Final Project Report on the concept and benefits for improving TP using AOC data

Document information	
Project title	Improved Airline Flight Plan Information into ATC Trajectory Prediction (TP) Tool
Project N°	05.05.02
Project Manager	NATS
Deliverable Name	Final Project Report on the concept and benefits for improving TP using AOC data
Deliverable ID	D04
Edition	00.01.03
Template Version	02.00.00

Task contributors

National Air Traffic Services Ltd (NATS), EUROCONTROL

Abstract

This document is the last deliverable for SESAR P 05.05.02. It provides the final set of Operational Requirements for use of Airline Operational Control (AOC) data in the computation of ground-based trajectory prediction. The report documents the results of validation exercise VP-301 (Release 2). The validation was performed using actual operational scenarios and operational data on a near-operational system and evaluated the performance benefits by gathering expert judgement. The document reports the Cost Benefit Analysis (CBA) for the concept identifying the costs and benefits associated with airspace users providing their actual take-off aircraft mass and speed profile flight planning data to Air Navigation Service Providers (ANSPs). The document also describes the Safety Criteria for the proposed concept.

Authoring & Approval

Prepared By		
Name & company	**Position / Title**	**Date**
[redacted] NATS	[redacted]	16/05/2012
[redacted] EUROCONTROL		16/05/2012
[redacted] EUROCONTROL		16/05/2012
[redacted] EUROCONTROL		16/05/2012
[redacted] EUROCONTROL		16/05/2012

Reviewed By		
Name & company	**Position / Title**	**Date**
[redacted] EUROCONTROL	[redacted]	09/05/2012
[redacted] NATS		02/05/2012
[redacted] EUROCONTROL		02/05/2012
[redacted] EUROCONTROL		09/05/2012
[redacted] EUROCONTROL		10/05/2012
[redacted] EUROCONTROL		09/05/2012
[redacted] EUROCONTROL		09/05/2012
[redacted] ENAV		09/05/2012
[redacted] Aviation Civile		10/05/2012
[redacted] Thales		09/05/2012
[redacted] Thales		09/05/2012
[redacted] Sicta		10/05/2012
[redacted] Novair		10/05/2012
[redacted] AENA		10/05/2012

Approved By		
Name & company	**Position / Title**	**Date**
[redacted] NATS	[redacted]	17/05/2012
[redacted] EUROCONTROL		17/05/2012

Document History

Edition	Date	Status	Author	Justification
00.00.01	25/04/2012	Draft	As Above	Document Ready for Review
00.01.01	16/05/2012	Final	As Above	Comments included and document updated.
00.01.02	14/08/2012	Final	As Above	Revised in response to SJU Comments.
00.01.03	11/04/2013	Final	As Above	Including comments from SE3.

Intellectual Property Rights (foreground)

The foreground of this deliverable is owned by the SJU.

Table of Contents

List of tables

List of figures

Executive summary

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.

This document provides the final set of Operational Requirements for ground ATC systems that facilitate the use of Airline Operational Control (AOC) data in the computation of ground-based trajectory prediction. The prime objective of these requirements is to improve the accuracy of the computed trajectory prediction (TP). The performance of such TPs influences the operational benefits of the advanced controller tools like CDnR and AMAN.

The proposed set of Operational Requirements will be included in the consolidated set of operational requirements for the TMA Trajectory Management Framework.

The document describes the validation process and results for the concept of using operator flight planning (AOC) data to improve ground-based trajectory predictions (TP) accuracy. The results of the V3 validation exercise VP-301 are reported (Release 2).

The V3 validation results reported in this document build on the V2 validation exercises results reported earlier in this project Ref. [13]. This validation stage covers complex operational scenarios as well as cost benefit analysis and safety criteria.

The V3 validation demonstrated the concept on a (near-) operational system and tested the following key areas:

- The resulting benefit to operations.
- The ability to implement the concept.
- The assessment that the concept has not reduced safety.
- The possibility of introducing this concept as part of the early benefit implementations.

The document also reports the Cost Benefit Analysis (CBA) performed for the concept of using AOC data in the computation of ground-based trajectory prediction (TP) tools. The CBA aimed to identify the costs and benefits associated with airlines providing their actual take-off aircraft mass and speed profile flight planning data to Air Navigation Service Providers (ANSP).

ANSP Benefits

- Safety benefits due to a reduction in the number of missed conflicts resulting in avoiding increased/peaks of controller workload. There is also a knock-on effect that avoiding safety incidents also saves the costs associated with investigating them.
- Controller workload reduction since the improved trajectory predictions will reduce the number of false alerts that controllers receive, so they will perform fewer unnecessary actions.

ANSP Costs – these are limited to ground system software development costs as costs such as software maintenance, training etc. are considered to be sufficiently small that they would be covered by current planned budgets.

Airline Results

The Airline model focused on the benefit that improved trajectories would reduce the number of false conflict alerts shown to controllers and therefore fewer climbing aircraft (in climb/cruise conflicts) would have to level-off unnecessarily. The model provides results at ECAC level and for an individual airline that is sharing the additional data.

Based on all the assumptions made in the model, a positive Benefit to Cost ratio (B/C) ranging between 6.7 and 8.2 is calculated for airlines with a fleet of mainly single and twin aisle aircraft.

The magnitude of the Net Present Value is small. However it is acceptable in a 'kaizen' (continuous improvement) style of management taking into account that the B/C is possibly high enough, except for Regional types of aircraft.

1 Introduction

During SESAR step 1, no interaction with the Reference Business Trajectory (RBT) takes place during departure and the main trajectory management interactions take place in the arrival metering, sequencing and merging phases based on i4D and ASPA S&M concepts [8]. However, Air Traffic Control (ATC) will need detailed, up-to-date trajectory data to drive advanced controller tools, such as Conflict Detection and Resolution (CDnR), 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 adequate 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 has to be derived from 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 tools. Previous research has shown that the provision of operator flight-planning data could permit significant improvements in the performance of TP applications. This project investigates the operational use of flight-planning data provided by airspace users to produce Trajectory Predictors and assess the benefits to (ATM) system performance [9].

Since 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, however the more operators participating the greater the benefits expected.

The project focused on defining the operational uses of the data and demonstrated the operational benefits that can be achieved for the interested stakeholders. It validated the requirements for exchanging data between airspace users and ATC systems but has not investigated the means of achieving this.

1.1 Scope of the document

This is the final operational technical deliverable from this project. The scope of this document covers a number of different areas that can be summarised as follows:

<u>Final set of Operational Requirements</u>: Within the scope of this document is to introduce the final set of Operational Requirements to the concept of using operator flight planning data to improve trajectory prediction in SESAR Time Based Operations implementation, this is based on the preliminary set of Operational Requirements as described in [10].

This project introduces the concept for use of AOC data to improve Trajectory Prediction [11] and the associated operational requirements. This project will be prior to the advent of standards and infrastructure to support full trajectory exchange between aircraft and ATC systems. Projects P 05.05.01 and P 04.05 primarily address longer term solutions.

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.

<u>V3 validation activities:</u> Within the scope of this document is to provide the validation process and results for the concept of using operator flight planning data to improve trajectory predictions. The document uses the validation plan as defined in D02 Ref [12] towards E-OCVM V3 Re [7]. The results at V3 validation stage are based on the validation results at V2 stage as reported in [13]. The document describes how stakeholders' needs defined and formalised as a set of requirements in the *Preliminary Operational Requirements* Ref. [10] and the updated final set of these requirements as defined in this document are validated.

As such the document details the V3 validation activities and results for the project aiming to validate the concept as defined in D01 Ref. [11].

Cost Benefit Analysis: Another activity that fits within the scope of this document is to report about the Cost Benefit Analysis (CBA) performed for the concept of using AOC data in computing ground trajectory prediction as defined in [11]. The report includes the CBA results and the assumptions that were made to produce them as well as the CBA model. Also the report contains a description of the process that was followed to produce the CBA results.

1.2 Purpose of the document

The purpose of this document is:

- Introduce the final operational requirements for the use of operational flight data in the computation of ATC trajectory prediction.
- Report the validation process and results for the concept of using operator flight planning data to improve trajectory prediction in ATC operational system.
- Report cost benefit analysis process and results for the concept of using operator flight planning data to improve trajectory prediction in ATC operational system.
- Report safety assessment for the concept of using operator flight planning data to improve trajectory prediction in ATC operational system.

As such the document concludes V3 validation, Cost Benefit Analysis (CBA) activities and safety assessment of project 05.05.02.

1.3 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.

SESAR P 05.05.01: 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 P 05.05.01 it is important for this document to be read by this work package to ensure that the results from using airline flight plan data will be considered with the wider TMA Trajectory Management Framework.

SESAR P 05.02: There are two main objectives to this work package:

- Develop, refine and provide detail as required to the ATM Target Concept for TMA operations (SESAR CONOPS).
- Provide a validation strategy which is derived from both a top down and bottom up approach.

By making this document available to SESAR P 05.02 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 results reported by P 05.05.02 in this document to be considered in the overall TMA concept assessment.

SESAR P 05.03: The objective of project P 05.03 is to perform a pre-operational validation across several concept functions/elements of the TMA operation. Considering this document by P 05.03 makes sure that the results from the use of FOC data concept and the validation approach are considered in integration validation activities for stage V3.

SESAR P 05.06.02: The fast time simulation of the effects of TP accuracy on tactical de-confliction of CCDs may be of interest to improve the availability of efficient vertical profiles.

SESAR WP 03: While this project performs its own integrated validation, the techniques and strategy may be used in future integrated validation which may include the concept of using additional planning information to enhance ground based TP capability.

SESAR P 07.06.02: The overall objectives of project 07.06.02 are to refine the definition of the business/mission trajectory, its lifecycle, the associated procedures and system functions to support trajectory sharing and progressive refinement/optimisation at network level. The project also ensures consistency with the other initiatives including Flight Object Programme (ICOG) and future FPL concept (ICAO). The project collects airlines data and hence sharing information through this document will be in the interest of both projects and SESAR project in general.

SESAR WP 08: 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 08 will ensure that the results from using AOC parameters will be considered in the framework.

SESAR WP 10.02: 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.

SESAR P 10.02.01: The objective of this project is to describe how the ATC system will develop the trajectory management services that will be required to satisfy the TM related operational requirements from the various operational work packages.

SESAR WP 11: It is important the flight plan data adopted in project 05.05.02 are approved by the FOC projects within WP11.

SESAR WP 16: The validation results in this document together with the initial CBA results reported in this document should provide the inputs to the CBA as specified by WP16. As such the validation results reported in this document should be aligned to the higher level WP16 strategy.

Airspace Users: Making the validation and cost benefit results in this document available to airspace users would help to demonstrate the concept and the benefit from using AOC data to various operators.

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 operational requirements proposed in this document with the various suppliers.

1.4 Project Background

A trajectory prediction function is an essential component of many current and planned ATC support tools (e.g. DMAN, AMAN, MTCD …). The utility and potential of the ATC tools required by Time Based Operations as per SESAR SJU Story Board will be limited by the accuracy of the trajectory predictor.

Existing trajectory prediction functions have known limitations in accuracy, particularly for climbing and descending flight profiles. Current ATC tools can encounter limited controller acceptability due to their high false alert rates and re-sequencing rates which result from the poor accuracy of trajectory predictions.

The introduction of SESAR time and trajectory based concepts will necessitate much higher controller reliance on ATC support tools. The full potential of such tools will not be achieved unless the trajectory prediction accuracy can be improved. I.e. TP-based ATC tools will not provide operational benefits such as increased capacity and environmental gains unless the underlying TP performance is improved.

This project assesses the use of flight-planning data provided by airspace users in improving the accuracy of ground Trajectory Predictor. The poor accuracy of Trajectory Prediction in most cases is due to lack of knowledge of aircraft operation condition rather than the TP model itself.

1.5 Project Scope

This project is focussed on the near-term use of airline flight-planning data, prior to the advent of standards and infrastructure to support full trajectory exchange between aircraft and ATC systems.

The provisions of airline flight-planning data should permit significant improvements in the performance of ATC trajectory prediction systems. These trajectory prediction systems are a core function with many advanced controller tools, such as Medium Term Conflict Detection (MTCD) and Arrival Manager (AMAN).This project investigates the operational use of flight-planning data provided by airspace users in computing ground-based trajectory prediction and also assesses the benefits.

This project focuses on defining the operational uses of the data and demonstrating the operational benefits that can be achieved. It assesses the requirements for exchanging data between airline and ATC systems but not investigate the means of achieving this.

1.6 Relationship to Other Deliverables

This document is one of five deliverables from project 05.05.02.

Project 05.05.02 deliverables in details are:

Deliverable one is “D01 – Concept for use of AOC data to improve Trajectory Prediction” Ref. [11] that introduced the concept of using operator flight planning data to improve ground trajectory prediction.

The second deliverable is “D06 – Preliminary Operational Requirements for use of AOC data” Ref. [10] that provides a preliminary set of operational requirements for the use of Airline Operational Control (AOC) data in the computation of ground-based trajectory predictions. The final set of operational requirements is included in the current document.

The third deliverable is “D02 – Validation Plan for Enhanced TP using AOC data” Ref. [12] that presented the strategy and plan for phases V2 and V3 validation of the concept of using AOC data in ground-based trajectory prediction. The document described various exercises to be performed during the V2 and V3 validation phases.

The fourth document is “D03 – Validation Results for Enhanced TP using AOC data” Ref. [13] that provides all V2 validation results and observations for the concept described in D01 and operational requirements as described in D06 based on the validation plan as described in D02.

This document is the final technical deliverable to this project. The document includes the final set of operational requirements together with V3 validation results that include cost benefit analysis results.

1.7 Structure of the document

This document is the last technical deliverable for SESAR P 05.05.02. As such the document will be reporting on various issues: final operational requirements, V3 validation and Cost Benefit analysis, so each section of the document will follow the appropriate SESAR template. The document is the final deliverable as defined in Ref. [9].

The document consists of twelve sections. Section 2 provides the final set of Operational Requirements for the use of AOC data in computing ground trajectory prediction. Section 3 provides a summary of V2 validation activities and results. Section 4 covers the concept of the V3 validation while section 5 describes the conduct of V3 validation exercises and section 6 summarises the V3 exercises reported results including Exercise VP-301 results (Release 2).

Section 7 covers the Cost Benefit Analysis methodology while section 8 reports the CBA results. Section 9 covers Safety Benefit issues related to the introduction of the concept of using AOC data in computing ground trajectory prediction. Finally section 10 provides conclusions and recommendations.

The document also contains a number of appendices:

Appendix A: This appendix covers the coverage matrix completed with validation exercises results and validation objectives analysis status.

Appendix B: This appendix covers the sectors selection process with their arguments and time interval.

Appendix C: This appendix gives a summary of the recorded data and operators data collected to be used in this validation.

Appendix D: This appendix gives a quick overview of the various tools and environment used in this validation.

Appendix E: This appendix lists various results from the subjective validation activity [0301.0100].

Appendix F: This appendix covers the EXCEL Airlines Cost Benefit Analysis model.

Appendix G: This appendix gives background to the sensitivity analysis for the CBA model.

Appendix H: This appendix gives background to the probabilistic analysis for the CBA model.

Appendix I: This appendix gives overview of validation objectives status for P 05.05.02

1.8 Acronyms and Terminology

Term	Definition
ACARS	Aircraft Communications Addressing and Reporting System
ADD	Architecture Definition Document
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.
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
AOC	Airline Operational Control
AP16	EUROCONTROL-FAA Action Plan 16
ASM	Airspace Management
ASPA	Airborne Spacing
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
B/C	Benefit to Cost Ratio
BADA	Base of Aircraft Data – EUROCONTROL
BADA reference mass	BADA reference mass is the mass for which other BADA performance

Term	Definition
	coefficients are calculated.
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.
CBA	Cost Benefit Analysis
CCD	Continuous Climb Departure
CDA	Continuous Descent Approach
CDnR	Conflict Detection and Resolution
CFMU	Central Flow Management Unit – EUROCONTROL
CFSP	Computerised Flight Plan Service Provider
CI	Cost Index
CM	Conformance Monitoring
CNS	Communication, Navigation and Surveillance
CO_2	Carbon Dioxide
CPDLC	Controller Pilot Datalink Communications
CTA	Controlled Time of Arrival
CTAS	Center-TRACON Automation System – FAA
DAP	Downlinked Airborne Parameters
DMAN	Departure Manager
DOD	Detailed Operational Description
DST	Decision Support Tools
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology
ECAC	European Civil Aviation Conference
ECTL	EUROCONTROL
EMOSIA	European Models for ATM Strategic Investment Analysis
ETA	Estimated Time of Arrival
ETFMS	Enhanced Tactical Flow Management System

Term	Definition
ETO	Estimated Time Overhead
EU	European Union
EUA	European Emission Allowance
EU ETS	European Union Emissions Trading Scheme
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.
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.
FMP	Flow Management Position
FOC	Flight Operations Centre
FPL	ICAO Flight Plan message
FTE	Full Time Equivalent
FSS	Flight Service Station (USA)
FTS	Fast Time Simulator
GAT	General Air Traffic
I4D	Initial 4D (from B04.02)
iFACTS	Interim Future Area Control Tools Set – NATS
IFPS	Integrated Flight Plan Processing System
IFR	Instrument Flight Rules
INTEROP	Interoperability Requirements
IRS	Interface Requirements Specification

Term	Definition
MAC-AIM	Mid Air Collision Accident Incident Model
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.
MTOW	Measured Take-Off Weight
NPV	Net Present Value
OAT	Operational Air Traffic
OFA	Operational Focus Areas
OFPL	Operational Flight Plan
OSED	Operational Service and Environment Definition
PBN	Performance Based Navigation
PDC	Pre Departure Clearance
RAVE	Replay-Aided Validation Environment (NATS).
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).
RFL	Requested Flight Level
RMT	Reference Mission Trajectory
RNAV	Area Navigation
RNP	Required Navigation Performance
RPL	Repetitive Flight Plan
SAAM	System for traffic Assignment & Analysis at Macroscopic level
SC	Safety Criteria
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

Term	Definition
SITA	Société Internationale de Télécommunications Aéronautiques Airlines télécommunications and Information Service
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
SPR	Safety and Performance Requirements
STAR	Standard Terminal Arrival Route
SUT	System Under Test
SWIM	System Wide Information Management
TAD	Technical Architecture Description
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.
TPRT	Trajectory Predictor Research Tool (NATS)
TOM	Take-Off Mass
TOC	Top of Climb
TOD	Top of Descent
TS	Technical Specification
T/D	Touch-Down
T/O	Take-Off
VALP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VFR	Visual Flight Rules

Term	Definition
VOPI	Value of Perfect Information
VP	Verification Plan
VR	Verification Report
VS	Verification Strategy
W.d	Working days
WOC	Wing Operations Centre

2 Operational Requirements for use of AOC data

This project introduces the use of operational flight plan data in the computation of ground-based Trajectory Prediction (TP). In this section of the document we present the final operational requirements for the use of AOC data. This final set of requirements is based on the initial set of operational requirements as described in Ref. [10].

2.1 Operational Concept Description

This project is focussed on the near-term use of operator flight planning data, no interaction with the Reference Business Trajectory (RBT) takes place during departure and only limited interaction takes place during arrival metering [8]. However, Air Traffic Control (ATC) will need detailed, up-to-date trajectory data to drive advanced controller tools, such as Conflict Detection and Resolution (CDnR), Arrival Manager (AMAN), Departure Manager (DMAN) and Conformance Monitoring (CM).

Therefore, ATC will need to operate local (ground-based) 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. This project will investigate the operational use of flight-planning data provided by airspace users and assess the benefits to (ATM) system performance [9].

The scope of potential changes required to make use of flight planning data are limited to ground systems (airline, military and ATC). The concept does not require a change to flight operations to provide a benefit from improved TP performance. 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. The project will not specify how TP systems should implement the data.

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. Some of the parameters most likely to be able to improve trajectory accuracy are considered in this project:

- Take-Off Mass (TOM)
- Climb/Descend Speed
- True Airspeed
- Mach number (or TAS & temperature)
- Fuel used (planned)

The operators taking part in this project agreed to sharing flight planning information to investigate 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 agreed to share the data. The participating operators understand the benefit of providing this AOC data to ATC systems for their respective specific flights. Without the supply of this data it will difficult for the ATC systems to provide them with their preferences.

2.2 Detailed Operating Methods

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 (New SESAR) 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). The client applications will be the same client applications as in the current baseline.

2.2.1 Previous Operating Method

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), CDnR.

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 validation environment and traffic information are included. For more details see validation environments in Appendix D while traffic samples are covered in Appendix B and Appendix C.

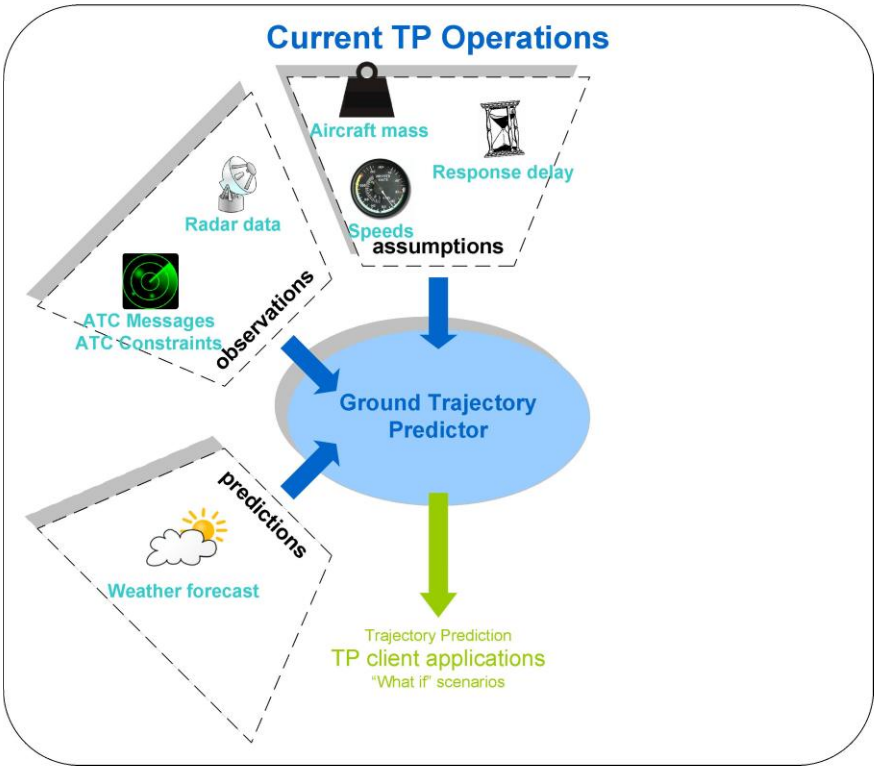

Figure 1: Current system (ground TP)

2.2.2 New SESAR Operating Method

The modified (New SESAR) system consists 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 scope of validation must include the TP component as well as its ATC tools which make use of TP results.

The ATC environment and traffic characteristics also affect their potential benefits and must be reflected in the validation activities. Environment and traffic details are detailed in Appendix D, Appendix C and Appendix B.

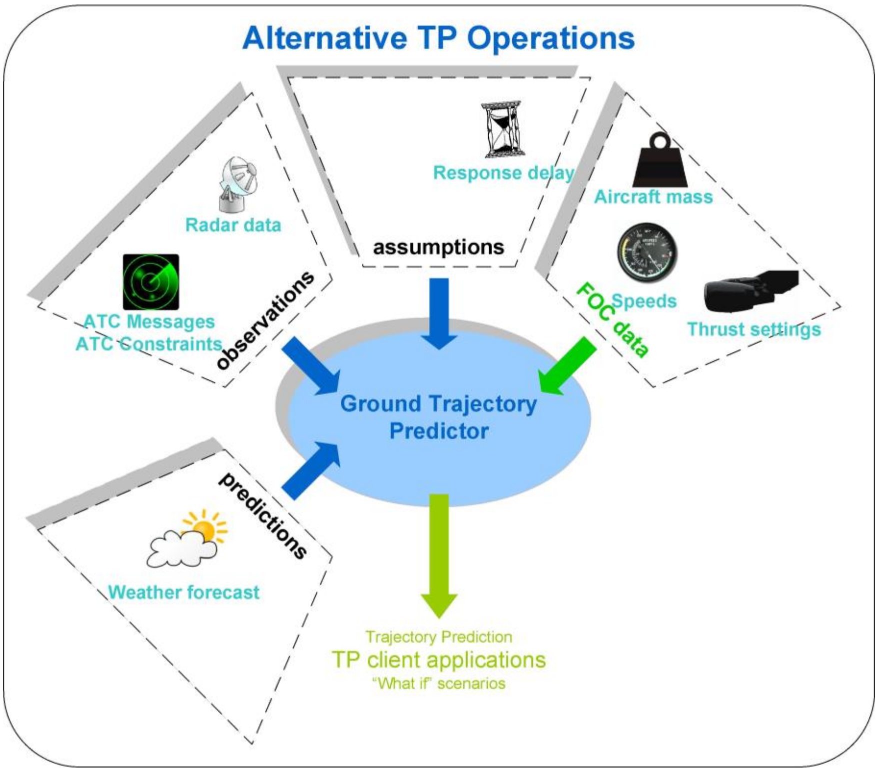

Figure 2: Alternative system (ground TP using AOC data)

Remark 1: AOC data amount may vary in quantity and quality (e.g. aircraft equipage, AOC arrangement, ground TP improvement across Europe).

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

The selected flight planning parameters to improve TP performance is considered.

In Table 1 a list of the core flight planning parameters to improve TP performance is considered, while in Table 2 a list of supporting AOC parameters that is used in the computation of TP is considered.

During the validation activities we restricted the assessment on parameters in Table 1; parameters in Table 2 were not included in this assessment.

Parameter	Potential Value for TP Accuracy improvement
Preferred climb speed (CAS / Mach)	Easily implemented and demonstrated potential benefit in previous research. Easiest when reported as CAS & Mach
Preferred descent speed (CAS / Mach)	Easily implemented and demonstrated potential benefit in previous research. Easiest when reported as CAS & Mach
Take-Off Mass	Is easily implemented and has demonstrated potential benefit in previous research. Enables aircraft performance to be more accurately modelled, and reduces uncertainty. The accuracy of this parameter depends on the source of the data and time before flight.
Indicator if TOM is calculated or planned	May further reduce prediction uncertainty as mass is more certain depends if the TOM calculated based on assumptions regarding number of passengers, bags and fuel or it is the load-

Parameter	Potential Value for TP Accuracy improvement
	sheet TOM.

Table 1: Core flight planning parameters to improve TP performance

Parameter	Potential Value for TP Accuracy improvement
All parameters below are considered to be reported for every significant point in the flight plan (i.e. waypoint, TOD/TOC). Note that this includes the climb and descent phases.	
Position	Needed for interpolation of fuel used/speed profile.
Altitude	Speed profile likely to be altitude dependent (not distance).
Point Significance (Waypoint name, TOD)	Supports determining the vertical profile and reduction in vertical uncertainty.
TAS	During climb, the preferred cruise speed is estimate by ATC. Supports determining the speed profile.
Mach Number	During climb, the preferred cruise Mach is estimate by ATC. Supports determining the speed profile.
Fuel used	Relatively easy to implement, provides more accurate estimate of instantaneous mass.

Table 2: Supporting flight planning parameters to improve TP performance

2.2.3 Differences between new and previous Operating Methods

The main difference between the current and new SESAR operating method is that the new SESAR system uses AOC data in the computation of ground Trajectory Prediction (TP).

2.3 Operational Requirements

This section considers the final set of operational requirements.

