Concept for use of AOC data to improve Trajectory Prediction

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Abstract

This document details the concept of improving ground based trajectory prediction systems by using additional information generated in the airspace user's flight planning process. Based on prior research on this concept, an in-depth analysis of ground based TP systems and, a questionnaire on the flight planning process to various airspace users, a list of the most promising parameters is established. The concept is subsequently applied to a number of example scenarios which are used to identify possible cost-benefit mechanisms. This document concludes the V1 phase of the project.

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Executive summary

Previous research has shown that the use of additional operator flight planning information in ground based Trajectory Predictor (TP) applications has the potential to improve the performance of ATC tools that use predicted trajectories and therefore the ATM system performance.

This project is focussed on the near-term use of flight planning data, prior to the advent of standards and infrastructure to support full trajectory exchange between aircraft and ATC systems. As such the concept is to be one of the early wins from the SESAR research phase.

One of the main sources of uncertainty in predicted trajectories is the fact that assumptions are made on a certain set of inputs describing flight intent. Some of these inputs are more accurately or even exactly known by the operators. This study identifies a subset of parameters which are particularly promising to improve TP accuracy.

In this project, an analysis of current flight planning operations in collaboration with airspace users demonstrates that operators are likely to be able and willing to share such information as long as:

1. It results in a benefit to their operations,
2. It does not require high initial investment and very little additional operating effort,
3. The data is accessible by ATSUs only and will not be stored longer than necessary, and
4. The system developed for sharing is consistent with future SESAR developments (i.e. sharing is performed over an initial version of SWIM).

The report proposes a number of example scenarios in which improved TP performance may lead to improved ATM performance. Subsequently, a number of cost-benefit mechanisms are identified.

This study recommends:

1. To develop specifications for an initial version of SWIM in collaboration with Work Package 8 that addresses the needs for this short term project and the data sensitivity needs for the AUs,
2. To further analyse the accuracy properties and requirements on the identified parameters,
3. To objectively determine the effect of using FOC parameters on TP performance, and
4. To subsequently determine the effect of improved TP performance on ATM performance.

1 Introduction

During SESAR step 1, no interaction with the Reference Business Trajectory (RBT) takes place during departure and only limited interaction takes place during arrival metering [1]. However, Air Traffic Control (ATC) will need detailed, up-to-date trajectory data to drive advanced controller tools, such as Conflict Detection and Resolution (CD&R), Arrival Manager (AMAN), Departure Manager (DMAN) and Conformance Monitoring (CM).

Furthermore, it is recognised that in some situations the Shared Business Trajectory (SBT)/Reference Business Trajectory (RBT) may also not be available for such tools when:

- The information is not sufficiently detailed for the purpose of the tool,
- The aircraft concerned is not yet equipped for data sharing (mixed equipage), or
- The required trajectory is based on different input data ('What-If').

Therefore, ATC will need to operate local Trajectory Predictors (TP) based on the actual state and intentions of the aircraft.

The performance of such TPs influences the operational benefits of the advanced controller tool. Previous research has shown that the provision of operator flight-planning data should permit significant improvements in the performance of TP applications. This project will investigate the operational use of flight-planning data provided by airspace users and assess the benefits to (ATM) system performance [2].

Because the scope of potential changes required to make use of flight planning data are limited to ground systems (airline, military and ATC) an opportunity exists to develop and implement the concept in the relatively near-term.

The concept does not require a change to flight operations to provide a benefit from improved TP performance. This also implies that benefits may arise even if not all operators are participating. Therefore the concept also does not require a mandate on sharing flight planning information.

The project focuses on defining the operational uses of the data and demonstrating the operational benefits that can be achieved. It will assess the requirements for exchanging data between operators and ATC systems but not investigate the means of achieving this – i.e. the work will determine the operational requirement for communications. Similarly, it will not specify how TP systems should implement the data.

1.1 Purpose of the document

The purpose of this document is to introduce the concept of using operator flight planning data to improve trajectory prediction within the wider context of the SESAR story board. Secondly, the document aims to establish how improved trajectory prediction should lead to a benefit to Airspace Users (AU). As such the document concludes V1 of project 5.5.2.

Note that this document should not be considered as an OSED. Instead, this document will feed into the OSED for project 5.5.1 [3].

1.2 Scope of the document

The scope of this document is to introduce the concept of using operator flight planning data to improve trajectory prediction in SESAR Time Based Operations implementation. This contribution from project 5.5.2 will be prior to the advent of standards and infrastructure to support full trajectory exchange between aircraft and ATC systems while project 5.5.1 and also 4.5 primarily address longer term solutions. As such the operator data concerned will be limited to that data that is available at the Flight Operations Centre (FOC)/Wing Operations Centre (WOC).

In general, the above statement limits the data of interest to flight planning data available before take-off. Some operators currently do also update their flight plan at the FOC while the aircraft is airborne. The project will allow for such updates from the FOC to be used but will not require operators to perform such flight planning updates.

The project will focus on the application in the SESAR Terminal Manoeuvring Area (TMA). Therefore, the scope will limit itself to the effects of the concept for aircraft that are between take-off and Top of Climb (TOC), or between Top of Descent (TOD) and landing. Note that ground based TP applications may be applied in Air Traffic Controller (ATCO) tools during all phases of flight and therefore the concept may apply to the wider use of TPs by ATC.

Finally, the project limits itself to predictions of trajectories that can be described by a Business Trajectory (BT). Trajectories that can not be defined by a sequence of 4D points between origin and destination are not considered.

1.3 Background

The project will bring together existing research results in the TP domain to complete V1. A number of research studies took place to investigate the improvements in TP used by ATC service providers by using data from aircraft operators in the calculation of TP.

This report covers some of these studies forming “baseline TP capability” on which this project will build. The section summarises these studies; a more detailed survey of these studies is presented in chapter 2.

Study of the Acquisition of Data from Aircraft Operators to Aid Trajectory Prediction Calculation

This Eurocontrol study performed an assessment of the data required to compute trajectory predictions [4]. Secondly, it identified data that could be obtained from Aircraft Operators (AO) or other sources to produce more accurate predictions. The study used the BADA[1] profiles in its comparisons.

Climb Trajectory Prediction Enhancement Using Airline Flight-Planning Information

The paper studies the impact of airline flight planning data such as aircraft state, aircraft performance, pilot intent, and atmospheric data on ground-based climb TP accuracy [6].

The study concluded the following:

1. Current input data has been shown to be broadly defined for generic aircraft types and nominal airline preference, without taking into account the operational considerations of specific flights or performance variations among individual aircraft of a given type.
2. Flight-planning data from Airline Operational Control (AOC) centres could offer substantial improvement under certain conditions in en-route climb prediction accuracy.

FASTI Operational Requirement for Trajectory Prediction

The FASTI program delivered the FASTI Operational Requirement for Trajectory Prediction Volume 2 [7]. The purpose of the study was to specify the required performance of the trajectory prediction in order to allow the accomplishment of the FASTI operational concept in a target environment, and to describe the process by which measurements are taken.

The requirements and behaviour of the TP are described in Volume 1 of this document [8].

The report described the required accuracy of the trajectory when the aircraft is cleared and operated in accordance with the flight intent.

Aircraft Data Aiming at Predicting the Trajectory

ADAPT2 is another Eurocontrol project that explored ways to use Aircraft Derived Data (ADD) in the computation of an industrial TP [9]. ADAPT2 is the follow-up of the ADAPT1 project and part of the SESAR early start activities [10].

ADAPT2 results demonstrated that certain ADD parameters can be introduced in current industrial TP architectures without major restructuring of the TP engine and indicate that some of them reduce the 4D trajectory prediction uncertainties of CDA profiles.

[1] For more information about BADA see [5].

CFMU Flight Data Interoperability business case

The CFMU Flight Data Interoperability business case is another report considered in the preparation of SESAR P5.5.2 [11]. The report covers a study launched by the Central Flow Management Unit (CFMU) intended to propose solutions improving the flight data interoperability between AO/ Computerised Flight Plan Service Provider (CFSP) and the CFMU. The lack of interoperability between the AOs and the CFMU is responsible for a number of flight data inconsistencies that impacted on the operational performance of flight planning and Air Traffic Flow and Capacity Management (ATFCM) operations.

The study developed a business case covering the identification and analysis of potential options, the associated benefits and constraints. Secondly it quantitatively assessed the size of the benefits and of related costs.

1.4 Intended audience

This section lists specific projects or groups that may have an interest in this report. In general the reader is assumed to be familiar with the ATM process in particular in the TMA environment and the associated terminology.

1. **SESAR WP 5.5.1:** This project addresses the definition of the business and mission trajectory, the capture and drafting of operational requirements on the creation, amendments and distribution of the reference business/mission trajectory within the TMA environment. In light of the scope of WP 5.5.1 it is important for this document to be read by this work package to ensure that the proposed use of airline flight plan data remains consistent with the wider TMA Trajectory Management Framework. Furthermore, the concept described in this document should feed into the OSED of project 5.5.1.
2. **SESAR WP 5.2:** There are two main objectives to this work package:
    a. Develop, refine and provide detail as required to the ATM Target Concept for TMA operations (SESAR CONOPS).
    b. Provide a validation strategy which is derived from both a top down and bottom up approach.

    By making this document available to SESAR WP 5.2 it is ensured that the use of airline flight plan data is consistent with and supports the wider TMA operational concept. That would allow the concept requirements as defined by this project to be included in the overall TMA concept. These requirements can then be assessed in integrated validation activities.
3. **SESAR WP 5.3:** The objective of this project is to perform a pre-operational validation across several concept functions/elements of the TMA operation. Considering this document by WP 5.3 makes sure that the use of FOC data concept is considered in integration validation activities for stage V3.
4. **SESAR WP 10.2:** This SWP defines and validates the technical enablers of ground ATC systems relating to trajectory management, specifically the contribution of ATC systems to the amendment and distribution of the RBT and Mission Trajectory (MT) in the realm of En-route and TMA.
5. **SESAR WP 10.2.1:** The objective of this project is to describe how the ATC system will support the trajectory management services that will be developed by the various operational work packages. Considering this document by WP 10.2.1 will ensure that the operational requirements will be considered for inclusion in prototype tools developed by WP10, which will then be used for V3 validation.
6. **SESAR WP 8:** This work package objective is to establish the framework which defines seamless information interchange between all providers and users of shared ATM information. It is likely that the flight planning information will need to be distributed over SWIM. Considering this document by WP 8 will insure that the AOC parameters proposed in this document will be considered in the framework.
7. **SESAR WP 11:** It is important the flight plan data adopted in 5.5.2 are approved by the FOC projects within WP11.
8. **Airspace Users:** Making this document available to operators would help to develop a common understanding approach to which FOC parameters would be available and helps to establish the concept among various operators.

9. **Flight planning system manufacturers:** It is possible that some flight planning systems may need modification to supply the required parameters. Making the document available to flight planning system manufactures would help in establishing the concept proposed in this document with the various suppliers.

1.5 Structure of the document

As described in the background section, the concept of using additional flight planning data in ground based TP applications has been studied before. In chapter 2, a number of prior studies are reviewed. Furthermore, this section summarises a number of research publications on trajectory prediction which support the development of the associated TP concept.

In chapter 3 the ground based TP, its operating environment and its use is described. By detailing the trajectory prediction process, the main causes of inaccuracy are determined. This leads to an identification of which flight planning parameters might enhance TP performance.

Chapter 4 analyses the flight planning process as performed by different operators. This analysis is supported by input from civil and military operators through a questionnaire. Based on the analysis, a list of available parameters and their accuracy is determined. By combining this list with the list of potential TP inputs from chapter 3, a list of most promising parameters is established.

As chapter 3 and 4 establish a potential source of flight planning data and their needs, chapter 5 will look at the process of sharing the additional flight planning parameters from the operator's FOC to the relevant Air Traffic Service Units (ATSU). It is assumed that the data will need to be shared over – an initial version of – SWIM. The section also identifies the issues that may constrain the sharing process.

The combination of chapters 3, 4, and 5 effectively establish the concept of using flight planning data in ground based TP applications. The next step is to apply the improved TP to an operational environment. The operational concept will be placed in a number of example scenarios in chapter 6. These scenarios are selected based on the projects' familiarity with the situations and the associated roles of trajectory prediction.

Based on the scenarios, chapter 7 describes the cost-benefit mechanism using input from WP 16 which leads to a set of proposed costs and benefits for further analysis.

Chapter 8 finally draws conclusions from the above sections. These conclusions should form the basis for the next phase of the project.

1.6 Acronyms and Terminology

Term	Definition
ACARS	Aircraft Communications Addressing and Reporting System
ADD	Aircraft Derived Data
ADEP	Airport of Departure
ADES	Airport of Destination
Aircraft Intent	Aircraft Intent is the aircraft operations plan that defines precisely HOW the aircraft intends to meet the constraints and preferences defined in the Flight Intent. Aircraft Intent constitutes an unambiguous description of the trajectory, essential to provide interoperability among the stakeholders [12].
AMAN	Arrival Manager: An ATM tool that determines the optimal arrival sequence times at the aerodrome and/or possibly at other common route fixes (e.g. IAF)
ANSP	Air Navigation Service Provider
AO	Aircraft Operator

Term	Definition
AOC	Airline Operational Control
AP16	Eurocontrol-FAA Action Plan 16
ASM	Airspace Management
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSU	Air Traffic Service Unit
AU	Airspace User
BADA	Base of Aircraft Data – Eurocontrol
BT	The Business Trajectory (BT) is the representation of an airspace user's intention with respect to a given flight, guaranteeing the best outcome for this flight (as seen from the airspace user's perspective), respecting momentary and permanent constraints. The term Business Trajectory describes a concept of operation, rather than a set of data.
CDA	Continuous Descent Approach
CD&R	Conflict Detection and Resolution
CFMU	Central Flow Management Unit – Eurocontrol
CFSP	Computerised Flight Plan Service Provider
CI	Cost Index
CM	Conformance Monitoring
CPDLC	Controller Pilot Datalink Communications
CTA	Controlled Time of Arrival
CTAS	Center-TRACON Automation System – FAA
DAP	Downlinked Airborne Parameters
DMAN	Departure Manager
DST	Decision Support Tools
E-ATMS	European Air Traffic Management System
ETA	Estimated Time of Arrival

Term	Definition
ETO	Estimated Time Overhead
FACTS	Future Area Control Tools Set – NATS
FASTI	First ATC System Tools Implementation
FDP	Flight Data Processing
Flight Intent	The Flight Intent is an element of the Flight Object that describes the constraints and preferences that are applicable to the flight. It describes what needs to be achieved [1].
Flight Object (FO)	The Flight Object (FO) represents the system instance view of a particular flight. It is the flight object that is shared among the stakeholders The information in the FO includes aircraft identity, Communications, Navigation and Surveillance (CNS) and related capabilities, flight performance parameters, flight crew capabilities including for separation procedures, and the flight plan (which may or may not be a 4DT), together with any alternatives being considered. Once a flight is being executed, the flight plan in the flight object includes the “cleared” flight profile, plus any desired or proposed changes to the profile, and current aircraft position and near-term intent information. Allocation of responsibility for separation management along flight segments is also likely to be stored [1].
FOC	Flight Operations Centre
FPL	ICAO Flight Plan message
FSS	Flight Service Station (USA)
GAT	General Air Traffic
I4D	Initial 4D (from B04.02 [1])
iFACTS	Interim Future Area Control Tools Set – NATS
IFPS	Integrated Flight Plan Processing System
IFR	Instrument Flight Rules
MSP	Multi-Sector Planner
MT	The military Mission Trajectory (MT) is similar, but more complex than a civil Business Trajectory. A military mission trajectory will usually consist of a transit to and from an airspace reservation with mission specific dimensions and characteristics. Outside and inside of an airspace reservation a single trajectory could be used by multiple aircraft [13].
OAT	Operational Air Traffic
OFPL	Operational Flight Plan
PBN	Performance Based Navigation
PDC	Pre Departure Clearance

Term	Definition
RBT	The Reference Business Trajectory refers to the Business Trajectory during the execution phase of the flight. It is the Business Trajectory which the airspace user agrees to fly and the Air Navigation Service Providers (ANSP) and Airports agree to facilitate (subject to separation provision) [1].
RMT	Reference Mission Trajectory
RNAV	Area Navigation
RNP	Required Navigation Performance
RPL	Repetitive Flight Plan
SBT	Shared Business Trajectory
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
TBO	Trajectory Based Operations refers to the use of 4D trajectories as the basis for planning and executing all flight operations supported by the air navigation service provider.
TCT	Tactical Controller Tool (separation assurance support)
TMA	Terminal Manoeuvring Area. Within scope of SESAR, the TMA is defined as the airspace containing that portion of the flight between take-off and Top of Climb and between Top of Descent and landing.
TP	Trajectory Predictor. From B04.02: Trajectory prediction is the process that estimates a future trajectory of an aircraft through computation. This is performed by a Trajectory Predictor [1].
TOM	Take-Off Mass
TOC	Top of Climb
TOD	Top of Descent
T/D	Touch-Down
T/O	Take-Off
VFR	Visual Flight Rules
WOC	Wing Operations Centre

2 Literature review

This chapter represents a literature review of a number of studies that investigate the improvements in ground-based trajectory prediction by using data from aircraft operators and airspace users.

