in the cruise phase. The crew needs to modify the trajectory and queries Pilot3.	Different cruise location where Pilot3 is triggered could be considered. Different location and nature of the weather zones to avoid could be considered.

Scenario ID	Name	Short description	Other considerations
LH-CRZ-060	Turbulence in current FL for long haul	Turbulence experienced in current FL. The aircraft crew queries Pilot3 to explore other possible FLs (and/or routes).	Different cruise location where Pilot3 is triggered could be considered. Different size of turbulence layer could be considered.
LH-CRZ-070	Oceanic clearance changed in flight.	The aircraft receives an update of the Oceanic clearance before entering oceanic airspace (i.e., change of the Cruise flight level and/or route). The aircraft crew queries Pilot3 with the new clearance and to explore other alternatives and ask ATC.	
LH-CRZ-080	Delay at destination TMA for long haul known in cruise.	Delay expected in the arrival flow (holding stacks, speed reduction...) while the aircraft is still in cruise.	Different values of the expected arrival delay could be considered.
LH-CRZ-090	Update on issued time of arrival at TMA	A time of arrival at the TMA is issued to a flight.	
LH-DES-010	Early descent for long haul	The ATC instructs to descent earlier than planned in the FMS.	Descent speed could be adjusted.
LH-DES-020	Delay at destination TMA for long haul known in descent.	Delay expected in the arrival flow (holding stacks, speed reduction...) while the aircraft has initiated the descent.	In this case flight might be fully controlled by ATC and Pilot3 might not be able to be triggered.

7 Next steps and look ahead

This deliverable has presented the high-level requirements and approach to the development of Pilot3. This deliverable is based on the proposal but incorporates the development produced during the first 4 month of the project. There are tasks being carried out and planned on all the main activities:

- The methodology to perform the multi-criteria optimisation is being finalised in WP2 - Multi-criteria decision making techniques and will be reported in D2.1 Trade-off report on multi-criteria decision making techniques (due April 2020) achieving Milestone MS2 - Multi-criteria decision making technique selected.
- A consultation with the Advisory Board is taking place to obtain further feedback on:
  - the definition of optimisation parameters to be considered by Pilot3,
  - the interaction of pilots with the tool, and
  - the prioritisation of parameters to consider for the case studies
- The modelling details of the optimisation framework are being developed as part of WP4 - Model development activities. Particular focus is given to the consideration of uncertainties. Different technical sessions have been carried out between members of the consortium. WP4 activities also include the definition of requirements for the different sub-modules within Pilot3 with focus on the integration between these elements.
- The requirements for the interface are also considered in parallel to the definition of the optimisation methodology (as part of WP2).
- The case studies will be further developed considering the feedback from the Advisory Board and incorporated, along with the validation approach, in D5.1 - Verification and validation plan (due July 2020).
- The acquisition of data is advancing with particular focus on the definition and acquisition of datasets required for the training of machine learning models in the Operational ATM Estimator, the Performance Indicator Estimator. Work is also under way to select datasets required to model the different case studies. For example, identifying days in which weather are interesting from Pilot3 perspective (e.g., with high or low uncertainty on them). The definition of the datasets and the interaction with the Advisory Board will be reported in D3.1 - Airlines data collection report (due July 2020) achieving milestone MS3 - Airlines data collected and analysed.
- Dissemination activities are being performed and D7.2 - Project communication, dissemination and exploitation report will be delivered in April 2020.

Once the optimisation methodology is defined, focus will shift towards the development of the prototype with the objective of producing a first prototype of Pilot3 by M17 of the project (March

2021) which will be reported in D4.1 - Crew Assistant Decision model description (first release) and D4.2 - Crew Assistant Decision model software package (first release).