[REQ] 1

Identifier	REQ-05.05.02-OSED-0100.0100
Requirement	*Airspace user shall provide AOC data to an agreed pre-defined format, minimum accuracy and frequency or schedule as agreed with each airspace user participating.*
Title	Airspace user data input
Status	<Final>
Rationale	To ensure the accuracy of the computed TP.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 2

Identifier	REQ-05.05.02-OSED-0100.0200
Requirement	*The ground ATC-system shall check that the supplied AOC data is in pre-defined format.*
Title	AOC data format
Status	<Final>
Rationale	To ensure the correct representation of the AOC data in the TP model.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	N/A

[REQ] 3

Identifier	REQ-05.05.02-OSED-0100.0300
Requirement	*The means of transport of AOC data shall be in line with future SWIM architecture.*
Title	SWIM processing
Status	<Final>
Rationale	To comply with SESAR high-level design.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	N/A

[REQ] 4

Identifier	REQ-05.05.02-OSED-0200.0000
Requirement	*The ground ATC-systems shall have the mechanism to receive AOC data.*
Title	ATC-system able to receive and handle AOC data
Status	<Final>
Rationale	To be able to use AOC in the computation of TP.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 5

Identifier	REQ-05.05.02-OSED-0200.0100
Requirement	*The ground ATC-system shall accept any delivered data that in compliance with the specified format and agreed accuracy as per Req. REQ-05.05.02-OSED-0100.0100.*
Title	AOC Data Acceptance
Status	<Final>
Rationale	To secure system's access to the supplied AOC data.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 6

Identifier	REQ-05.05.02-OSED-0200.0200
Requirement	*The ground ATC-system shall perform the necessary verification of the provided data to check that the provided AOC data are within the valid range for each of these data items as agreed with each airspace user.*
Title	AOC Data Verification
Status	<Final>
Rationale	To handle and remove gross error in the supplied AOC data.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 7

Identifier	REQ-05.05.02-OSED-0300.0000
Requirement	*The ground ATC-system shall use the received AOC Data in its Trajectory Prediction calculation.*
Title	ATC-system uses AOC Data in Trajectory Prediction calculation
Status	<Final>
Rationale	To improve the accuracy of the computed TP.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 8

Identifier	REQ-05.05.02-OSED-0300.0100
Requirement	*In the case of faulty data, the ground ATC-system shall use the baseline system in calculating the required Trajectory Prediction.*
Title	Gross-Error data handling
Status	<Final>
Rationale	To ensure ground system stability.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 9

Identifier	REQ-05.05.02-OSED-0300.0200
Requirement	*The TP component shall report internally to the ground ATC-system which scheme (baseline or "AOC data enabled") is used in calculating the trajectory prediction.*
Title	ATC-system Internal Reporting
Status	<Final>
Rationale	That is for traceability purpose.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 10

Identifier	REQ-05.05.02-OSED-0400.0000
Requirement	*The ground ATC-system shall be able to work with "mix mode" functionality, i.e. some flights are supported by AOC data others are not (baseline).*
Title	Mixed Mode Functionality
Status	<Final>
Rationale	The AOC data concept is not mandatory and this functionality is required to ensure the usability of the system all the time.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 11

Identifier	REQ-05.05.02-OSED-0400.0100
Requirement	*If there is no suitable AOC data available the ground ATC-*system shall be able to make trajectory predictions without AOC data.
Title	AOC data not available
Status	<Final>
Rationale	The AOC data concept is not mandatory and this functionality is required to ensure the usability of the system all the time.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 12

Identifier	REQ-05.05.02-OSED-0400.0200
Requirement	*If the AOC data is available for a flight the ground ATC-system shall aim to improve the accuracy of the trajectory prediction for that flight by using the provided AOC data.*
Title	AOC data available
Status	<Final>
Rationale	To improve the quality of produced TP.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 13

Identifier	REQ-05.05.02-OSED-0400.0300
Requirement	*If AOC data is available for a flight that shall not require AOC data to be available for other flights.*
Title	ATC-system ability to switch between two options
Status	<Final>
Rationale	The AOC data concept is not mandatory and this functionality is required to ensure the usability of the system all the time.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 14

Identifier	REQ-05.05.02-OSED-0500.0000
Requirement	*The ground ATC-system shall observe various data access restrictions as agreed with airspace users.*
Title	Data Access Restrictions
Status	<Final>
Rationale	To observe airspace user's restrictions in the data handling.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

[REQ] 15

Identifier	REQ-05.05.02-OSED-0500.0100
Requirement	*The system shall comply with any time restrictions that have been agreed with airspace users not to keep the AOC supplied data after the completion of a flight.*
Title	Data access time restriction mechanism
Status	<Final>
Rationale	To observe airspace user's restrictions in the data handling.
Category	<Operational>
Validation Method	<Review of Design>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.02-DOD-0003.0001	N/A
<APPLIES_TO>	<Operational Process> or <Operational Service>	<i4D>	<Partial>

2.4 Traceability of Operational Requirements to OIs

The high-level operational requirement for this project is defined in the 4.2 Detailed Operational Descriptions, Ref. [19]:

Identifier	REQ-04.02-DOD-0003.0001
Requirement	Trajectory data as available from AOC shall be used to improve ground Trajectory Prediction accuracy.

This section traces the Operational Requirements defined and validated by P05.05.02 to the Operational Improvements (OIs) as identified in the DoD Ref. [19]:

Operational Requirement Identifier	Requirement Description	OIs Code	OIs Description	OSEDs Ref (Master or Contributing)
REQ-05.05.02-OSED-0100.0200	*The ground ATC-system shall check that the supplied AOC data is in pre-defined format.*	CM-0104 Automated Controller Support for Trajectory Management	*Automated tools support the ATC team in identifying, assessing and resolving local complexity situations through assessment of evolving traffic patterns and evaluation of opportunities to de-conflict or to synchronise trajectories.*	5.5.2 5.6.5 5.6.7 5.7.2 5.9
REQ-05.05.02-OSED-0400.0100	If there is no suitable AOC data available the ground ATC-system shall be able to make trajectory predictions without AOC data.			
REQ-05.05.02-OSED-0400.0000	The ground ATC-system shall be able to work with "mix mode" functionality, i.e. some flights are supported by AOC data others are not (baseline).	CM-0204 Automated Support for Medium Term Conflict Detection & Resolution and Trajectory Conformance Monitoring	The system provides real-time assistance to the tactical controller for monitoring trajectory conformance and provides resolution advisory information based upon predicted conflict detection.	5.5.2 5.9
REQ-05.05.02-OSED-0400.0200	If the AOC data is available for a flight the ground ATC-system shall aim to improve the accuracy of the trajectory prediction for that flight by using the provided AOC data.			
REQ-05.05.02-OSED-0400.0300	If AOC data is available for a flight that shall not require AOC data to be available for other flights.			
REQ-05.05.02-OSED-0100.0100	Airspace user shall provide AOC data to an agreed pre-defined format, minimum accuracy and frequency or schedule as agreed with each airspace user participating.	IS-0301 Interoperability between AOC and ATM Systems	Use of trajectory data as available from AOC (initially probably on a low periodicity basis) incl. ATOW, engine variant, actual wind profiles, possibly intent data (next waypoint(s)) and airline thrust setting policy, as a complement to ICAO flight plan/ surveillance data /qualified extrapolation, for improved accuracy of ground-based TP computations.	5.5.2
REQ-05.05.02-OSED-0200.0100	The ground ATC-system shall accept any delivered data that in compliance with the specified format and agreed accuracy as per Req. REQ-05.05.02-OSED-0100.0100.			
REQ-05.05.02-OSED-0100.0300	The means of transport of AOC data shall be in line with future SWIM architecture.			
REQ-05.05.02-OSED-0500.0100	The system shall comply with any time restrictions that have been agreed with airspace users not to keep the AOC supplied data after the completion of a flight.			
REQ-05.05.02-OSED-0500.0000	The ground ATC-system shall observe various data access restrictions as agreed with airspace users.			
REQ-05.05.02-OSED-0200.0000	The ground ATC-systems shall have the mechanism to receive AOC data.			

REQ-05.05.02-OSED-0200.0200	The ground ATC-system shall perform the necessary verification of the provided data to check that the provided AOC data are within the valid range for each of these data items as agreed with each airspace user.			
REQ-05.05.02-OSED-0300.0000	The ground ATC-system shall use the received AOC Data in its Trajectory Prediction calculation.			
REQ-05.05.02-OSED-0300.0100	In the case of faulty data, the ground ATC-system shall use the baseline system in calculating the required Trajectory Prediction.			
REQ-05.05.02-OSED-0300.0200	The TP component shall report internally to the ground ATC-system which scheme (baseline or “AOC data enabled”) is used in calculating the trajectory prediction.			

Table 3: Traceability of Operational Requirements to Operational Improvements

Note: Some of the OIs are studied by more than one project. 5.5.2 does not assess the full scope of these OIs - see column “OSEDs Ref (Master or Contributing)” in Table **3**.

3 Summary of V2 Validation Activities

3.1 Introduction

The results for the V2 stage validation of the concept of using AOC data in ground based trajectory prediction were presented in deliverable D03 Ref. [13]. Validation was performed in 5 exercises: two analyses using actual operational data to determine the effects on TP accuracy, two to translate the change in accuracy in example operational scenarios and an integrated simulation to gather expert judgement on the effects on an example ATC tool implementation of TP. The final exercise applies the concept to a present-day operational system and evaluates the effects on the ATC tool itself.

This section of the document gives a summary of these activities and highlights the results from V2 stage validation.

The V3 stage validation is covered in the remaining of this document.

3.2 List of V2 Validation Exercises

Exercise Number	Exercise Description
EXE-05.05.02-VALP-0069.0100	This exercise aims to determine the effect on accuracy of the AOC parameters to current/near term TP systems.
EXE-05.05.02-VALP-0069.0200	This exercise concerns with the sensitivity of the computed TP to the accuracy of various AOC.
EXE-05.05.02-VALP-0069.0400	This exercise aims to assess the impact of TP improvements on conflict detection support tools.
EXE-05.05.02-VALP-0300.0100	This exercise aims to determine the effect of each AOC parameter on the accuracy of computed TP and the overall system performance.

Table 4: List of V2 Validation Exercises

3.3 Summary of Validation Scenarios

The validation scenario preparation was guided by the concept as described in D01 Ref [11] and the proposed validation plan D02 Ref. [12]. The concept of using AOC data in computation of ground TP is independent of the application that uses the computed TP.

The scenarios required to test TP accuracy are independent of the application of the TP in a tool. These scenarios will therefore require flight segments with strong vertical components but do not require particular types of ATC operation.

The validation at ATC tools performance level will require an operation in which current or near-term TP-driven ATC tools are used. As an example of these tools we consider NATS iFACTS system. iFACTS is used in London Area Control centre. This area is consistent with the definition of SESAR TMA. The traffic in this area covered by London Area Control centre includes a large amount of climbs and descends.

The TP used in this system is considered representative for current or near-term TP systems in the TMA. Therefore the validation of TP accuracy and ATC tool performance will be based on the iFACTS system.

To drive this validation a selection of operational days and sectors took place to ensure the traffic level and reasonable level of climb and descent flights that can be in the validation scenario.

3.4 Summary of Assumptions

The validation strategy is built on the results of the analysis of TP accuracy of the iFACTS TP algorithm based on recorded operational data (EXE-05.05.02-VALP-0069.0100). This introduces a number of assumptions that affect the complete validation at V2 stage:

- The iFACTS TP algorithm is a BADA based model similar to most of the current and near term TP algorithms. For this reason the iFACTS TP algorithm and its behaviour can be considered a representative for current and near-term TP algorithms in general.
- The recorded accuracy of the iFACTS TP in the London Area airspace is representative of the accuracy of CDnR TMA TPs. This includes the applications of TP that are tested in the fast time simulations of the Paris airspace.
- The recorded dataset provides sufficient variation in fleet, operations, tactical instructions and meteorological effects to allow application of the results in general cases.
- The AOC data provided in a form that allows the use of such data without large pre-processing activities.

3.5 Choice of methods and techniques

Supported Metric / Indicator	Platform / Tool	Method or Technique
TP Accuracy	TPRT	➢ Mathematical modelling. ➢ Sensitivity Statistical Analysis.
Safety	The V&V Tool SAMM	Fast Time Simulation
Efficiency	The V&V Tool SAMM	Fast Time Simulation
Safety	RAVE	Real Time Simulation
Efficiency	RAVE	Real Time Simulation

Table 5: Methods and Techniques

3.6 Validation Exercises Reports and Results

3.6.1 EXE-05.05.02-VALP-0069.0100

3.6.1.1 Exercise Scope

This validation exercise addressed the concept of using AOC data in computing ground Trajectory Prediction.

This phase of validation was concerned with the improvements in accuracy of trajectory prediction with introduction of various AOC parameters into the computation of Trajectory Prediction.

3.6.1.2 Summary of Exercise Results

The accuracy of the Trajectory Prediction is validated by performing comparison of the TP generated using baseline with no AOC data versus TP generated using AOC reported mass, AOC reported speed and the combination between AOC mass and speed. AOC reported data is the data provided by participated airlines to this project.

The following summary presents the objectives and exercises results:

Validation Objective ID	Validation Objective Title	Success Criterion[1]	Exercise Results
OBJ-05.05.02-VALP-0010.0010	Validate that the accuracy of the TP improves considerably when AOC data is used as an information source.	The accuracy of a predicted trajectory is improved considerably when AOC data is used in the prediction when compared to the accuracy without the use of AOC data.	There are a number of cases where accuracy improved: 1. AOC mass for climbed aircraft. 2. AOC speed for climbed aircraft. 3. AOC mass and speed for climbed aircraft. 4. AOC mass for decent aircraft.
OBJ-05.05.02-VALP-0050.0010	Validate that the selected AOC data can be used in current or near-term TP algorithms.	The TP algorithm used in the test is representative of current or near term TP systems.	Minor modification introduced to iFACTS TP algorithms that allowed the use of AOC data in the iFACTS system.
OBJ-05.05.02-VALP-0050.0110	Validate that AOC data can be used in current or near-term ATC tools that use trajectory prediction.	AOC data is used in a demonstration using current or near-term operational ATC tools.	The sample data used is a mixed of AOC supported and non-supported aircraft.

Table 6: EXE 0069.0100 Validation Objectives and exercises results

3.6.1.2.1 Results per KPA

Efficiency:

Rate of false conflict alerts due to TP errors, involving aircraft in climb, are improving by 10% for conflicts with one aircraft in climb (using AOC mass and speed combined), hence the rate of stopped continuous climb due to conflict alerts is reducing (at most) by 10%.

Safety:

Using AOC mass and speed combined in the case of climbed aircraft brought significant improvement in the accuracy of the computed TP that should result in a reduction in missed and false conflict rates.

In the case of descent the results were much less conclusive than the case of climb.

3.6.2 EXE-05.05.02-VALP-0069.0200

3.6.2.1 Exercise Scope

This validation exercise addressed the concept of using AOC data in computing ground Trajectory Prediction.

This phase of validation was concerned with the sensitivity of the computed Trajectory Prediction to the accuracy of the various AOC parameters provided by airspace users and used in the computation of the Trajectory Prediction.

[1]Note that a validation objective can have more than 1 success criterion, please make them appear in the same cell

3.6.2.2 Summary of Exercise Results

The sensitivity of the Trajectory Prediction validated. The exercise is to determine the required accuracy of the AOC data to ensure that the TP accuracy benefits determined in exercise 0069.0100 are maintained. The comparison of the TP generated using reported AOC data versus TP generated using modified AOC reported data (i.e. adding or subtracting a percentage error). To do so, a part of exercises will be repeated while parameter values are deviated from their original values. Accuracy is subsequently analysed identically as performed in exercise 0069.0100.

The following summary presents the objectives and exercises results:

Validation Objective ID	Validation Objective Title	Success Criterion[2]	Exercise Results
OBJ-05.05.02-VALP-0010.0110	Validate that TP stability is not adversely affected by the introduction of AOC data.	A variation limit on the AOC parameters can be established that ensures accuracy equal or greater than the stability without AOC data.	The effect of modification introduced to reported AOC data investigated and stability of the ATC system using TP with AOC data validated.
OBJ-05.05.02-VALP-0010.0010	Validate that the accuracy of the TP improves considerably when AOC data is used as an information source.	The accuracy of a predicted trajectory is improved considerably when AOC data is used in the prediction when compared to the accuracy without the use of AOC data.	The accuracy improvement gained in EXE 0069.0100 maintained.

Table 7: EXE 0069.0200 Validation Objectives and exercises results

3.6.2.2.1 Results per KPA

Safety:

Using AOC mass and speed combined in the case of climbed aircraft brought significant improvement in the accuracy of the computed TP that should result in a reduction in missed and false conflict rates. To make sure this gained accuracy is maintained accuracy requirements to the reported AOC data plays a vital rule to ensure the outcome of the project and hence the safety of the proposed scheme.

3.6.3 EXE-05.05.02-VALP-0069.0400

3.6.3.1 Exercise Scope

The exercise scope and justification provided in the validation plan D02 Ref. [12], section 4.4.1 are summarised here.

“Level: The exercise is at ATM system level: It assesses the impact of ground TP trajectory prediction improvement on conflict detection decision support tools quality:

Conflict detection tools are using ground TP to assess the potential conflicts and provide the ATCO with conflict alerts. Due to the trajectory uncertainty, false conflicts (conflicts that are predicted but do not occur) and missed conflicts (conflicts that will occur but were not predicted) alerts are expected.

To get the maximum benefit (safety and efficiency) these missed and false alerts shall be minimised.

Using TP improved predictions can participate to this minimisation and lead to quick-win benefits, like the use of more continuous climb (CCD).

[2] Note that a validation objective can have more than 1 success criterion, please make them appear in the same cell

The main hypothesis is that both the rate of false and missed alarms are reduced thanks to the use of improved trajectory predictions (CRT-05.05.02-VALP-0030.0110). As a consequence, more continuous climb clearance can be used, leading to an efficiency improvement (CRT-05.05.02-VALP-0030.0120).

The following performance indicators will be used:

- Safety: Rate missed conflict alarms.
- Efficiency: Number of continuous climbs clearances. Rate of false alerts reduced.

The airspace of interest are ECAC, and the core area, above FL70 (TCT and MTCD[3] tools are not used at lower levels) as a high density airspace.

3.6.3.2 Summary of Exercise Results

Missed and false conflict alert rates due to TP errors in AOC cases are compared to the missed and false conflict alert rates with a baseline TP (no AOC data).

The following summary presents the upper-bounds of the performance benefits expected by using AOC data for conflict detection tools applications.

Validation Objective ID	Validation Objective Title	Success Criterion[4]	Exercise Results
OBJ-05.05.02-VALP-0020.0010	Validate that CDnR tool performance in a high density Area Control airspace improves in when the underlying TP is supported by AOC data.	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	There is a benefit in using AOC data for CDnR tool performance. Highest benefit is obtained by using AOC mass and speed data combined. See detailed objectives results below.
OBJ-05.05.02-VALP-0030.0110	Validate that improved TP accuracy achieved through the use of AOC data leads to improved operational performance when used in a CDnR system in for a Departure Controller	The rates of false and missed alerts of CDnR tool are reduced. (CRT-05.05.02-VALP-0030.0110) The number of continuous climbs available through the CDnR tool is increased. (CRT-05.05.02-VALP-0030.0120)	(ECAC and high density core area results are similar) Compared to performance without the use of AOC Data, Missed conflicts alert rates due to TP errors, reduces by 10% (look-ahead 8-18 minutes) using Mass and Speed AOC data combined, for conflicts with at least one aircraft in climb. The reduction is about 12% for look-ahead 5-8 minutes. Benefits for conflicts missed alerts cruise/cruise are small. False conflicts alert rates due to TP errors, reduces from 5% (cruise/cruise) to 10% (cruise/climb) (look-ahead 8-

[3] http://www.eurocontrol.int/fasti/public/standard_page/Tools.html

[4] Note that a validation objective can have more than 1 success criterion, please make them appear in the same cell

			18 minutes) using Mass and Speed AOC data combined, depending in conflict type. The reduction numbers are similar for look-ahead times 5-8 minutes. -The increase in continuous climb is related to the false alert rate reduction for conflicts (involving at least on aircraft in climb): The false alert rates decreasing by 10%, the rate of continuous climb stopped unnecessary due to a false alert will reduce at most by 10%.

Table 8: EXE 0069.0400 Validation Objectives and exercises results

3.6.3.2.1 Results per KPA

Efficiency:

It is assumed that, when receiving a conflict alert, involving at least one aircraft in climb, the ATCO will stop the climb. If this was a false alert (no conflict would have really occurred), an opportunity to climb continuously has been lost.

Rate of false conflict alerts due to TP errors, involving aircraft in climb, are improving by 10% for conflicts with one aircraft in climb (using AOC mass and speed combined), hence the rate of stopped continuous climb due to conflict alerts is reducing (at most) by 10%.

Safety:

Safety increases as missed (help ATCO in conflicts detection) and false rates (decrease WL) decrease. Using AOC mass and speed combined brought a reduction in missed and false conflict rates of about 10% (depends on conflict type, benefits usually higher when aircraft in climb are involved in the conflict.

3.6.4 EXE-05.05.02-VALP-0300.0100

3.6.4.1 Exercise Scope

This validation exercise addressed the concept of using AOC data in computing ground Trajectory Prediction.

This phase of validation was concerned with the introduction of various parameters and investigating the impact of each parameter on the accuracy and stability of the computed Trajectory Prediction and the overall performance of the system.

3.6.4.2 Summary of Exercise Results

Validation Objective ID	Validation Objective Title	Success Criterion[5]	Exercise Results
OBJ-05.05.02-VALP-	Validate that AOC parameter values outside their expected scope can be detected and data can be rejected on	Demonstrated that grossly incorrect values for AOC data parameters can be	Investigated during system test prior to simulation activity.

[5]Note that a validation objective can have more than 1 success criterion, please make them appear in the same cell

0040.0010	that basis.	detected.	
OBJ-05.05.02-VALP-0040.0020	Demonstrate possibility of using AOC data for a subset of flights in an operational system.	An operational system is demonstrated to use AOC data in a subset of the flights it handles	AOC data successfully applied for a subset of flights.
OBJ-05.05.02-VALP-0040.0210	Validate that TP system can be developed to accept all incoming data regardless of the presence of grossly incorrect values.	AOC data with grossly incorrect values is taken into the system. (Note that OBJ-05.05.02-VALP-0040.0010 prevents this data from subsequently being used)	Investigated during system test prior to simulation activity.
OBJ-05.05.02-VALP-0040.0310	Validate that a TP system can be developed that uses baseline functionality without use of AOC data when grossly incorrect AOC data is provided.	TP system generates usable trajectory based on the baseline algorithm for aircraft for which grossly incorrect AOC data is supplied.	Investigated during system test prior to simulation activity.
OBJ-05.05.02-VALP-0050.0110	Validate that AOC data can be used in current or near-term ATC tools that use trajectory prediction.	AOC data is used in a demonstration using current or near-term operational ATC tools.	AOC data successfully demonstrated in a near-term operational ATC toolset (iFACTS).
OBJ-05.05.02-VALP-0070.0010	Validate that ATC-system (iFACTS) able to receive and handle AOC data.	AOC data provided to iFACTS system that received it and demonstrated the ability to handle it.	AOC data successfully provided, received and handled by a near-term operational ATC toolset (iFACTS).

Table 9: EXE 0300.0100 Validation Objectives and exercises results

3.6.4.2.1 Results per KPA

The number of differences observed in interactions was limited and as such this validation exercise's results are difficult to report it per KPA.

3.7 Conclusions and recommendations

3.7.1 Conclusions

A number of activities took place to validate the use of mass and speed AOC data in computing TP. The V2 validation took place in three stages:

- Objective analysis through validation of Trajectory Prediction accuracy improvements.
- Subjective analysis through validation of ATC tools, e.g. iFACTS Conflict Detection and Resolution.
- Assessment of the impact of Trajectory Prediction improvement on conflict detection decision support tools quality.

For the climb phase of the flight all three activities came to the conclusion that the use of mass and speed AOC data gives the best improvements.

In details:

- From the objective analysis:

Using AOC mass and speed data in the computation of trajectory prediction brings the best results for the altitude error rate improvements. The results are statistically significant for the overall sample, which contains all aircraft range categories, as well as for each aircraft range category.

- From the subjective analysis:

The introduction of AOC mass and speed data into TP does produce noticeable differences in the information displayed in the TP/MTCD tools. These differences were most noticeable for aircraft in the climb phase.

- From statistical analysis:

The introduction of combination of mass and speed AOC data into the computation of the iFACTS TP took place. The associated TP errors for the traffic considered and the modelling of these errors to an ETFMS traffic sample leads to:

  - Brings safety benefit by reducing the missed and false conflict alert rates due to TP errors.
  - Brings an efficiency benefit as false alert rate due to TP errors improves: the number of continuous climb cancelled due to false alert rates is reduced.

In the case of using mass AOC data alone or speed AOC data alone for the climb phase still some benefits were observed but these were relatively less than when it is a combined mass and speed AOC data.

In the case of descent the results were much less conclusive whatever the sample size.

3.7.2 Recommendations

At V2 level, it is recommended to share AOC data for improving the performance of conflict detection tools. Sharing and using both AOC mass and speed in ground TP systems will bring the maximum benefit.

There is a relationship between this work and SESAR P 7.6.2. Both projects require and use similar set of AOC data. Collaboration between the two projects would help to consolidate the AOC data requirements and its use in improving the accuracy of computed TP.

It is recommended that the validation is continued at V3 level through exercise EXE-05.05.02-VALP-0301.0100 and the business case is developed further. The V3 Validation activities and results are reported in this report, see chapters: 4, 5, and 6.

4 Context of the V3 Validation

This section considers the validation of the concept of using operator flight planning data to enhance Air Traffic Management (ATM) services by improving Trajectory Predictor (TP) performance. This concept is described in Ref [11]. This validation stage followed stage V2 validation that is fully reported in D03 Ref.[13] and summary of it can be found in Chapter 4.

Since this is an early benefit, Step 1 project, no validation objectives from higher level projects have been set. The planned validation aims to determine benefits for higher level projects based on the benefit mechanism defined in D01 Ref. [11].

This validation follows the validation plan described in D02, Ref. [12]. D02 provides the validation plan for the concept of using operator flight planning data to improve trajectory predictions towards E-OCVM V2 and V3 Ref. [7].

4.1 Concept Overview

This project is focussed on the near-term use of operator flight planning data. For more details about the project and its objectives see 2.1.

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.

This validation activity building on the results from V2 validation activities aims to establish the actual benefits of the proposed additional flight plan parameters to operational applications of TP. This study demonstrates the concept on a near-operational system to validate the possibility of early implementation and gathered expert judgement on the effects on ATC tools. This demonstration and subjective validation used NATS' Replay-Aided Validation Environment (RAVE) system.

To establish the benefit to operations, the effect of the improved TP performance on actual operations was assessed. Detailed scenarios that evaluate the effect of TP improvements on controller tools by operational ATCOs were considered during this stage of validation.

One of the arguments that support early implementation is that the concept is expected to provide benefits even if not all operators are participating. The project validated this statement by analysing benefits for mixed equipage scenarios.

The costs of implementation and operation of the concept together with the expected benefits from introducing this concept forms another part of the V3 phase. The CBA task was addressed separately in collaboration with WP 16. The details of this activity are reported in Chapter 7.