2.1 Introduction

Various studies took place to investigate the improvements in the TP used by ATC service providers by using data from aircraft operators in the calculation of trajectory prediction. In the coming sections we survey some of these reports aiming to make use of the finding and recommendations from them in our use of AOC data in computing ground trajectory predictions.

2.2 Study of the acquisition of data from aircraft operators to aid Trajectory Prediction calculation

This study was conducted by Eurocontrol and a report "*Study of the Acquisition of Data from Aircraft Operators to Aid Trajectory Prediction Calculation*" was produced to summarise the study, findings and recommendations [4].

The study analyses the data required to compute trajectory predictions. Since there are many different trajectory prediction algorithms, the need of input parameters varies accordingly. The general set of parameters can be identified as follows:

1. Flight plan route.
2. Airspace description, for example: waypoints, airways.
3. Aircraft characteristics: The key characteristics are:
    a. Aircraft type,
    b. Engine type,
    c. Engine degradation, and
    d. Mass; this is the sum of the masses of the airframe, fuel, passengers and freight.
4. Environmental Parameters: that includes Temperature profile, Wind profile, and Atmospheric pressure.
5. Operating procedures: This set varies from one company to another but the common set is:
    a. Speed law,
    b. Timing of manoeuvres,
    c. Acceleration with rate of climb, and
    d. Take-off and climb thrust reduction.

The study identifies data that could be obtained from AOs or other sources to produce more accurate predictions.

The aircraft type is a source of accuracy problems since the ICAO aircraft type designator provided in the flight plan has no distinction between the aircraft sub-models and the sub-types of aircraft will assume to have the same performance characteristics.

Mass is another factor. The analysis demonstrated the importance of having an accurate estimation of the take-off mass. However, information such as the mass of freight, passengers and fuel are only known accurately by the AO at the later stages of flight planning. It is believed that ATC could not need such information before pre-flight phase (i.e. 30 minutes before tack-off). It is believed that only take-off mass matters with an indication of its status (estimate, actual) and accuracy (+/- xKg).

The study noted that different engine types may be fitted to the same aircraft type which result in different thrusts for different airframes. Hence for accurate trajectory prediction the engine type needs to be known.

The study used a set of climb profiles and compared it with the BADA profiles[2]. It was observed that BADA climb profiles sometimes make the aircraft appear to climb steeper than it does in reality.

It was concluded that the operating procedures and individual pilot actions have a real impact on the climbing profile and need to be known in order to improve trajectory predictions.

The study found that typically the following information is provided to flight planning systems by AO to generate flight plans (OFPLs):

1. Full aircraft type with engine characteristics.
2. Operating procedures, such as climb speed, cruise speed and descent speed.
3. The AO may place a priority on minimising fuel consumption or the duration of the flight.
4. Various elements that contribute to the overall weight.
5. Airport of Departure (ADEP) and destination airport (ADES), and alternate.
6. Estimated time of departure (ETD), to allow the meteorological forecast to be applied.

The OFPL does not provide a highly accurate trajectory prediction and it may be revised. For the factors affecting the accuracy of the OFPL see [4].

It is noted that the OFPL is established about 4 or 5 hours before the estimated time of departure with an accurate airframe mass and an estimation of the mass of passengers and freight.

In conclusion, the data available on ground from AOs could help to support improvements to trajectory prediction. However, there remain several inaccuracies inherent in the data which could be supplied and which would affect the quality of such predictions.

The main objective of this study was to determine whether it is possible to obtain better information for trajectory prediction on ground from AOs, with a particular focus on improving prediction in the early stages of flight.

The study proposed solutions to the ground based Trajectory Prediction based on using only the information available from AOs on ground. Using this approach is the most suitable one for our task in SESAR P5.5.2 and it is based on the distribution of information by ground-based flight planning systems of AOs to ATC Systems.

As it is defined earlier better prediction to input parameters could help in improving the accuracy of ground trajectory prediction.

The study also addressed the distribution of this data, several options exist, including:

1. The ICAO FPL could be extended with the required data being added in specific new fields and the data forwarded to ATS by Integrated Flight Plan Processing Systen (IFPS).
2. A specific new message containing the required data could be distributed directly to ATS by AOs.

The advantage of the first solution is that the infrastructure for distributing FPLs by AOs already exists.

The main problem concerns the timeliness of updates, since FPLs are normally filed several hours before the time of flight so it would be difficult to take account of updates since there is no communication of data from gate to FOC in this scope.

The second solution would offer a means of avoiding the problems of timeliness, but would introduce requirements to prepare and distribute new messages. It would be necessary to improve existing links between AOs and ATS to ensure direct communication (e.g. to ensure full connectivity of AOs and ATSUs).

Conclusion

The report makes the following recommendations:

1. Arrangements for the provision of Operational Flight Plans (OFPL), full aircraft type, engine fit and approximate take-off mass by AOs should be established on an experimental basis and trials carried out to evaluate the data provided.

[2] For more information about BADA see [5].

2. An impact assessment of the provision of these data on the wide range of different TPs found in ATS systems should be made.
3. An impact assessment on Aircraft Operator (AO)-Air Traffic Service (ATS) communications of these changes should be assessed to determine the costs and feasibility of full scale implementation.
4. Further investigations should be made of the practicalities of delivering updates of airframe and take-off mass data via the Pre Departure Clearance (PDC) and Downlinked Airborne Parameters (DAP) datalink applications. This should involve experiments and trials.

2.3 Climb Trajectory Prediction Enhancement Using Airline Flight-Planning Information

Another study on the US Center-TRACON Automation System (CTAS) was reported in a paper published by R.A. Coppenbarger [6]. The study addressed the issue that trajectory predictions in en route airspace rely upon the availability of aircraft state, aircraft performance, pilot intent, and atmospheric data. The paper studied the impact of airline flight planning data on CTAS en route climb trajectory prediction accuracy. The climb trajectory synthesis process is first described along with existing input data. Flight–planning data parameters, available from a typical airline operations centre, are then discussed along with their potential usefulness to CTAS. Results are then presented to show the significant impact of airline-provided take-off mass, speed-profile, and thrust calibration data on CTAS climb trajectory prediction performance.

The accuracy of trajectory predictions in en route airspace impacts ATM conflict predictions and Estimated Times of Arrival (ETA) to control fixes. Preliminary studies have shown that trajectory uncertainties can significantly affect the schedules and manoeuvre advisories that CTAS generates to manage traffic flows and resolve separation conflicts. For the airspace user, inaccurate trajectory predictions may result in less-than-optimal manoeuvre advisories in response to a given traffic management problem. These include *missed advisories* and *false advisories*. Missed advisories refer to the lost opportunity of resolving a traffic management problem in a manner most efficient to the airspace user. An example of a missed advisory is the failure to resolve a conflict between two aircraft at the earliest opportunity, requiring the least amount of fuel-burn between them. False advisories refer to the suggestion of an unnecessary manoeuvre that may cause an aircraft to depart from its most efficient trajectory.

In an operational environment, user information can be acquired from either ground-based or airborne sources. For the purpose of this project SESAR WP5.5.2 we focus our discussion on Ground-based sources, which can readily provide pre-departure flight planning data, include AOC centres and Flight Service Stations (FSS). The study also includes a description of pertinent data elements that are either available or derivable from AOC flight planning resources.

The primary limitation of current airline data in CTAS is that it represents nominal performance and preference characteristics for all aircraft of a given type, without considering variations associated with specific flight operations or aircraft sub-types.

The ATM flight plan is limited to a broad description of aircraft type, expected route waypoints, and anticipated cruise altitude and airspeed. Detailed operational flight plans, available from AOC centres, can provide a rich source of calibration and intent data for improving ATM trajectory predictions, especially for en-route climbs (above 10,000 ft). This data includes such items as aircraft mass, thrust and drag performance factors, and speed profile intent.

The following AOC data is available:

1. Airframe and Engine Type.
2. Estimated Take-off Mass.
3. Thrust and Drag Calibration Factors.
4. Climb Speed Profile.
5. Climb Throttle Setting and Acceleration Procedure.

Conclusion

The main conclusion from this study is that current input data has been shown to be broadly defined for generic aircraft types and nominal airline preference, without taking into account the operational considerations of specific flights or performance variations among individual aircraft of a given type.

Flight-planning data from AOC centres could offer substantial improvement under certain conditions in en-route climb prediction accuracy, promising capacity and efficiency benefits for the airspace user. In particular, AOC-provided take-off mass, speed profile, and engine type specification can significantly reduce climb trajectory uncertainty. Although the results of this analysis indicate significant potential benefits of including AOC performance and intent data in the ATM trajectory prediction process, aircraft performance models must be of sufficient fidelity in order to appropriately benefit from airline information. The following results indicate the potential improvement that AOC flight-planning data has on CTAS climb trajectory predictions. In particular, the actual or anticipated impact of AOC takeoff weight, speed profile, and thrust calibration data on CTAS. Based on data collected from two major airlines, the observed operational range in takeoff weight among a variety of common aircraft types show maximum variations of up to 50% of mean takeoff weight for certain aircraft types. For more details on these results see Ref. [5].

2.4 FASTI Operational Requirement for Trajectory Prediction

Another report by Eurocontrol is '*FASTI Operational Requirement for Trajectory Prediction Volume 2*' [7]. The purpose of the study was to specify the required performance of the TP in order to allow the accomplishment of the FASTI operational concept in a target environment, and to describe the process by which measurements are taken. The document also provides guidelines on techniques that might be employed by the TP in order to achieve the required accuracy.

These requirements are intended to be used by Air Navigation Service Providers (ANSP) in the planning and procurement of ATM systems, particularly those including the FASTI controller tools.

The requirements and behaviour of the TP are described in Volume 1 of this document [8]. The latter report states that, in order to calculate the trajectory, the flight intent has to be supplemented with some assumptions on how the aircraft will be flown (aircraft intent) and an aircraft performance model. In volume 2 the project described the required accuracy of the trajectory when the aircraft is cleared and operated in accordance with the flight intent. Requirements are specified separately depending on whether the trajectory is subject to conformance updates from the monitoring aids.

2.5 Aircraft Data Aiming at Predicting the Trajectory

ADAPT2 is another Eurocontrol project that explored ways to use ADD in the computation of an industrial TP [9]. ADAPT2 is the follow-up of the ADAPT1 and part of the SESAR early start activities [10].

The TP performance analysis provided by ADAPT2 seeks to determine which ADD items and ADD combinations can be used with such a TP and quantify the improvements they bring.

ADAPT2 focuses in particular on trajectory prediction of flights following RNAV routes and applying continuous descent approaches. TP performance metrics include the uncertainty of vertical, longitudinal and temporal trajectory predictions from top of descent to touchdown for look-ahead times up to 20 minutes.

TP performance assessment was realised through simulation runs on the modified ground TP (by Thales AS) using ADD inputs extracted from onboard recordings collected from live RNAV/CDA flights.

ADAPT2 results demonstrated that certain ADD parameters (FMS 4D trajectory information, aircraft mass, ground speed, TAS, aircraft weather information) can be introduced in current industrial TP architectures without major restructuring of the TP engine and indicate that some of them reduce the 4D trajectory prediction uncertainties of CDA profiles. In particular significant benefits from using FMS 4D trajectory information and aircraft mass have been observed.

The results also demonstrate that the introduction of 4D trajectory brings a significant improvement in the average response from 58 seconds for baseline (no 4D trajectory) to (11—16) seconds in the modified one.

Similarly the use of mass resulted in deviating close to 0 nautical miles compared with deviation of about 2.5 nautical miles using the baseline (no mass).

2.6 CFMU Flight Data Interoperability Business Case

The CFMU Flight Data Interoperability business case is another report considered in the preparation of SESAR WP5.5.2 [11]. The report covers a study launched by the Central Flow Management Unit (CFMU) intended to propose solutions to improve the flight data interoperability between AO/CFSP and the CFMU. The lack of interoperability between the AOs and the CFMU is responsible for a number of flight data inconsistencies that impacted on the operational performance of flight planning and ATFCM operations.

The study developed a business case covering the identification and analysis of potential options, the associated benefits and constraints and assessing quantitatively the size of the benefits and of related costs.

The Business Case was developed through the following activities:

1. Identification of key options to increase flight data interoperability and development of the baseline.
2. Assessment of the associated costs for each option.
3. Assessment of the operational benefits and benefits mechanism for each option.
4. Identification of the main risks.
5. Alignment with concerned actors strategies and constraints.

Several options were proposed introducing various concepts of operations, implying different levels of changes in AO/CFMU flight data exchanges that can be associated to different levels of benefits for ATFM.

The Flight Data Interoperability Programme is a short-term programme whose time schedule is defined as follows:

1. The specifications followed by the development of the programme, including a pilot phase, are planned from 2010 to 2012 / 2013. The pilot phase is intended to test the concept of operations in real conditions.
2. The deployment and operational phase should take place from 2012 / 2013 until the beginning of SESAR in 2020.

3 The ground based trajectory predictor

3.1 Introduction

Since the 1970s the development of technology for Decision Support Tools (DST) on ATM tools has more and more shifted from situation-based to systems based on trajectory predictions.

In 2003 European and United States experts formed together Action Plan 16 (AP16). AP16 group focused on all issues related to TP in airborne and ground based systems. The AP16 group published a white paper describing the structure of a generic TP using the common terminology that was used at that time in a number of research initiatives [12].

3.2 Operational environment

Ground trajectory prediction can be considered a service for some DST for a higher level user in the ATM system. TP is used by most ATSUs in controlled airspace. The use of TP and related higher level client applications apply to both TMA and en-route airspace.

This document will focus on application in Terminal operations. This does not however limit the possible applicability of the concept to the TMA and indeed similar research is already done by the CFMU as described in section 2.6.

3.3 Current purpose

Ground TP and TP systems are used potentially in a number of components:

1. Flow Management (CFMU).
2. Flight Data Processing (FDP) (VAFORIT,EUROCAT).
3. CD&R; the main purpose of the CD&R is to detect potential medium term interactions along aircraft trajectories and allow early/efficient detection and resolution of tactical conflicts. An example of such use is NATS iFACTS.
4. Advanced Trajectory planning and conflict detection tool (ERATO).
5. The Arrival Manager (AMAN) is a planning tool that will automatically provide an optimised arrivals sequence. The arrival manager receives input from various sources to provide ground trajectory prediction.

Although the concept may be applicable to all implementations of TPs, this study will focus on two specific examples applied in the TMA: The AMAN and CD&R application.

3.4 Purpose of ground based TP in SESAR concept

The purpose of this study is to investigate various data elements that can be provided by FOCs to improve the accuracy of ground based TP. The improved ground TP will have its direct impact on the success of SESAR step 1 “Time Based Operations”.

Step1 initiates arrival airport time prioritisation together with wide use of data-link and the deployment of initial trajectory based operations through use of a controlled time of arrival and ASAS to sequence traffic and manage queues.

Performance Based Navigation (PBN) will be used to systemise/optimise route structures and procedures, primarily for Standard Instrument Departures (SID) and Standard Terminal Arrival Routes (STAR) in TMA. Pilots, controllers and operation planners will have automation support and management tools bringing safety, environmental and flight efficiency improvements.

The introduction of these techniques during SESAR step 1 will improve ATC systems to be ready for SESAR step 2 “Trajectory Based Operations”.

3.5 How does ground TP work

Ground TP is fundamental to many ATM decision support tools. Hence the development, performance improvements and validation of trajectory predictors lie on the critical paths to the deployment and success of such ATM decision support tools.

Main research activities in Europe and United States focus on technology that supports trajectory predictions. This shift of approach in technology development will enable airspace users to plan and execute their operations in collaboration with the ATM service providers by means of 4D trajectories (Business/Mission Trajectory terminology).

The generation and/or adaptation of trajectory information are performed by a TP. It can be considered as a service for some client application that provides support for a higher level user in the ATM system.

The generic structure of the TP comprises four processes: Preparation, Computation, Up-date and Export. In this general structure, it is the TP client application that interfaces with the Flight Object and decides how and when to use the information within the Flight Object to meet its needs.

In the following sections we have a summary of each of these four processes:

3.5.1 Preparation process

The preparation process builds an initial condition and a Behaviour Model from input state and intent information provided by the TP client process.

3.5.2 Computation process

The Computation process computes the predicted trajectory information from the behaviour model.