8 References

1. Bishop, C. M., 2006. Pattern recognition and machine learning, Springer.
2. Commercial Market Outlook 2019 – 2038, 2019. Available at: https://www.boeing.com/resources/boeingdotcom/commercial/market/commercial-market-outlook/assets/downloads/cmo-sept-2019-report-final.pdf (accessed 26.02.2020)
3. Dalmau, R., Melgosa, M., Vilardaga, S. and Prats, X., 2018, A Fast and Flexible Aircraft Trajectory Predictor and Optimiser for ATM Research Applications. Proceedings of the 8th International Conference on Research in Air Transportation (ICRAT).
4. European Commission, 2008, Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003 87 EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.
5. Efthymiou, M., Papatheodorou, A., 2019. EU Emissions Trading scheme in aviation: Policy analysis and suggestions. Journal of Cleaner Production 237
6. EU, 2013, Decision No 377/2013/EU of the European Parliament and of the Council of 24 April 2013 derogating temporarily from Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community.
7. EU, 2014, Regulation (EU) No 421/2014 of the European Parliament and of the Council of 16 April 2014 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in view of the implementation by 2020 of an international agreement applying a single global market-based measure to international aviation emissions.
8. SESAR JU, 2019, European ATM Master Plan (2020 edition), 2019. Available at: https://www.sesarju.eu/masterplan (accessed 20.02.2020).
9. European Aviation Environmental Report 2019, 2019. Available at: https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf accessed 18.02.2020).
10. European Commission, DG MOVE E3 -Single European Sky, 2018. Impact assessment of options for the regulatory approach in RP3 of the SES Performance and Charging Schemes - Final Report. Available at: https://ec.europa.eu/transport/sites/transport/files/studies/2018-ia-options-regulatory-approach-rp3-ses-performance-charging-schemes.pdf (accessed 04.03.2020).
11. Friedman, J.H., 2001, Greedy function approximation: a gradient boosting machine. Annals of statistics, pages 1189–1232.
12. ICAO, 2016. Capacity and Efficiency – 2016–2030 Global Air Navigation Plan. Available at: https://www.icao.int/publications/Documents/9750_5ed_en.pdf (accessed 22.02.2020).
13. ICAO, 2019. Resolution A40-19: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

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14. ICAO, 2019. North Atlantic Operations and Airspace Manual. Available at: https://www.faa.gov/air_traffic/separation_standards/rvsm/documents/NAT_Doc007_EN_Edition_V2019-2_eff_from_28MAR2019.pdf (accessed 19.02.2020).
15. Meleo, L., Nava, C. R., Pozzi, C., 2016. Aviation and the costs of the European Emission Trading Scheme: The case of Italy. Energy Policy 88, 138-147.
16. Rodríguez, A., Navarro, S., 2014. Design of an algorithm for UDPP (User Driven Priorisation Process) based on combinatorial auctions , Final Degree Project Report. Universitat Autònoma de Barcelona - Escola d'Enginyeria.
17. SESAR ConOps (Concept of Operations), 2017. Available at: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5b6d2b912&appId=PPGMS (accessed 25.02.2020)
18. SESAR JU, 2020. Industrial research projects. Available at: https://www.sesarju.eu/news/second-wave-sesar-industrial-research-gets-underway (accessed 26.02.2020).
19. SESAR Solutions Catalogue, 2019. Available at: https://www.sesarju.eu/sites/default/files/documents/reports/SESAR_Solutions_Catalogue_2019_web.pdf (accessed 25.02.2020)
20. Siegel, E., 2013, Predictive Analytics: The Power to Predict Who Will Click, Buy, Lie, or Die.
21. Single European Sky PRB, 2019, PRB Monitoring Report 2018. Available at: http://www.atceuc.org/uploads/docs/prb-monitoring-report-2018.pdf (accessed 26.02.2020)
22. Universal – Weather and Aviation, 2015. Available at: https://www.universalweather.com/blog/successfully-managing-north-atlantic-tracks-part-2-flying-the-tracks/ (accessed 25.02.2020).
23. Vapnik, V., 2013, The nature of statistical learning theory. Springer Science & Business Media.