EXE-05.05.02-VALP-0301.0100:	*EXE-05.05.02-VALP-0301.0100: aims to determine the effect of each AOC parameter on the accuracy of computed TP and the overall system performance*
Leading organization	National Air Traffic Services (NATS)
Validation exercise objectives	See D02 Ref. [12], Section 4.6.1.4.
Rationale	This activity determines the effect of each AOC parameter on the computed TP and the overall system performance.
Supporting DOD / Operational Scenario / Use Case	N/A
OI steps addressed	CM-0104 CM-0204 IS-0301
Enablers addressed	For details see D02 Ref. [12], Section 4.6.1.8.
Applicable Operational Context	For details see D02 Ref. [12], Section 4.6.1.2.

Expected results per KPA	See Section 6.3.3.
Validation Technique	See D02 Ref. [12], Section 4.6.1.8.
Dependent Validation Exercises	EXE-05.05.02-VALP-0069.0100 EXE-05.05.02-VALP-0300.0100

Table 10: EXE-0301.0100 Validation of the impact of using AOC data on TP and CDnR system

4.2 Summary of Validation Exercise/s

4.2.1 Summary of Expected Exercise/s outcomes

This section provides a summary of the expected outcomes of the validation exercises that are under the scope of this validation report.

Table 11 gives a summary of the expected validation exercises outcome per relevant stakeholder and in compliance with the project Ref. [9].

Stakeholder	Involvement	Expected Validation outcome
ATC Service Provider	End User	Evidence that the use of AOC data can be implemented on the general TP architecture of present day systems.
		Evidence that the implementation of AOC data can be done with minimum changes to the general TP architecture of present day systems.
		Evidence of improved performance of advanced tools and evidence that that will in turn lead to improved performance of the ATM system.
		Evidence that the concept of using AOC data and the expected improvement of TP accuracy does not adversely affect safety.
Airspace User	End User	Evidence that the generation and filing of flight planning data does not require high workload from operator flight planners.
		Evidence that sharing AOC data will lead to capacity, efficiency and environmental benefits to the operator.
		Evidence that these benefits outweigh the cost of implementation and operation of the concept.
		Evidence that commercially sensitive information is adequately protected against use for other purposes that ATM performance improvement.
		Evidence that the concept of using AOC data and the expected improvement of TP accuracy does not adversely affect safety while not putting excessive requirements on the operators.
ATC Tools Suppliers	Provider	Evidence that the use of AOC data can be implemented on the general TP architecture of present day systems.
		Evidence of considerable improvement of TP accuracy
CFPS Suppliers	Provider	Evidence that parameters required are generally available in CFPS

Table 11: Summary of expected validation exercises outcome

4.2.2 Benefit mechanisms investigated

This section covers two issues:

- Benefit to operations.
- Effects on safety.

4.2.2.1 Benefit to operations

The TP function is core to many ATC current tools. Improving the TP accuracy leads to performance improvements for ATC tools using TP, so the TP accuracy gain is a key to all other benefits. Trajectory predictions are only part of the inputs to an ATC tool. Effects of TP accuracy on the actual operation are therefore expected to be affected by other factors in the ATC tool. Furthermore, AOC data may improve the accuracy of some inputs to TP. Other inputs (for example wind prediction accuracy) may have a larger effect on accuracy.

Also, the AOC data itself will be subject to error. Any TP accuracy improvement has to be maintained under the expected AOC data error to be considered relevant.

So, the accuracy improvement has to be considerable before it can be expected to have noticeable effects on operation tools and hence operations.

The main objective of this validation is to test that such improvement of controller tools is expected to lead to operational benefits.

4.2.2.2 Effects on safety

Safety is the most single important factor in the acceptance of a new concept. Testing the effect on safety will take the following stages:

- The first factor that needs to be considered is whether the introduction of the AOC data as a new source of data could introduce its inherent errors.
- Secondly it is important to test and validate that the implementation of the concept will not lead to any reduction of safety.
- The third objective in this exercise is to test if the introduction of AOC data in computing trajectory prediction will lead to safety benefit.
- Fourth validation objective is to determine whether it is possible to detect grossly incorrect values. This supports the requirement to accept faulty data without endangering safety.

4.2.3 Summary of Validation Objectives and success criteria

Section 4.1 gives an overview to the validation exercises. The link to the high level objectives can be found in section 4.2.3.1. Note that some operational requirements related to the use of AMAN and performance improvements as defined in the concept document D01 Ref. [11] have not been validated statistically due to a relatively limited set of sample data for the arrival phase.

An overview of requirements coverage can be found in the validation plan document D02, Ref. [12].

4.2.3.1 Link to high level objectives

Step 1 Validation Targets for OFA 03.01.01: Trajectory Management Framework

- **ENV/FUEL EFF**: no target, but some benefit achieved. See Table 12 for details.
- **Airspace Capacity**: N/A
- **Airport Capacity**: no target
- **Predictability/Flight Duration Variability**: –0.12% (En route Variability and TMA departure variability. For AMAN part, it might have an impact but could not be evaluated.
- **Cost Effectiveness**: Direct link to capacity.
- **Safety**: Reduction of false and missed alerts By the TP not by the ATCO (he might often be able to detect that the CD&R tool didn't see the conflict) have been evaluated, but how these alerts translate into Mid-Air collision rates is not known.

From B4.1			5.5.2 Data Sources		
KPA	**KPI**	**5.5.2 Exercise Objective**	**V2 Validation**	**V3 Validation**	**Cost Benefit Analysis**
SAF1 ATM-related safety outcome	SAF11 O1 I1 Safety level: Accident probability per operation (flight) relative to the 2005 baseline	Validate that ATM system performance improvement through CDnR with no Adverse effects on safety	1.No adverse effect on safety. 2.Reduction in number of missed alerts by 10%.	During V3 validation ATCOs comments concluded that no adverse effect on safety	VOID. This KPI is not concerned with CBA.
ENV1 Environmental Sustainability Outcome ENV11 Atmospheric Effects ENV1111 Gaseous Emissions	ENV1111 O1 I1 **O1 I1:** Average fuel consumption per flight as a result of ATM improvements	Validate that Trajectory accuracy improvement that leads to improvement in average fuel consumption.			Assuming: 1.ECAC wide. 2.100% data sharing and usage. 3.Number of flights per year = 8 760 000 That leads to about 2 million kg fuel economy a year, This leads to an average fuel consumption reduction linked to level-off avoidance = 200g per flight.
	ENV1111 **O1 I2:** Average CO2 emission per flight as a result of ATM improvements	Validate that Trajectory accuracy improvement that leads to improvement in average CO2 emission.			Assuming: 100% data sharing and usage. There is an estimated reduction of 6100 metric tons of CO_2 a year. This leads to an average CO_2 emission reduction = 700g of CO_2
CAP2 Local airspace capacity	CAP2 O1 I1 Hourly number of IFR flights able to enter the airspace volume	Validate that ATM system performance improvement through CDnR Baseline operation without AOC data	Rate of conflict alerts due to TP errors reduced by 10% that would lead to capacity improvements.	With AOC data applied controllers expressed a preference in 12% of cases. That should lead to increase in the number of handled flights.	Assuming: 100% data sharing and usage. 300 false alerts avoided per day, (see Figure 10) that means 109500 conflict resolution actions avoided per year annually at ECAC level. The average conflict resolution time = 51 seconds. Expected impact on flight duration variability is assumed to be negligible, Calculation of controller workload reduction = 109500 avoided conflict resolutions x 51 seconds (Ref [18]) = 5584500 seconds saved. (93075 minutes or 1551 hours)
PRD1 Business trajectory predictability	PRD1112 Arrival punctuality	Validate that Trajectory accuracy improvement as a result of using AOC data.	Rate of conflict alerts due to TP errors improved by 10% that will improve continuous climb. Arrival punctuality is not concerned by the exercise anymore, as we couldn't do the AMAN evaluation. However, for the		

			concerned part of the trajectory where the project has an impact (i.e. more continuous climbs), the impact on timing is considered negligible.		
CEF1 ATM Cost Effectivenes s	CEF112 O1 I1 Total annual en route and terminal ANS cost in Europe, €/flight				As a result of improved TP, there is level-offs avoidance which translate into some money saving: Money saving per flight = (Total benefit – Total cost) / number of flights, since: Total cost = € 225,700.0 Total benefit = € 1503,386 Number of flights per year = 8760,000 Then: Benefit per flight = (1503386 – 225700) / 8760000 = € 0.146.

Table 12: Link to high-level objectives

4.2.3.2 Early benefit option

A key benefit to this concept is the possibility of early implementation, which is due to the limited changes required to current and near term systems (both ground and airborne). The concept will also provide benefits even if not all airspace users participate.

4.2.3.3 Choice of metrics and indicators

Metric / Indicator	Related SESAR Indicator	Justification
Time difference at point	Accuracy	Improved TP accuracy is the key for any system improvements.
Level difference at point	Accuracy	Improved TP accuracy is the key for any system improvements.
Number of missed/false alerts	Safety	Reduced number of missed and/or false alert should lead to safety improvements.

Table 13: Metrics and Indicators

4.2.4 Summary of Validation Scenarios

The validation scenario preparation was guided by the concept as described in D01 Ref [11] and the proposed validation plan D02 Ref. [12]. The concept of using AOC data in computation of ground TP is independent of the application that uses the computed TP.

The validation at ATC tools performance level will require an operation in which current or near-term TP-driven ATC tools are used. As an example of these tools we consider NATS iFACTS system. iFACTS is used in London Area Control centre. This area is consistent with the definition of SESAR TMA. The traffic in this area covered by London Area Control centre includes a large amount of climbs and descends.

The TP used in this system is considered representative for current or near-term TP systems in the TMA. Therefore the validation of ATC tool performance will be based on the iFACTS system.

Therefore, to drive this validation, a selection of operational days and sectors took place to ensure the traffic level and reasonable level of climb and descent flights that can be in the validation scenario.

Collected data that represent these scenarios formed a part of this activity, and Table 14 gives a summary of these scenarios. For full details see Appendix B, also AOC data provided by participating airlines played a role in setting-up these scenarios.

Sectors	Arguments	Time Interval
Brecon Region **Sectors:** LAC 5, 23 **Feeders:** 6, 36, 8, 3, 7, 9, TC Ockham, PC Wallasey, PC S29, Ireland FIR (via OLDI	The arguments to select this region are: ➢ These sectors have a significant amount of vertical change (in/out of LTMA to West, in/out of Manchester to South). ➢ The crossing at Brecon provides significant opportunity for interactions. ➢ Mixed fleet present (trans-Atlantic). ➢ With cooperation of various airlines that provided the validation activity with a broad range of flights. ➢ Relatively large arrival and departure peaks for heavy aircraft. ➢ Heavy aircraft arrival and departure peak not within the same interval. ➢ Vertical changes achieved by stepped procedures instead of continuous climb/descent. However, many aircraft do get further clearances before reaching level flight.	Time interval between 15:00 and 18:00 is selected which provides a good mix of supported types.
Dover Region **Sectors:** LAC 15, 16, 17 **Feeders:** TC BIG, TIMBA, 25, Paris/Reims FIR (via OLDI)	The arguments to select this region are: ➢ Sector 17 has long descents (delegated from France FIR) often 'when ready'. ➢ Lowest amount of sectors (3 + 3 feeders). ➢ Largest amount of SJU supported traffic into LTMA. ➢ NetJets (business jets) most likely to be represented. ➢ Regional aircraft best represented. ➢ With BA broadest variety of types/ranges in arrivals and departures at the same time. ➢ Strong variety of heavy use (by BA) ranging from 200 to 6000 nm	Time interval between 09:00 and 12:00 is selected which provides a good mix of supported types.

Table 14: Summary of proposed scenarios

4.2.5 Summary of Assumptions

In Chapter 6 validation exercises will be addressed in details including the assumptions for each exercise. However, the validation strategy is built on the results of the analysis of TP accuracy of the iFACTS TP algorithm based on recorded operational data (EXE-05.05.02-VALP-0069.0100) as detailed in D03 Ref. [13]. This introduces a number of assumptions that affect the complete validation:

- ➢ The iFACTS TP algorithm is a BADA based model similar to most of the current and near term TP algorithms. For this reason the iFACTS TP algorithm and its behaviour can be considered a representative for current and near term TP algorithms in general.
- ➢ The recorded accuracy of the iFACTS TP in the London Area airspace is representative of the accuracy of CDnR TMA TPs.

- The recorded dataset provides sufficient variation in fleet, operations, tactical instructions and meteorological effects to allow application of the results in general cases.
- The AOC data provided in a form that allows the use of such data without large pre-processing activities.

4.2.6 Choice of methods and techniques

Supported Metric / Indicator	Platform / Tool	Method or Technique
Safety	RAVE	Real Time Simulation
Efficiency	RAVE	Real Time Simulation

Table 15: Methods and Techniques

1

4.2.7 Validation Exercises List and dependencies

This section lists the validation exercises and dependencies. This can be summarized in the following diagram:

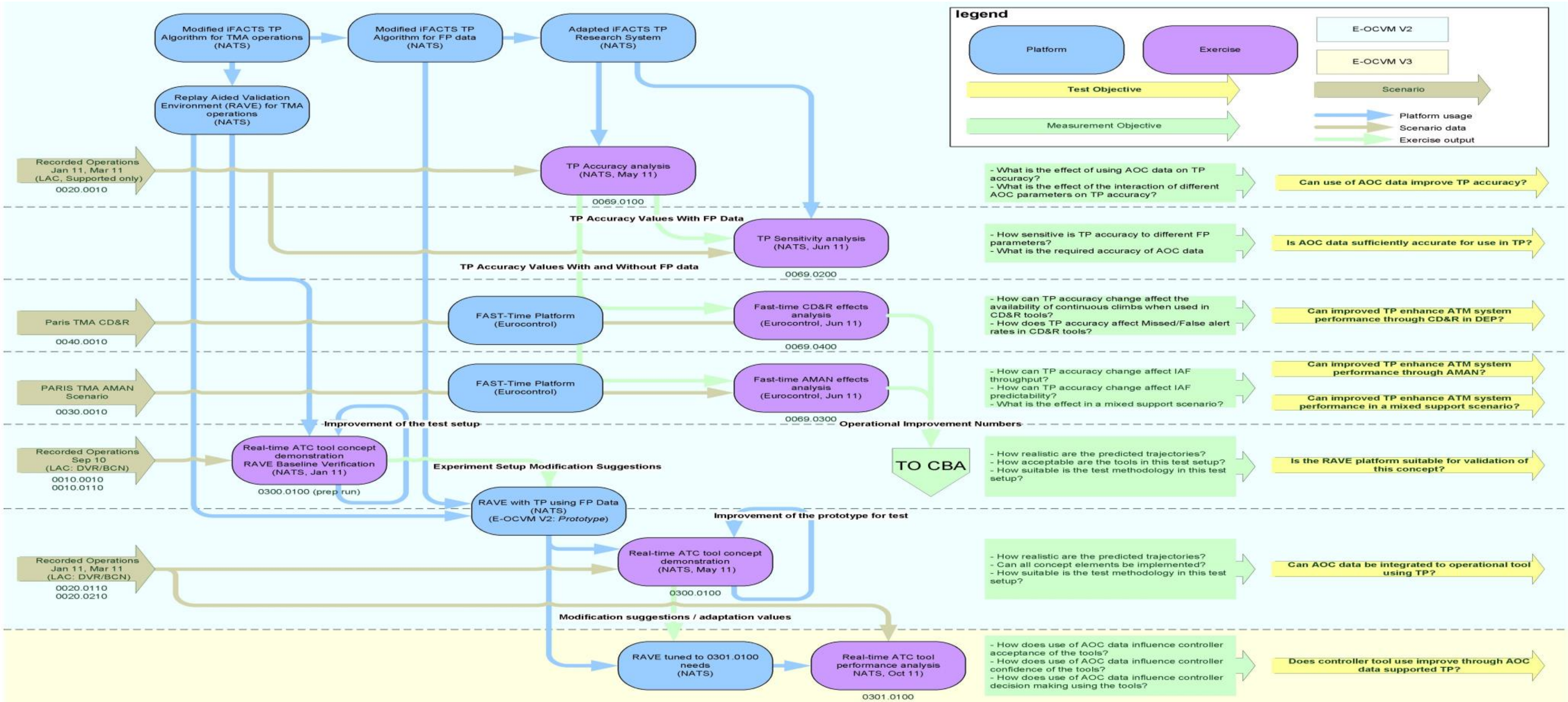

Figure 3: Validation Exercises List and dependencies

5 Conduct of V3 Validation Exercises

5.1 Exercises Preparation for EXE-05.05.02-VALP-0301.0100

This section covers the preparation of validation exercises considered in this report. All validation activities use NATS iFACTS model.

NATS iFACTS system provides the controller with an advanced set of support tools in order to reduce workload and so increase the amount of traffic he/she can comfortably handle. These tools are based on Trajectory Prediction (TP). iFACTS systems provide decision making support and facilitate the early detection of conflicts in and around the sector.

This validation exercise uses the NATS Replay-Aided Validation Environment (RAVE).

The NATS Replay-Aided Validation Environment (RAVE) replays recorded radar data with actual tactical instructions so that the near-term TP/MTCD ATC tools suite (iFACTS, as used in this exercise) thus receives exactly the same inputs as in normal operation. For more details regarding RAVE system see appendix D.3.

The preparation for this exercise consists of the following steps:

1. Select suitable date from live operation that contains appropriate level of traffic.
2. Collect various data types required to compute trajectory predictions that include: radar data, RT data, and metrological data.
3. Select all required data for the selected date above to test RAVE.
4. Collect the corresponding AOC data that is matching the selected date above.
5. Handle the collected data and perform some manipulation of the traffic sample collected for this such that individual aircraft radar tracks could be moved forward or backward in time, or to have their cruise level adjusted. This method allowed changes to be made to the traffic sample to ensure that a suitable and comprehensive range of interactions took place.

5.2 Exercises Execution

The following table gives a list of the validation exercise with its start and end execution dates as well as the corresponding dates for its analysis.

Exercise ID	Exercise Title	Actual Exercise execution start date	Actual Exercise execution end date	Actual Exercise start analysis date	Actual Exercise end date
EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	21/03/2011	11/11/2011	14/11/2011	01/02/2012

Table 16: Exercises execution/analysis dates

5.3 Deviations from the planned activities

This section provides a list and description for any changes or modifications to the validation plan Ref. [12]. The changes with respect to the content within the Validation Plan should be highlighted within each subsection. Any change (update/creation/deletion) in validation objectives, validation scenarios, validation requirements or in the validation exercises should be expressed in the same way as described in the validation plan.

In the following sub-sections these deviations to the validation strategy or/and validation plan will be covered.

5.3.1 Deviations with respect to the Validation Strategy

There is no deviation from the validation strategy as described in Ref. [12].

5.3.2 Deviations with respect to the Validation Plan

There is no deviation from the validation plan as described in Ref. [12].

6 V3 Validation Exercise Report: EXE-05.05.02-VALP-0301.0100

This section provides validation exercise report for exercise EXE-05.05-02-VALP-0301.0100. This report in accordance with the validation plan as described in Ref. [12].

6.1 Exercise Scope

This validation exercise addressed the concept of using AOC data in computing ground Trajectory Prediction.

This phase of validation was concerned with the introduction of various parameters and investigating the impact of each parameter on the accuracy and stability of the computed Trajectory Prediction and the overall performance of the system.

6.1.1 Exercise Level

This exercise covered both functionality and ground ATC system levels.

6.1.2 Description of the Operational concept being addressed

This validation exercise addressed the concept of using AOC data in computing ground Trajectory Prediction.

The following set of operational requirements was validated:

- REQ-05.05.02-OSED-0100.0100
- REQ-05.05.02-OSED-0100.0200
- REQ-05.05.02-OSED-0200.0100
- REQ-05.05.02-OSED-0200.0200
- REQ-05.05.02-OSED-0300.0100
- REQ-05.05.02-OSED-0300.0200
- REQ-05.05.02-OSED-0400.0000
- REQ-05.05.02-OSED-0400.0100
- REQ-05.05.02-OSED-0400.0200
- REQ-05.05.02-OSED-0400.0300
- REQ-05.05.02-OSED-0500.0100
- REQ-05.05.02-OSED-0500.0200

This phase of validation of the concept of the use of AOC data to improve Trajectory Prediction was a V3 activity.

6.2 Conduct of Validation Exercise

6.2.1 Exercise Preparation

The NATS Replay-Aided Validation Environment (RAVE) replays recorded radar data with actual tactical instructions so that the near-term TP/MTCD ATC tools suite (iFACTS, as used in this exercise) thus receives exactly the same inputs as in normal operation. For more details regarding RAVE system see Appendix D.3.

A suitable date was selected from live operations, same as described in Appendix C. A set of sectors was selected in the required airspace aiming to maximise the benefit from this exercise. For more details regarding the selected sectors see Appendix B.

Various data types on these selected days were recorded including radar data along with the accompanying RT. The RT was transcribed and converted into tactical HMI inputs to the NATS RAVE system. For more details regarding various data types required for this system see Appendix C.

The RAVE system uses UK NAS output for Flight Plans along with recorded MET data for the sample days supplied by the UK Met office.

The Airline Operational Control (AOC) data used in the validation was specific data supplied by the airlines contributed to this validation activity for each specific aircraft on that particular day. For more details regarding the data collected for this validation Appendix C.

The tools suite produced trajectories on the basis of the tactical instructions, supplemented by the AOC data as applied on a run by run basis. This enabled the trajectories to be compared against the flight profile for the aircraft actually flown on the day.

In this way each run of this exercise was entirely repeatable and facilitated direct comparison between different combinations of AOC data and to changes in uncertainty parameters of the trajectory prediction tools.

The collection of various data types followed by a data handling activity that allowed for some manipulation of the traffic sample such that individual aircraft radar tracks could be moved forward or backward in time, or to have their cruise level adjusted. The aircraft performance, climb & descent rates, speed, navigation etc. all remain identical and are unaffected by the adjustment process. The entire aircraft profile is moved in one piece. This method allowed changes to be made to the traffic sample to ensure that a suitable and comprehensive range of interactions took place in order to fully test the application of AOC data in a full range of interaction geometries and flight attitudes.

6.2.2 Exercise Execution

6.2.2.1 Introduction

This validation exercise is based on the successful conclusion of exercise EXE-05.05.02-VALP-0300.0100, full details for that exercise can be found in Ref. [13] .

During the validation activity the Real-Time simulation took place with the operation from two NATS operational controllers provided independent opinions for a scripted series of interactions involving a mixture of AOC supported and non-supported aircraft, in climb, level flight and descent.

The Real-Time validation activity was broken down into 8 runs using 3 traffic samples. Two of the traffic samples used the BCN scenario and the third was based on the DVR scenario. In each simulation run, 2 instances of the RAVE platform were used, on adjacent screens running simultaneously, one showing near-term TP/MTCD tools (iFACTS) with no additional AOC data, the other showing TP/MTCD tools with varied configurations of AOC data applied. During the Real-Time simulation the following validation objective was evaluated in detail:

OBJ-05.05.02-VALP-0020.0010

During the conduct of this validation exercise and results analysis phase we had to observe various security restrictions and conditions as indicated by the airlines supported the project and provided AOC data subject to these security restrictions.

6.2.2.2 Airspace

DVR and BCN scenarios were chosen as they covered a wide variety of flight and interaction geometries. Two NATS Swanwick AC controllers took part, one valid for DVR airspace, the other valid for BCN.

6.2.2.3 Traffic samples

Three traffic samples were used: one DVR and two BCN samples. The traffic samples were taken from recordings of radar and RT of actual traffic on two days: 21st January 2011 and 28th March 2011. The resulting samples had been reviewed by the Validation team in detail, initially identifying suitably busy periods, along with examination and logging of all of the interactions in terms of aircraft type, potential AOC equipage, relative climb/descent attitudes, navigational status and predicted closest approach distances.

As the samples were recordings of actual ATC the traffic was, as expected, separated. In order to establish a comprehensive range of interaction geometries and flight attitudes involving AOC supported and non-supported aircraft, some manipulation of the traffic samples took place. The entire flight profiles of a number of aircraft were adjusted, either by advancing or delaying the start time, or by moving it vertically.

Specific aircraft, and their resulting interactions, were carefully chosen such that any necessary alterations were kept to a minimum whilst stimulating the required geometries and attitudes of interactions.

In this manner a detailed script of interactions was formulated enabling the repeatable testing of a full range of interaction geometries and flight attitudes.

6.2.2.4 Scripts

The resulting scripted lists covered all possible combinations, i.e.: interactions between AOC supported and non-AOC supported aircraft, both supported, neither supported, climbing aircraft, descending aircraft, aircraft on their own navigation and those on headings. Care had been taken to ensure that closest approach distances (CAP) were realistic and meaningful to the participating controllers e.g. if the CAP of an interaction is within 5 miles (therefore classified as a Breached interaction) then a controller will have to act upon it immediately, irrespective of whether or not there is any variation due to the application of AOC data.

In this manner the two participating controllers were asked to independently assess the same interactions. Then, as the samples were repeated with different AOC data configurations, reassess the same interactions in a structured manner.

6.2.2.5 Simulation configuration

Two instances of each scenario were replayed simultaneously on 2 radar suites, side by side. For each run screen A was run in standard configuration utilising the near-term TP/MTCD ATC tools suite but without AOC data, while screen B, configured identically, displayed the various AOC and uncertainty configurations as and when applied.

The scenarios were run with the facility to be able to “pause” the playback at any desired point, allowing detailed examination of displays.

The attention of the participating controllers was drawn to each of the scripted interactions in turn and they were encouraged, by the validation observers, to select each flight and compare the presentation of the flight profiles and interaction details as displayed in the toolsets between the AOC and non-AOC screens.

The participants were asked to express their opinions in terms of the displayed urgency, severity and position for each interaction, on each of the 2 screens, and then to express any preference for either configuration A or B (or neither). These opinions were recorded on a standardised form along with any verbal comments.

The controllers were not informed as to which screen was displaying AOC data or of which interactions involved AOC-supported aircraft. In this sense, the exercise was conducted as a blind test.

In this manner it was therefore possible to record detailed controller opinions for a wide range of interactions of varying geometries and attitudes with varying AOC data configurations. Thus, as described below, detailed results were gained into which configurations of AOC data, uncertainty levels and flight attitude were the most useful in aiding controller’s ATC decision making.

6.2.3 Deviation from the planned activities

Reflecting the high level of experience with the iFACTS toolset demonstrated by the participating controllers during this workshop, it became apparent during first day of the activity that it was only when applying both mass and speed AOC data that sufficient difference was observed in the portrayal of the interactions for substantive preferences to be expressed. Thus during the second day the opportunity was taken to deviate from the planned exercise in order to explore a range of uncertainty levels in order to determine their significance.

Two further runs were added at the end of second day to explore error cases in support of OBJ-05.05.02-VALP-0040.0210, from the validation objectives of EXE-05.05.02-VALP-0300.0100.

6.3 Summary of Exercises Results

Here the results of the Validation Exercises that provides a summary. The summary is presented in the table below given as an example. This shows the summary of results compared to the success criteria identified within the Validation Plan Ref. [12]. The analysis should cover all the Validation Objectives embedded in all Validation Exercises as per the corresponding Validation Plan.

Exercise ID	Exercise Title	Validation Objective ID	Validation Objective Title	Success Criterion	Exercise Results
EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0020.0010	Validate that CDnR tool performance in high density Area Control airspace improves in when the underling TP is supported by AOC data.	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	Noticeable improvements in the performance of CDnR when the underlying TP is supported by AOC data.