3.5.3 Update process

The update process checks the conformance of the computed trajectory with the trajectory constraints specified by the TP client in the input *flight intent*. In the case of non-conformance, the *update process* adapts *behaviour model* and/or input flight intent data. Re-computation of the trajectory should result in a better match. The *processing strategies* defined by the TP client process guide the update process.

3.5.4 Export process

The *export process* delivers the output data of the TP to the TP client process. This includes:

- The predicted trajectory;
- Errors and warning messages informing the TP client on the availability and/or quality of the output data;
- In the case that the initial behaviour model did not result in a computed trajectory that matches all constraints, an updated behaviour model is made available to the TP client process, possibly for updating the *flight script* information in the *flight object*;
- In the latter case the TP client process may also want to be informed about the specific preferences and constraints that have been relaxed to compute a matching trajectory.

The TP Client is any function in the SESAR system that requires the support of a Trajectory Predictor. It is the interface between the TP and the higher level services in the ATM system.

The synchronization of flight data among stakeholders in the ATM system is ensured through the Flight Object. Stakeholders, actively involved in the TM processes, may require adaptation of the trajectory information to meet their specific requirements. These stakeholders are considered TP clients.

The TP Client specifies in the Processing Strategies how the TP should perform the matching of the Predicted Trajectory to the constraints and preferences specified in the Input Flight Intent. Through Configuration Control the TP Client may define processing characteristics of the TP, e.g. select a specific integration method, aircraft performance model, functionality of the export function, etc.

The TP Client may use the computed output information from the TP for internal processing, e.g., “What-if” and/or, in the case that it has the authority, to update the information in the Flight Object

The definition of unambiguous TP performance requirements is key to ensure that the TP client will be capable of meeting its own higher level performance requirements.

3.6 TP data view

The TP-Data View as described by AP16 is an expansion of the TP-Process View identifying interfaces and key data sets. The description is generic and is presented by Figure 1.

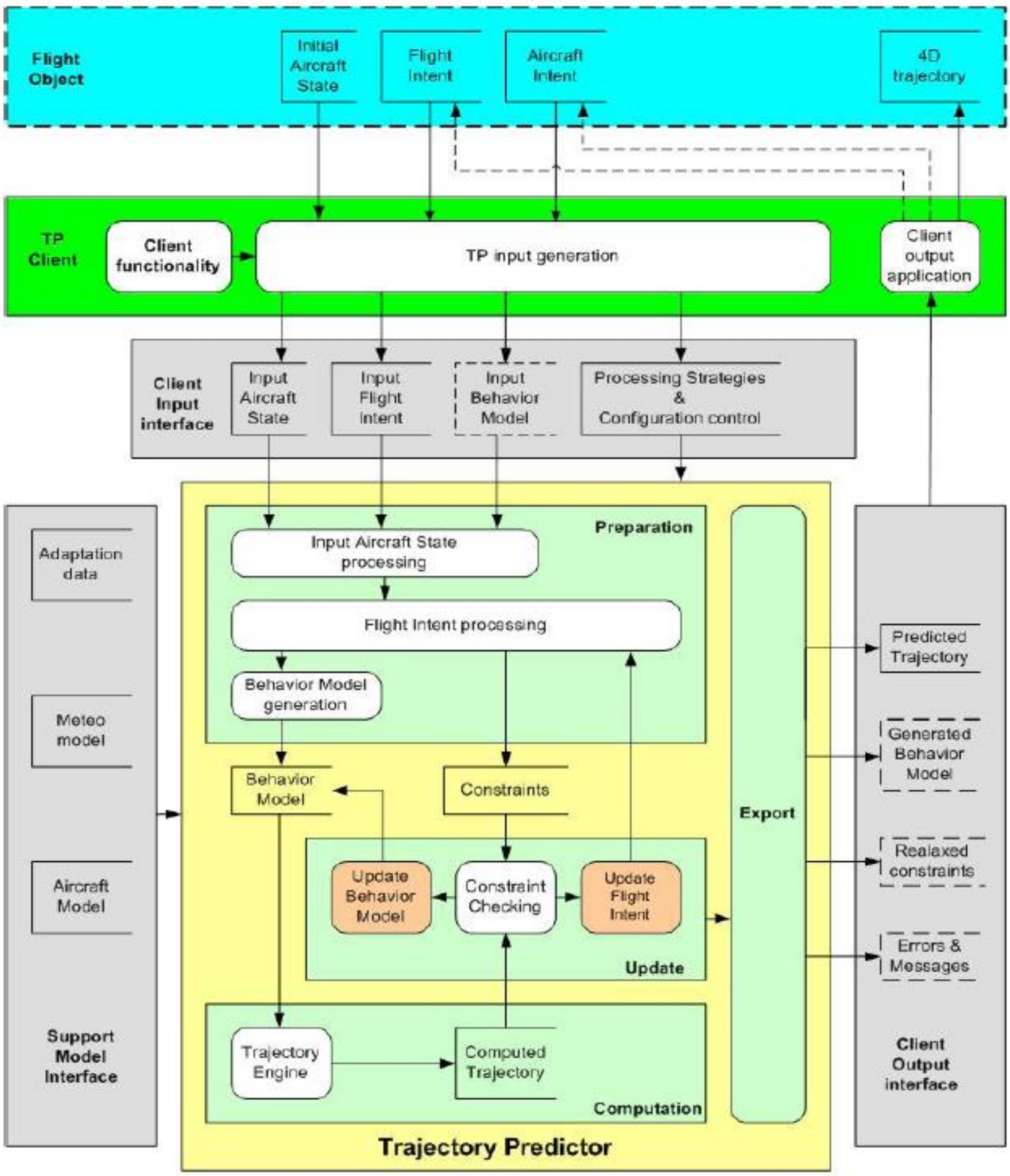


Figure 1: Trajectory Prediction – Data View (Source AP16)

In the Figure 1 the “closed” boxes refer to generic processes, whereas the “open” boxes identify data containers. Dashed lines indicate optional data paths and system elements. The structure is generic in that it describes the data containers and processes that may exist in a TP. Whether a specific process of data container can actually be identified in a specific TP depends on the implementation for the specific use case. It is important to identify and define these generic elements to facilitate unambiguous system performance specifications.

3.7 Ground TP data requirement

The computation of ground-based TP requires access to variety of data items. The required data may be accessed from a number of sources with different levels of accuracy. Accessing more accurate data helps to improve the accuracy of the produced trajectory prediction.

From previous TP activities and various studies we came to the conclusion that the input data to ground-based TP from accuracy point of view can be grouped into three categories:

1. Observations,
2. Predictions, and
3. Assumptions.

3.7.1 Observations

The data items classified under this category are collected from observation and are updated in a dynamic way with a high rate of update. As a result this group of data items tend to be very accurate. We do not believe items under this category will benefit from the data provided by FOCs. Aircraft position and speed are typical examples of data under this category.

3.7.2 Predictions

Unlike the first group of data the preparation of this group of data items require the used of appropriate mathematical models. The accuracy of the resulted data depends on input data and the model used to perform the prediction which introduces error associated to the predicted data. The decision to use the current source of data or replacing it with the equivalent from AOC will need to be addressed on parameter by parameter basis.

One example of data that fits in this group is the MET-data which tends to be updated frequently in the ground side and hence we recommend using the current approach and get the MET-data provided to the TP component as the current mechanism. Another example is the fuel used during flight which can be predicted by models in the ground or by aircraft operators. The fact that aircraft operator can access more accurately updated data will lead to a more accurate prediction to this data item by AOC. This is an example of a parameter that can be predicted by the ground side but more accurately by AOC.

3.7.3 Assumptions

This group of parameters are based on assumptions, so the accuracy of these parameters is less than the other two groups. Examples of such parameters are climb speed, thrust settings and aircraft mass. This group represents the main group for potential improvement in accuracy based on using AOC data. This approach of using AOC data has been addressed in a number of studies, for more information regarding these studies and their recommendations, see chapter 2.

To be able to form the optimal set of data items that can be used from AOC data to improve ground TP, the following approach took place:

1. A questionnaire has been prepared, see Appendix C, to establish the parameters available from airspace users that they are prepared to share with the ground ATC users to improve the accuracy of the ground TP. The responses from various airlines contributed to this study developed the set of data items presented in Appendix A. For more details regarding the questionnaire see Chapter 4
2. The next stage of this study was to select a sub-set of data items that is of potential benefit in improving the accuracy of the ground TP by using these parameters. The table in Appendix A lists why certain parameters may be of use and others are unlikely to provide a benefit to a ground based TP in the TMA.
3. From the list of possibly suitable parameters, a further subset is selected; this set represents those parameters which are most likely to provide a benefit to TP and can relatively easy be implemented in current and near-term systems. This list is provided in Appendix B. This set is the core of this study. This subset has been developed on the recommendations from previous studies (e.g. [4]) and its direct use in the computation of trajectory prediction.

3.8 TP based ground ATC systems

In this section we present two examples: The first is the current ground baseline system that consists of the current ground TP together with its client applications but does not use AOC data. The second example represents the modified (alternative) system that consists of improved ground TP. The improved ground TP will use AOC data available before take-off (e.g. aircraft Take-Off Mass, TOM). The client applications will be the same client applications as in the current baseline.

3.8.1 Current ground system baseline

The current baseline system consists of the current ground TP together with its client applications. TP client applications considered in this work could be: arrival sequencing (AMAN tool), CD&R.

For the purpose of validation, not only the TP component but the entire system must be taken into account. The coverage must include the TP component and its client applications. Coverage of the environment and traffic information should be included.

This section will be covered in detail during the validation phase of the proposed concept.

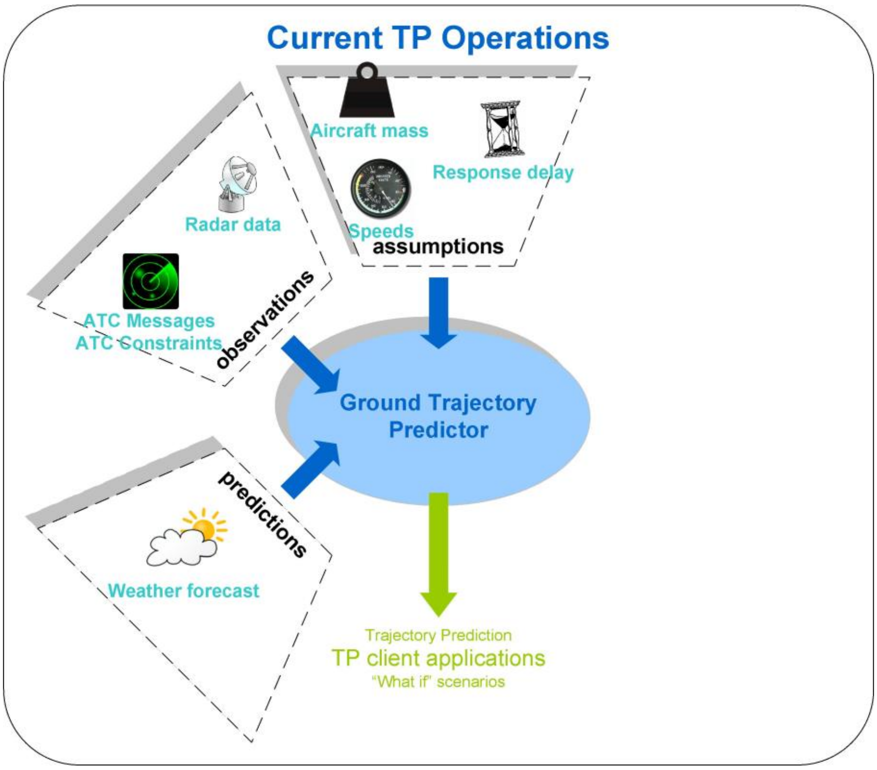


Figure 2: Current system (ground TP)

3.8.2 Modified ground system (using AOC data)

The modified (alternative) system could consist of improved ground TP. The improved ground TP will use AOC data available before take-off (e.g. aircraft TOM). The client applications will be the same client applications as in the current baseline. The client applications' settings may be updated to take maximum benefits of the improved ground TP predictions.

For the purpose of validation the full system must be taken into account not only the TP component. The coverage must include the TP component as well as its client applications. Coverage of the environment and traffic information should be included.

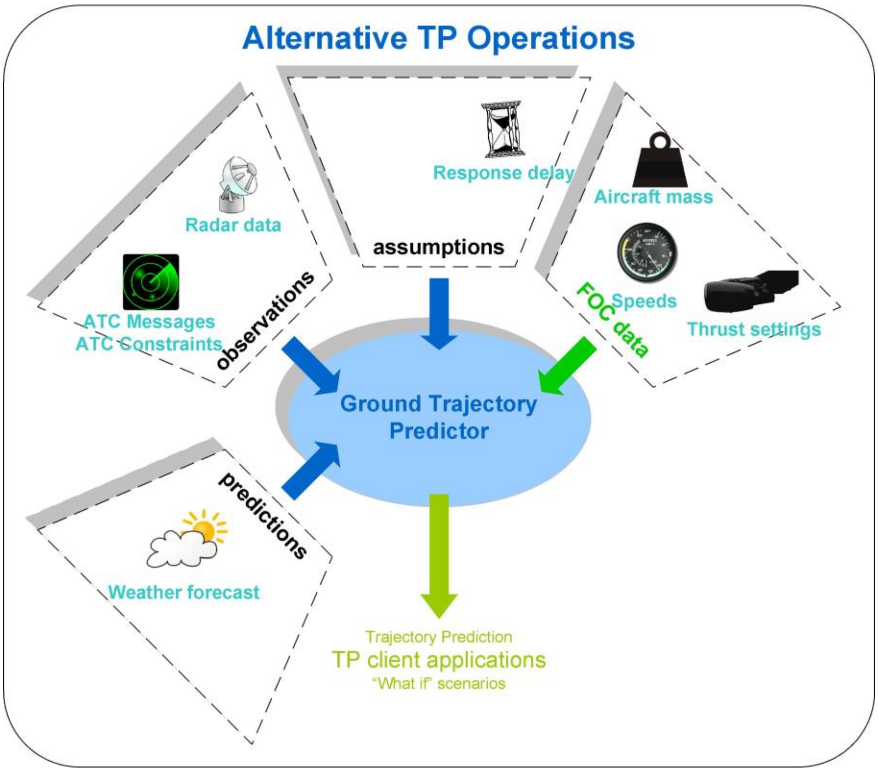


Figure 3: Alternative system (ground TP using AOC data)

Remark 1: AOC data amount may vary in quantity and quality (e.g. aircraft equipage, AOC arrangement, ground TP improvement across Europe). These could be seen as different alternatives to consider in the cost/benefit study.

Remark 2: During the study various alternatives could be considered: the TP client applications could also be modified to take advantage of the improved TP. Different level of TP deployment could be envisioned.

4 Airspace user flight planning data

The previous chapter has established what data may improve trajectory prediction. The next step is to analyse which of these parameters may be acquired from the operators' flight planning processes. Secondly, the accuracy of these parameters will be established to determine suitability in a TP process. This will ultimately lead to a list of available parameters which are most likely to improve TP performance.

To achieve the above goals, this chapter will consolidate and extend the results from previous work with recent information solicited through a questionnaire to airspace users.

Where applicable the section will distinguish between military and civilian operations. However, in doing so, the concept aims to treat the all airspace users equal. Therefore a main focus is on similarities despite the differences in operations.

The chapter is structured as follows:

- First the research method is elaborated to provide some background on the sources and limitation on the available information.
- Not all types of operations will be able to provide suitable flight planning information. Similarly, the concept can only provide a benefit if a ground based TP application is used by ATC to exercise control on the flight; the second section provides a scope of the airspace users and the type of operations to which the concept may apply.
- For these operations which may participate and benefit from the concept, the flight planning process will be described chronologically. This provides an overview of the time at which data is available, and the actors which have access to the data. Due to the difference in nature of operations, this section is separated in the civil and military planning processes.
- The chapter concludes with an analysis of the information available from the planning process. This includes the technical availability, the processes that influence parameter accuracy, and the possibilities for operators to share the information.

4.1 Method

Chapter 2 describes previous similar research by Eurocontrol. Based on this research and initial knowledge on potentially valuable parameters described in other previous research, a questionnaire to airspace users has been developed. Appendix C provides the questionnaire template. The main focus of the questionnaire is on the flight planning process and the available parameters.

This questionnaire has been distributed amongst various airspace users including airlines, business aviation operators, and military operators. Upon return of the questionnaires various discussions with the AUs have take place to further clarify the process. As the replies on the questionnaires contain commercially sensitive information, the replies have been consolidated into a general overview of different planning processes.

As many different operators with equally many different planning processes exist, this section will not be exhaustive in all possible variations. However, the scope of the supporting operators provides a good indication of the available information.