9 Acronyms

ADEP: Aerodrome of Departure

ADES: Aerodrome of Destination

ADS-B: Automatic Dependent Surveillance – Broadcast

AIP: Aeronautical Information Publication

AIRAC: Aeronautical Information Regulation and Control

AIXM: Aeronautical Information Exchange Model

AOBT: Actual Off-Block Time

AOC: Airline Operations Centre

ATAL Actual Time of Arrival

ATC: Air Traffic Control

ATCO: Air Traffic Control Officer

ATFCM: Air Traffic Flow and Capacity Management Measure

ATM: Air Traffic Management

ATSU: Air Traffic Services Unit

AU: Airspace Users

BADA: Base of Aircraft Data

BDT: Business Development Trajectory

CARATS: Collaborative Action for Renovation of Air Traffic Systems

CDM: Collaborative Decision Making

CMATS: Civil Military Air Traffic Management System

ConOps: Concept of Operations

CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation

CSJU: Clean Sky 2 Joint Undertaking

CTA: Controlled Time of Arrival

CTO: Controlled Time Over

DDR2: Demand Data Repository (second phase)

DX.Y: Deliverable number (X=workpackage, Y=deliverable numbering within workpackage)

E-AMAN: Extended Arrival Manager

EATM: European ATM

ECMFW: European Centre for Medium-Range Weather Forecasts

EEA: European Economic Area

EOBT: Estimated Off-Block Time

ETA: Estimated Time of Arrival

EU: European Union

EU-ETS: European Union Emissions Trading System

EUMETSAT: European Organisation for the Exploitation of Meteorological Satellites

FOC: Flight Operations Centre

GDP: Gross Domestic Product

GFS: Global Forecast System

GRIB: GRIdded Binary

H2020: Horizon 2020 research programme

HMI: Human machine interface

ICAO: International Civil Aviation Organization

INX: Short name of Pilot3 partner: Fundación Instituto de Investigación Innaxis

JCAB: Japan Civil Aviation Bureau

JSON: JavaScript Object Notation

KEA: Key Performance Environment indicator based on Actual trajectory

KEP: Key Performance Environment indicator based on last filled flight Plan

KPA: Key Performance Area

KPI: Key Performance Indicator

MNPS: Minimum Navigation Performance Specification

MS: Milestone

NAT HLA: NAT High Level Airspace

NAT MNPSA: North Atlantic Minimum Navigational Performance Specifications Airspace

NAT: North Atlantic Tracks

NAT-OTS: NAT Organised Track Structures

NMF: Network Management Function

NOAA: National Oceanic and Atmospheric Administration

PACE: Short name of Pilot3 partner: PACE Aerospace Engineering and Information Technology GmbH

PACOTS: Pacific Organised Track System

PBCS: Performance Based Communication and Surveillance

PBN: Performance Based Navigation

PI: Performance Indicator

PRB: Performance Review Body

PRISME: Pan-European Repository of Information Supporting the Management of EATM

RAD: Route Availability Document

RBT: Reference Business Trajectory

RLatSM: Reduced Lateral Separation Minimum

RP3: Reference Period 3

RPK: Revenue Passenger Kilometres

RVSM: Reduced Vertical Separation Minimum

SBT: Shared Business Trajectory

SES: Single European Sky

SESAR JU: Single European Sky ATM Research Joint Undertaking

SESAR: Single European Sky ATM Research

SID: Standard Instrument Departure

SOBT: Scheduled Off-Block Time

STAM: Short Term Air Traffic Flow and Capacity Management Measure

STAR: Standard Terminal Arrival Route

TBO: Trajectory Based Operations

TMA: Terminal Manoeuvring Area

TSAT: Target Start-up Approval Time

TTOT: Target Take-Off Time

UDPP: User Driven Prioritisation Process

UoW: Short name of Pilot3 coordinator: University of Westminster

UPC: Short name of Pilot3 partner: Universitat Politècnica de Catalunya

WP: Workpackage

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