Table 17: Summary of Validation Exercise Results

Validation Objective ID	Validation Objective Title	Success Criterion	Exercise Results
OBJ-05.05.02-VALP-0020.0010	Validate that CDnR tool performance in high density Area Control airspace improves in when the underling TP is supported by AOC data.	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	Noticeable improvements in the performance of CDnR when the underlying TP is supported by AOC data.
OBJ-05.05.02-VALP-0040.0210	Validate that TP system can be developed to accept all incoming data regardless of the presence of grossly incorrect values.	AOC data with grossly incorrect values is taken into the system. (Note that OBJ-05.05.02-VALP-0040.0010 prevents this data from subsequently being used)	The system successfully switched to current base line using the default BADA values.

Table 18: Validation Objectives and exercises results for EXE 0301.0100

For more detailed results from this validation activity, see Appendix E.

6.3.1 Summary of Objective Findings

With the same interaction probed on each of the two radar suites, differences in the displays of the TP/MTCD toolsets were apparent between the AOC supported presentation and the non-AOC supported.

Visually comparing the display of the MTCD tools, differences were often noted in the predicted positions of interactions, typically with small variations of the order of 1 or 2 miles in the predicted separation distance at closest approach point (CAP), or of 1 or 2 minutes of predicted time until CAP. There were also occasions when the classification (and associated colour) of an interaction differed between the two displays e.g. Not Assured (yellow) in one and Potential Breach (orange) in the other.

Similarly the application of AOC data was seen to have influenced the climb profile of some aircraft such that, typically, the climb rate was portrayed by the tools as having increased and the top-of-climb point achieved earlier. The same display also revealed the varied amounts of uncertainty applied run by run.

However, the differences as observed were frequently not considered to be of sufficient magnitude to have any impact upon the assessment of an interaction or on the ATC decision making process. On occasions, when the participants expressed a preference for one display over the other, that choice was almost exclusively for the more severe and, therefore, cautious interpretation.

A summary of subjective findings was compiled at the end of this exercise. These were confirmed by the participating controllers as correctly reflecting their opinions:

- Overall, a number of differences were observed in interactions between AOC and non-AOC supported flights.
- Those differences were predominantly for aircraft in the climb phase.
- Significant differences were only observed when both Mass and Speed data were applied, combined with reduced uncertainty.
- Improving only the nominal (and leaving the uncertainty unchanged) did not make a significant difference to the interactions
- Where differences were observed, whichever was the more cautious option was selected. This was due to:
    - Trust and confidence in the tools (limited at present as iFACTS is a new system).
    - The more cautious approach is more in line with current MOPs.
- Ability to issue different clearances not achieved with these changes due to above issues:
    - Requires trust and confidence in the tools
    - This is not present as it’s a new ATC system
- May also require changes to airspace and procedures to enable different clearances to be issued
- The application of incorrect AOC mass data did not adversely affect the performances of the TP/MTCD toolset.

6.3.2 Results on concept clarification

Not applicable.

6.3.3 Results per KPA

A number of differences were observed in interactions and it is reasonable to believe that the introduction of AOC data would improve both efficiency and safety of the system. Results are covered as presented per KPA in details in Table 12.

6.3.4 Results impacting regulation and standardisation initiatives

At the end of this project, and after the completion of V3 the information reported standards will need to be developed for the provision of AOC data to ensure both AOC/ATC interoperability and AOC data reliability this seems to be linked with work performed by P 7.6.2.

6.4 Analysis of Exercise Results

Validation Objective ID	Validation Objective Title	Success Criterion	Exercise Results	Validation Objective Analysis Status per Exercise
OBJ-05.05.02-VALP-0020.0010	Validate that CDnR tool performance in high density Area Control airspace improves in when the underling TP is supported by AOC data.	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	Noticeable improvements in the performance of CDnR when the underlying TP is supported by AOC data.	Success Criterion is achieved. OK
OBJ-05.05.02-VALP-0040.0210	Validate that TP system can be developed to accept all incoming data regardless of the presence of grossly incorrect values.	AOC data with grossly incorrect values is taken into the system. (Note that OBJ-05.05.02-VALP-0040.0010 prevents this data from subsequently being used)	The system successfully switched to current base line using the default BADA values.	Success Criterion is achieved. OK

Table 19: Validation Objectives Analysis Status in EX 0301.0100

6.4.1 Unexpected Behaviours/Results

The following unexpected behaviour was noticed during the exercises preparation:

The business jets aircraft category was included in the list of aircraft to consider but has been discarded due to the small sample collected. This might not be a problem as this category represents a pretty small segment of the European traffic (however, they might cause conflicts with different aircraft that is included in this study, which could be more complex to solve/detect by the ATCO and his CDnR tools).

6.5 Confidence in Results of Validation Exercise

6.5.1 Quality of Validation Exercise Results

This exercise used recordings of real operational scenarios with associated RT, flight plan and meteorological information on operational algorithms implemented on a validation platform. This was supplemented with specific AOC data obtained directly from a number of airlines.

A number of validation scenarios during workshops with the participation of operational ATCOs and the results are reported in this document. The report in this section considered the quality of the results for the validation exercises. For more details about the results and its quality see Appendix E.

The dual-suite configuration of the validation platform allowed for direct real time comparison between AOC supported and non-supported iterations simultaneously. The comprehensive script encompassed a comprehensive range of interactions for AOC supported aircraft in all attitudes and phases of flight.

6.5.1.1 Traffic samples

Despite minor manipulation of the traffic sample to engineer some specific scenarios, the majority of the traffic samples were unmodified recordings of real radar. Therefore, the traffic was already separated and many of the interactions no longer required ATC decisions to be made. Thus the small differences observed with AOC data applied made little impact on the controllers' opinion.

6.5.1.2 iFACTS specific considerations

This exercise was conducted using the iFACTS system in standard configuration and, as such, the results of this activity must necessarily reflect the requirements and limitations of iFACTS which, in turn, imposes some limitations as to the applicability of the AOC data.

In particular, during level flight iFACTS uses radar derived track ground speed. Therefore, it was not anticipated that the use of AOC speed data would have any effect upon the standard iFACTS trajectory prediction during this phase of flight. This was borne out during this exercise. In practise, iFACTS already used a more accurate data source in the (recorded) radar derived ground speed than in the AOC prediction of speed.

Similarly, when a descend-when-ready instruction is entered into iFACTS the aircraft's descent rate and uncertainty are calculated to coincide with either a fix or the sector boundary. For this reason the application of reduced uncertainty during the descent is over-ridden by the iFACTS level-by functionality.

Other applications of TP/MTCD tool technology may not have these same limitations and may therefore allow a different level of support of AOC data.

6.5.2 Significance of Validation Exercise Results

This validation activity used NATS' RAVE system as its validation environment with the use of AOC data collected from live flights. As such the significance of validation results can be summarised as follows:

Statistical significance: has been ensured during the exercise by controlling sample size versus the minimum effect to be detected.

Operational significance:

- AOC data used has been collected from live flights, hence is representative of real data in today's operations.
- Different aircraft categories were considered that make the reported results more representative to today's operations.
- The validation used NATS' RAVE system which uses live recorded data in computing TP which adds significant value to the results and CDnR assessment. However, it depends on current iFACTS implementation and results may vary with other implementation/operational tools.
- The participants to the workshops were validated operational controllers that add great significant to the observations and findings of this exercise.

6.6 Requirement Coverage

Ops. Req. ID	Ops. Req. Title	OI	Exercise ID	Exercise Title	Validation Objective ID	Validation Objective Title	Validation Objective Analysis Status per exercise	Validation Objective Analysis Status	Req. V&V Status
REQ-05.05.02-OSED-0100.0100	Airspace user data input.		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	OK	OK	OK
REQ-05.05.02-OSED-0100.0200	SWIM Processing		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis		Refer to SWIM			
REQ-05.05.02-OSED-0200.0100	AOC Data Acceptance		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0040.0210	Unconditional data acceptance	OK	OK	OK
REQ-05.05.02-OSED-0200.0200	AOC Data Verification		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	OK	OK	OK
REQ-05.05.02-OSED-0300.0100	Gross-Error data handling		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0040.0310	Correct fall back to baseline operation	OK	OK	OK
REQ-05.05.02-OSED-	ATC-system Internal Reporting		EXE-05.05.02-VALP-	Real-time ATC tool performance	OBJ-05.05.02-VALP-	Correct fall back to baseline	OK	OK	OK

0300.0200			0301.0100	analysis	0040.0310	operation			
REQ-05.05.02-OSED-0400.0000	Mixed Mode Functionality		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode	OK	OK	OK
REQ-05.05.02-OSED-0400.0100	AOC data not available		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0040.0020	Baseline operation without AOC data	OK	OK	OK
REQ-05.05.02-OSED-0400.0200	AOC data available		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0060.0010	Demonstrate use of AOC data in TP in operational system.	OK	OK	OK
REQ-05.05.02-OSED-0400.0300	ATC-system ability to switch between two options.		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode	OK	OK	OK
REQ-05.05.02-OSED-0500.0100	Data access time restriction mechanism		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis		Refer to SWIM			
REQ-05.05.02-OSED-0500.0200	Data access authorisation mechanism		EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis		Refer to SWIM			

Table 20: Requirements Coverage Synthesis

6.7 Overview of Validation Objectives Status for P 05.05.02

Coverage of the overview of validation objectives status for P 05.05.02 can be found in Appendix I.

6.8 Conclusions and recommendations

6.8.1 Conclusions

Through analysis of the subjective feedback, comments received and the comparisons detailed in Appendix E Table 34, Table 35 and Table 36 the introduction of AOC mass and speed data into TP does produce noticeable differences in the information displayed in the TP/MTCD tools. These differences were most noticeable for aircraft in the climb phase of flight, but some differences were also noted for aircraft in the descent.

The most noticeable differences is when AOC mass and speed data are used together while the least noticeable difference when AOC speed data is used alone.

It should be noted that in the majority of cases the introduction of AOC data did produce a noticeable difference in the display of interactions and trajectories. However, during this exercise, the conditions under which the differences were sufficient for the controllers to express a preference were limited to interactions involving climbing aircraft along with the application of both Mass and Speed data combined with reduced uncertainty. Under these circumstances, preferences were expressed for up to 30% of cases.

The system was robust to the application of incorrect AOC mass data. No preferences or inconsistencies were reported by the controllers under these conditions.

6.8.2 Recommendations

It is recommended to share AOC data for improving the performance of conflict detection tools.

The participant's controllers both suggested that traffic samples taken from busier times of the day would be of benefit.

It was observed that the controllers would take considerably less notice of an interaction predicted to be more than 10 miles apart and more than 10 minutes in the future, compared to a prediction around or below the 8 mile line. It is recommended that traffic samples for future activities should be engineered to include a high proportion of interactions within the range of 5-8 miles and 5-10 minutes. These would be interactions to which the controllers would need to take action and would also potentially show more critical differences between systems supported with AOC data and unsupported ones.

A range of levels of uncertainty were applied along with Mass & Speed AOC data and the results varied accordingly. Varied levels of uncertainty should be applied to non-AOC runs in order to prove that the differences noted were due to the application of AOC data.

7 Cost Benefit Analysis Methodology

7.1 Introduction

This section covers the Cost Benefit Analysis (CBA) performed for the concept of using Airline Flight Plan Information into Air Traffic Control (ATC) Trajectory Prediction (TP) Tools.

This study is based on the work that took place during project 05.05.02 in which the impact of the use of different airline flight planning parameters in improving the accuracy of ground trajectory prediction were investigated and validated. Take-off aircraft mass and speed profile were considered as the most interesting parameters.

Benefits when these two parameters are used in ground TP system are:

1. Fewer assumptions used to predict the trajectories.
2. Smaller uncertainties in the predicted trajectories.
3. More stable trajectory predictions.
4. More accurate trajectory predictions.

Due to data availability only the departure phase is considered in this Cost Benefit Analysis study, so the study considers only prediction improvement for climbing aircraft.

The computation of a more accurate trajectory prediction allowed the reduction of the trajectory prediction uncertainty. Figure 4 and Figure 5 show the impact of reducing trajectory prediction uncertainty. This reduced uncertainty buffer would provide benefits in the ATC system as controller tools would identify fewer false conflict alerts as well as there being fewer missed conflicts. Since false conflict alerts cause additional controller workload as the controller has to assess all conflict alerts and decide what action to take, so fewer false alerts would mean less unnecessary assessment and action but the project could not assessed this assumption due to lack of time. Also for the missed conflicts the controller has to resolve the conflict in a shorter time frame once it is identified.

Also from Figure 4 and Figure 5 the reduction of trajectory uncertainty would allow more continuous climb departures.

These improvements impact on the ATC system and translate into benefits for both the airlines and ANSPs because if there are fewer false conflict alerts then controllers will not need to resolve them, so the aircraft trajectories will not be impacted (e.g. via a level-off).

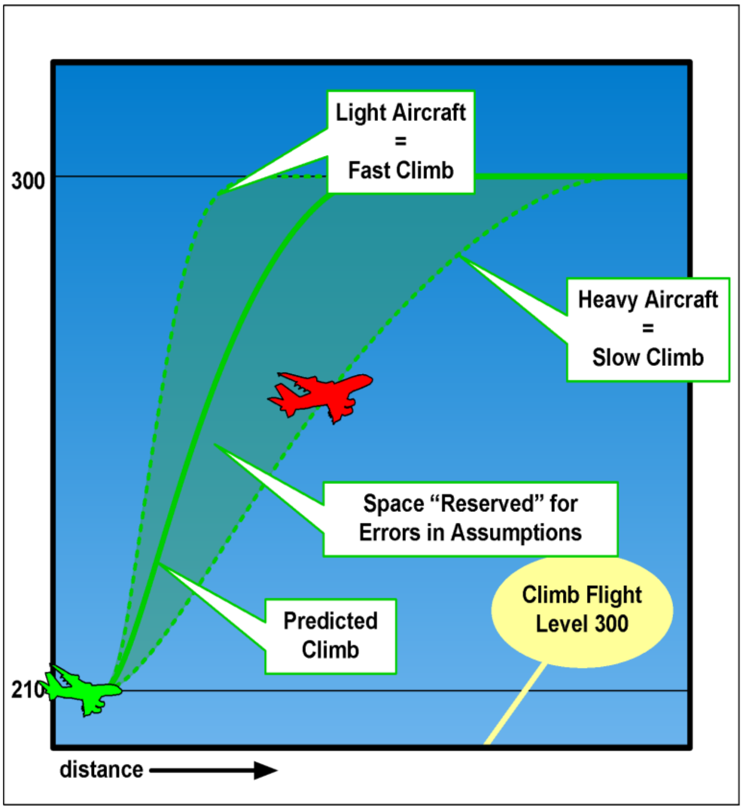

Figure 4 : Trajectory prediction and uncertainty zone, without AOC data

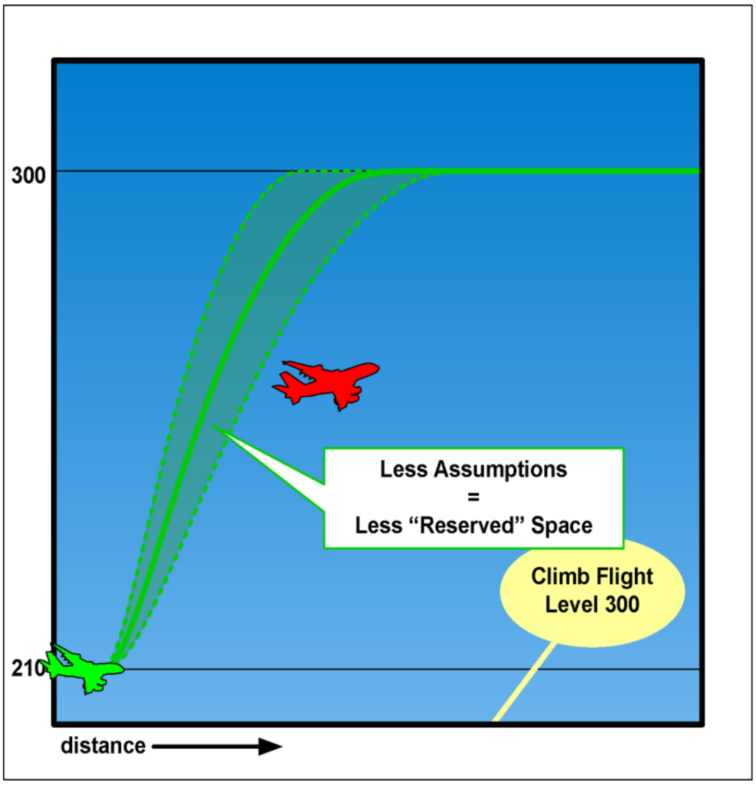

Figure 5 : Trajectory prediction and uncertainty zone, with AOC data (Mass & speed)

From the validation report (D03) Ref. [13], the main findings from the conflict detection model were that at ECAC and core area scale for the use of AOC Mass and speed information versus the use of current default values from BADA model for ground TP calculations there is:

- About 10% reduction in medium term conflict detection (for 5-8 minutes look-ahead before conflict) false alerts for climb/cruise conflicts.
- A similar reduction (about 10%) observed on climb/climb conflict alerts.
- No benefits in cruise phase (as expected).
- Likelihood that there are some benefits associated to the descent phase, linked to improved arrival management, but this could not be assessed during the validation due to lack of suitable data.

If the project was implemented, these operational benefits could translate into ATC benefits (e.g. workload reduction, safety improvement) and Airline benefits (e.g. fuel economy), while its implementation will imply some costs (e.g. AOC data communication, ground TP software update). This CBA has been performed to assess the cost and benefit elements.

This CBA is looking at the near term situation where the airline would be providing the data directly to an ANSP in an ad-hoc fashion via bilateral agreements. It assumes that the same ANSP is managing both the TMA and the En-route sectors where the climb/cruise conflict would occur.

In the longer term this data could be provided via SWIM and the additional AOC data items could be provided by the airline to the Network Manager (NM) and then distributed to the relevant ANSPs (this link is being investigated in P 07.06.02 Business/Mission Trajectory Management).

7.2 Cost Benefit Analysis Objective

The Cost and Benefit Analysis objective is to achieve consensus and clarity in answering the following questions:

1. What is the economic value of the project?
2. What are the uncertainties and the risks associated to the decision?
3. According to the project evaluation what is the reasonable decision that could/should be taken?

For this project (P 05.05.02) the specific objective is to identify if this quick win project should be recommended for wide deployment. The results will feed the 'Go/No Go' decision to move from R&D to industrialisation (i.e. move from E-OCVM V3 phase to V4 phase, [7]).

To help answer these questions, information and data have been collected with regard to the following scoping topics:

- Relevant population impacted by the project
- Relevant alternatives to be considered
- Relevant evaluation of the project.

As detailed in Section 7.3, the CBA study has followed EMOSIA, EUROCONTROL's approach to CBA. EMOSIA standing for European Models for ATM Strategic Investment Analysis, see Ref. [14] is a comprehensive methodology developed by EUROCONTROL, designed for the European ATM/CNS community, aiming at producing informed decision-making on ATM investments. This approach was used and recommended during the SESAR definition phase.

7.3 Cost Benefit Analysis Methodology

Seeking stakeholder's ownership is preferred to stakeholder's buy-in, through "Scrum[6]" participant-driven meetings aimed at obtaining quick wins or results that can be further refined and detailed whenever necessary with a controlled number of iterations.

Two one-day workshops were necessary to complete the tasks and fulfil the objective for P 05.05.02 Cost Benefit Analysis.

Table 21 shows who attended each one.

Company	Workshop 1 (29 Jan 12)	Workshop 2 (01 March 12)
NATS	X	X
Flybe	X	
NOVAIR	X	X
BA		X
LIDO		X
ECTL	X	X

Table 21: Workshop Attendees

After presenting the CBA approach, the first workshop was devoted to:

- Framing the decision problem.
- Defining and understanding the problem solved by the project.
- Collecting information (namely the project documentation consisting of two documents: the project description, D01 [11] and the project validation D02 [12]) and data.
- Structuring the alternatives to be considered.
- Identifying main stakeholders.
- Identifying the main assumptions.
- Identifying the decision risks and uncertainties.

This one-day workshop ended up with a first draft of a conceptual model for each of the main stakeholders (ANSPs and airlines).

Using these inputs and through an exchange with the first workshop's participants, the CBA team divided into two sub-groups. One team developed the models, while the other audited and challenged the developments. This resulted in draft versions of the two models:

- One model, called the 'ANSP Model' is a conceptual model eliciting the benefit mechanisms from a service provider perspective; indeed, the benefits being difficult to quantify are nevertheless qualitatively proven; this conceptual model is detailed in section 7.4.

[6] In Scrum, projects are divided into succinct work cadences, known as sprints, which are typically one week, two weeks, or three weeks in duration. At the end of each sprint, stakeholders and team members meet to assess the progress of a project and plan its next steps. This allows a project's direction to be adjusted or reoriented based on completed work, not speculation or predictions.

- The other model, called the 'Airlines Model', is a quantitative analysis, using the Excel spread sheet software, from an airline perspective; a top-down version of the model calculates the cost and benefits at the ECAC level; a bottom-up version makes it possible for a specific airline to input its own data (number of yearly flights split into three types of aircraft: Regional, Single Aisle, and Twin Aisle) and calculate its potential Net Present Value (see 'relevant evaluation' paragraph below Ref. [15] for more details on NPV) and Benefit to Cost Ratio accruing from the project, this model is detailed in section 7.5.

The relevant population was set to three stakeholder segments:

- Airlines in general (regional, low-cost, flag carriers, cargo, charters).
- ATC service providers operating in TMAs.
- General public through environmental considerations and calculations contained in the airlines model.

The 'Airlines Model' is not at the moment calibrated for airspace users other than airlines because none of these stakeholder segments (General aviation, Business aviation, Military) attended the workshops. Nevertheless the model could be calibrated for these kinds of airspace users.

The relevant alternatives considered in the CBA are:
1. Business as usual (or do-nothing scenario): the current situation without precise data on mass and speed in the Trajectory Prediction continues
2. Investment in Trajectory Prediction accuracy by providing more precise mass and speed data

The relevant evaluation has been limited to two indicators:
1. The Net Present Value, where the difference between the benefits and costs is discounted to calculate today's value of the project.
2. The Benefit to Cost Ratio, giving the reward of the project per money unit spent.

All monetary values are in Euro (€); the time horizon is set to 5 years in the simulations but can be entered as an input; the discount rate used is 8% to represent the cost of capital of an airline.

The two models were presented, discussed, challenged and updated during the second one-day workshop.

During this workshop the CBA team carefully distinguished between three actions:

- **Verification:** consisting of verifying the model is mathematically and logically consistent through a standard set of tests ensuring that frequent usual errors have been avoided; obviously this operation cannot guarantee the model is error-free but does guarantee that a minimum of quality checks has been undertaken

- **Calibration:** giving the scope of the model validity; at the moment the model is calibrated for the airlines segment of the airspace users; calibrating the model for another kind of airspace user is possible but would require changes to the set of data inputs and the assumptions in the model

- **Validation:** consisting of the stakeholders using the model with their own data and checking with independent sets of experimental data that the model predictions conform to these experimental data

7.4 ANSP View

During the first CBA workshop, an initial cost/benefits qualitative model was devised for the ANSP, it focussed on measuring improvements compared to the current situation. After the workshop questionnaires were sent to the participants to try and get data to quantify ANSP benefits, however too few elements were obtained to actually build a quantitative model.

The CBA team reviewed and updated the conceptual models and then presented them during the second workshop (Figure 6 to Figure 9).

Remark: Some ANSP costs elements (e.g. ANSP ground TP software update) are included in the Airlines model (see section 7.5) due to the current cost recovery model.

7.4.1 Qualitative Model Description

Two main ANSP actors were listed as getting benefits thanks to the AOC data sharing: the flow management position & air traffic controllers.

For each actor, two conceptual models are proposed:

1. A “current situation” model showing the negative impact events chain (orange coloured) from ground TP inaccuracy to the relevant key performance areas (hexagonal shapes).
2. A “future situation” model showing the benefits events chain (blue coloured) counteracting the negative impacts presented in the previous model (from AOC data usage to the same key performance area identified in the previous model). Remark: light blue coloured cells contain some quantification coming from the validation report.

In summary:

- For the flow management position Figure 6 and Figure 7, ground Trajectory Prediction improvement will help improve flow management decisions (e.g. opening/closing sectors, regulations) leading to improved environment and economic cost effectiveness.
- For the controller (planning & executive) see Figure 8 and Figure 9, ground Trajectory Prediction improvements will lead to improved medium term detection conflicts alerts (i.e. less false and missed alerts). Reduction in false alerts and lower missed alert rates will lead to benefits in safety and effectiveness (workload and safety incidents reduction). The workload reduction will also lead to an improved planning/executive controller’s productivity providing improved financial cost effectiveness and have its impact on safety (less risk of work overload).