4.2 The airspace user

This section will describe the operators that will be considered in this study. To be able to prove additional operator data, the operator needs to perform detailed flight planning and have the ability to provide the data from flight planning to the ATSUs.

To benefit from enhanced ground based trajectory prediction, the operation has to be in controlled airspace. Furthermore, the profile of the flight has to be such that the trajectory of the aircraft can be predicted.

4.2.1 Civilian operator

Most civilian operations are suitable to participate in the concept. The main exception to this statement is Visual Flight Rules (VFR) traffic as the route of this traffic is not predicable.

Although all Instrument Flight Rules (IFR) traffic will have filed a flight plan, not all operations will have the capability to produce details significant to trajectory prediction.

Finally, this research will initially focus on operators with centralised and electronic flight planning as these are most likely to be able to provide the information at limited additional effort per flight. Note that this does not preclude smaller operators to participate.

4.2.2 Military operator

Military operations can be divided according to two types of flight profiles: Operations with a flight profile similar to the business trajectory and operations with other profiles (mission trajectories and airspace constraints) [13].

Ground based TP within the scope of this work will only be able to predict trajectories according to the first profile while inside the airspace of interest. For these operations, sharing additional flight planning data may benefit operations.

Note that the fact that TPs will only predict the first type of profile does not exclude aircraft to fly other types of profiles in the same airspace; although no predictions may be generated by the TP of interest in this research, tools may still provide means to take account of the military profiles.

4.3 Flight planning

Flight planning serves a number of purposes:

- First of all, to determine the conditions under which a flight can safely be performed:
  - Determine the mass / centre of gravity of the aircraft to ensure safe operation,
  - Determine the route which can safely be navigated including weather, alternate destinations in case of abnormal situations, and
  - Determine the amount of fuel necessary for the safe execution of the flight including reserves to reach the alternate destinations.
- Secondly, to inform ATC of the intentions of the flight. This also enables ATC to determine constraints on time and route of the flight such that ATC is capable of providing the required capacity.
- Thirdly, to apply considerations toward the operators' objectives. In case of the civilian operators this may include for example:
  - Costs of fuel, crew, aircraft deprecation/lease, ATC, payload, delay,
  - Taking advantage of meteorological conditions such as jet streams,
  - Crew rostering,
  - Aircraft rotation and positioning (in particular for non-scheduled operations),
  - Fuel tankering (buying and shipping additional fuel from an airport with lower fuel prices), and
  - Selection of preferred alternates (more support for airline / passengers).
- For military operators the operators' objectives may include
  - Mission objectives (Time over Target), and
  - Diplomatic agreements for over-flight.

4.4 The flight planning process

This section aims to provide a general description of the flight planning process. The replies to the questionnaires demonstrate that a lot of variations exist between different operators as well as within operators: With 4 civilian operators, 5 different planning processes were observed.

This section aims to provide a general overview that includes most of the variations but at the same time provide sufficient scope to determine which parameters are generally available at what time.

4.4.1 Civilian operator

For most scheduled and charter operations, flight planning starts before the start of the season to implement the operators' business objectives in its flight schedule. As take-off approaches, more detailed inputs to the planning process become available. Ultimately, the last planning takes place at closure of the flight.

4.4.1.1 Route planning and development

Scheduled operators as well as charter operators will typically plan routes several months before departure. These routes may provide one or more alternatives on a given Origin-Destination (O/D)-pair that meet the operators' business objectives on for example:

- Payload capacity/demand,
- Route length / flight time,
- ATC costs,
- Fuel cost, and
- Aircraft / Crew rotation.

This phase is performed by operations / route planning departments of the operators.

4.4.1.2 Repetitive flight plan (RPL)

Some scheduled airlines choose to file a flight plan to the CFMU at the start of the season. This is particularly used on repetitive sectors where no realistic alternate routes are available. By filing an RPL, the operator does not need to perform and complete the planning process 3 hours in advance, nor is it required to file the plan, and verify that the CFMU accepts the plan. This leads to a workload reduction in flights where detailed planning is unlikely to provide additional efficiency benefits,

The OFPL still has to be planned to ensure a safe flight within the constraints of the filed RPL. With a number of operators, this planning task is fully delegated to the flight crew. The latter implies that flight planning details need not always be available at the FOC for flights filed through RPLs.

4.4.1.3 Detailed flight planning

For most (scheduled and unscheduled) operators, detailed flight planning starts 10-4 hours before departure. At this stage most operational data on the flight (crew, aircraft, estimate of payload, ATC restrictions, and -for unscheduled operations- destinations) are available. Furthermore, most meteorological forecast data is produced in 6 hour cycles.

At this stage a number of operators will produce the flight plans for the entire rotation of a crew/aircraft for a day. Again, aircraft mass and fuel details are often completed by the crew just before departure.

The current CFMU setup requires that the flight plan is filed 3 hours before departure [14]. Flight plans that are filed later will be processed only when possible. If processing is not possible, departure may be delayed.

This stage of the planning process is performed by the operators' FOCs / dispatchers.

4.4.1.4 Crew flight planning

Typically, a flight crew will be briefed within two hours before the planned departure. As the crew has the final responsibility for the safe execution, they will verify and accept the flight plan.

Although an FOC will have planned for a certain amount of fuel, the crew will have the authority to upload more fuel if deemed necessary. Due to economic pressure, the use of this authority is decreasing however.

4.4.1.5 Flight closure

Once all payloads are on board, the calculated payload mass is compared against the planned mass. When the mass difference is above a certain threshold, a new flight plan will have to be calculated. Similarly, when the weather forecast has changed considerably, the crew or the FOC/dispatcher may decide to recalculate the flight plan.

A number of airlines choose to always recalculate the flight plan shortly before departure. This is particularly applied to long haul operations. These flight plans are not formally filed but ensure the plan is optimised to the most actual knowledge of the situation.

4.4.2 Military operator

Military air operations reach from single aircraft operations to multi aircraft operations including up to 100 airframes that differ significantly from normal General Air Traffic (GAT) flight operations. The complexity of such operations requires adequate and careful planning processes. They differ in regard to their planning areas, like training, operations and ad hoc flights (scramble flights), their objective and timeliness as well as on the executing organisation, e.g. NATO or a national regime. Depending on these circumstances, operations are prepared in the flight planning cycles below.

4.4.2.1 Flight planning cycles

4.4.2.1.1 Long term planning (LP)

The higher the complexity of military exercises, the more aircraft, objectives and partners are involved, the longer the planning cycle becomes as to coordinate all relevant issues from purely military tactics to Airspace Management (ASM) issues. Such planning cycles would start at least 6 months prior to mission execution and would include ASM coordination right from the start as the airspace requests would embrace larger volume of airspace than provided by national airspace structures. Flight data information should normally not be relevant to this study, as these massive operations would (to the highest extent) be executed in segregated airspace only from military airfields collocated to such airspace.

4.4.2.1.2 Medium term planning (MP)

Military exercises with less complexity as well as airframe deployments will be planned within a timeframe of about 1 up to 6 months. Such exercises will be executed in segregated airspace, but flights to and from such airspaces will transit shared airspace. Flight data of such exercises is relevant to this study and would be available at least 4 weeks in advance, but of course depending on short term developments. Deployments of military airframes will normally be performed according to Operational Air Traffic (OAT) flight rules thus transiting shared airspace for the whole flight. Flight data are relevant to this study and should be available likewise to MP exercises.

Note: Future trajectory management developments will take into account the main characteristics of military flights: discontinuity of cruise phase (generally to enter in segregated airspace) implying a stop/restart cruise phase process, joining and splitting trajectories (multi aircraft formation management), synchronisation of flights (trajectories departing from different airfields for the same mission objectives) (see section 4.4.2.2).

4.4.2.1.3 Short term planning (SP)

This planning cycle embraces the majority of flight operations especially the daily routine flight operations as well as air to air refuelling (sometimes up to 6 weeks in advance), and scramble flights. Starting from less than one week preparation it reaches operation plus 2 hours and depending on individual countries and missions even closer to operation. As routine flying is performed daily, relevant flight data should be readily available between 3 to 7 days in advance.

4.4.2.2 Military specifics

4.4.2.2.1 Scramble flight

The term Scramble flight within ATM community is generally connected with a mission against aircraft suspected as a potential air threat (Renegade) -Scramble A or with a training mission for maintaining the readiness for Scramble A missions– Scramble-T. Scramble A flights have (with individual national exceptions) the priority against all civil flights and are not governed by the civil market rules. Aircraft suspected or confirmed as an air threat is called “Renegade”. They are absolutely unforeseen; the fighter is controlled by an Air Defence (AD) ATCO to the suspected or confirmed as Renegade aircraft on the most direct trajectory which can cause a dramatic situation in the air, especially in high density areas. Scramble flight can be classified as a short-time contingency and need preliminary (very) short term planning. As they need to be executed immediately within in a certain reaction time they heavily rely on pre-set coordination and already established procedure to ensure its execution for national security reasons. Therefore no flight data would be available at all.

4.4.2.2.2 Discontinuity of cruise phase

For flight operations requiring the usage of an airspace reservation, the cruise phase will stop and restart at entry/exit points of those airspace. The flight inside the airspace reservation will not be described in a flight plan (random flight profiles, high energy operations, etc.). Additionally, for every kind of routine flight operations it has to be considered that task allocation for military missions might change on short notice even during flight having an effect on the trajectory. The dependent flight data might not be available beforehand.

4.4.2.2.3 Synchronisation of flight

Especially for exercises but also for routing flight operations like air to air refuelling individual trajectories have to be synchronised (also in the TP) in order to allow for precise join up procedures. The individual flight data will then be collocated to a formation flight (in a way deactivated) and after being split again activated for individual trajectories according to the mission.

4.4.2.2.4 Multi-aircraft formation

Military air operation will also be performed in multi-aircraft formations with just one flight plan but up to 4 (rarely more) airframes. If, for unforeseen reasons this formation has to split individual flight data cannot be available today. In the future, individual Reference Mission Trajectories (RMT) should be uploaded in every aircraft systems. In case of unpredicted formation splitting, the concerned aircraft will perform a RMT revision through new ATC clearances. Flight data will be available through real-time exchange between aircraft and ground systems. In case of emergency, regardless the nature of the flight (BT or MT); the trajectory will be managed in response to immediacy.

4.5 Flight planning data

This section describes the parameters that are used in flight planning or produced as an output of the process. A detailed list of those parameters is given in Appendix A. This section will describe the parameters in a number of groups and the most important processes affecting the parameters.

4.5.1 Parameters available in the process

A first group of parameters describe the properties of the aircraft to be used. These may be as detailed as the specific aircraft type or even the exact airframe. At the moment the ICAO flight plan does already list the ICAO designator and the aircraft registration (DOC 4444 [15]). The latter is unique to each aircraft; therefore this information is not additional to the current available information.

A second group determines the boundary conditions on the available routes. These include items that may prevent the aircraft from flying certain routes due to technical or operational limitations. For the military operators, the available diplomatic clearances limit the number of sovereign states that can be over flown.

The third group lists parameters specific to the flight but which do not form part of the profile of the flight. These include inputs and outputs that are independent of time or flight progress. An example of such data is the planned take-off mass.

The fourth category concerns those items which are planned or calculated together with the planned 4D trajectory. These items are specified at a trajectory point (i.e. waypoint, trajectory change point). Examples of these parameters are the trajectory itself, forecasted wind conditions and estimated fuel burn. Note that not all parameters are always specified at every point (e.g. altitude is often only given for cruise stages).

4.5.2 Parameter accuracy

For parameters to be able to improve current and future ground based TP applications, the accuracy of these parameters has to be more than the accuracy currently achieved. Therefore it is important to determine the main processes that influence parameter accuracy.

Appendix A provides some indications of accuracy for some of the parameters. However, for other parameters, it is difficult to state accuracy as either the true value is difficult to measure or aircraft is controlled to meet that parameter (for example cruise speed). In the latter case, the parameter is accurate until a deviation from the flight-plan is forced (either by ATC or by the operator) at which time it becomes irrelevant.

Note that this section evaluates the accuracy in the context of a TP application in the TMA. This limits the length of the flight and therefore also the effect that some errors may have. An example is error in the amount of fuel burned during the time that the TP operates.

4.5.2.1 Payload mass variation

The flight plan assumes a certain payload mass resulting in a certain take-off mass, the *planned take-off mass*. However, especially for passenger operations, not all planned payload may actually be transported. This can be due to missed connections or due to passengers choosing not to fly.

Only at closure of the flight, the *calculated take-off mass* is determined. This includes the calculated mass of the payload and the final amount of fuel uplifted.

Most operators' Standard Operating Procedures (SOP) will require a full recalculation of the flight plan when the difference between the planned and calculated mass passes a certain threshold (typically in the order of 500-2000 kg depending on the size of the aircraft). Therefore this threshold provides a boundary on the variation between planned and calculated mass.

However, the calculated mass may still contain approximations. In particular, the mass of passengers (including hand luggage) is taken as a standardised value. It is possible however to use information such as population mass statistics to estimate an error bound on this value.

The planned take-off mass is often known at the FOC as it is part of the flight planning process. As predicted, but not yet realised in 1998 [4], The FOC is increasingly provided with the calculated take-off mass before departure of the aircraft. In some cases, the FOC will even rerun the planning system to optimise the flight before departure.

The varying mass may subsequently influence the vertical profile. This in turn may lead to variation in items such as flight duration, and fuel consumption. However, as indicated, the maximum difference between planned take-off mass, calculated take-off mass and actual take-off mass can be considered to be bounded.

Since calculated mass is easier to obtain than actual mass, and planned mass even more easily, the effect of these differences on TP should be analysed. Taking into account the fact that the relative size of the difference compared to the total aircraft mass is likely to be very small.

4.5.2.2 Change of operational preferences

Shortly before departure, the operator may choose to adjust the flight plan to account for the business needs at that time. In most cases this is a choice to increase the flight speed to compensate for delays. Often, this is performed by increasing the Cost Index (CI) and does not lead to a recalculation of the flight plan.

Another reason to change the flight plan may be significant changes in weather forecasts. These may lead to a change in flight plan, in which case it is likely that the FOC is informed or even executes the planning.

4.5.2.3 Weather forecast

Each weather forecast may have errors. The accuracy of a weather forecast decreases with increasing time horizon. As most weather is provided at 6 hour cycles, it is possible that the forecast used in planning a long haul flight is 20 hours old by the time the aircraft arrives in a TMA.

Wind conditions may have significant effect on the effective ground speed of the aircraft and thus the Estimated Times Overhead (ETO) of the flight plan and thus potentially fuel burn. It is unlikely however that weather has a large effect on the preferred speed profile.

Ambient temperatures have significant effect on engine power output and therefore take-off and climb performance. As such any temperature error may lead to a deviation from the planned vertical profile which will affect fuel burn, ETO and the location of TOC.

Secondly, the speed of sound is proportional to the square root of the temperature. Aircraft that fly a constant Mach number may thus have a different ground speed due to temperature prediction errors. Again this may lead to ETO, fuel burn differences over long cruise distances. Speed profiles during climb and descent typically include short periods of constant Mach in which the temperature difference is unlikely to cause large deviations.

4.5.2.4 Deviation from plan by ATC

Finally ATC itself may have significant effect on the accuracy of the flight plan. This particularly concerns routes which may become shorter as well as longer, cruise altitudes, and to a limited degree speeds.

At short time horizons, ATC is however aware of the instructions given. This knowledge can be applied in the TP and therefore the TP will not need the associated data from the flight plan. Other effects such as changed fuel burn are unlikely to be significant in the context of the TP.

At longer time horizons (e.g. oceanic tracks), the deviation due to ATC may be significant in terms of ETO and possibly fuel burn and thus mass.

4.5.3 Parameters that can be made available to ATC

Based on most potential parameters identified in chapter 3, airspace users that support the project have been asked to identify which parameters could be shared. Similarly, the operators were asked which parameters could be shared within the short term to support the further development work on the project. The results of this discussion are listed in Appendix B.

All respondents are willing to share all requested parameters when available from the planning process; as planning systems and aircraft differ, not all inputs and outputs are available. However, as only 3 responses have been included, it is recommended that the project acquires input from more operators as part of the next phase of the project.

On mass and fuel consumption data, operators do clearly indicate a need for confidentiality of the data. Furthermore, the data should not be stored longer than necessary as the resulting database would be of high commercial value to third parties.

4.6 Conclusion

From previous research and from the results of the questionnaire and subsequent discussions it is clear that potentially useful inputs to TP systems can be found in the operators' flight planning processes. At the same time, the operators generally indicate to be willing to consider the sharing of additional information. Similarly, some military operations may be able to provide similar information for those flights that will be controlled using TP based tools.

Analysis of the flight planning process shows that a number of parameters of interest are only available close to closure of the flight. Initial data is available but may deviate from the final values. It is clear that some analysis needs to be performed on the accuracy of both planned information and calculated values.

At the moment, not all data available at closure of the flight may be available to the FOC. Part of the above analysis should be to establish the need for such detailed information and if required the infrastructure to collect it.

5 Improving TP using FOC/WOC data

The previous sections describe when flight planning data is generated by the operators and how this data may improve the performance of ground based TP systems. This section will look at how this data can be shared with ATSUs and what issues constrain the sharing of data.

Some of the flight planning data may be commercially sensitive or, in case of military operators, security sensitive. Furthermore, the sharing of data should not significantly increase effort or costs for the operators. The section will start by describing the operators' needs in sharing additional flight planning data.

To use the data in ATC systems, it has to meet certain requirements. Section 5.2 will raise the constraints that may limit the use of data in ATC systems.

Based on the constraints from operators and ATC, the next section proposes an outline concept for sharing the data.

5.1 AU Constraints on sharing of flight planning data

This section describes the needs of the AU in the concept of sharing additional flight planning parameters. The following individuals have actively participated in the preparation of this section.

Table 1: Airspace User representatives participating in establishing AU constraints on concept

Name	Organisation/Company	Position / Title
Jacqueline Coquel	Air France	Flight Support/ ATFCM expert
Christopher Knox	Swiss Airlines	Flight Operations Officer
Jean-Philippe Ramu	EBAA/NetJets	NetJets SESAR Project Manager/Flight Crew
Peter Sandgren	Novair	Operation Center Coordinator
Mark Wilson	Swiss Airlines	Flight Operations Officer
Ulrika Ziverts	Novair	Novair SESAR Project Manager/Flight Crew

5.1.1 General

In general, the AUs participating in this project have indicated willingness to share information with the ATC TP systems in order to improve the accuracy of the calculations, provided the resulting benefits to operation outweigh the costs. The latter requires that the improved accuracy of the predictions result in more optimal operations for the AUs (e.g. through less imposed restrictions on preferred vertical profiles and operating speeds etc.), there are benefits to be achieved. The following sections highlight the aspects that were identified during the discussions between the AUs internally and between the AUs and the project team in step 1 of project 5.5.2, that need to be taken into account.

5.1.2 Operational

From an operational point of view, the mechanism for feeding information to the TP tools must be automatic. This is especially important for large operators. Any manual step required for sharing the information will both increase workload for the FOC and result in a lower capture rate on the ATS side due to the fact that people sometimes will forget to submit the information. Some parameters would naturally belong in the ICAO flight plan and it might be wise to consider revising the format to include those. Examples of such parameters are speed during climb and descent. On the other hand, the sharing of TP information must also consider the sharing of ATS owned assumptions such as the expected runway in use and respective SIDs and STARs.

5.1.2.1 The sharing process

Due to information availability, it might be necessary to send the information at more than one occasion before the flight. A lot of information is available already at the planning stage, several hours before departure. At this stage, the TOM is estimated based on current passenger figures, cargo and assumed fuel. This mass, even though estimated, is probably a lot more accurate than the generalised assumption of mass used by the TP systems today. However, it is only after the load sheet has been produced, based on actual figures, that the actual TOM is known. To achieve very accurate mass figures, it would be necessary to send updated information to ATS just before departure. Applying the SESAR CONOPS of shared information, the owner of the accurate TOM is the flight crew and the use of this particular information by ATS and other organisations should be facilitated as such. The definition of the Controller Pilot Datalink Communication (CPDLC) message "Departure Clearance Request" contains aircraft mass as one of the parameters to be transferred from the aircraft to ATS. At the time of requesting a departure clearance, the final figures might not always be available. An update of the mass after the final load sheet has been completed might be necessary.

Table 2 is an extract from the Safety & Performance Requirements considering CPDLC:

Table 2: Information in Departure Clearance Request Data on CPDLC. (Source: FAA[3])

Departure clearance request data	Information provided in departure clearance request to aid in providing a departure clearance and optional specifying the preferred departure runway, level and route.	Sequence: Aircraft Flight Identification (O) Aircraft Type (O) Departure Position (O) Aircraft Weight (O) ATIS Code (O) Departure Pilot Preferences (O)

CPDLC departure clearance capability will be mandatory in a couple of years according EC 29-2009.

The transfer of TOM and other parameters of interest (e.g. Flex temperature if any) between the aircraft and ATS should preferably be automatic. If parameters need to be manually entered into an interface, there is both a risk of error and an increased workload for crew. If this route is taken, this effect on flight crew workload should be investigated.

Before transfer of parameters from the aircraft to ATS is a reality (and for non equipped aircraft later on), actual TOM needs to be transferred from a ground system to ATS. Depending on the size and nature of the company and type of operations, this will be associated with different levels of challenge. E.g. many small charter operators create manual load sheets on the out stations (where there also quite often is no ACARS coverage). A copy of the load sheet is given to the ground staff just before departure. In this case, it might be a challenge to set up a procedure for providing ATS with the actual TOM before departure.

5.1.2.2 Ensuring information consistency

It is important that the mechanism for providing the TP systems with information is logically coupled with the process of updating the ATC flight plan. The situation must never arise that the TP tools use detailed information about the wrong aircraft due to a late change of aircraft and the failure to notify the TP systems about this change. This would be detrimental to the accuracy of the predictions in cases where the change of aircraft individual also implies a change of aircraft type. Further, there must be checks in the TP systems for unreasonable figures to detect erroneous information provided by the airlines. The TP tool must maintain a strategic tool enabling to choose the best trajectory option based on available data at the time of calculation, but must still consider sufficient margin for aircraft separation in order not to augment the severity of traffic conflicts (e.g. two traffics in continuous climb and/or continuous descent are more difficult to de-conflict because the vertical dimension must be used with caution).

[3] SPR-H-Part3-CPDLC-Feb3 , page 5-92, retrieved at: http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/atc_comms_services/sc214/current_docs/

5.1.2.3 Acceptance of updates

The information, when submitted, must be accepted without consequence. If a flight plan is updated at a late stage today, the remark “Late Updater” is received. This would not be acceptable when updating parameters to be used for the trajectory predictions close to departure in order to achieve high accuracy.

5.1.3 Technical

5.1.3.1 AU investment

In order to gain maximum benefit of improved trajectory predictions, it is important that information is provided by as many AUs as possible. An important factor for achieving this is that the investment cost of the mechanisms for providing ATS with the required information is not too high. Although the individual AU probably will benefit from improved trajectory predictions, it might be difficult to quantify these benefits creating a business case that covers high investment costs. This is especially true before the majority of TP tools in Europe have implemented this functionality.

5.1.3.2 Consistence with further SESAR development

For the same reason, it is very important that any new mechanism developed for transferring the information is closely in line with the SWIM concept. In the coming years, the AUs will have to implement mechanisms for publishing information to SWIM. Much of the information that might be interesting for the TP tools will be available in the SBT and RBTs that the AUs will publish. Investing a lot of money in developing solutions for transferring similar information in different ways will be difficult to motivate.

5.1.3.3 Common interface to all ATSUs

It also goes without saying that the mechanisms for sharing information between the AUs and ATS must be generic for all different TP tool providers. There must not be specificities associated with the sharing of information to different tools.

5.1.3.4 Information security

The transfer of the information between the AUs and ATS must be made through secure channels. Any information that needs to be temporarily stored on the ATS side must be done so in a manner that makes non authorized access to the information impossible.

5.1.4 Commercial sensitivity of information

It is difficult to state which commercial issues all different AUs might have with sharing data. It will most likely depend on which parameters are requested.

A lot of the potentially interesting parameters will be mandatory to share in the future concepts, e.g. through the SBT/RBT, and should therefore not pose a problem.

The parameters associated with the highest level of commercial sensitivity might be the take-off mass and fuel figures for the flight. However, many AUs would probably be willing to share this information if it is beneficial for them and provided that the information is treated confidentially. The shared information must not be distributed further. It must neither be stored after the completion of the flight. Detailed information on a large number of a company’s flights would, from a commercial perspective, constitute a very sensitive material.

5.2 ATSU constraints on the using data

Not all data provided to an ATC system can directly be used. This section lists the general issues that may constrain the use of data. These will need to be addressed during the later stages of the project.

5.2.1 Operational

As an ATC unit will deal with many aircraft during a given period, the data should be provided and handled automatically without requiring human intervention.

5.2.2 Technical

Data has to be available for use when an aircraft leaves the ground. Since the last update can be after closure of the flight, the data sharing system should be able to provide the data sufficiently quickly.

5.2.3 Security

The sharing system should not enable unauthorised interference with the ATC system.

5.2.4 Safety

Incorrect inputs into a TP are likely to result in incorrect trajectories. This may lead to false or missed alerts and will lead to a reduction of the benefit of the TP driven tools.

The risk of incorrect flight planning data can however be addressed at both sides: ensure correct data is provided by the FOC and verify data when received by the ATSU. Further research should analyse the required accuracy of the different input parameters from FOCs and the means to achieve this accuracy.

5.2.5 Legal

As a consequence of the above issue, the responsibility of the correctness of the data should be established.

Secondly, to comply with incident investigation requirements, all inputs to an ATC system will need to be stored for a (limited) time.

5.3 Sharing flight planning data with ATSUs

Based on the above constraints a concept for sharing additional flight planning parameters can be made. Note that operators already do share flight plan data (the ICAO flight plan) with ATC through the IFPS.

5.3.1 Flight planning

The operator will perform the flight planning process as done now. When more accurate data is available (for example, calculated take-off mass instead of planned take-off mass) this data is collected at the FOC.

The update of parameters continues until the flight is closed. These updates may, but are not required to, include a full computation of the flight plan.

5.3.2 Publication

After the flight is closed, the FOC publishes the data; it should be possible to implement the sharing system early to provide the early benefits. However, it should be compatible with later SESAR developments to limit system development costs. Therefore, it is assumed that the data is shared on an early implementation of the SWIM system. Since the data is commercially sensitive, it is protected from access by anyone but ATSUs.

The technical requirements to enable sharing but limit access will need to be considered in development of SWIM. This development is assumed to be handled by Work Package 8.

5.3.3 Collection

The ATSUs subscribe to the data and collect the data from SWIM.

5.3.4 Preparation

Once the data is retrieved it may need some form of preparation. It is expected that this will at least include some form of verification of validity. Depending on the TP system in use, more preparation steps may be required.

Once prepared and valid, the data is made available to the TP system.

5.3.5 Use

Once the aircraft is airborne and the ATC system has received surveillance data providing position and speeds, the TP system starts predicting trajectories.

6 Scenarios

This section describes a number of example scenarios in which the use of operator flight planning data in ground based TP applications may improve current operations. As such they are considered relevant to SESAR Step 1 in which limited sharing/modification of the RBT takes place.

The first three scenarios are based on operational concepts that may be validated using the means available to the project. These include a departure scenario in a complex multi-airport airspace such as London, a descent scenario applicable to a large part of the western European airspace and an arrival management scenario applicable to most large European airports.

However, as TP systems are used in other applications, this chapter will conclude with two examples of other applications in which improved TP may benefit operations.

6.1 Scenario 1: CD&R while departing in the London TMA

The London TMA is an example of a complex multi-airport TMA with a very high traffic density. To be able to maintain a high runway throughput at Heathrow airport, most arriving traffic to Heathrow will occupy the holding stack for some time.

For departing traffic, these stacks form major obstacles during the climb. At the moment, departing traffic is often requested to fly level at low altitude for a significant period until the traffic is clear of the stacks. Technically, some aircraft may however be able to climb sufficiently fast to safely pass over the stack. However, uncertainty in the possible and preferred vertical profiles of the aircraft often forces the departure controller to keep the aircraft at low altitude.

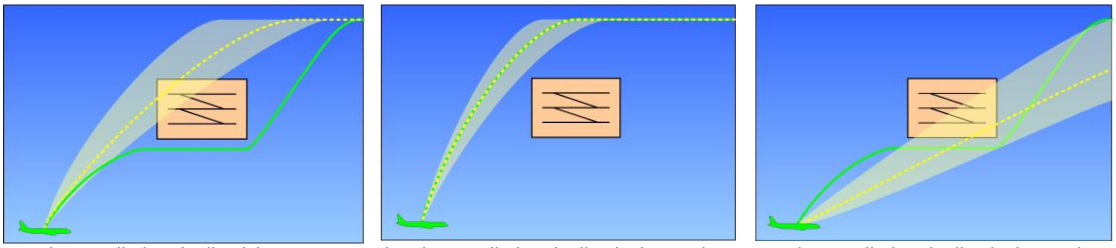
Note that this situation is not only applicable in airspaces with holding stacks but also in airspaces with other obstacles in the departure path such as arriving streams and other departing traffic.

6.1.1 Scenario 1a: Without FOC climb profile information

Figure 4a shows a predicted trajectory that passes through a holding stack. If the controller would issue a clearance to climb over the stack, two different problems could arise:

- When the aircraft is incapable of climbing sufficiently fast, the tactical controller will need to issue further tactical instructions to avoid the stack. This would increase the workload and result in a longer path for the aircraft.
- When the aircraft is capable of climbing sufficiently fast, the climb may still need to deviate from the operator's plan leading to a higher than planned fuel burn or deviation from the planned arrival time.

To maintain separation and reduce complexity in current operations, the tactical controller will issue a clearance until an altitude below the stack. Only once the aircraft has cleared the stack, a climb clearance to a higher altitude is given.



a: The prediction (yellow) intersects the holding stack. The controller has no option but to keep the aircraft below the stack until the stack is passed (green).

b: The prediction (yellow) shows that the aircraft is planning to and capable of climbing above the holding stack. The controller can now issue a climb to higher altitude (green).

c: The prediction (yellow) shows that the aircraft is not planning to, or incapable of climbing above the holding stack. The lower route (green) is more likely to be closer to the preferred trajectory.

Figure 4: Effect of operator input in TP on controller selection of climb options

6.1.2 Scenario 1b: With FOC climb profile information

When more details are known about the planned profile (for example climb speed, aircraft mass) a trajectory can be predicted that is more accurate and also more closely reflects the operator's preferences.

The first situation (Figure 4b) shows a climb profile for an aircraft which is able to execute a fast climb and for which the operator prefers a fast climb. The resulting prediction passes safely over the stack. Therefore the tactical controller will issue a climb clearance to a higher altitude (possibly cruise level). While the aircraft is climbing, the controller will monitor separation from the stack. Only when the aircraft does not climb as foreseen will the controller need to take action.

The second situation (Figure 4c) shows a climb profile for an aircraft for which a shallow climb is planned. In this case the controller issues the same clearance as in the baseline situation.

6.2 Scenario 2: CD&R during descent

This scenario describes the effect of uncertainty in handling conflicts between a descending aircraft and other traffic. These situations occur often in the upper airspace when aircraft have to descend from their cruise level through the cruise levels of other aircraft when descending into a TMA. With the high amount of airports below the Western European airspace, many locations exist where insufficient space is available to completely rely on lateral separation of arriving traffic from departing and over flying traffic.

In this scenario, one aircraft is planned to arrive at a given point (for example, the initial approach fix) at a given altitude. To determine the point of descend; the controller uses a trajectory prediction to determine a what-if scenario for the latest possible descent. In essence the controller determines the last possible point where a descend instruction can be given without risking that the aircraft will not be able to reach the desired altitude at the given point.

A second aircraft is currently climbing to its cruise level below the probed aircraft. Trajectories are also predicted for this aircraft; however the controller will not give any instructions to this aircraft.

The controller has two options:

- to descend the first aircraft immediately, and fly level below the climbing aircraft at a less than optimal altitude,
- to remain at cruise altitude until the climbing aircraft is passed and then descend

6.2.1 Scenario 2a: Without improved TP accuracy

As demonstrated in Figure 5, the probed trajectory itself does not interact with any aircraft. However, due to the uncertainty of the possible descent profile, the instruction to descend has to be given early. When the aircraft would descent from that point, it could have a conflict with the climbing aircraft.

To ensure that the aircraft remain separated and to be certain that the desired altitude is reached at the planned location, the controller will have to descend the aircraft now. This will result in level flight at a suboptimal altitude and thus higher fuel burn.