7.4.1.1 Flow Management Position (FMP) models

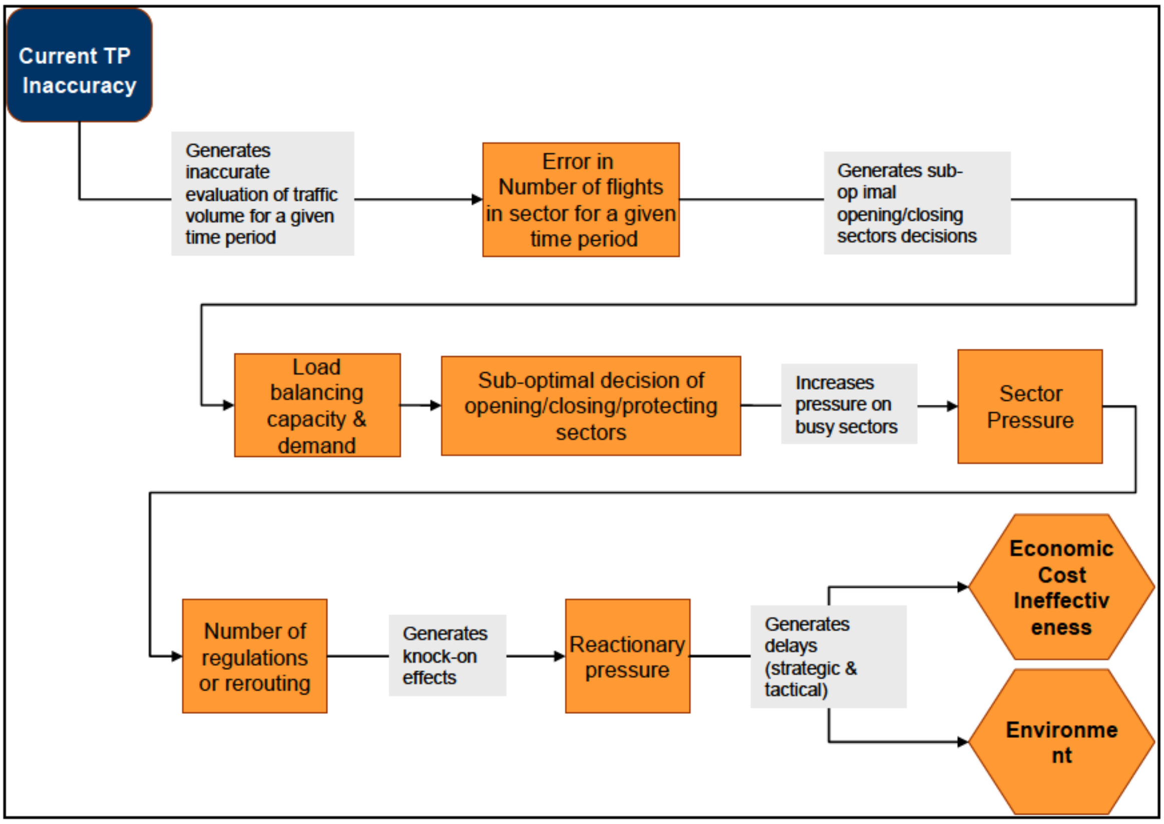

Figure 6: Current situation - Flow Management Position (FMP)

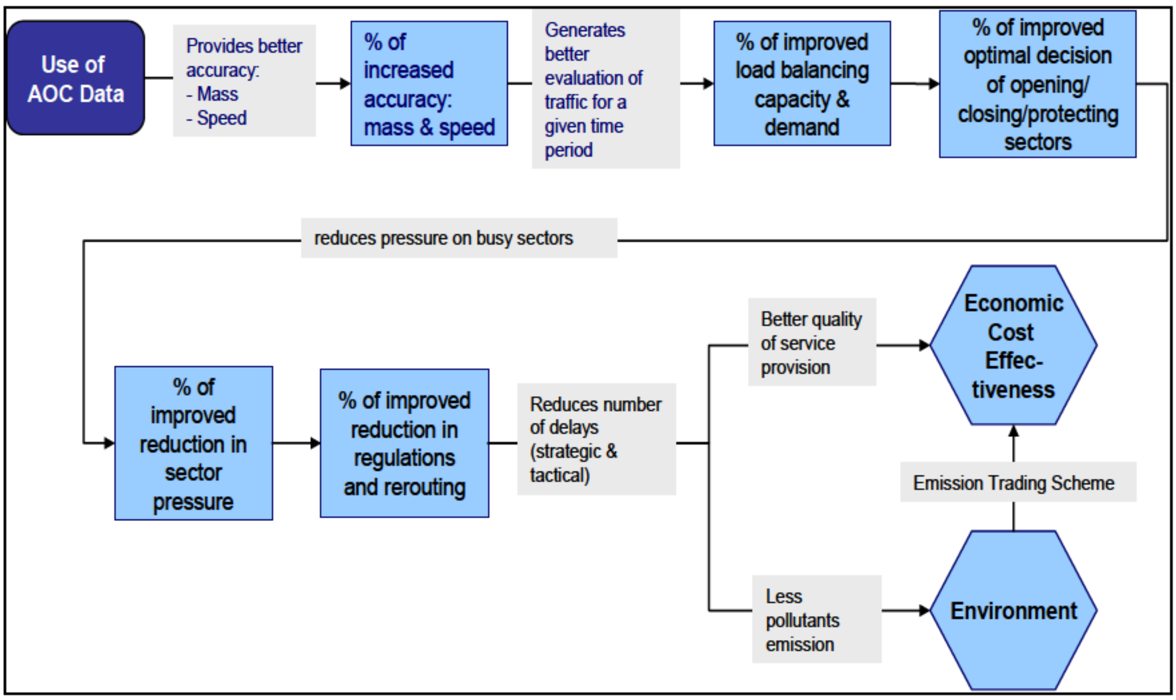

Figure 7: Future Situation - Flow Management Position (FMP)

7.4.1.2 Controller models

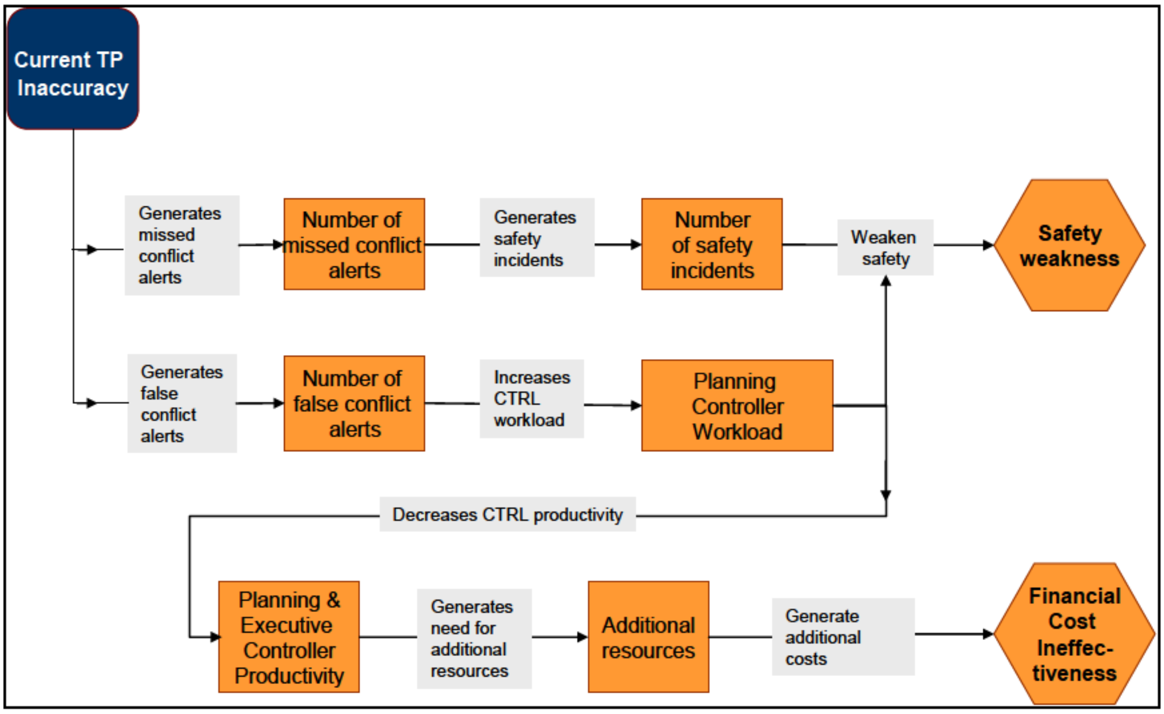

Figure 8: Current situation – Controller

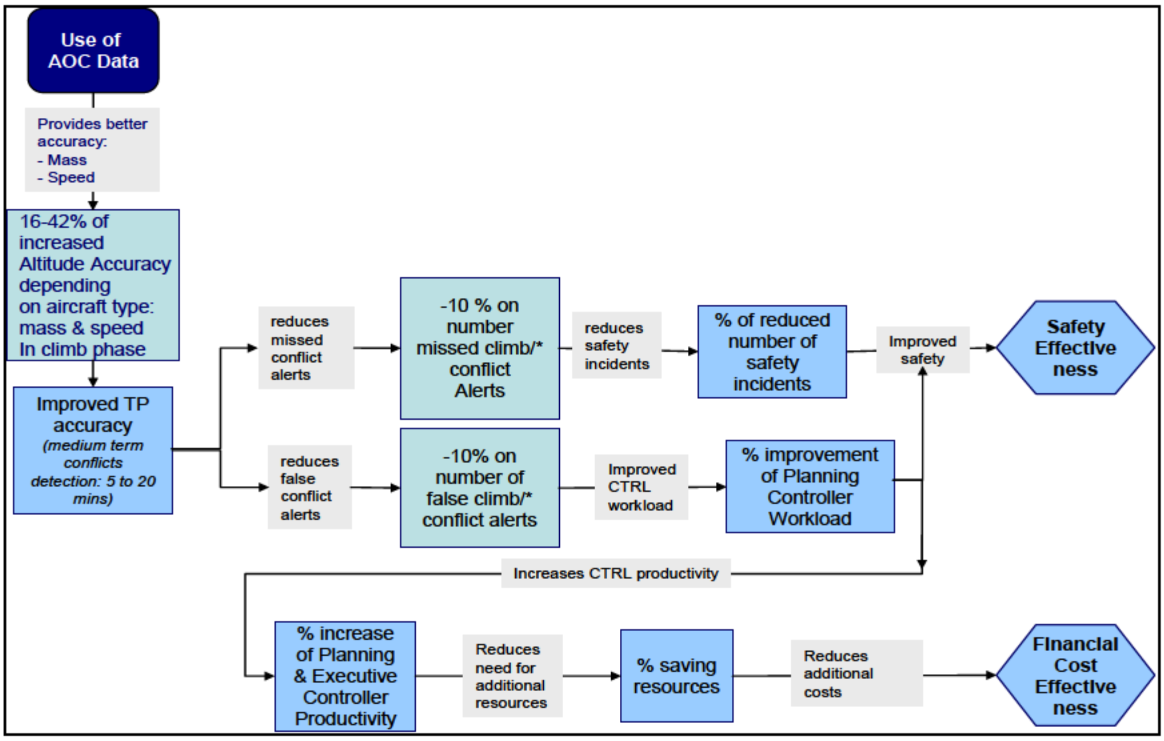

Figure 9: Future Situation - Controller

7.5 Airlines View

During the first CBA workshop, an initial cost/benefits qualitative model was devised for the Airlines. The main airline benefit focussed on improved flight profiles due to aircraft not having to level-off due to controller actions resulting from a false conflict alert. The main benefit would be reduced fuel burn, although smaller benefits linked to flight duration and mechanical stress were also identified. These smaller benefits have not been quantified in the Airlines Model.

The main cost for the airlines would be in providing the AOC take-off aircraft mass and speed profile data to the ANSP handling the departure.

After the first workshop the CBA team developed the following lottery approach diagrams, Figure 10 and Figure 11, to quantify the reduced occurrence of level-off benefits. The data and logic in these diagrams was used to develop the Airlines Model within Excel. An overview of the development process is described in section 7.3.

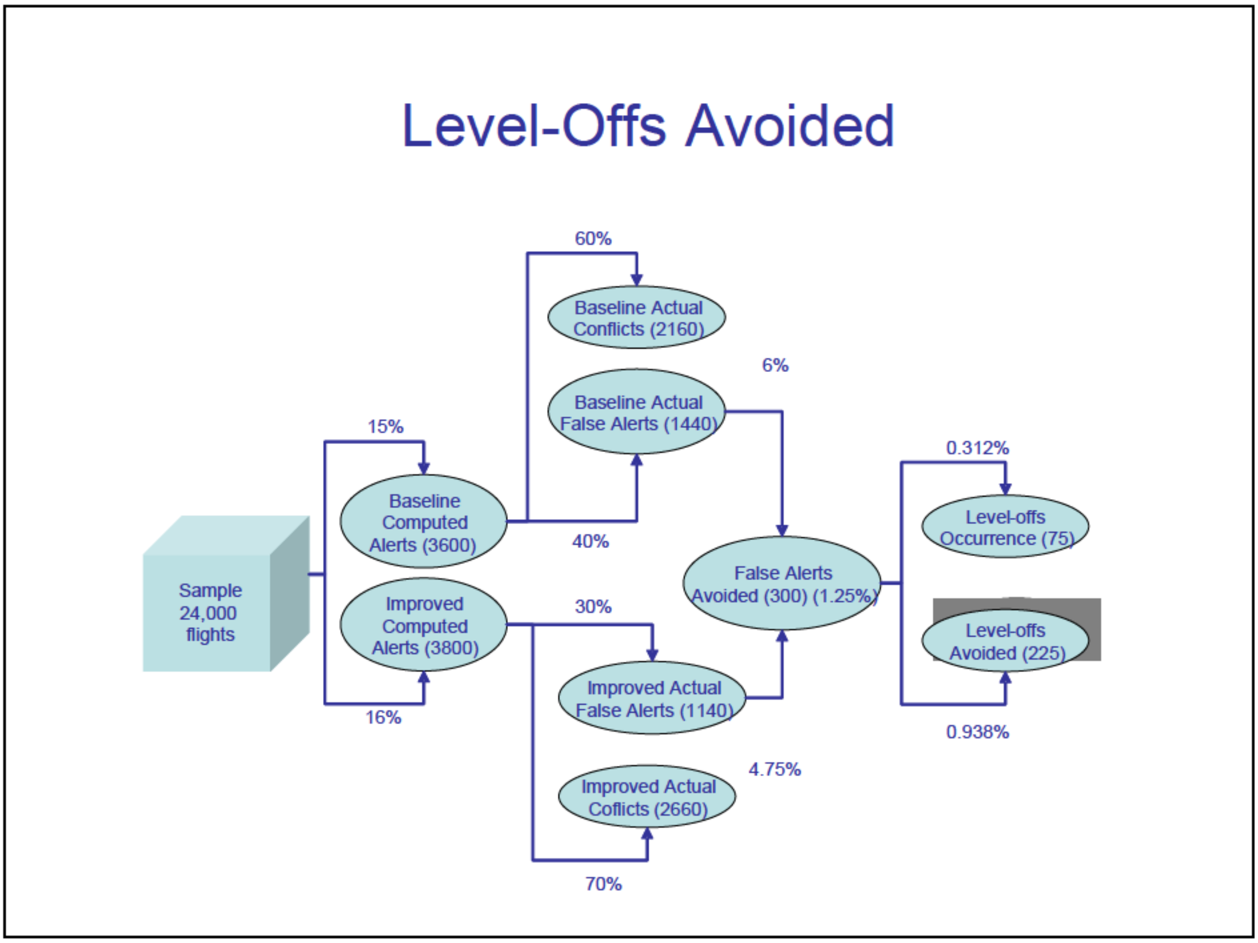

Figure 10: Identifying the number of level-offs that could be avoided (at ECAC level) using Validation results

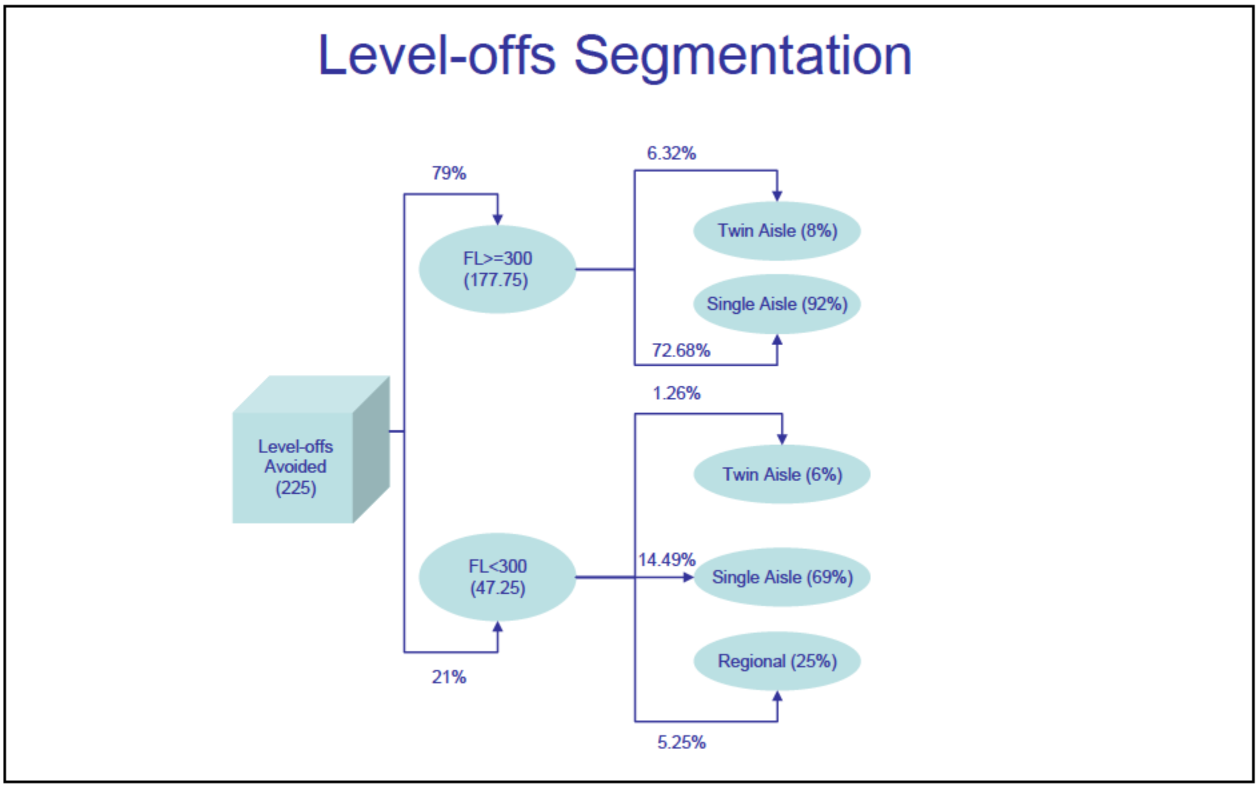

Figure 11: Breakdown of level-offs avoided by flight level and types of aircraft

The Airline Model and its results were presented at the second CBA workshop. Following participant inputs the software development costs (see section 7.5.2) and the percentage of airlines sharing their data were updated (see sections 7.5.1 and 8.4.2).

7.5.1 Benefit Assumptions

The benefits side of the Airline Model is based on the following assumptions:

- Benefits only come from climb/cruise conflicts; climb/climb conflicts alerts were ignored as they are rarely solved using level-offs and the associated benefit is difficult to assess.
- All airlines participate and share the mass & speed information (before take-off), i.e. 100% flight data sharing.
- This assumption was considered overly optimistic in the second CBA workshop and the model was updated to allow variable participation rates (see section 8.4.2).
- Level-offs avoided below FL 300 assumes a level-off avoided distribution (i.e. of climb/cruise conflicts) similar in each aircraft type proportion as for the global traffic. Level-offs avoided at FL 300 & above assumes that regional flights are not included as these aircraft types are usually not capable of reaching those altitudes.

Full details of the model parameters that are used to calculate the benefits in the Airlines Model can be found in Table 37, Table 38, Table 39 and Table 40 in Appendix F.

7.5.2 Cost Assumptions

As ANSP costs are generally charged to the airlines via cost recovery they are included in the Airline Model.

The main costs that were considered are:

- **Flight plan (FPL) transmission costs:** these are based on an increase of 10% of a typical FPL SITA message size to provide mass & speed information from about 250 characters to about 275; i.e. 0.075*10% = € 0.0075 per flight plan. It is assumed that the flight plan transmissions are sent to the ANSP where the departure will take place. These costs have hence been counted once, this assumes that any level-off would be avoided within the En-route sectors of the same ANSP that received the AOC data (with the current ad-hoc data sharing it is assumed that another ANSP would not have access to the AOC data sent to the departure ANSP).
- **Software development costs:** these represent the necessary investment by the main ground system suppliers on their platforms as well as costs for ANSPs who develop their own ground systems to use the additional AOC data. This includes also adaptation of industry developments for different ANSP platform specificities. These costs, which relate to the development from scratch for a single system to be able to use the AOC data, represent the expected development costs and not the price at which industry would sell such modifications. The cost for one development is estimated at 1 full time equivalent (FTE) calculated as follows: 200 w.d. at 400€/day. This was multiplied by 10 to represent the main ground system suppliers and ANSPs who develop their own ground systems.
- **Depreciation:** the accounting period in years for a given asset (e.g. updated ground system using AOC data) used in deriving the amortisation of investment expenditure is set to 5 years [16].
- **Discount rate** is the annual rate used to discount a stream of cash flows in order to calculate their Net Present Value (NPV). The rate of 8% currently used by some major airlines and ANSPs has been applied.
- **Environmental costs** which in fact would be a benefit for the airlines as tradable EU Allowance permits have been considered due to less fuel consumption (see section 8.3).

Remark: Costs for updating Flight Planning systems are considered negligible and are not included.

The cost inputs to the CBA model are included in Table 40 in Appendix F.

8 Cost Benefit Analysis Results

8.1 ANSP Cost Benefit Analysis Results

8.1.1 ANSP Benefits

Although not quantified the ANSP benefits deserve attention and consideration. They are twofold:

- A Safety benefit due to a reduction in the number of missed conflicts. A missed conflict results in the controller becoming aware of a conflict later than usual and having less time to react as well as a more limited set of resolution options available to them. In the worst case this can result in a loss of separation, in any case it increases controller workload. Therefore reducing the number of missed conflicts provides a safety benefit and a benefit avoiding increased controller workload. There is also a knock-on effect that avoiding safety incidents also saves the costs associated with investigating them.
- Controller workload reduction because the improved trajectory predictions will reduce the number of false alerts that controllers receive, so they will perform fewer unnecessary actions. This should result in controllers having an increased confidence in the controller tools. Also that could lead to potential increase in sector capacity which benefits both ANSP and airlines.

These benefits have been acknowledged by the CBA working group.

8.1.2 ANSP Costs

Cost for software development is estimated at 1 FTE per industry ground supplier plus ANSPs who develop their own ground system (where these costs represent the expected development costs and not the price at which industry would sell such modifications). These costs are included in the Airline CBA model due to the current cost recovery model.

Other costs such as software maintenance, training etc. are considered to be sufficiently small that they would be covered by current planned budgets.

8.2 Airline Cost Benefit Analysis Results

In the following tables 4 different cases are considered (each assuming 100% data sharing):

- A so-called typical “main Airline” with 381,790 flights per year made by a fleet of regional aircraft (flying 5 legs a day), single aisle aircraft (flying 4 legs a day), and twin aisle aircraft (flying 2 legs a day); for such an airline the NPV is €287,739 after 5 years and the B/C is 7.8.
- A so-called typical “low-cost Airline” with 527,425 flights per year with just a fleet of single aisle (flying 5 legs a day); the NPV is €421,972 after 5 years with a B/C of 8.2.
- A so-called typical “regional Airline” with 141,229 flights per year (flying 5 legs a day); the NPV is negative, -€9,643 after 5 years with a B/C of 0.4 because the cost of transmitting the data is greater than the benefits of level-offs avoidance.
- The ECAC data set with 8,760,000 flights per year gives an NPV of €5,509,545 and a B/C of 6.7.

Based on the assumptions described in section 7.5, a positive Benefit to Cost ratio ranging between 6.7 and 8.2 is calculated whenever airlines have a fleet comprising mainly single and twin aisle aircraft. For a fleet of only regional aircraft the result shows a negative impact: for each euro invested the return is € 0.4 generating a negative NPV. This is explained by the fact that the additional fuel burn due to level-off is much higher for single and twin aisle aircraft than for regional aircraft.

These results assume 100% data sharing and represent the most optimistic situation.

The reader is invited to make their own calculations using the Excel spread sheet developed by the project, see Appendix F.1 for details on how to get the Excel file.

Regional	91,250
Single	210,240
Twin	80,300
Total	381,790

Main Airline type data set	
Level-offs avoided below FL 300 per year	21,766 € per year
Level-offs avoided @ FL 300 & above per year	54,799 € per year
Total Benefit	76,565 € per year
Total Cost	9,837 € per year
Benefit to cost ratio	7.8
Net present value	287,739 € after 5 y

Table 22: Main Airline type data set results

Low Cost type data set	
Regional	0
Single	527,425
Twin	0
Total	527,425

Low Cost type data set	
Level-offs avoided below FL 300 per year	32,634 € per year
Level-offs avoided @ FL 300 & above per year	78,812 € per year
Total Benefit	111,446 € per year
Total Cost	13,589 € per year
Benefit to cost ratio	8.2
Net present value	421,972 € after 5 y

Table 23: Low Cost Airline type data set results

Regional type data set	
Regional	141,229
Single	0
Twin	0
Total	141,229

Regional type data set	
Level-offs avoided below FL 300 per year	1,402.46 € per year
Level-offs avoided @ FL 300 & above per year	0.00 € per year
Total Benefit	1,402.46 € per year
Total Cost	3,638.74 € per year
Benefit to cost ratio	0.4
Net present value	-9,643 € after 5 y

Table 24: Regional Airline type data set results

ECAC data set	
Regional:	2,190,000
Single Aisle:	6,044,400
Twin Aisle:	525,600
Total	8,760,000

Your airline results	
Level-offs avoided below FL 300 per year	447,129.04 € per year
Level-offs avoided @ FL 300 & above per year	1,056,257.19 € per year
Total Benefit	1,503,386.23 € per year
Total Cost	225,700.00 € per year
Benefit to cost ratio	6.7
Net present value	5,509,545 € after 5 y

Table 25: ECAC data set results

8.3 Environment Results

The Airlines model also looks at the Environmental benefits associated with the fuel burn reduction as a result of the avoided level-offs.

While other greenhouse gases are generated such as nitrogen oxides, sulphur oxides and water vapour, the principal greenhouse gas emission from powered aircraft in flight is CO_2. The latter is the gas considered in the Airline model.

To mitigate the climate impacts of aviation, the EU has decided to impose since 1st January 2012 a cap on CO_2 emissions from all domestic and international flights – from or to anywhere in the world – that arrive at or depart from an EU airport. This was done in 2008 by integrating aviation into the EU Emissions Trading System (EU ETS) which, according to the Commission, would be the most cost-efficient and environmentally effective option for controlling aviation emissions. The relevant EU Directive (2008/101/EC) foresees that 85% of the EU allowances (EUA) will be allotted to the aircraft operators free of charge and the remaining 15% will be available for auctioning.

A EUA is a permit to emit one metric tonne of CO_2 under the ETS. The price per permit is rather volatile and can vary between 5€ and 35 €. The current price of 8 € was used in the model.

The ECAC-wide (not per airline) results (with 100% data sharing) are:

Avoided total cost of CO_2	**228,594**	**€ per year**
Total unused EUA[7] permits	**6,101**	**per year**
Total unused EUA in €	**48,806**	**€ per year**

Table 26: EUA data results

The avoided total cost of CO_2 is given for information. It is not a cost as such for the airlines. It is an international overview of shadow prices for aircraft based on damage as well as prevention cost approaches in order to find a level of incentive for reducing emissions.

8.4 Cost Benefit Sensitivity Analysis

8.4.1 Airlines Model: Sensitivity Analysis - Overall

A sensitivity analysis is a statistical technique in which inputs are changed one at a time or in combination while the effect upon a particular variable is observed.

A high level sensitivity analysis was performed on the ECAC model inputs (assuming 100% data sharing) by giving the main input parameters a range of +/- 10%. The results are shown in a tornado diagram in Figure 12 (more details on tornado diagrams can be found in Appendix G).

[7] European Emission Allowance

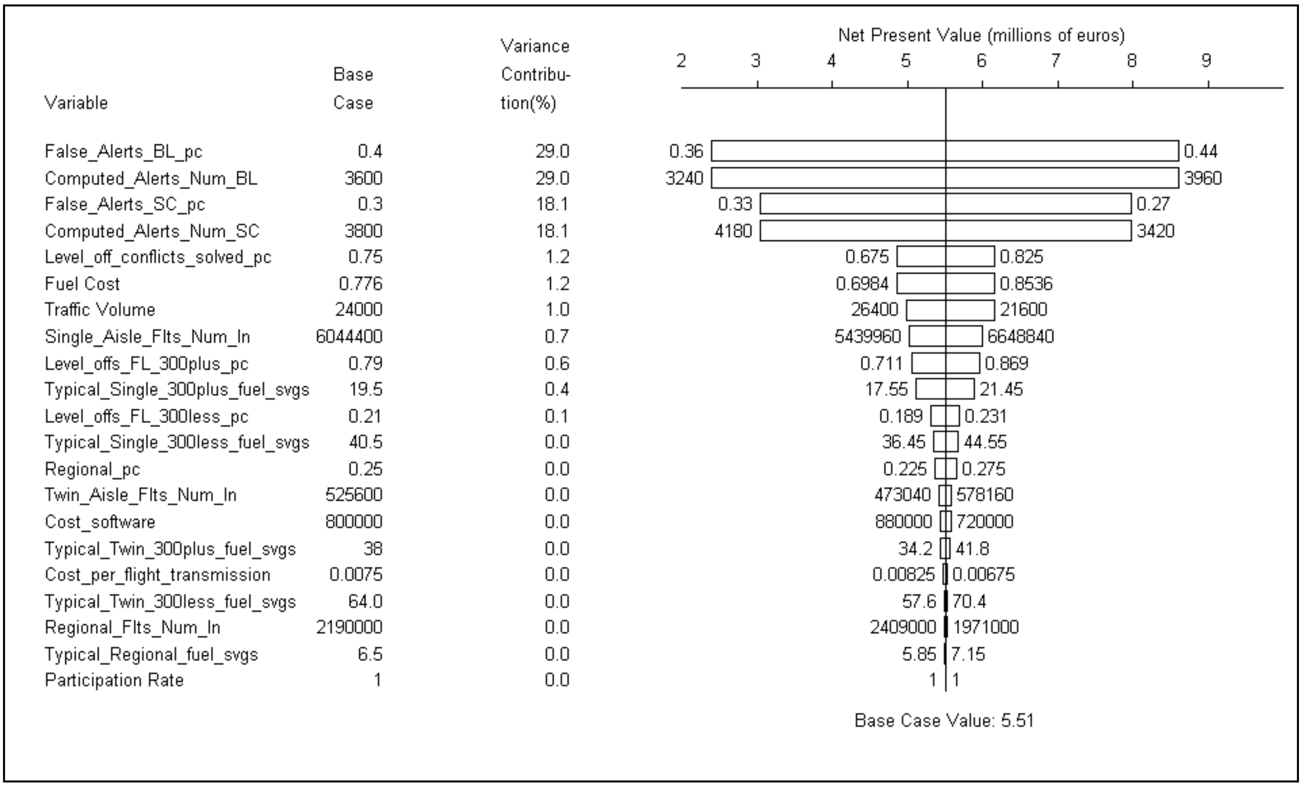

Figure 12: AOC Tornado diagram

The variables at the top of the list contribute the most to the variability of the expected results. (Details of the variables can be found in Appendix F. The name shown in the tornado diagram can be found in the 'short name' column of the tables.) If further effort were available to improve the Airlines CBA model then getting improved data for these variables (e.g. false alert rate data from an operational tool to augment the modelling data) would be the first improvement to make.

The top 4 variables listed in the tornado diagram are all used to calculate how many fewer false alerts there would be if the proposed concept to use AOC data in computing trajectory prediction was implemented. The top axis shows the impact that changes in these values would have on the NPV; so a reduction in the 'Percentage of baseline false alerts' (False_Alerts_BL_pc) from 40% to 36% would reduce the NPV from 5.51 million Euros to just under 2.4 million Euros.

Percentage of baseline false alerts (False_Alerts_BL_pc)	B/C	NPV
36%	3.5	2,397,805
40%	6.7	5,509,545
44%	9.9	8,621,285

Table 27: Sensitivity Changes - % baseline false alerts

Table 27 shows the results for different percentages of false alerts that could occur without the AOC data concept being implemented. The values show that a higher percentage of false alerts in the baseline will result in higher benefits once the concept is implemented, hence the increased benefits for the higher percentage value.

Percentage of improved false alerts (False_Alerts_SC_pc)	B/C	NPV
33%	4.1	3,046,084
30%	6.7	5,509,545
27%	9.2	7,973,006

Table 28: Sensitivity Changes - % improved false alerts

Table 28 refers to the percentage of false alerts that occur when the use of AOC data concept is implemented. Here a lower percentage of false alerts will result in fewer level-offs and more benefits for the airlines.

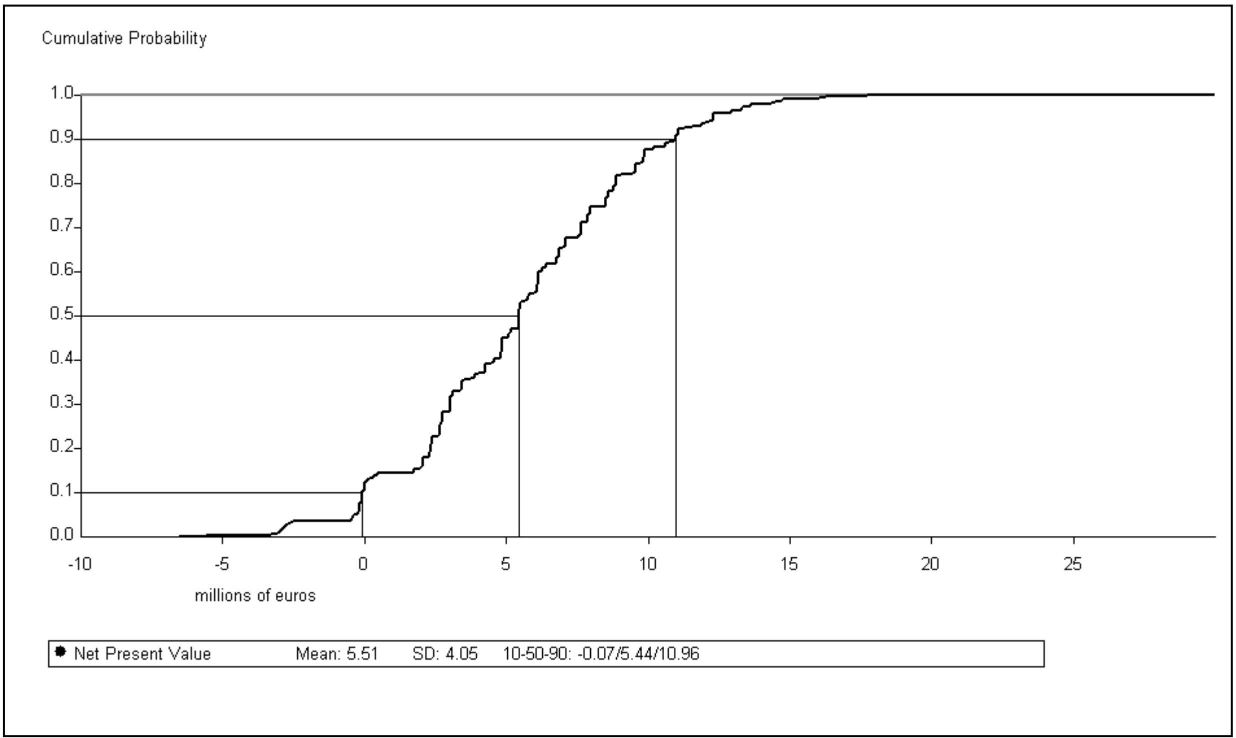

Figure 13: Cumulative Probability Curve for the concept of using AOC

The risk of the project is evaluated by means of cumulative probability curve[8], see Figure 13. It should be read as follows: the Y axis value gives the probability to get up to the X outcome value (in million Euros); or in an equivalent way, the (1-Y) probability to get the X outcome value or more.

Under the assumptions of the model the cumulative probability curve reveals that there is a 50% probability of obtaining a result of 5.5 M Euros or more (at ECAC level). There is only a 10% probability that this project (at ECAC level) would lose money.

See Appendix A for further explanation of the Probabilistic Analysis.

8.4.2 Airlines Model: Sensitivity Analysis – Participation Rate (% of flight data sharing)

During the second workshop the question was raised over the impact of lower data sharing participation rates. A draw back of a lower participation rate is that the cost for the ground and the data communication’s infrastructure are not reduced proportionally. Also it may be necessary to have a "critical participation mass" to avoid that the accurate predictions are of low use if used against lower accuracy ones in the conflict detection process.

The approach taken to model this in the Airlines model involved introducing a Participation Rate. This rate directly impacts the number of level-off avoided (i.e. a participation rate of 10% reduces the level-offs avoided from 225 to 22.5).

The following assumptions were also made:

[8] The probabilistic approach used in this review is based on the construction of a decision tree where every possible outcome of the project is weighted with its associated probability; the sum of every possible outcome given the probabilities is used to build the cumulative probability curve

- Software costs are assumed to be paid by all flights via the cost recovery aspect of the route charging mechanism
- Flight Plan transmission costs are only paid by the participating airlines
- There are fewer benefits but they only go to the participating airlines (as it is their climbing aircraft that would be levelled-off)
- The distribution of all participants is similar to the ECAC traffic distribution meaning that the conflict distribution (and associated false alerts) is similar.

The following table shows an example of how the benefit and cost ratios and the NPV values differ with different participation rates. The ECAC data set shows that with a participation rate of over 11.5% the benefits exceed the costs. This includes the impact of the software development costs that are paid by all airlines (data sharing/participating and non-data sharing/non-participating).

The Data Sharing Airlines columns show how the overall benefits increase as more airlines share data, however the benefit and cost ratio remains constant because while the benefits are increasing so are the costs linked to data communication. The Data Sharing Airlines represent the percentage of airline participation which has the same flight category distribution as the ECAC traffic, i.e. 50% participation = 50% of ECAC traffic.

	Data Sharing Airlines		ECAC data	
Participation Rate	B/C	NPV	B/C	NPV
11.5%	6.7	633,598	1	23,001
30%	6.7	1,652,864	2.5	1,169,905
50%	6.7	2,754,773	3.9	2,409,802
75%	6.7	4,132,159	5.4	3,959,674
100%	6.7	5,509,545	6.7	5,509,545

Changing the participation rate does not change the different airline ‘type’ results in section 8.2 , Table 22 and Table 23 because those results are already presuming that each airline is sharing their data.

8.4.3 CBA Conclusions and Recommendations

8.4.3.1 Conclusions

The overall magnitude of the Net Present Value (NPV) is small whether at the ECAC level or a (fictitious but plausible) airline level; the proposed use of AOC data is a low cost/low benefit change to current operations. However, there is clearly a good business argument for implementation for single- and twin-aisle aircraft, which the analysis suggests would produce a Benefit/Cost ratio of between 6 and 8.

For Regional types of aircraft, the business case is less compelling; the CBA suggests that for every € invested, the return would only be € 0.4. This is primarily because Regional aircraft types burn low amounts of fuel and tend to fly close to their Requested Flight Level (RFL) so the scope for realising benefits is restricted significantly.

The results from this study carry an important caveat, namely that the scenarios considered assume that 100% of aircraft will be participating in the provision of the additional flight information. This assumption is extremely optimistic and should be treated with caution; it gives a ‘best-case’ result for the realisation of benefits. It should also be noted that a lack of commitment to participate on the part of some airlines will reduce the scope for overall benefits and in turn this can create unwillingness among other airlines to pay the costs of providing the additional data when the full benefits cannot be realised due to less-than-universal participation. The 100% assumption is not a requirement to implement the system; however it would be needed to realise the benefits mentioned above

Nevertheless, the B/C ratio (for single- and twin-aisle) is sufficiently high at 6-8 for 100% data sharing that reduced participation should still produce a positive B/C ratio, even if it is lower. The impact of different participation rates (% of flight data sharing) show that airlines that share their AOC data get benefits.

To get benefits at ECAC level the participation rate has to be above 11.5% of traffic otherwise there are not enough benefits to outweigh the software development costs that are paid by all airlines (both data sharing and non-data-sharing).

Further analysis on lower levels of participation is needed to demonstrate how far the benefits are likely to be reduced.

A further point to note is that it is entirely feasible for airlines to provide additional data beyond the mass and speed data considered here, to the point where they share all information about a given flight and thereby reduce uncertainty. However, the cost of obtaining this additional data is likely to be prohibitive while adding little to the ANSPs ability to improve the flight profile. The 'value of perfect information' (VOPI) is likely to be exceeded by its cost due to the 'laws of diminishing returns'. Mass and speed data can be considered to represent the most cost beneficial data that can be utilised by the ANSP to realise benefits for the airlines.

Other caveats:

- The Airline Model is based on a fixed fuel price and variances can be expected. Should the price exceed a certain amount airlines may decide to reduce the number of flights?
- The model is based on fuel consumption for existing fleets and does not take into account replacement with more fuel efficient aircraft.

8.4.3.2 Recommendations

At the end of the CBA study the following points are recommended:

- There is a positive business argument for implementing the AOC data in computing ground trajectory prediction for single- and twin-aisle aircraft, which the analysis suggests would produce a Benefit/Cost ratio of between 6 and 8 in the case of 100% participation.
- From the level of participation analysis in section 8.4.2 it is save to conclude that for participation rates above 12% the benefits cover the costs.

9 Safety Assessment

9.1 Introduction

This section considers the results of the various validation activities to the concept of using AOC data in computing ground Trajectory Prediction with the safety implications in mind. It determines what conclusions can be drawn from a safety perspective, raising recommendations for further work where appropriate.

It should be acknowledged that P 05.05.02 is not fully compliant with the methodologies outlined in the SESAR Safety Reference Material, [17]. This project was initiated well in advance of the publication of this material.

9.2 Safety Assessment Analysis

This safety assessment activity is based on the results of the validation activities took place during V2 and V3 of this project. For more details of these validation activities and their results see chapters 3 and **Error! Reference source not found.**. From these results it is likely that the use of AOC data would reduce the risk of a mid-air collision. It has been demonstrated that the use of AOC projected aircraft mass and speed along the aircraft route in the computation of ground-based Trajectory Prediction increases the accuracy of the predicted aircraft trajectories. The exact manifestations of the effects have not been fully established and are subject to further work.

It is expected, however, that there will be a reduction in the number of aircraft deviation alerts and a corresponding reduction in the number of false separation monitor alerts and other knock-on benefits which have not yet been established. These improvements are expected to improve both the performance of tactical conflict management and traffic planning and synchronisation barriers of the SESAR Mid Air Collision Accident Incident Model (MAC-AIM).

The following safety criteria are therefore considered applicable to the concept of using AOC data in computing Trajectory Prediction:

- <u>**SC 1:**</u> There shall be a reduction in the number of imminent infringements despite increasing traffic levels.
- <u>**SC 2:**</u> There shall be a reduction in the number of tactical conflicts despite increasing traffic levels.
- <u>**SC 3:**</u> There shall be a reduction in the number of ATC induced tactical conflicts despite increasing traffic levels.

9.2.1 Safety Related Validation Activities

Throughout the safety study the following validation activities were considered relevant:

9.2.1.1 Sensitivity Analysis

Exercise EXE-05.05.02-VALP-0069.0200 covers the sensitivity of the ground-based TP to the accuracy of the AOC data provided and used in the computation of the ground-based TP, for more details see [13], section 6.2. The sensitivity analysis introduced a range of perturbation errors to the provided values of the AOC data for aircraft mass and speed. It established that ±10% error in the mass and speed values had no appreciable effect on the trajectory predictions. The analysis concluded that when setting up MOUs with the AOCs an acceptable ±10% error tolerance should be established. There was, however, no assessment as to the whether the AOCs would be capable of achieving this degree of accuracy, see recommendation 1. Additionally, the analysis did not consider the effects of failure to comply with the MOU, which are also addressed through recommendation 1.

9.2.1.2 Objective Analysis

Exercise EXE-05.05.02-VALP-0069.0100 and its results cover the objective analysis of the introduction of AOC data to the computation of ground-based Trajectory Prediction; for more details see [13], section 6.1. The exercise identified the extent of the improvement in trajectory prediction (TP) when the trajectories are computed using AOC data. This was achieved by establishing the delta between revised trajectories calculated using AOC data and the actual radar data and comparing it to the delta between the trajectories when calculated with the default BARDA value. It was demonstrated that the inputting of AOC projected aircraft mass and speed along the aircraft route into the iFACTs trajectory prediction models significantly increases the accuracy of the predicted aircraft trajectories. It is likely that this will result in improvements to the operation of the tactical and planner controller toolset which largely employs the trajectory prediction data. The exact manifestations of the effects on the toolset have not been fully established and are subject to further work, see recommendation 2. The analysis aggregated the AOC data from a number of airlines including: BA, Lufthansa, American airlines and Flybe. It is therefore quite possible that this will result errors from individuals operators being shielded, see recommendation 3. Additionally the analysis was specific to the climb phase of flight only, see recommendation 4.

9.2.1.3 Subjective analysis

Exercise EXE-05.05.02-VALP-0300.0100 and Exercise EXE-05.05.02-VALP-0301.0100 were investigating the impact of each parameter provided from AOC data on the accuracy and stability of the computed Trajectory Prediction and the overall performance of the system, for more details see [13], section 6.4 and section 4 of this document. The subjective analysis explored the impact of this TP improvement on the controller task. Controllers where presented with two instances of the same data; one using AOC data in computing Trajectory Prediction and the other using the default BADA values. Controllers were asked to compare the differences in performance of the iFACTS toolset. Over the 12 day simulation, 12 % of cases an improvement was reported and in all cases no degradation was reported. These results need to be supplemented by objective data, see recommendation 2.

9.3 Safety Assessment Recommendations

These recommendations should be carried forward and addressed in the industrialisation phase of the project (V4) prior to implementation.

1. For each AOC data parameter, the mass and speed data that is being provided should be compared to the actual aircraft data to establish whether each AOC data value provided can achieve the ±10% tolerance specified in the MOU over a statistically significant timeframe. Furthermore, there has been no failure case analysis, this analysis should also be extended to establish the effects on the TP and subsequently the controller toolset when AOC data is provided outside the error tolerances and whether the effects are acceptable or need to be appropriated mitigated.

2. It is necessary to establish how the improvements in TP accuracy manifest themselves in the controller toolset. All the tools that to employ TP data need to be identified. For each tool real life scenarios should be extracted and the improvement in the TP accuracy directly compared to use of the default values. The direct effect on the controller role needs to be established objectively. Note: it is possible that the effects could be detrimental to safety if, for example, the improvements were to move rather than remove false interactions.

3. There is likely to be a variation between the accuracy and quality of the AOC data being provided by each operator. It is therefore recommended that the quality of the AOC data be examined from operator to operator to confirm that each AOC is able to provide data within the required tolerance.

4. The scope of the analysis should be increased to cover the effects of the AOC data for all phases of flight.

10 Conclusions and Recommendations

10.1 Conclusions

This is the final technical report for P 05.05.02. The report covers a number of activities.

This document provides the final set of Operational Requirements for ground ATC systems that facilitate the use of Airline Operational Control (AOC) data in the computation of ground-based trajectory prediction. The prime objective of these requirements is to improve the accuracy of the computed trajectory prediction (TP). These operational requirements are derived from the proposed concept for use of AOC data to improve Trajectory Prediction, Ref. [11].

The proposed set of Operational Requirements will be included in the consolidated set of operational requirements for the TMA Trajectory Management Framework.

The proposed concept included recommendations for the security of provided AOC data:

1. The ground ATC-system shall observe various data access restrictions as agreed with airspace user.
2. The ground ATC-system shall comply with any time restrictions that have been agreed with airspace users not to keep the AOC supplied data after the completion of flight.

The document also reports all validation activities took place to validate the use of mass and speed AOC data in computing TP. Both V2 and V3 validation activities are covered in this project.

The V2 validation covered the following aspects:

Validate that the accuracy of the TP improves when AOC data is used as input.

- Validate that the selected AOC data can be used in current or near-term TP.
- Validate that TP stability is not adversely affected by the introduction of AOC data.
- Validate that CDnR tool performance improves when the underlying TP is supported by AOC data.
- Validate that improved TP that used AOC data as input leads to improved operational performance when used in CDnR for departure.
- Demonstrate the possibility of using AOC data in current or near-term ATC tools.
- Demonstrate the possibility of using AOC data for a subset of flights in operational system (mix-mode operation).
- Validate that AOC data can be used in current or near-term ATC tools.
- Validate that current or near-term ATC tool is able to receive and handle AOC data.

AT the end of this validation stage the project is able to report on the accuracy of the improved TP that uses AOC data and ability of the current or near-term ATC tools to use a modified TP as well as baseline TP. Full details of these activities can be found in Ref. [13] and chapter 4 of this document.

Based on the results from V2 validation, V3 validation activities took place through the validation of ATC tools and the performance of Cost Benefit Analysis. We used the iFACTS model to perform this validation with the contribution of operational controllers. Analysis of controller's feedback, comments received and the comparisons are detailed in Appendix E Table 34, Table 35 and Table 36.

During V3 activities the project validated that CDnR tool performance improves when the underling TP is supported by AOC data. By performing this activity the project completes the loop starting from the input AOC data considering the computation of TP that uses AOC data then the introduction of such TP into current ATC tools and the validation of the concept in various combinations. Finally the real-time ATC tool performance analysis concluded the validation while the cost benefit analysis addresses the business case.

The introduction of AOC mass and speed data into TP does produce noticeable differences in the information displayed in the TP/MTCD tools. These differences were most noticeable for aircraft in the climb phase of flight, but some differences were also noted for aircraft in the descent.

The most noticeable differences is when AOC mass and speed data are used together while the least noticeable difference when AOC speed data is used alone.

It should be noted that in the majority of cases the introduction of AOC data did produce a noticeable difference in the display of interactions and trajectories. However, during this exercise, the conditions under which the differences were sufficient for the controllers to express a preference were limited to interactions involving climbing aircraft along with the application of both Mass and Speed data combined with reduced uncertainty. Under these circumstances, preferences were expressed for up to 30% of cases.

In the case of descent the results were much less conclusive this is due to the small size of data and the lack of enough scenarios to allow us to draw significant conclusions.

The system was robust to the application of incorrect AOC mass data. No preferences or inconsistencies were reported by the controllers under these conditions.

The document addressed the safety assessment of the use of AOC data in computing ground TP:

1. The safety assessment concluded that the use of AOC data would reduce the risk of mid-air collision.

2. The use of AOC data in the computation of TP increases the accuracy of TP that will reduce the number of aircraft deviation alerts and a corresponding reduction in the number of false separation monitor alerts and other known benefits.

In conclusion to the Cost Benefit Analysis study the overall magnitude of the Net Present Value (NPV) is small whether at the ECAC level or a (fictitious but plausible) airline level; the proposed use of AOC data is a low cost/low benefit change to current operations. However, there is clearly a good business argument for implementation for single- and twin-aisle aircraft, which the analysis suggests would produce a Benefit/Cost ratio of between 6 and 8.

For Regional types of aircraft, the business case is less compelling; the CBA suggests that for every € invested, the return would only be € 0.4. This is primarily because Regional aircraft types burn low amounts of fuel and tend to fly close to their Requested Flight Level (RFL) so the scope for realising benefits is restricted significantly.

The results from this study carry an important caveat, namely that the scenarios considered assume that 100% of aircraft will be participating in the provision of the additional flight information. This assumption is optimistic and should be treated with caution; it gives a 'best-case' result for the realisation of benefits. It should also be noted that a lack of commitment to participate on the part of some airlines will reduce the scope for benefits and in turn this can create unwillingness among other airlines to pay the costs of providing the additional data when the benefits cannot be realised due to less-than-universal participation. The 100% assumption is not a requirement to implement the system; however it would be needed to realise the benefits mentioned above.

Nevertheless, the B/C ratio (for single- and twin-aisle) is sufficiently high at 6-8 for 100% data provision that reduced participation should still produce a positive B/C ratio, even if it is lower. From the level of participation analysis it is concluded that for participation rates above 12% the benefits cover the costs.

It is also important to note that the positive CBA conclusions in this report are based on the London TMA data (e.g. the current false alerts or current conflicts detected used in the CBA scenarios come from the London TMA and are extrapolated for ECAC). For other TMA in Europe these scenarios and CBA could be different.

A further point to note is that it is entirely feasible for airlines to provide additional data beyond the mass and speed data considered here, to the point where they share all information about a given flight and thereby reduce uncertainty. However, the cost of obtaining this additional data is likely to be prohibitive while adding little to the ANSPs ability to improve the flight profile. The 'value of perfect information' (VOPI) is likely to be exceeded by its cost due to the 'laws of diminishing returns'. Mass and speed data can be considered to represent the most cost beneficial that can be utilised by the ANSP to realise benefits for the airlines.

10.2 Recommendations

It is recommended to share AOC data for improving the performance of conflict detection tools. The performance improvement in conflict detection tools could lead to an increase in capacity or productivity for the same team of controllers.

A range of levels of uncertainty were applied during the V3 activities along with Mass & Speed AOC data and the results varied accordingly. Varied levels of uncertainty should be applied to non-AOC runs in order to prove that the differences noted were due to the application of AOC data.

There is a relationship between this work and P 07.06.02. Both projects require and use similar set of AOC data. Collaboration between the two projects would help to consolidate the AOC data requirements and its use in improving the accuracy of computed TP. It is recommended to share all results in this report with P 07.06.02.

It was observed that the controllers would take considerably less notice of an interaction predicted to be more than 10 miles apart and more than 10 minutes in the future, compared to a prediction around or below the 8 mile line. It is recommended that traffic samples for future activities during V4-V5 should be engineered to include a high proportion of interactions within the range of 5-8 miles and 5-10 minutes. These would be interactions to which the controllers would need to take action and would also potentially show more critical differences between systems supported with AOC data and unsupported ones.

At the end of the Cost Benefit study for the use of AOC data in computing ground trajectory prediction the following is recommended: There is a positive business argument for implementing the AOC data in computing ground trajectory prediction for single- and twin-aisle aircraft, which the analysis suggests would produce a Benefit/Cost ratio of between 6 and 8 in the case of 100% participation.

It is recommended to disseminate the Excel Airline CBA model to various interesting airlines so that they can enter their own data and make their own CBA conclusions.

11 References

11.1 Applicable Documents

[1] V&V Plan Latest version
[2] SESAR Validation Report Latest version
[3] SESAR Requirements and V&V Guidelines 02.00.00
[4] SESAR V&V Strategy Latest version
[5] SESAR Template Toolbox User Manual Latest version
[6] Requirements and V&V Guidelines 02.00.00
[7] European Operational Concept Validation Methodology (E-OCVM) - 3.0 [Feb 2010]

11.2 Reference Documents

[8] **SESAR B.04.02**: SESAR Trajectory Management Document, Edition 00.02.90, Sep 2010
[9] **SESAR 05.05.02**: PIR Part 1, Edition 00.04.00, May 2010
[10] **SESAR 05.05.02:** Preliminary Operational Requirements for use of AOC data, 05.05.02-D06, 00.01.00, 17 Dec 2010
[11] **SESAR 05.05.02:** Concept for use of AOC data to improve Trajectory Prediction, 05.05.02-D01, 00.01.01, 03 December 2010
[12] **SESAR 05.05.02**: Validation Plan for Enhanced TP using AOC data, 05.05.02-D02, 00.01.01 21 January 2011
[13] **SESAR 05.05.02**: Validation Results for Enhanced TP using AOC data, 05.05.02-D03, 00.01.01, 21 December 2011
[14] http://www.eurocontrol.int/ecosoc/gallery/content/public/documents/General/EMOSIA-User-Guide1-1.pdf
[15] **SESAR,** D06-01_05, ATM CBA for Beginners, V 01.00.00, 17/12/2010
[16]http://www.eurocontrol.int/ecosoc/gallery/content/public/documents/CBA%20examples/Standard_Inputs_fin.pdf
[17]**SESAR,** Safety Reference Material, 00.02.00, 15 December 2011
[18] **CAA – REPORT**: Warning time and look-ahead time requirements for conflict Alert
[19] SESAR P4.2: Detailed Operational Description (DOD) Step 1, Edition 00.03.00, Dec 2011

Appendix A Coverage Matrix

In this appendix two coverage matrices are provided:

- One to relate to the high level performance requirements which cannot be directly translated to operational requirements. These have been described in D02 Ref. [12].
- One to relate to the operational requirements specified in [10].