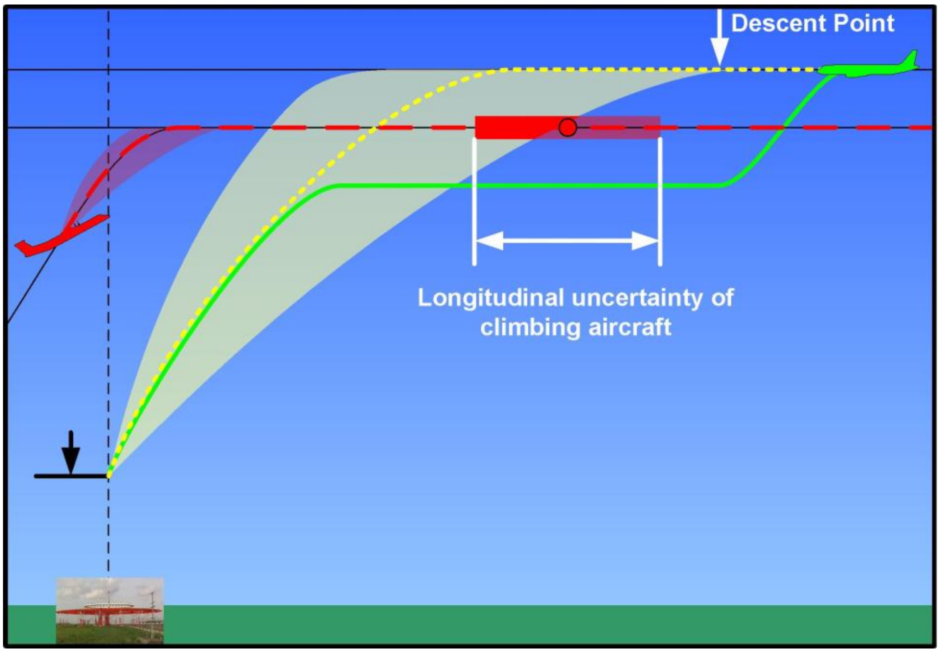


Figure 5: Descent planning using current TP

6.2.2 Scenario 2b: With improved TP accuracy

In Figure 6, predictions for both aircraft are improved by using additional data from the FOC flight planning. The result is reduced uncertainty on the possible descend profiles for the arriving aircraft and a reduced uncertainty on the location of the departing aircraft when the arriving aircraft starts to descend.

It is now clear to the controller that the descent can be delayed until the departing aircraft has passed. The arriving aircraft will continue at its optimal cruise level and perform a continuous descent to the target point. The instruction is given at such a moment that the arriving aircraft is capable of reaching the target attitude, but not before the aircraft is clear of the climbing aircraft.

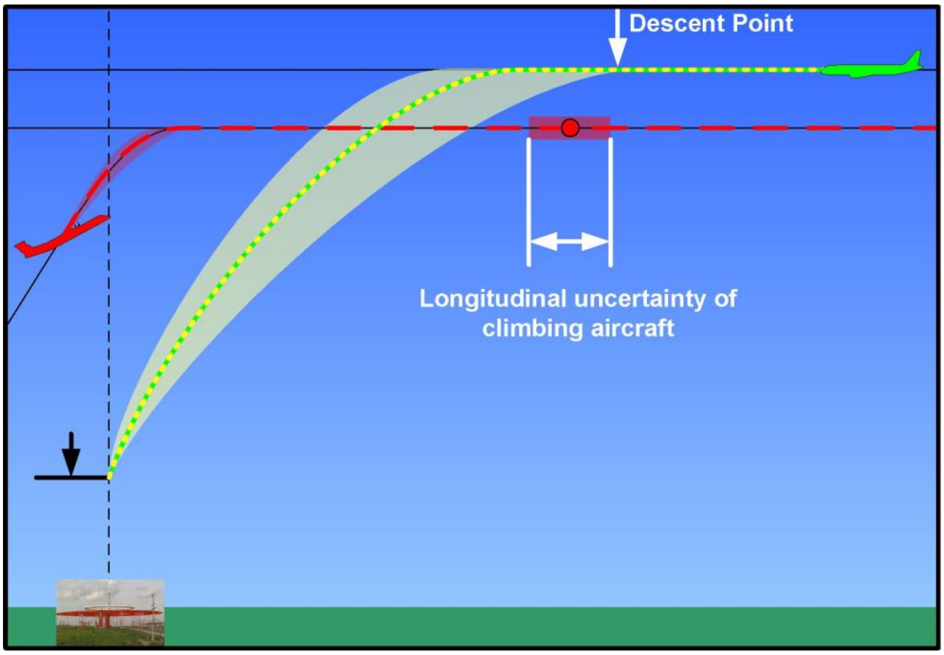


Figure 6: Descent planning using improved TP

6.3 Scenario 3: Arrival management

The third scenario describes the role of TP in arrival management and I4D. This scenario considers arrival management to airports which have sufficient runway capacity to achieve the desired throughput without recourse to holding stacks, but with sufficient traffic to require active arrival metering. These include most of the large airports in Europe. In particular, in mixed equipage and ramp-up scenarios, a ground based TP is required. In this case, the TP supplies the trajectories for those aircraft for which no predictions are available.

As aircraft arrive at the AMAN horizon, a prediction to the metering fix is produced. This prediction is used to determine an optimal sequence which subsequently may lead to Controlled Times of Arrival (CTA) or, when aircraft are not able to fly a CTA, controller action to meet the metering time.

However, if predictions are inaccurate, these actions are based on an incorrect prediction of the actual arrival time. This could mean that the aircraft arrive at the metering point with either too much or too little spacing or that multiple counteracting corrective actions need to be taken.

6.3.1 Scenario 3a: AMAN without improved TP accuracy

Figure 7 shows an example arrival management display showing a sequence that is sufficiently spaced. However, due to prediction error the actual sequence 10 minute later is different and shows an overlap.

The arrival manager will now have to request upstream controllers to take corrective actions to resolve the potential conflict.

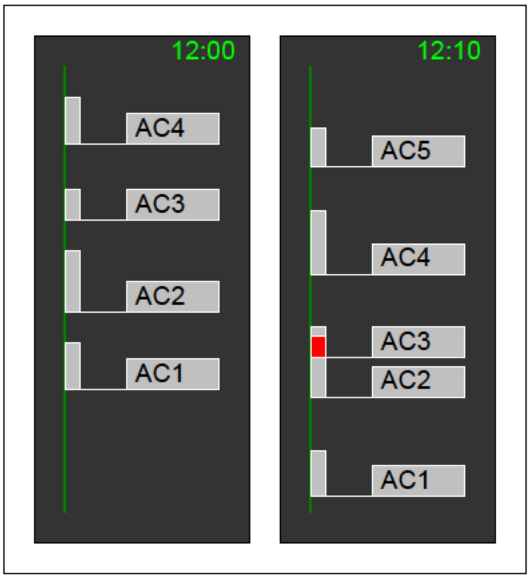


Figure 7: An example AMAN display evolution with an inaccurate TP

6.3.2 Scenario 3b: AMAN with improved TP accuracy

Figure 8 shows the same display as in scenario 3a. By using FOC flight planning data, the error of the TP has reduced. Therefore the display already shows the future sequence problem.

The arrival manager will again have to request upstream controllers to take corrective actions to resolve the potential conflict. However, since these actions are taken earlier, less deviation is required.

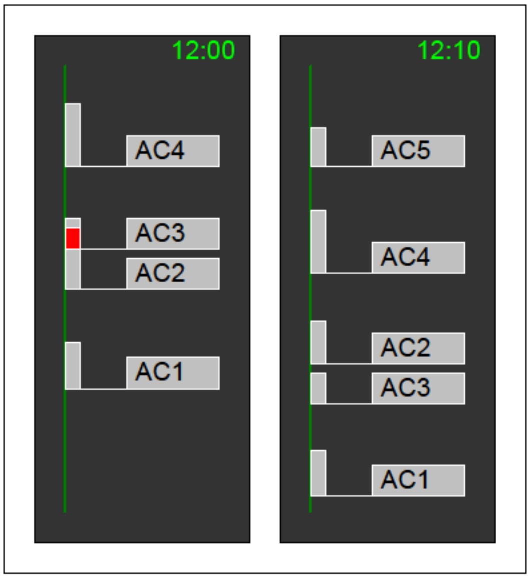


Figure 8: An example AMAN display evolution with an accurate TP

6.4 Other scenarios

These scenarios are given as examples of other applications of TP where improvements through FOC planning data may benefit the operation. However, these scenarios will not be addressed within the further scope of this project due to constraints on validation means and resources.

6.4.1 Scenario 4: Departure manager

Especially in complex terminal airspaces with multiple airports, a departure manager will need to rely on TP to determine free departure trajectories. As demonstrated in scenarios 1 and 2, improved accuracy will lead to more available trajectories being accepted in the system.

6.4.2 Scenario 5: P-RNAV CDAs to the runway

The final example is for low density operations where a lower required capacity (lower density airports, night time operations) enables the application of long continuous descents to the runway thresholds.

Currently, the main issue is that executing a continuous descent while decelerating limits the amount of freedom available to adjust separation between aircraft on the approach. Therefore separation has to be ensured beforehand by providing conservative initial separation at the start of the approach. Since the initial separation is conservative, final separation will tend to be larger than required. This reduces available runway throughput.

By having accurate predictions of the last part of the flight the controller can determine separation throughout the approach and thus reduce the initial separation margins.

7 Cost/Benefit Analysis of ground based TP improvement to ATM system

7.1 Introduction

This chapter covers the initial Cost/Benefit concept associated with this study, built with the participation of WP16 (R&D Transversal areas).

It consists of a number of sections, each of which covers an element that is required to perform the required study:

Section 7.2: cost elements of FOC data usage scenarios in TMA (cf. chapter 6).

Section 7.3: benefits mechanism of FOC data usage scenarios in TMA (cf. chapter 6).

Section 7.4: Initial CBA diagram (no costs and values available at this study stage) with costs and benefits inputs and associations represented.

7.2 Costs

The following figure presents the different costs categories associated to the scenarios using AOC data and their different stakeholders. Below the figure, assumptions associated to some of costs are presented.

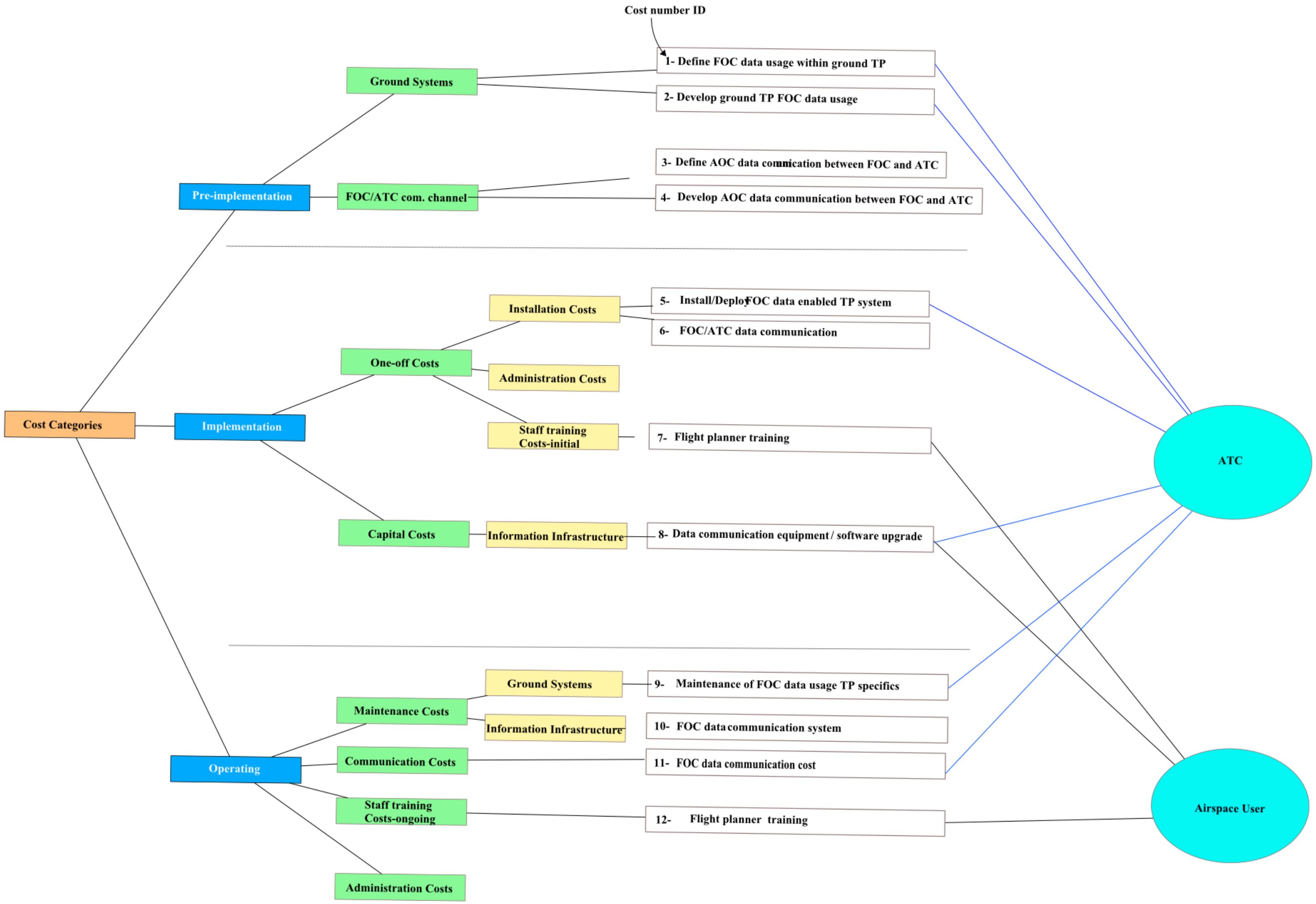


Figure 9: Cost categories for FOC data usage in ground TP

Some assumptions about the costs are presented below, with their associate Cost number ID.

- (costs ID 1 and 2) TP development improvement for using FOC data can be performed by ANSPs or by the industry. The costs are associated to the ANSP only and the industry stakeholder is discarded from this CBA.
- (costs ID 3, 4, 6 and 10) For current operations and STEP 1, it is believed that FOC data will be shared using existing FOC/ATC communication channels (depending on local implementation). Once SWIM available, with its wide interoperability and flexibility, the FOC data will be shared using it. This may have a low impact on SWIM (including in terms of cost).
- (cost ID 8) Current communication hardware equipment is expected to be unmodified for using FOC data information.
- (costs ID 7 and 12) Flight planner (or flight dispatcher) may have specific tasks associated to the FOC data sharing. However, it is believed that in most cases, this data sharing will be done automatically.
- Costs associated to studies and researches are not specifically covered.

7.3 Benefits

The following figures (Figure 10 and Figure 11) present the benefits mechanism associated to AOC data usage scenarios vs. baseline (non-usage).

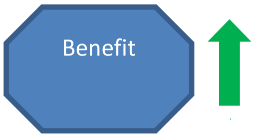
The diagrams contain three shapes:

A new feature introduced by AOC data usage, this can bring benefits or have negative impacts.

Indicators are measurable and allow the benefits of the feature to be quantified.

A green arrow indicates an improvement and a red arrow a drawback.

Downwards indicates a decrease and upwards indicates an increase.



A benefit (green arrow) (or a negative impact red arrow) for a stakeholder that is brought about by AOC data usage.

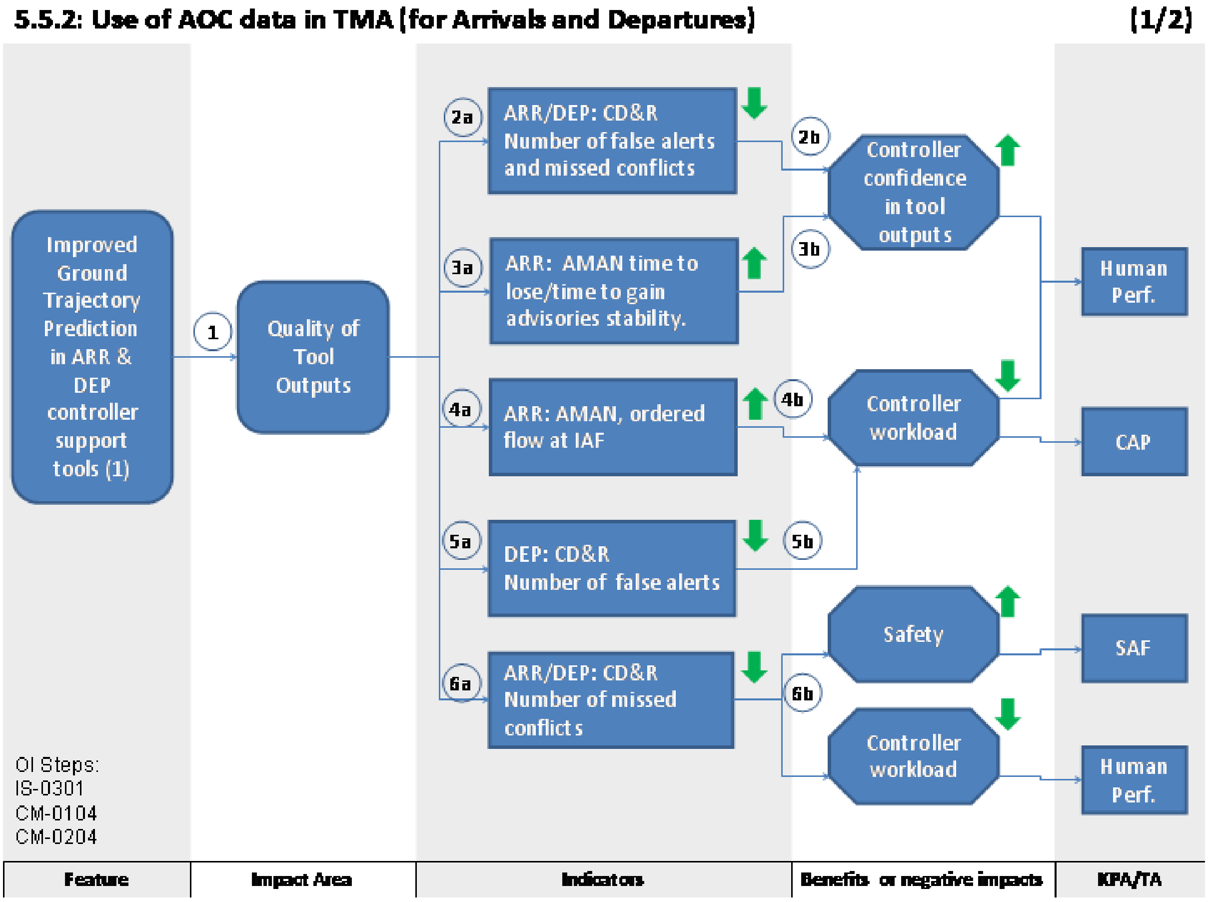


Figure 10: Benefits mechanism for FOC data usage in ground TP, TMA

Feature Description: Improvement in ground trajectory prediction means that the predicted trajectory is accurate (e.g. small average error vs. actual trajectory, low bias) and precise (e.g. small standard-deviation error, low variability). This improvement will be measured in time, vertical and lateral dimensions, for different time horizons. The numbers below refer to the numbers on Figure 10 and Figure 11.