Requirement ID	Requirement Text	Req V&V Status	V&V Objective ID	V&V Objective Text	V&V Objective Analysis Status	V&V Objective Analysis Status per Exercise	Exercise ID	Exercise Title
OBJ-05.05.02-VALP-0000.0100	TP accuracy improvement	OK	OBJ-05.05.02-VALP-0010.0010	Trajectory accuracy improvement	OK	OK	EXE-05.05.02-VALP-0069.0100	TP Accuracy analysis
OBJ-05.05.02-VALP-0000.0200	ATM system performance improvement	OK	OBJ-05.05.02-VALP-0020.0010	CDnR tool performance improvement	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
			OBJ-05.05.02-VALP-0030.0010	ATM system performance improvement through AMAN	NOK	NOK	EXE-05.05.02-VALP-00069.0300	Fast-time AMAN effects analysis
			OBJ-05.05.02-VALP-0030.0110	ATM system performance improvement through CDnR	OK	OK	EXE-05.05.02-VALP-00069.0400	Fast-time CDNR effects analysis
OBJ-05.05.02-VALP-0000.0300	No adverse effects on safety	OK	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	OK	OK	EXE-05.05.02-VALP-0069.0200	TP Sensitivity analysis
			OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
OBJ-05.05.02-VALP-0000.0400	Early benefit option	OK	OBJ-05.05.02-VALP-0050.0010	Ability to apply concept to current TP systems	OK	OK	EXE-05.05.02-VALP-0069.0100	TP Accuracy analysis
			OBJ-05.05.02-	Ability to apply	OK	OK	EXE-05.05.02-	Real-time ATC tool

			VALP-0050.0110	concept to ATC tools that use TP systems			VALP-0300.0100	concept demonstration
			OBJ-05.05.02-VALP-0060.0010	Some benefit achieved without full AOC data support	NOK	NOK	EXE-05.05.02-VALP-0069.0300	Fast-time AMAN effects analysis
OBJ-05.05.02-VALP-0020.0010	ATM system performance improvement	OK	OBJ-05.05.02-VALP-0020.0010	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	OK	OK	EXE-05.05.02-VALP-0301.0100	Validate that CDnR tool performance in high density Area Control airspace improves when the underling TP is supported by AOC data.

Table 29: Preliminary high level performance requirements Coverage Matrix

Requirement ID	Requirement Text	Req V&V Status	V&V Objective ID	V&V Objective Text	V&V Objective Analysis Status	V&V Objective Analysis Status per Exercise	Exercise ID	Exercise Title
REQ-05.05.02-OSED-0200.0000	ATC-system able to receive and handle Flight Plan Data	OK	OBJ-05.05.02-VALP-0070.0010	Prototype concept demonstration	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0300.0000	ATC-system uses Flight Plan Data in Trajectory Prediction calculation	OK	OBJ-05.05.02-VALP-0010.0010	Trajectory accuracy improvement	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0400.0100	AOC data not available	OK	OBJ-05.05.02-VALP-0040.0020	Baseline operation without AOC data	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration

REQ-05.05.02-OSED-0400.0200	AOC data available	OK	OBJ-05.05.02-VALP-0060.0010	Demonstrate use of AOC data in TP in operational system.	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0400.0300	ATC-system ability to switch between two options.	OK	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0100.0200	SWIM Processing	NOK		Refer to SWIM[9]	NOK	NOK		
REQ-05.05.02-OSED-0100.0100	Airspace user data input.	OK	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	OK	OK	EXE-05.05.02-VALP-0069.0200	TP Sensitivity analysis
REQ-05.05.02-OSED-0200.0100	AOC Data Acceptance	OK	OBJ-05.05.02-VALP-0040.0210	Unconditional data acceptance	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0200.0200	AOC Data Verification	OK	OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0300.0100	Gross-Error data handling	OK	OBJ-05.05.02-VALP-0040.0310	Correct fall back to baseline operation	OK	OK	EXE-05.05.02-VALP-0300.0100	Real-time ATC tool concept demonstration
REQ-05.05.02-OSED-0100.0100	Airspace user data input.	OK	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0100.0200	SWIM Processing			Refer to SWIM			EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0200.0100	AOC Data Acceptance	OK	OBJ-05.05.02-VALP-0040.0210	Unconditional data acceptance	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0200.0200	AOC Data Verification	OK	OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0300.0100	Gross-Error data handling	OK	OBJ-05.05.02-VALP-0040.0310	Correct fall back to baseline operation	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0300.0200	ATC-system Internal Reporting	OK	OBJ-05.05.02-VALP-0040.0310	Correct fall back to baseline	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis

[9] These operational requirements will feed the design and implementation of SWIM and will be verified and validated within those projects.

				operation				
REQ-05.05.02-OSED-0400.0000	Mixed Mode Functionality	OK	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0400.0100	AOC data not available	OK	OBJ-05.05.02-VALP-0040.0020	Baseline operation without AOC data	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0400.0200	AOC data available	OK	OBJ-05.05.02-VALP-0060.0010	Demonstrate use of AOC data in TP in operational system.	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0400.0300	ATC-system ability to switch between two options.	OK	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode	OK	OK	EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0500.0100	Data access time restriction mechanism			Refer to SWIM			EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis
REQ-05.05.02-OSED-0500.0200	Data access authorisation mechanism			Refer to SWIM			EXE-05.05.02-VALP-0301.0100	Real-time ATC tool performance analysis

Table 30: Preliminary requirements Coverage Matrix

<u>Details of the fields of the coverage matrix:</u>

Req Validation Status: synthesis of analysis status of associated Validation objectives

Validation Objective Analysis Status: Final analysis status of the Validation Objective: synthesis of its Analysis Status in all Exercises it is embedded in.

Validation Objective Analysis Status per Exercise: analysis status of the Validation Objective in the considered exercise

Appendix B Sectors Selection

NATS iFACTS system is only being tested/used in LACC sectors. A trial based in London TC would test both the tool in its current form as well as the effects of trajectory prediction on TC controllers.

A number of LACC sectors have a significant vertical component and indeed climb and descend aircraft from their cruise level until low levels in TC.

The above two statements suggest that validation of the tools in the SESAR definition of the TMA may be achieved by application of the concept to LACC sectors.

B.1 Brecon

- Sectors: LAC 5, 23
- Feeders: 6, 36, 8, 3, 7, 9, TC Ockham, PC Wallasey, PC S29, Ireland FIR (via OLDI)

B.1.1 Arguments

- \+ These sectors have a significant amount of vertical change (in/out of LTMA to West, in/out of Manchester to South).
- \+ The crossing at Brecon provides significant opportunity for interactions.
- \+ Mixed fleet present (trans-Atlantic), see Figure 14.
- Sector has lowest amount of SJU-supported traffic.
- 0 Vertical changes achieved by stepped procedures instead of continuous climb/descent. However, many aircraft do get further clearances before reaching level flight.
- \+ With cooperation of BA and SJU traffic has a broad fleet mix, see Figure 14.
- \+ Relatively large arrival and departure peaks for heavy aircraft.
- Heavy aircraft arrival and departure peak not within the same interval.

B.1.2 Time interval

To capture the departing heavies (for which weight variance strongly depends on sector length), the interval between 15:00 and 18:00 is selected, see Figure 14.

If cooperation of BA is not possible this is not the most optimal slot. However, slots in optimal period (09:00-15:00) would not benefit from potential BA cooperation.

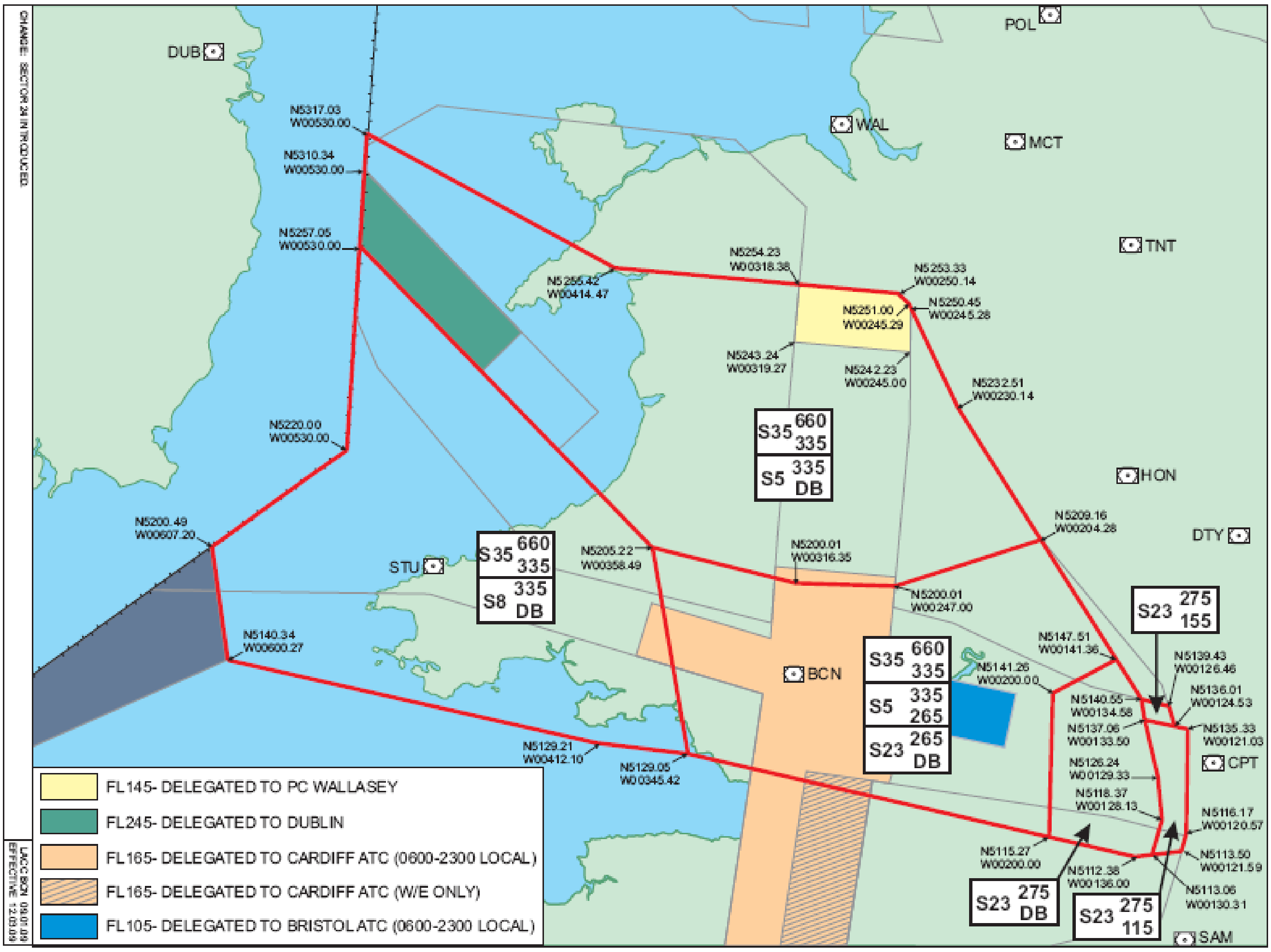

Figure 14: LAC Brecon Sector

B.2 Dover

- Sectors: LAC 15, 16, 17
- Feeders: TC BIG, TIMBA, 25, Paris/Reims FIR (via OLDI)

B.2.1 Arguments

- \+ Sector 17 has long descents (delegated from France FIR) often ‘when ready’.
- \+ Lowest amount of sectors (3 + 3 feeders).
- \+ Largest amount of SJU supported traffic into LTMA.
- \+ NetJets (business jets) most likely to be represented
- \+ Regional aircraft best represented
- \+ With BA broadest variety of types/ranges in arrivals and departures at the same time
- Traffic is more unidirectional, arrivals and departures separated.
- \+ Strong variety of heavy use (by BA) ranging from 200 to 6000 nm

B.2.2 Time interval

09:00 – 12:00 provides a good mix of supported types both inbound outbound.

Even without BA cooperation, this interval provides a good mix of traffic.

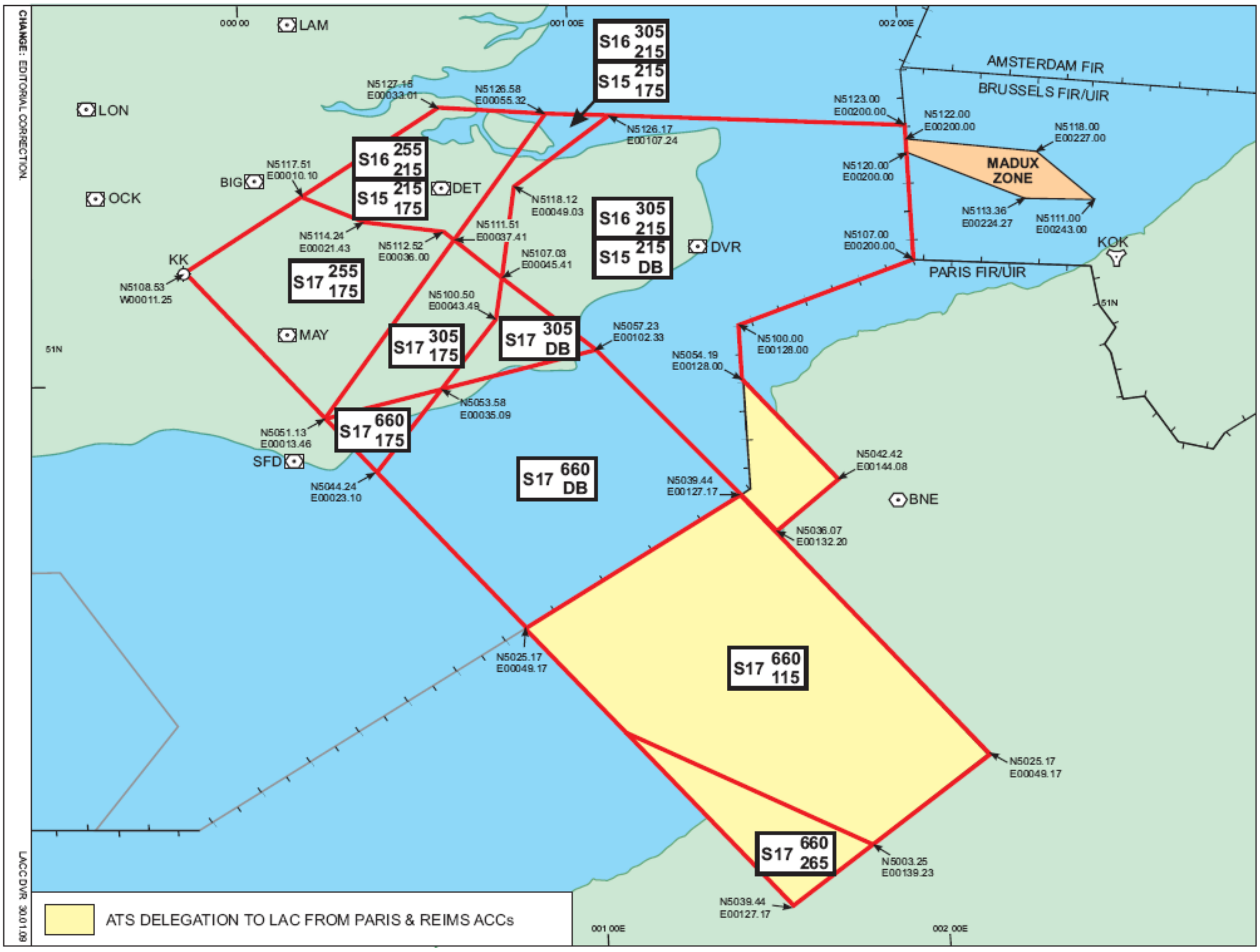

Figure 15: LAC Dover Sectors

Appendix C Collected Data

C.1 Overview

The table below provides the high level properties of the recorded data.

	21 January 2011	28 March 2011
Number of AC sectors (including bandboxes sectors)	27	29
Number of TC sectors (including bandboxes sectors)	17	17
Hours of R/T transcribed	134	120
Number of tactical instructions	27681	27711
Number of flights on day in UK FIR	5370	6074
Number of suitable flights for TP testing	2588	2792
Number of suitable flights for which AOC data is available	730	655
General weather	Calm, high pressure area over UK, CAVU	Calm, cold, CAVU
Approximate location of NAT Eastbound	Landfall above Northern Ireland	Landfall South of Ireland
Approximate location of NAT Westbound	Oceanic entry west of Ireland	Oceanic entry west of Ireland

Table 31: High level properties of recorded data

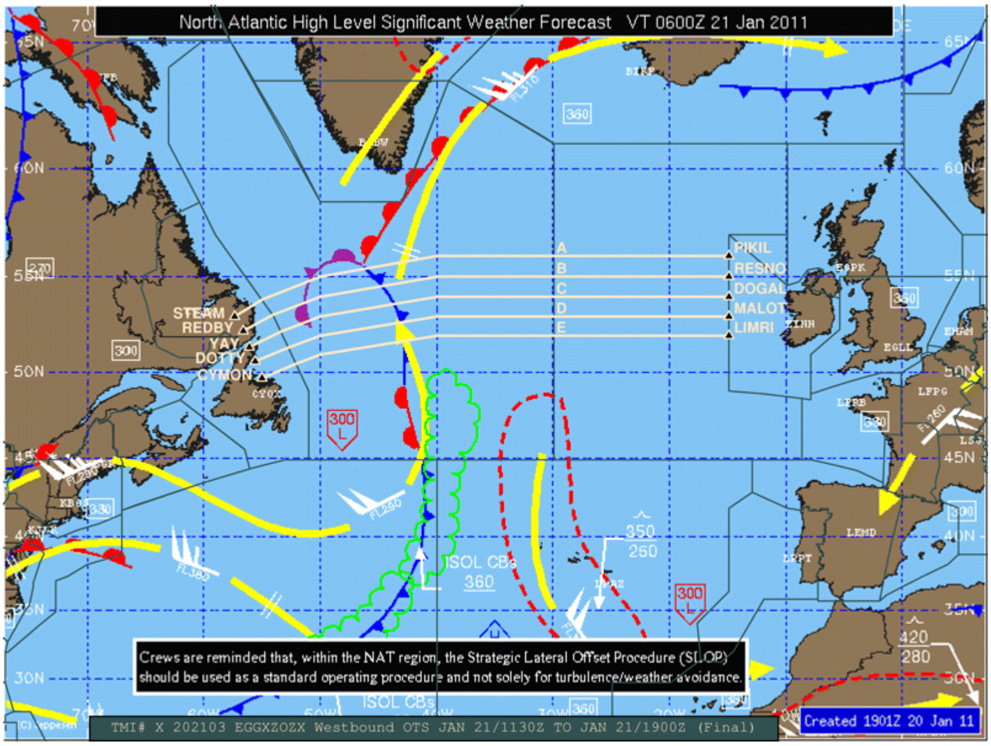

Figure 16: The westbound NAT tracks on the 21st of January.

Note to Figure 16: While not available, the tracks on the 28th of March were very similar, providing a westbound Atlantic departure stream through the Brecon sector (source: Jeppessen).

C.2 Operator flight planning data

Data is collected with the help of the following airlines:

- British Airways (all flights operating under call signs SPEEDBIRD, FLYER and SHUTTLE)
- Flybe
- NetJets Europe
- Swiss
- United Airlines
- Virgin Atlantic

In total, these airlines supplied data for 2677 flights. As the study requires the associated other inputs to the TP research system, this provides 1385 flights for analysis.

Figures (Figure 17 to Figure 20) provide an overview of the different routes included in the analysis. From the map, it is clear that Latin American and Asian flights are not included. This is mainly due to the choice of recorded sectors and the selection of supporting airlines.

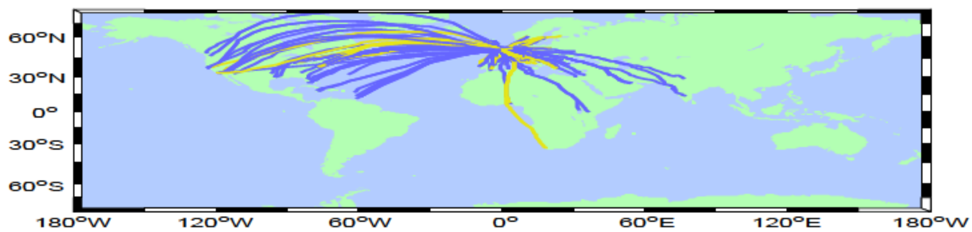

Figure 17: Overview of flights on the 21st of January included in the analysis; blue tracks represent outbound flights, yellow tracks represent inbound flights.

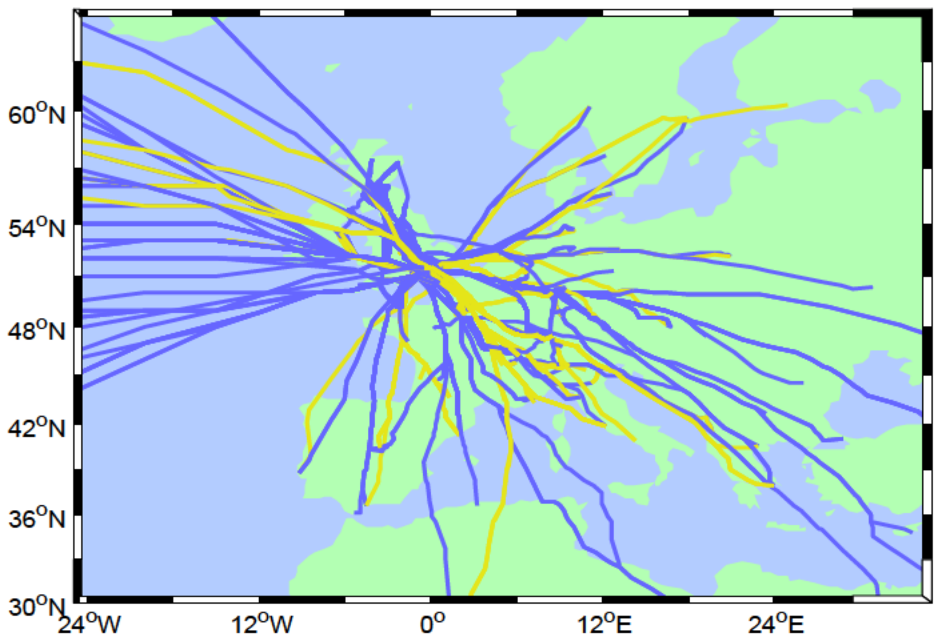

Figure 18: European detail overview of flights on the 21st of January included in the analysis; blue tracks represent outbound flights, yellow tracks represent inbound flights.

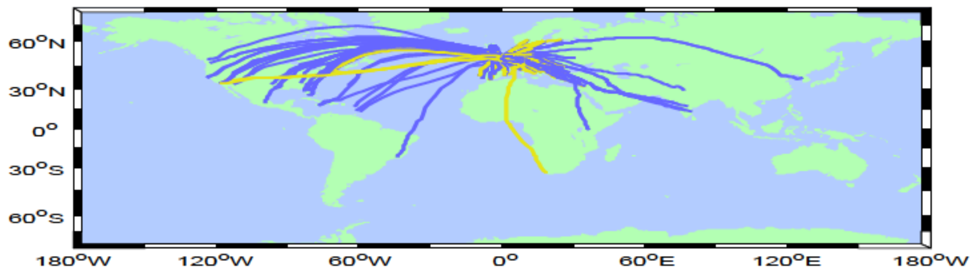

Figure 19: Overview of flights on the 28th of March included in the analysis; blue tracks represent outbound flights, yellow tracks represent inbound flights.

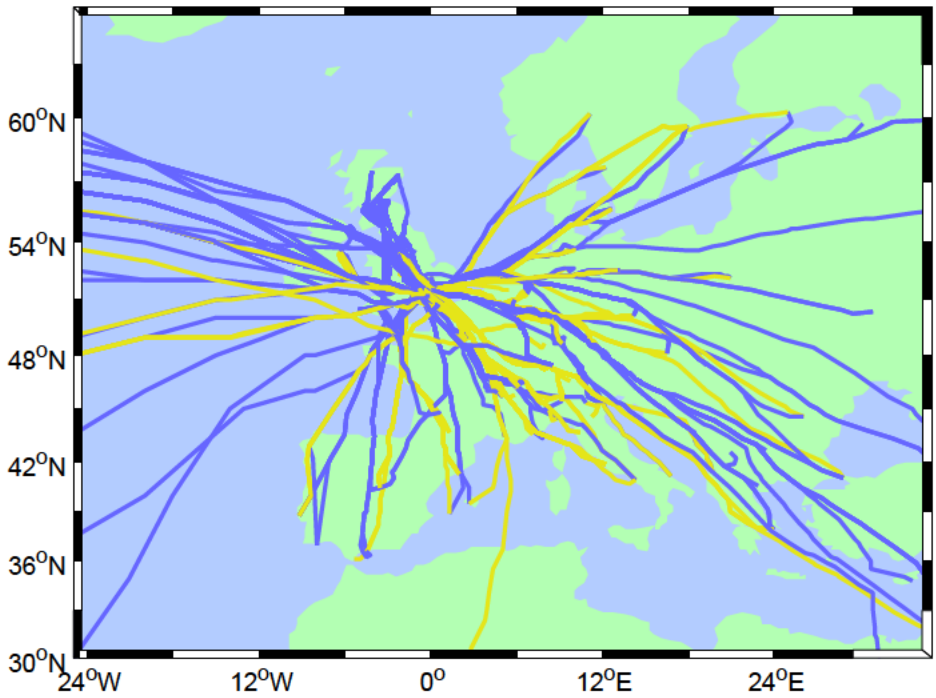

Figure 20: European detail overview of flights on the 28th of March included in the analysis; blue tracks represent outbound flights, yellow tracks represent inbound flights.

Type	Range category	Number of useable flights
A318	2	6
A319	2	167
A320	2	206
A321	2	54
A333	3	2
A343	4	6
A346	4	17

B734	2	97
B744	4	66
B763	3	46
B772	3	80
B77W	4	8
BE40	5	6
C550	5	7
C56X	5	11
DH8D	1	339
E170	1	42
E190	1	134
E195	1	1
F2TH	5	2
FA7X	5	3
GLF5	5	2
H25B	5	15
RJ1H	1	34

Table 32: Number of flights / aircraft types with associated flight planning data

Range Category	Take-off mass with en-route fuel burn estimate	Climb CAS	Climb Mach	Cruise Mach*	Descent CAS	Descent Mach
	Number of suitable flights					
1	550	428	89	548	89	89
2	530	389	389	503	0	0
3	128	41	41	127	0	0
4	97	37	37	95	0	0
5	46	45	38	46	27	27
(*) Or TAS and forecast temperature						

Table 33: Parameters Analysis by range category

Appendix D Validation Environments

This appendix covers NATS iFACTS system as well as different tools and systems that this project has used to perform various phases of analysis.

D.1 iFACTS System

NATS iFACTS system provides the controller with an advanced set of support tools in order to reduce workload and so increase the amount of traffic he/she can comfortably handle. These tools are based on Trajectory Prediction (TP). iFACTS systems provide decision making support and facilitate the early detection of conflicts in and around the sector.

The first stage of iFACTS introduced operationally in spring 2009 delivered 85% of the system's functionality. In June 2011, iFACTS entered live service in the AC operations room at NATS.

The main iFACTS Tools are:

D.1.1 Trajectory Prediction (TP)

Trajectory Prediction (TP) is one of the key underlying features of iFACTS and is used to support the conflict detection and resolution process. TP takes an aircraft's current position and calculates where it will be up to 18 minutes into the future, based on its current level, heading and speed. If any tactical clearances are entered into the system, the trajectory is updated.

D.1.2 Medium Term Conflict Detection (MTCD)

Trajectory Prediction enables the system to predict with reasonable confidence where all aircraft will be at some point in the future. This enables the system to detect any potential conflicts which may arise. Medium Term Conflict Detection (MTCD) compares trajectories for each pair of aircraft in order to determine the separation that is likely to exist. Any Interactions are then classified according to the geometry and category of the interaction, using a combination of colour and symbols. The interaction symbol indicates whether the aircraft are head-on, crossing or catch-up, whilst the colour of the interaction denotes the degree of separation which is expected to exist. A traffic light system of colours is used i.e. red, orange, yellow, and green. They all indicate a potential conflict, but green indicates that the controller has taken an action to actively ensure separation. Severity is then Red (most severe), Orange then Yellow.