(1) Improved TP will mean that there are better trajectory predictions being used in the controller tools which will increase the quality of the tool outputs; AMAN for arrivals and Conflict Detection & Resolution (CD&R) tools (e.g. TCT) for departures.

[Another benefit for departures that is not currently described in the benefit mechanism is to allow the CD&R tools to have a longer look-ahead time thereby extending their range.]

(2a) ARR/DEP: Improved trajectory predictions in the Conflict Detection (CD&R) tools (e.g. TCT) will reduce the uncertainty associated with the detected conflicts which will reduce the number of false alerts and of missed conflicts.

(2b) this will increase the controllers' confidence in the conflict detection tool outputs which links to Human Performance.

(3a) ARR: Improved trajectory predictions will lead to more stable arrival sequence with current AMAN horizons and longer, stable arrival sequences with extended AMAN horizons.

(3b) this will increase the controllers' confidence in the AMAN output and its advice which links to Human Performance.

(4a) ARR: The improvement in the quality of the AMAN outputs will lead to a more ordered arrival sequence (e.g. higher arrival rate and adapted spacing).

(4b) this will lead to a reduction in controller workload which links to both Capacity and Human Performance.

(5a) DEP: The improvement in the quality of the tool outputs will enable a lower number of false alerts.

(5b) this will lead to a reduction in controller workload which links to both Capacity and Human Performance.

(6a) ARR/DEP: The reduction in the number of missed conflicts will lead to fewer 'last minute' actions by the controller.

(6b) this will lead to an increase in safety. It will also impact controller workload which links to Human Performance.

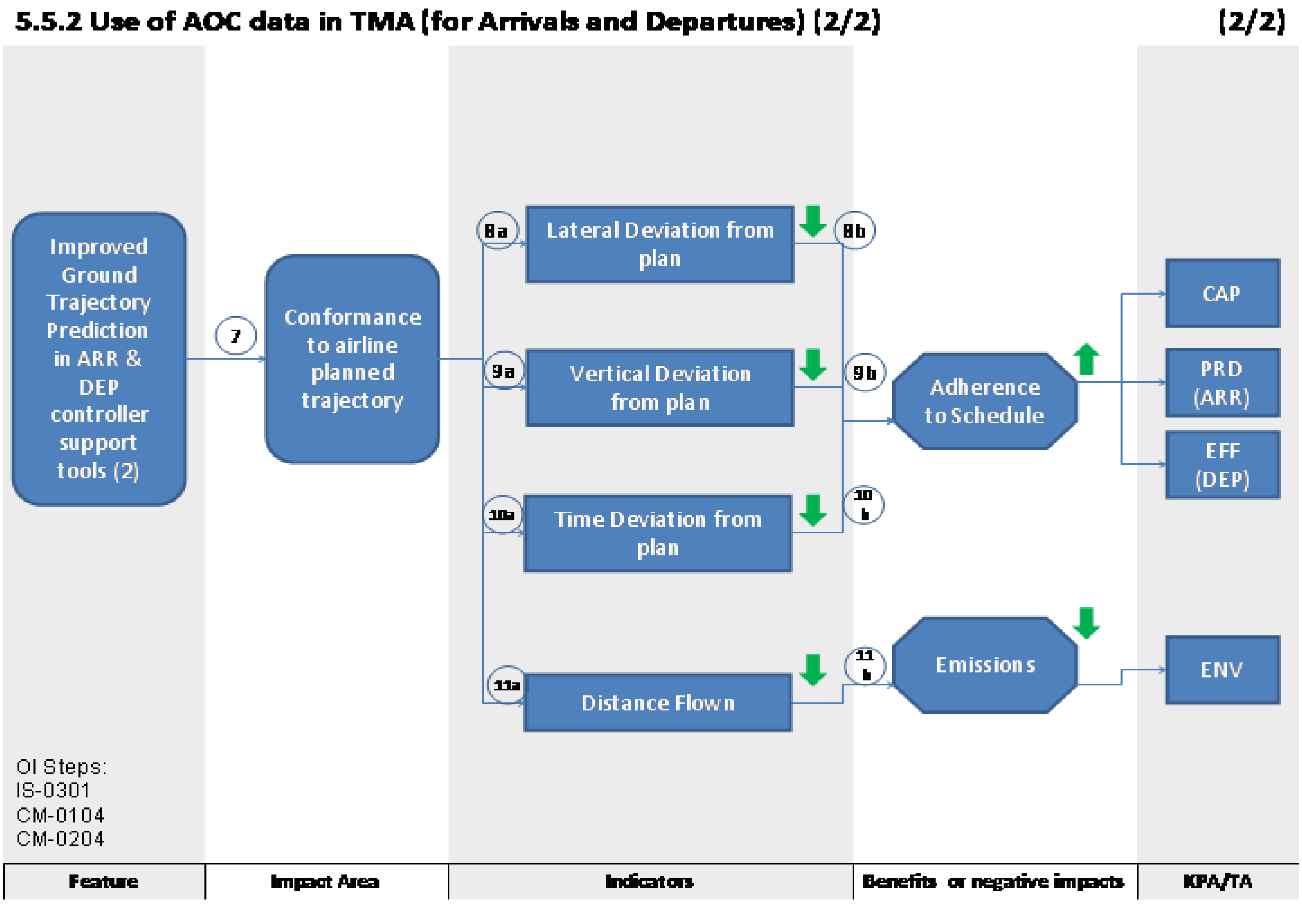


Figure 11: Benefits mechanism for FOC data usage in ground TP, TMA (continued)

(7) A more stable arrival sequence and fewer false conflict alerts (DEP) will lead to fewer flights having their planned trajectories/routes modified (e.g. path stretching, level-off, either to help organise the arrival queue or to avoid a conflict that wasn't going to happen).

The impact of (7) on (8), (9) & (10) will lead to:

(8a/9a/10a) reduced lateral, vertical and time deviations from the planned airline trajectories.

(8b/9b/10b) This will lead to an increased adherence to airline schedules which links to Capacity (Improved adherence to schedules can allow the 'uncertainty buffers' to be reduced thereby increasing the arrival rate), Predictability (arrival delays) and Efficiency (departure delays).

The impact of (7) on (11) will lead to:

(11a) a reduction in the distance flown and less level-offs (e.g. continuous climb) this will be reflected in reduced fuel consumption (for route extensions and level-offs at lower levels).

(11b) this will lead to reduced emissions which link to Environment.

7.4 Costs-Benefits model

The model presented in Figure 13 is an initial model (no costs/benefits values). It will be updated and expanded with stakeholder inputs. The input data required to feed the model and the sources of that data will then be identified. This will ensure that the model can provide the CBA results at the end of the project/lifecycle phase.

Remarks about the CBA model figure (Figure 12 and Figure 13):

1. Single-lined dark contour nodes represent observed values (data input). These are the most "external" nodes presented in the model.
2. Double-lined contour nodes combine all their input nodes information into higher level output information, using a user-defined formula (not shown on the figures).

For example, on Figure 12, "operating costs ATC" output is the sum of its four input costs : "ATC ground TP systems OC", "FOC/ATC Communication channel", "FOC Data Communication costs" and "Admin ANSP (OC)".

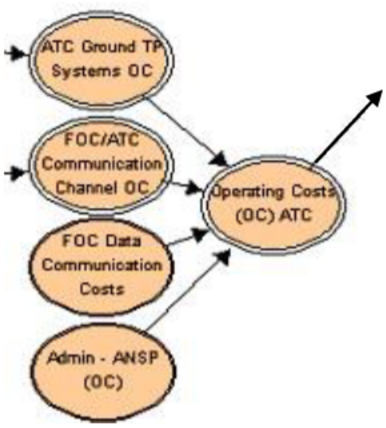


Figure 12 : Sub-part of the CBA initial model

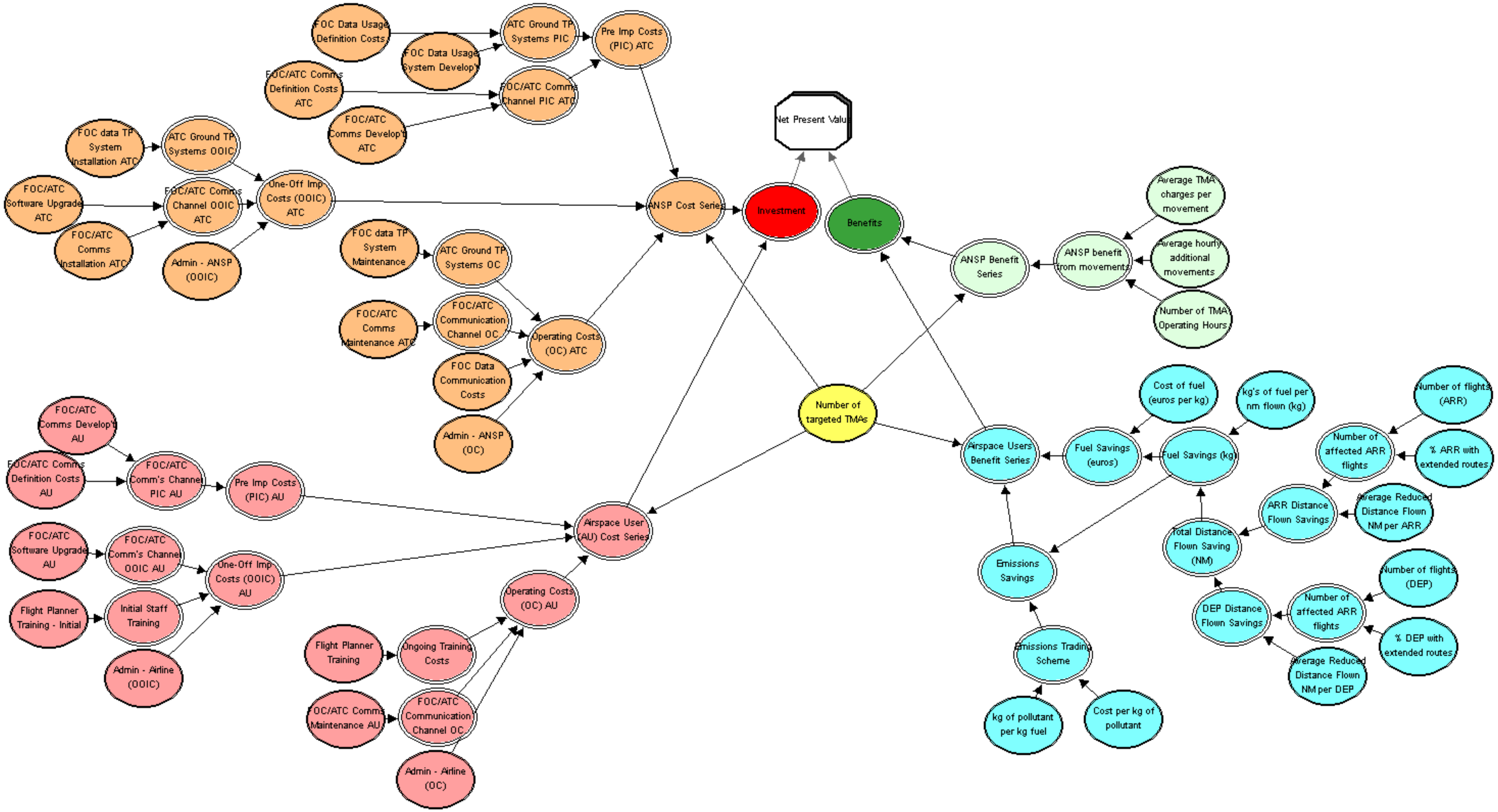


Figure 13: Initial CBA model

8 Conclusions

This project is focussed on the near-term use of operator flight planning data, prior to the advent of standards and infrastructure to support full trajectory exchange between aircraft and ATC systems. As such the concept is to be one of the early wins from the SESAR research phase.

Previous research has shown that the use of additional flight planning information in ground based TP applications has the potential to improve the performance of ATC tools that use predicted trajectories. However, some of the studies indicated that the information infrastructure at the airlines was still insufficient to support sharing actual flight planning data but that improvements were likely. This document establishes that at present, much more data is available at the operators' FOCs.

One of the main sources of uncertainty in predicted trajectories is the fact that assumptions are made on a certain set of inputs describing flight intent. Some of these inputs are more accurately or even exactly known by the operator. The parameters most likely to be able to improve trajectory accuracy are:

- Take-Off Mass (TOM)
- Climb/Descend Speed
- Altitude (during climb/descent)
- Waypoint types
- True Airspeed
- Mach number (or TAS & temperature)
- Fuel used
- Thrust settings

Provided that the benefits outweigh the costs, the operators taking part in this project indicate to be open to sharing flight planning information if that would lead to improvements to operations. Key needs for AUs in this concept are:

- A low investment and maintenance cost,
- The ability to automate the transmission process (no significant additional workload),
- Data should be accessible only to ATSUs and should not be stored longer than necessary.

Under these conditions the participating operators are willing to share the above data whenever available. However, as this is only a limited set of operators, it is recommended that other operators are consulted during the next stage of the project.

Based on a number of scenarios in high capacity European airspace a number of cost-benefit mechanisms are proposed. Key benefits are identified in an increased number of continuous climbs and continuous descents and a more stable arrival management processes.

During the next phase of the project should establish the actual suitability of the proposed additional flight plan parameters to TP applications. This study consists of two separate analyses:

1. The effective accuracy of the parameters of interest.
2. The sensitivity of TP output to each parameter; as inaccuracies always exist, it is important to establish the effects of such accuracies on the TP performance. If the inaccuracy of the parameter does not generate large inaccuracies of the TP output, the parameter can be used.

Assuming that the parameters are available, the effect on TP performance should be established objectively. This is planned as part of the V2 phase of the project. However, the output of this work does not directly guarantee a benefit to operations.

To establish the benefit to operations, the effect of the improved TP performance on actual operations is to be established. This requires a more detailed elaboration of the example scenarios.

Based on example scenarios the suggested benefits to operations by using improved TP capability can be tested. V2 of the project foresees the analysis of system benefits through fast-time simulations. V3 will see evaluation of the effect of TP improvements on controller tools by operational ATCOs.

One of the arguments that support early implementation is that the concept is expected to provide benefits even if not all operators are participating. It is recommended that the next stages of the project validate this statement by analysing benefits for mixed equipage scenarios as well as for full equipage scenarios.

Whereas the above steps will provide inputs to quantify benefits to operations, a further analysis of the costs of implementation and operation of the concept needs to be performed. This will be addressed during both the V2 and V3 phase in collaboration with Work Package 16.

As the above steps will provide a view on what data should be included in the concept, the process and means for collecting and communicating that data to the TP systems should be established. It is assumed that this will be done in strong collaboration with Work Package 8 and Work Package 11.

9 References

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Appendix A Data available from flight planning

The concept developed in this project aims to improve Air Traffic Control (ATC) services by enhancing the ground based Trajectory Prediction (TP) capabilities using flight planning data that is currently not available to ATC. This concept is based on using more actual and exact data on the operation of a particular flight. These improved prediction capabilities should improve ATC tools which should subsequently lead to an increase in safety, an increase in flight efficiency and a decrease in workload, both for ATC as well as flight crew.

To develop an understanding of flight planning processes across a range of representative airspace users a questionnaire has been prepared and distributed amount a number of representatives from airspace users, see Appendix C.

The primary questions the questionnaire addressed are:

1. What data is available at the Airline Operations Centre (AOC)/Flight Operations Centre (FOC) before take-off of a flight?
2. How accurate is that data?
3. How long before take-off is that data available?
4. What are the requirements from the airline's point of view regarding sharing this data?

The main outcome from this questionnaire is listed in the table below:

Table 3: Parameters available from the operator's flight planning process

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Aircraft Type	Detailed aircraft type specification	All	n/a	Occasionally the aircraft is changed shortly before departure. However, these errors as considered part of a wider issue than the scope of this project.	Yes	Performance details
Engine Type	Exact engine type on aircraft	All, is element of aircraft type	n/a	See aircraft type	Yes (may be considered part of aircraft type)	Significant effect on climb performance [6].
FMS Type	Type of FMS that the aircraft is fitted with (operator choice)	Some, where applicable	n/a		No	Modelling requires detailed knowledge and emulation of proprietary FMS algorithms

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Aircraft navigation capabilities	Navigational capabilities that limited routing of the aircraft (RVSM, RNP)	All	n/a		Yes (already in FPL)	Route choices
Crew qualifications	Operational qualifications of crew that limit navigation	Some	n/a		Part of aircraft navigation capabilities	Route choices
Alternates	Alternate destinations	All	n/a		No	ATC will be informed when deviating to alternate.
Aerodrome opening hours	Opening hours of aerodromes that limit use of alternates	Some	n/a		No	Will only affect selection of alternates
MIL: Diplomatic clearance	Permission to over fly sovereign airspace	All	n/a		Yes	Route choices
Cost Index	Selected cost index for the flight	Some	Unknown	Pilot's choice, late changes to circumstance	No	Modelling requires detailed knowledge of proprietary FMS CI implementation
Preferred climb speed (CAS / Mach)	Speed (profile) during the climb to initial cruise level	All, mostly implicit	Unknown	Pilot's choice, late changes to circumstance	Yes	Is easily implemented and demonstrated potential in previous research [6].
Preferred descent speed (CAS / Mach)	Speed (profile) during the descent to arrival	All, mostly implicit	Unknown	Pilot's choice, late changes to circumstance	Yes	Is easily implemented and demonstrated potential in previous research [6].
Taxi fuel consumption	Fuel used during taxi	Some	Unknown, expected to be < 100kg (see fuel used)	Based on taxi time.	No	Unlikely to be significant with respect to total mass
Taxi time	Predicted time needed for taxi	Some	Unknown	Based on estimate / historical data (minutes)	No	Taxi already completed upon use of ground based TP.
Operational empty mass	Mass of aircraft without payload or usable fuel	All	Less than 100 kg		See TOM	Potential, TOM more useful

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Payload Mass		Initially planned for all. Final may depend on flight (outbound verses inbound)	Initially estimated. Estimated in detail at closure of flight.	No-shows, standardised passenger mass	See TOM	Potential, TOM more useful
Fuel Mass		Initially planned for all. Final may depend on flight (outbound verses inbound)	Actual fuel on board is known accurately (less than 100 kg).	Crew discretion	See TOM	Potential, TOM more useful
Take-Off Mass	Planned/calculated take-off mass	See Payload/Fuel	Both plan and final TOM are estimates. Difference between the two is often bounded, typically less than 2000 kg for long haul, less than 1000kg for short haul.	See Payload Mass and Fuel mass.	Yes	Is easily implemented and has demonstrated potential in previous research (REF).
Indicator if TOM is calculated or planned		All	n/a		Yes	Defines margin of uncertainty around mass.
Position	Location of point	All			Yes	Needed for interpolation of fuel used/speed profile
ETO	Expected time overhead at each point	All	2 min when not deviating	Wind & Temp forecast, deviation	No	Time unlikely to be more accurate than ATC prediction in TMA time horizon.

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Altitude	Altitude at points in the flight plan	All, some only at cruise altitudes	During climb/descent unknown; strongly dependent on lateral route. During cruise according to standards	Temperature, lateral route in departure, ATC.	Yes	Vertical profile during climb and descent
Point Significance (Waypoint name, TOD)	Type of point (waypoint, TOC/TOC, FIR border), type of turn (fly-by, fly-over)	All			Yes	TOC/TOD needed for vertical profile, turn type usable in route prediction
Distance Flown/To Go	Distance flown at each waypoint, may be stated per segment or cumulative	All	Within 1 nm when not deviating	Deviation from plan (ATC)	Yes, in combination with other parameters	Need for interpolation of other parameters (altitude, speed, mass)
Magnetic course of segment		Most			No	Is output of trajectory prediction
True course of segment		Most			No	Is output of trajectory prediction
TAS	True airspeed over point	Most			Yes	Suitable for derivation of speed profile
Ground speed	The predicted ground speed	Some		Wind & Temp forecast	No	Based on MET forecast at planning, ATC likely to have more up-to-date forecast.
Mach Number	Planned mach number at each point	Some, often implicit in TAS			Yes	Suitable for derivation of speed profile
Distance through air	Distance flown relative to air (including wind)	Few			No	May provide more accurate derivation of profile (results in still air profile). However is seldom easily available

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Fuel flow	Fuel flow at each point	Some			No	Difference between interpolation of fuel used and calculation based on fuel flow is expected to be negligible.
Fuel used/required	Fuel used or fuel remaining at each point	All	100 kg on short haul, 500 kg on long haul	Wind & Temp forecast	Yes	May be significant percentage of total aircraft mass (especially in long-haul operations)
Thrust settings	Thrust setting over point	All, mostly implicit			Yes	Large deviations from standard thrust settings (e.g. de-rated climb) have significant effect on vertical profile
Winddir at altitude	Forecast wind direction at point	All		Wind forecast	No	Based on MET forecast at planning, ATC likely to have more up-to-date forecast.
Windspeed at altitude	Forecast wind speed at point	All		Wind forecast	No	Based on MET forecast at planning, ATC likely to have more up-to-date forecast.
Headwind component	The component of wind along the segment's direction	Some		Wind forecast	No	Based on MET forecast at planning, ATC likely to have more up-to-date forecast.
Temperature at altitude	Forecast temperature at point	Some		Temperature forecast	Yes (TAS <> M)	May be used to convert determine preferred Mach number if only TAS is given. Note that a TP often has temperature as an input, but this is most likely to be more accurate from ATC MET sources
Temperature deviation to ISA	Deviation of forecast temperature from ISA conditions	Few		Temperature forecast	No	Based on MET forecast at planning, ATC likely to have more up-to-date forecast.

Parameter	Description	Available at FOC	Typical Accuracy	Major factor	Potential for use in TP	Value to TP accuracy
Sheer / Wind Variation	Indication of wind variation / turbulence at point. Used by pilot to decide on possible alternative routing.	Few		Weather forecast	No	If pilot does select alternate route, ATC will be informed.
Tropopause altitude	Forecast tropopause altitude at point	Few			No	Tropopause altitude is mainly dependent on latitude; TP applications are unlikely to include a broad latitude interval. Otherwise this could be modelled directly.
Minimum Safe Altitude of segment		Some			No	ATC is aware of local MSA

Appendix B Most promising parameters

This table provides those parameters which the project found most promising to improve ground TP performance. To support short term implementation, the parameters should also support relatively easy implementation in present day systems.

The selection criteria of these parameters based on:

1. The observations and recommendations from previous work that these parameters are of potential value to ground TP ([4], [6]).
2. These parameters can be implemented and validated in the current TP system.

Based on this list, AUs contributing to the project have been asked to indicate their ability and willingness to share these parameters with ATC. The number in the 3rd column indicates the number of operators that responded positively. The final column indicates the number of airspace users from the same group that are able and willing to provide such data for the validation exercises in the next phase of the project.

Note: At the moment the table is based on input from 3 operators, the project recommends that further operators are consulted during the next stage of the project.

Table 4: Flight planning parameters which are most promising to improve TP performance

Parameter	Value	Willing to share in the future concept	Capable and willing to share during tests (Dec '10-Mar '11)
Preferred climb speed (CAS / Mach)	Is easily implemented and demonstrated potential in previous research. Easiest when reported as CAS & Mach	3	3
Preferred descent speed (CAS / Mach)	Is easily implemented and demonstrated potential in previous research. Easiest when reported as CAS & Mach	3	3
Take-Off Mass	Is easily implemented and has demonstrated potential in previous research.	3, Provided the information is transferred securely and not stored after the completion of the flight.	3
Indicator if TOM is calculated or planned	May further reduce prediction uncertainty as mass is more certain when TOM is calculated.	3	3
All parameters below are considered to be reported for every significant point in the flightplan (i.e. waypoint, TOD/TOC). Note that this includes the climb and descent phases.			
Position	Needed for interpolation of fuel used/speed profile	3	3
Altitude	Speed profile likely to be altitude dependent (not distance).	3, Note, not always available outside cruise	3

Parameter	Value	Willing to share in the future concept	Capable and willing to share during tests (Dec '10-Mar '11)
		altitudes	
Point Significance (Waypoint name, TOD)	Needed to determine vertical profile	3	3
TAS	During climb, the preferred cruise speed is estimate by ATC	3	3
Mach Number	During climb, the preferred cruise Mach is estimate by ATC.	2, Not always available, may become more available in future.	2
Distance through air	During climb, the preferred cruise Mach is estimate by ATC.		
Fuel used/required	Relatively easy to implement, provides more accurate estimate of instantaneous mass.	3, Provided the information is transferred securely and not stored after the completion of the flight.	3
Thrust settings	Significant effect on climb profile, relatively easy to model.	2 (as far as available) Sometimes solely discretion of flight crew.	1
Temperature at altitude	Easy to derive preferred Mach number if TAS is given (needs TAS). Direct use of Mach number is likely to be more suitable. Note that temperature data from the flight plan is not used for direct TP inputs.	3	3

Appendix C Operator questionnaire

C.1 Introduction

This questionnaire forms part of a knowledge gathering phase of SESAR Project 5.5.2: Improved Airline Flight Plan Information into Air Traffic Control (ATC) Trajectory Prediction (TP) Tools.

C.1.1 Context

The concept developed in this project aims to improve Air Traffic Control (ATC) services by enhancing the ground based Trajectory Prediction (TP) capabilities using flight planning data that is currently not available to ATC. This concept is based on using more actual and exact data on the operation of a particular flight.

These improved prediction capabilities should improve ATC tools which should subsequently lead to an increase in safety, an increase in flight efficiency and a decrease in workload, both for ATC as well as flight crew.

Note that the concept aims to improve ATC tools without requiring changes to the operation of the flight. The concept therefore will not restrict or limit operations. Similarly, the concept is based on the use of available extra information and therefore is optional for each individual flight. Sharing data may be beneficial to the ATM system and the flight itself but is left at the Airspace User's (AU) discretion.

C.1.2 Purpose of the questionnaire

Using this questionnaire, the project will develop an understanding of flight planning processes across a range of representative airspace users, the results of which will be fed into the concept.

The primary questions that this questionnaire should help answering are:

- What data is available at the Airline Operations Centre (AOC)/Flight Operations Centre (FOC) before take-off of a flight?
- How accurate is that data?
- How long before take-off is that data available?
- What are the requirements from the airline's point of view regarding sharing this data?

C.1.3 Answering Guidelines

A good understanding of the flight planning process and the available data is crucial for the development of a successful concept. Be as informative as possible; do not hesitate to use extra space.

If appropriate, do not hesitate to extend tables.

If possible, please provide an example flight planning output (for example a pilots' flight plan sheet) when returning the questionnaire.

C.1.4 Confidentiality

Individual operators' replies given in sections 3, 4 and 5 will be treated as commercial in confidence. The combined output from these sections of the questionnaire will be consolidated in a general overview of flight planning processes without mentioning individual operators. Please refer to the SJU covering letter for more details.

Answers given in section 2, 6 and 7 will be shared with the project's airline partners to support their task of consolidating the operators' needs and requirements in the concept.

C.1.5 Contact

If you have any questions or need any further information on this questionnaire, please contact NATS [redacted] details given on cover).

C.1.6 Acronyms and Terminology

Term	Definition
AOC	Airline Operations Centre / Principal flight planning office of an airline
ATC	Air Traffic Control
ATSU	Air Traffic Service Units (i.e. ANSPs, CFMU and other organisations responsible for day-to-day Air Traffic Management)
CAS	Calibrated Airspeed
FMS	Flight Management System
FOC	Flight Operations Centre
TAS	True Airspeed
TP	Trajectory Prediction
SESAR	Single European Sky ATM Research Programme
WOC	Wing Operations Centre

C.2 General background

C.2.1 Respondents

Q	Please provide details of the respondent(s): 1. Name(s) 2. Expertise 3. Contact details for follow-up on this questionnaire
A	1 2

C.3 The flight planning process

This section of the questionnaire aims to generate an overview of the flight planning process within the airline including the departments involved, tools used and the development cycle of the flight plan.

C.3.1 Timeline

Q	Please describe the evolution of the flight plan: i.e. When is a first plan generated? When is it updated? When is the last possible update before take-off? And what drives these points (for example availability of certain data, need to provide plan to flight crew)? Where applicable, please indicate differences between normal and non-normal situations.
A	

C.3.2 Actors

Q	Which departments are involved in flight planning and at what stage? What is their role?
A	

Q	1. What role does the flight crew have in flight planning? 2. Is updated information available at the AOC/FOC after possible input from the crew?
A	1 2

C.3.3 Tools

Q	What tools are used to perform flight planning?
A	

C.4 The information available

This section aims to establish which information is available at the AOC/FOC which may be beneficial to Trajectory Prediction systems. The section is divided in inputs and outputs. Each section will discuss a number of specific parameters and afterward elicit any other information.

C.4.1 Inputs

Zero Fuel Weight

Q	1. To what accuracy is the Empty Weight of the Airframe known and used in flight planning? 2. How is the weight of passengers and/or cargo determined? 3. How accurate is the planned weight and what, if any, sources of error may exist between the planned payload weight and the actual payload weight? 4. Is the final payload weight available to the AOC/FOC before takeoff? How accurate is this value?
A	1 2

Operating preferences: speed schedule, cost index, thrust settings

Q	1. What operating preferences are planned and to what degree? 2. If applicable, please describe factors influencing the selection of the operating preferences? 3. Is this information available to the AOC/FOC (or could it be made available)? 4. How strictly are flights executed according to their planned preferences?
A	1 2

Meteorological data

Q	1. Which source provides the meteorological forecast for flight planning? 2. How much time before departure is the forecast generated? 3. How accurate is the forecast when compared to the weather experienced during the flight?
A	1 2

	3

Other Inputs

Q	Are any of the following parameters used as inputs to flight planning and are these parameters available (or could they be made available) at the FOC?	
A	**Parameter**	**Available at the FOC**
	Aircraft Type Engine Type FMS Type Cost index Thrust settings Aircraft navigation capabilities (those significant to selection of routing)	

Q	What other parameters are supplied as inputs to the flight planning process?	
A	**Parameter**	**Available at the FOC**

C.4.2 Outputs

Flight Profile

Q	Most flightplans include a prediction of the time and altitude at each significant point along the planned route. Many plans include more parameters at each of these points. Please indicate whether the parameters below are available. Please describe any other parameters that are available at each point. Where possible, please try to indicate the accuracy of the parameter and key sources of errors with respect to the flight execution.		
A	**Parameter**	**Indication of accuracy**	**Key sources of error**
	Time		
	Position		
	Altitude		
	TAS/Ground speed		
	Mach number		
	CAS		
	Distance Flown/To Go		
	Route / Location /		

	Significant point		
	Fuel used / remaining / required Or expected aircraft weight (See next question)		

Q	1. If the flight is executed according to the plan (i.e. no changes in routing, speeds, holding), how accurate is the estimate of amount of fuel used? 2. In a number of operators the crew has a final say on the amount of fuel to be uploaded. Is this discretion used in your airline and if so, how is this discretion applied? (How much extra fuel is typically taken, on what basis is this decided)? 3. What other factors may influence the planned amount of fuel versus the actual amount of fuel on board? 4. Is the final fuel weight available at the FOC before take-off?
A	1 2 3

C.5 Other Parameters

Q	Could you provide a list of parameters determined in the planning process that have not yet been discussed? Where possible, provide a qualitative indication of the accuracy of the parameter.	
A	**Parameter**	**Indication of accuracy**

C.6 Any other remarks

Q	Please feel free to provide any additional information which you think might benefit the project but can not be shared with other operators.
A	

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