D.1.3 Level Assessment Display (LAD)

The Level Assessment Display is used to answer the question "What level can I climb/descend to now?" It is made up of two elements – one area in which tactical clearances are entered or a Tactical What-if initiated, and a graphical display called the Level Assessment Display. The Level Assessment Display shows the hooked aircraft's predicted climb and descent profiles, along with the level achievable at significant points along the route. Interactions with other aircraft along the route are displayed, enabling the controller to make an informed decision as the whether or not the aircraft can be cleared to climb or descend through a level.

D.1.4 Separation Monitor (SM)

The Separation Monitor is the primary iFACTS tool to be used by the tactical controller to aid the monitoring of traffic in and around the sector. The Separation Monitor detects, classifies and displays all interactions predicted to occur over the next 10-15 minutes, based on current clearances.

D.1.5 Tactical What-if

The iFACTS system allows the user to perform a type of "what-if" style query as a way of checking what the results of a clearance would be before it is issued to an aircraft. The results of the query are shown in the Level Assessment Display and Separation Monitor with the border of both windows being Orange to indicate that it is in clearance probe mode.

D.2 Trajectory Prediction Research Tool (TPRT)

NATS Trajectory Prediction Research Tool (TPRT) is a Trajectory Prediction tool which allows TP performance to be assessed directly, without needing higher-level interfaces and system components. This is based on NATS iFACTS Trajectory Predictor (TP).

D.3 Replay-Aided Validation Environment (RAVE)

NATS RAVE is based on a modified version of the current implementation of iFACTS Real Time Simulator (LSS).

The main characteristics of NATS RAVE System can be summarized as follows:

1. RAVE system, as shown in Figure 21 below, contains all Core Engine components (TP, MTCD, and FPM).
2. RAVE system has an HMI component that allows subjective analysis of MTCD output to be performed.
3. RAVE system will be used to conduct subjective analysis of the MTCD and FPM performance, allowing the effects of changing Core Engine parameter values to be studied.
4. The logged output from RAVE system will also be used for objective analysis of the TP and MTCD.
5. RAVE system accepts recorded data from real operational scenarios as input for various data types.
6. RAVE system reads radar data, tactical instructions, recorded MET data, and uses UK NAS output for Flight Plans.
7. RAVE system includes all the logging facilities that allow the analysis to the output from this phase of the validation using appropriate analysis tools.

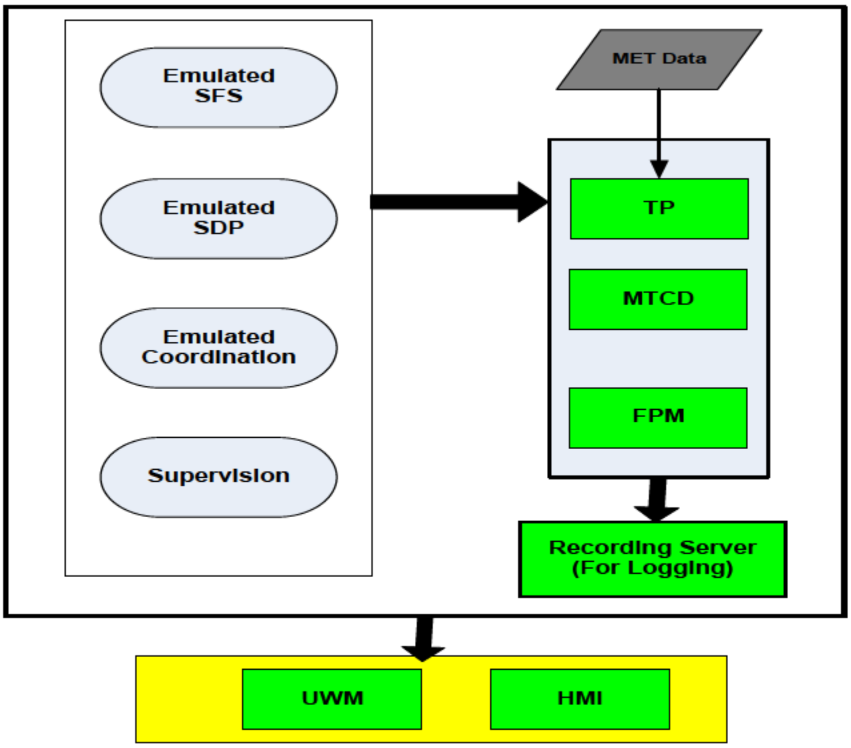

Figure 21: Overview of Replay-Aided Validation Environment (RAVE)

* ***UWM****Unit Workstation Manager*
* ***SDP****: Surveillance Data Processing*

Appendix E Subjective Validation Results (EXE 0301.0100)

E.1 Validation Scenario and system Preparation

The scenario was based in London TC and tested both the tool in its current form as well as the effects of trajectory prediction on TC controllers.

There were two scenarios based on:

- LAC Brecon (SCN-05.05.02-VALP-0020.0210) and
- LAC Dover (SCN-05.05.02-VALP-0020.0110).

E.1.1 LAC Brecon Scenario

The LAC Brecon scenario included the following characteristics:

- A significant vertical component with climbing and descending aircraft from their cruise level up from, or down to, low levels in TC.
- A significant amount of vertical change (in/out of LTMA to West, in/out of Manchester to South).
- The crossing point at Brecon provides significant opportunity for interactions.
- Vertical changes achieved by stepped procedures instead of continuous climb/descent.
- Relatively large arrival and departure peaks for heavy aircraft
- Heavy aircraft arrival and departure peak occur at different times.

E.1.2 LAC Dover Scenario

The LAC Dover scenario included the following characteristics:

- Sector 17 has long descents.
- Traffic is more unidirectional, arrivals and departures separated.
- Wide variety of heavy category aircraft ranging from 200 to 6000 nm.

E.1.3 Airspace Information

The validation of the tools in the SESAR definition of the TMA was achieved by application of the concept to LACC sectors. The following sectors were proposed for this validation:

LAC Brecon:

- Measured Sectors: LAC 5, 23
- Feed sectors: 6, 36, 8, 3, 7, 9, TC Ockham, PC Wallasey, PC S29, Ireland FIR (via OLDI)

LAC Dover:

- Measured Sectors: LAC 15, 16, 17
- Feed sectors: TC BIG, TIMBA, 25, Paris/Reims FIR (via OLDI)

E.1.4 Additional Information

Traffic Information

Assuming Continuous Climb Departures and Continuous Descent Arrivals profiles, flight vertical paths were adapted where needed to remove interim level clearances. These adaptations were documented.

Additional Data

In addition to the AOC data that formed major part of the information required for the validation activities there were a number of additional pieces of information required for the NATS RAVE system to compute a ground-based trajectory including:

Flight Plan Data

The flight plan data included:

- ICAO aircraft type designator.
- Start time.
- Start Fix.
- Cleared route – including origin and destination ICAO codes.
- True Air Speed (TAS).

Airspace data

The TP component of the NATS RAVE system required access to the airspace data. This included:

- A list of all fixes (including relevant fixes outside the UKFIR).
- Definition of sector volumes.

Radar data

Radar data was available at 6-second sample rate. The Radar plot data provided:

- Time.
- Aircraft position – system x, y coordinates.
- Smoothed Radar Data.
- The following Radar track parameters was also available for each Radar plot:
  - Ground velocity – ground speed and track
  - Altitude (climb/descent) rate – derived from Mode C

Tactical Instruction Data

Tactical data was entered into the NATS RAVE system directly.

Each tactical instruction was time-stamped. The time-stamp corresponded to the time the tactical data was entered through the HMI.

Aircraft Performance Data

The NATS RAVE system uses the BADA Aircraft Performance Model. The following data was provided by the aircraft performance model:

- True Air Speed
- Rate of Climb/Descent
- Bank angle

- For the aircraft performance model to provide the above data, it required:
- ICAO type
- Sea Level Temperature (From MET data)
- Mass Model
- Lateral / Vertical Manoeuvring State (Derived from Radar data)

Meteorological Data

The NATS RAVE system used forecast wind vector and temperature data. The wind and temperature data was obtained from forecast data in GRIB format from UK MET office.

The forecast data covered the entire UK FIR formatted as a configurable grid. The wind vector and temperature components were defined at each grid point.

All MET reports covered the day of recording and the previous day: 8 reports at 6 hour intervals starting at 00:00 on d-1 were available.

Coordination Data

Coordination data was input into the coordination server within the NATS RAVE system.

Exercise Assumptions

The exercise used sectors of the UK airspace that were consistent with the definition of SESAR TMA.

E.2 Validation Results

E.2.1 Vertical Profile

In response to OBJ-05.05.02-VALP-0040.0020, differences were only apparent during either the climb or descent phase.

Table 34 (below) shows that from 279 responses to interactions involving climbing aircraft with AOC data, 42 instances showed a preference (15%). Whilst from 141 responses to interactions involving descending aircraft with AOC data, 10 instances showed a preference (7%).

Summary	Climb			Level			Descend					
	Interactions with AOC data	Pref. A	Pref. B	Interactions with AOC data	Pref A	Pref B	Interactions with AOC data	Pref A	Pref B	Total Ints.	No. of Prefs.	%
Mass Only	109	7	4	12	0	0	41	3	5	162	19	11.73
Speed Only	70	5	5	8	0	0	34	0	0	112	10	8.93
Mass & Speed	100	15	6	14	0	0	66	0	2	180	23	12.78
Totals	**279**	**27**	**15**	**34**	**0**	**0**	**141**	**3**	**7**	**454**	**52**	**11.45**
No Uncertainty Change	59	3	5	8	0	0	41	3	2	108	13	12.04
Reduced Uncertainty	220	24	10	26	0	0	100	0	5	346	39	11.27
Totals	**279**	**27**	**15**	**34**	**0**	**0**	**141**	**3**	**7**	**454**	**52**	**11.45**
% Pref.	**15.05**	**42**		**0.0**	**0**		**7.09**	**10**				

Table 34: Summary table of controller responses sorted by AOC data type and uncertainty (non-AOC interactions excluded)

There was already a great deal of manipulation, in iFACTS, of the uncertainty during the descent phase to model the wide variations in descent profiles and to meet the airspace restrictions. This manipulation tended to overwhelm any influence that the introduction of AOC will have had.

In no cases were any differences noted for interactions involving AOC supported aircraft in level flight. As used in this exercise, the standard configuration of the system under test (SUT) uses radar derived ground speed to calculate the trajectory during this phase of flight. AOC data was therefore not expected to have an influence. Other near-term TP/MTCD systems could exhibit different behaviour in this regard.

E.2.2 Modification of Uncertainty

Subjectively the controllers reported that they noticed more difference between the 2 displays when the uncertainty was reduced. However, in practise, this made little difference to their overall choice of preference (see Table 35)

Summary	**Climb % Pref.**	**Level % Pref.**	**Descend % Pref.**
No Uncertainty Change	13.56	0	12.20
Reduced Uncertainty	15.45	0	5.00

Table 35: Proportions of controller responses to uncertainty settings

E.2.3 Differences between types of AOC data

With AOC mass data applied controllers expressed a preference in 12% of cases (including both standard and reduced uncertainty cases).

The assumption had been made prior to the exercise that it was unlikely that the participants would notice any difference with the application of speed-only data with standard uncertainty. Because of this, no runs were conducted with this configuration.

With the application of AOC speed data along with reduced uncertainty, 9% of cases observed elicited a choice from the controllers, and all of these were from climbing aircraft.

With the application of mass and speed data together, the participants subjectively appeared to notice the most difference in the display of interactions, but that observation is not substantially borne out by the results with 11.5% (standard uncertainty) and 13% (reduced uncertainty) rates of preference.

Summary	**Climb**		**Level**		**Descend**				
	Interactions with AOC data	**Pref. A B**	**Interactions with AOC data**	**Pref A B**	**Interactions with AOC data**	**Pref A B**	**Total Ints.**	**No. of Prefs.**	**%**
Mass AOC data + Std. Uncert.	55	3 2	6	0 0	21	3 2	82	10	12.20
Mass AOC data + Red. Uncert.	54	4 2	6	0 0	20	0 3	80	9	11.25
Speed AOC data + Std. Uncert.	Not Run -- No Data								
Speed AOC data + Red. Uncert.	70	5 5	8	0 0	34	0 0	112	10	8.93
Mass & Speed AOC Std. + Uncert. data	4	0 3	2	0 0	20	0 0	26	3	11.54
Mass & Speed AOC data + Red. Uncert.	96	15 3	12	0 0	46	0 2	154	20	12.99

Table 36: Summary table of controller responses sorted by AOC data as applied by run (non-AOC interactions excluded)

Notes:

1. There were no runs with speed data only with standard uncertainty.
2. Of 112 interactions examined using speed data with reduced uncertainty there were 10 preferences, equating to 8.93%.
3. 82 interactions were viewed with mass data and standard uncertainty, which produced 10 preferences, equating to 12.20%.
4. 80 interactions with mass data with reduced uncertainty were viewed with 9 preferences, 11.25%.
5. 26 interactions with mass and speed data with standard uncertainty elicited 3 preferences, equating to 11.54%.
6. 154 interactions using mass and speed data with reduced uncertainty revealed 20 preferences, equalling 12.99%.
7. A total of 279 interactions involving at least one climbing aircraft showed 42 preferences, equating to 15.05%.
8. 141 interactions involving at least one descending aircraft were viewed and showed 10 preferences, 7.09%.
9. 34 interactions where the AOC supported aircraft was level were assessed and no preferences were recorded.
10. As expected, no preferences were recorded for any of the non-AOC interactions.

Appendix F Airlines Cost Benefit Analysis Model

F.1 Excel Airline CBA Model File

To have a copy of the Excel Airline CBA Model file please contact any member of the Cost Benefit Analysis team contributed in this study. Names can be found at the front of this document. Please contact any member of the CBA team at firstname.lastname@eurocontrol.int (e.g. Kirsteen.purves@eurocontrol.int). They will be able to provide the file and support, if necessary.

F.2 Airline Model File Overview

This is a copy of table from the 'Table of Content' worksheet of Excel file; it describes the content of the different worksheets.

Table of content

Tab in this file	Description
Description	Description of the model
Model Inputs	Area where users can enter inputs on the number of flights by type of aircraft: regional, single and twin aisle
Model Outputs	Presentation of the results of the calculation: benefit, costs, Net Present Value, environmental impact
Model Assumptions	List of assumptions used in the model. For the benefits: Baseline, Base case and Scenario For the cost: communication, software development, and environment
Aircraft Assumptions	List of assumption used for the aircrafts: flights per aircraft type and additional fuel burn due to a level-off.
Trial	Proposed set of input figures to test the model

Figure 22: Table of content for the Airline Model Tool

F.2.1 "Description" worksheet

The worksheet 'Description' contains the logic for defining the number of Level-offs Avoided and the Level-offs Segmentation, included in this report as Figure 10 and Figure 11.

F.2.2 "Model Input" worksheet

The worksheet' Model Inputs' is shown in

Figure 23, it allows an airline to enter the specifics of their fleet as well as update parameters such as fuel cost and discount rate.

Aircraft category	Yearly number of flights by category	in %	Input Names
Regional:	91,250	24%	Regional_Flts_Num_In
Single Aisle:	210,240	55%	Single_Aisle_Flts_Num_In
Twin Aisle:	80,300	21%	Twin_Aisle_Flts_Num_In
Total flights	381,790	100%	Total_flights_In
Cost of fuel in € per kg *:	0.776		Fuel_Cost

* EUROCONTROL Recommended Value: 0.776€ per kg (date: 15.02.2012)

Environmental inputs		Input Names
European Emission Allowance permits	0	Airline_EUA_permits

Financial inputs		Input Names
Discount rate in %	8%	Discount_rate
Number of years	5	Number_of_years

Figure 23: Airline Model – Model Inputs Sheet

F.2.3 "Model Output" worksheet

The worksheet 'Model Outputs' is shown in Figure 24. It shows the results at ECAC level and also for the specific airline inputs entered in the 'Model Inputs' sheet (assuming the airline is sharing their AOC data). It also shows the results from the Environmental impact calculations.

ECAC-wide results

Level-offs avoided below FL 300 per year	**447,129 € per year**
Level-offs avoided @ FL 300 & above per year	**1,056,257 € per year**
Total Benefit	**1,503,386 € per year**
Total Cost	**225,700 € per year**
Benefit to cost ratio	**6.7**
Net present value	**5,509,545 € after 5 y**

Your airline results

Assuming your airline is **sharing data** (for all flights in the 'Model Inputs' sheet)

Level-offs avoided below FL 300 per year	**21,765.92 € per year**
Level-offs avoided @ FL 300 & above per year	**54,798.73 € per year**
Total Benefit	**76,564.65 € per year**
Total Cost	**9,836.76 € per year**
Benefit to cost ratio	**7.8**
Net present value	**287,739 € after 5 y**

Environmental impact

Avoided total cost of CO_2	**11,642 € per year**
Total unused EUA[(1)] permits	**311 per year**
Total unused EUA in €	**2,486 € per year**

[(1)] European Emission Allowance

Figure 24: Airline Model – Model Outputs Sheet

Note: In Figure 23 and Figure 24 the airline data and results are those for the Mainline Airline type.

F.2.4 "Model Assumptions" worksheet

The 'Model Assumptions' sheet contains Table 37, Table 38, Table 39 and Table 40. These 4 tables detail the parameters used in the Airline Model.

Table 37 lists the baseline constants; these are general inputs to the model.

Model Parameters	Short Name	Value	Unit	Source		Comment
Baseline constants						
Traffic volume ECAC, 24h day	Traffic_Sample_Size	24000	Number	Validation Report		Approximate number of flights considered in the traffic used for the modelling linked to conflict detection in the validation report.
Participation percentage	Participation_Rate	100%	Proportion	User setting		Value can be modified to correspond to the supposed level of airlines participation in sharing AOC data (i.e. take-off mass and speed). For example, a 50% participation level could be considered for few years, then a greater participation level.. The model assumes ECAC like traffic distribution (aircraft types) among the participants.
Percentage of conficts solved using a level-off	Level_off_conflicts_solved_pc	75%	%	Fast Time Simulation (ECAC wide) results, NATS ATC questionnaire answers		This is the percentage of climb/cruise conflicts (true or false) solved using level-off. Value has been chosen using operational input.
Number of days in a year	Days_in_Year_Num	365	Number			
Percentage of MTCD false alerts, leading to a conflict resolution	False_alert_conflict_resolution_pc	100%	%	NATS ATC questionnaire answers		This was set to 100%: for every alert (including false alerts, detected by comparing conflicts in a reference list (based on "perfect" trajectories) vs. conflicts detected using "TP noised" trajectories)) , ATC will always (100%) inititates conflict resolution action. This might not be always the case: the ATC will always assess the alert (ATCO questionnaire answer), and might discard or postpone the resolution waiting for a more certain/accurate information.

Table 37: Baseline constants used in the Airlines Model

Table 38 lists the base case assumptions; these are the values reflecting the business as usual situation with the sharing of the AOC data.

Model Parameters	Short Name	Value	Unit	Source		Comment
Base case assumptions						
Number of baseline computed alerts	Computed_Alerts_Num_BL	3,600	Number	Validation Report		Number of alerts (model) for **climb/cruise** conflicts based on trajectories with typical errors of a ground TP without AOC data. Climb/cruise conflicts only are considered as these are often solved using level-off. This is not the case for climb/climb conflicts.
Proportion of baseline computed alerts (per flight)	Computed_Alerts_Proportion_BL	0.15	Proportion	Validation Report		Previous number of baseline computed alerts divided by the traffic volume ECAC 24h.
Percentage of baseline false alerts	False_Alerts_BL_pc	40%	%	Validation Report		A false alert is detected when an alert is raised using the ground TP with typical errors without AOC data, and this alert does not exist using the reference known trajectories (no noise). The percentage of baseline false alerts is the number of baseline false alerts divided by the traffic volume ECAC 24h. These are modelled false alert rates, not operational ones.
Number of baseline false alerts	False_Alerts_BL_Num	1,440	Number	Validation Report		Number of alerts multiplied by the percentage of false alerts.
Level-off fuel burn	*See Table Level-off fuel burn*			Airlines partners		A table providing excess fuel burn (in kg) for 3 broad aircraft categories (regional, single aisle, double aisle), at different altitudes.

Table 38: Base Case Assumptions used in the Airlines Model

Table 39 lists the scenario assumptions; these are the values reflecting the situation with the sharing of the AOC data.

Model Parameters	Short Name	Value	Unit	Source		Comment
Scenario assumptions						
Number of improved computed alerts	Computed_Alerts_Num_SC	3,800	Number	Validation Report		Number of alerts (model) for climb/cruise conflicts based on trajectories with typical errors of a ground TP with AOC data. Comparing to the baseline case, there are less false conflict alerts and less missed conflict alerts
Proportion of improved computed alerts	Computed_Alerts_Proportion_SC	0.16	Proportion	Validation Report		Similar definition to base case
Percentage of improved false alerts	False_Alerts_SC_pc	30%	%	Validation Report		Similar definition to base case
Number of improved false alerts	False_Alerts_SC_Num	1,140	Number	Validation Report		Similar definition to base case
Number of false alerts avoided	False_Alerts_Improved_Num	300	Number	Validation Report		Difference between the numbers of false alerts with AOC data vs. Base case. A
Number of level-offs avoided	Level_Off_Avoided_Num	225	Number	Validation Report		This is the number of false alerts avoided multiplied by the percentage of conflicts solved using a level-off multiplied by the percentage of false alerts leading to conflict resolution. Then, this number is corrected
Percentage of level-offs avoided	Level_offs_avoided_pc	0.938%		Calculation		Number of level-offs avoided divided by the
Proportion of climb/cruise conflict alerts @ FL300 & above (ECAC traffic)	Level_offs_FL_300plus_pc	79%	%	Validation Report		This information is extrapolated from the validation report. All avoided level-off do not have the same benefit associated: it depends on the altitude (and associated fuel burn) where it happens. A separation at FL300 has been
Proportion of climb/cruise conflict alerts below FL300 (ECAC traffic)	Level_offs_FL_300less_pc	21%	%	Validation Report		This information is extrapolated from the validation report
Number of level-offs avoided @FL300 & above	Level_offs_avoided_FL_300plus_Num	178	Number	Calculation		Number of level-off avoided multiplied by the proportion of climb/cruise alerts at FL300 &
Number of level-offs avoided below FL300	Level_offs_avoided_FL_300less_Num	47	Number	Calculation		Number of level-off avoided multiplied by the proportion of climb/cruise alerts below
Daily percentage of level-offs avoided @FL300 & above	Level_offs_avoided_FL_300plus_pc	0.741%	%	Calculation		Number of level-offs avoided at FL300 & above divided by the ECAC traffic volume;
Daily percentage of level-offs avoided below FL300	Level_offs_avoided_FL_300less_pc	0.197%	%	Calculation		Number of level-offs avoided below FL300 divided by the ECAC traffic volume;

Table 39: Scenario assumptions used in the Airlines Model

Table 40 lists the cost assumptions used in the Airline model.

Cost assumptions						
Model Parameters	**Short Name**	**Value**	**Unit**	**Source**		**Comment**
Comms costs						
Cost in € for the increase of SITA Type B messages for one ATC flight plan.	Cost_per_flight_transmission	0.0075	€	SITA (Type B messages)		Cost based on an increase of 10% of a typical FPL SITA message size to provide mass & speed information from about 250 characters to about 275; i.e. 0.075*10% = €0.0075 per flight plan.
Software costs						
Cost in € for software development	Cost_software	800,000	€			Estimation per ANSP based on 1 FTE (200 w.d.) @400€/day. Cost calculated for 10 ANSP
Number of year of depreciation	Depreciation_years	5	Number	2011 ECTL Standard Inputs		
Cost in € for software development for one flight (1 year traffic sample)	Cost_software_per_flight	0.0183	€			Cost_software divided by the number of years of depreciation divided by the number of annual flights
Environmental costs						
Amount of CO_2 released per tonne fuel	CO2_released_ton	3.149	tonne	2011 ECTL Standard Inputs		
Cost of CO_2 in € per tonne fuel	CO2_cost_ton_euro	37.47	€	2011 ECTL Standard Inputs		
EUA (European Emission Allowance) in € per tonne of CO_2	EUA_benefit_euro	8	€	2011 ECTL Standard Inputs		One permit is emitted for 1 metric tonne of CO^2

Table 40: Cost Data used in the Airlines Model

F.2.5 "Aircraft Assumptions" worksheet

The 'Aircraft Assumptions' sheet contains Table 41.

Table 41 lists the aircraft assumptions; these are the values associated with the fuel burn savings from avoiding level-offs.

Level-Off fuel burn constants	Short Name	Value	Unit	Source	Comment
Proportion of flights per aircraft type					
Single Aisle B733 or similar	Single_B3_pc	35%	%	2011 Standard Inputs for EUROCONTROL CBA	
Single Aisle B73X or similar	Single_BX_pc	34%	%	2011 Standard Inputs for EUROCONTROL CBA	
Twin Aisle	Twin_pc	6%	%	2011 Standard Inputs for EUROCONTROL CBA	
Regional	Regional_pc	25%	%	2011 Standard Inputs for EUROCONTROL CBA	
ECAC number of flights 2010	ECAC_Flts_2010_Num	9,500,000	Number	2011 Standard Inputs for EUROCONTROL CBA	
Additional Fuel burn due to level-off					
Typical single aisle @ FL 300+ fuel savings	Typical_Single_300plus_fuel_svgs	19.5	kg per 4'	5.5.2. airspace users participants	
Typical single aisle @ FL 300- fuel savings	Typical_Single_300less_fuel_svgs	40.5	kg per 4'	5.5.2. airspace users participants	Average duration based on answers received from NATS ATC (about 5-6 minutes) and a ECTL Ops (about 2-3 minutes)
Typical twin aisle @ FL 300+ fuel savings	Typical_Twin_300plus_fuel_svgs	38.0	kg per 4'	5.5.2. airspace users participants	
Typical twin aisle @ FL 300- fuel savings	Typical_Twin_300less_fuel_svgs	64.0	kg per 4'	5.5.2. airspace users participants	
Typical regional @ FL240 fuel savings	Typical_Regional_fuel_svgs	6.5	kg per 4'	5.5.2. airspace users participants	

Table 41: Aircraft Assumptions used in the Airlines Model

F.2.6 "Trial" worksheet

The 'Trial' sheet contains the results tables shown in section 8.2.

Appendix G Sensitivity Analysis for CBA Model

Sensitivity analysis examines the sensitivity of the project's economic performance – its costs and benefits – to the variation of individual parameters in order to identify the most critical issues and the degree of their impact.

The most significant parameters to be considered in the conduct of a sensitivity analysis will vary from case to case and cannot be identified in advance.

The results of a sensitivity analysis are usually presented graphically. Tornado diagrams are the standard tool for this purpose.

A Tornado diagram compares the results of multiple analyses. The X-axis is drawn in the units of the expected value (typically NPV), and then for each variable (listed on the Y-axis), a bar is drawn between the extreme values of the expected value calculated from the lower and upper bound values (which requires data to be provided in ranges). Figure 25 shows the AOC concept Tornado diagram. The variable with the greatest range is plotted on the top of the graph, and the remaining variables proceed down the Y-axis with decreasing range. The longest bar in the graph is associated with the variable that has the largest potential impact on expected value, and thus needs careful attention.

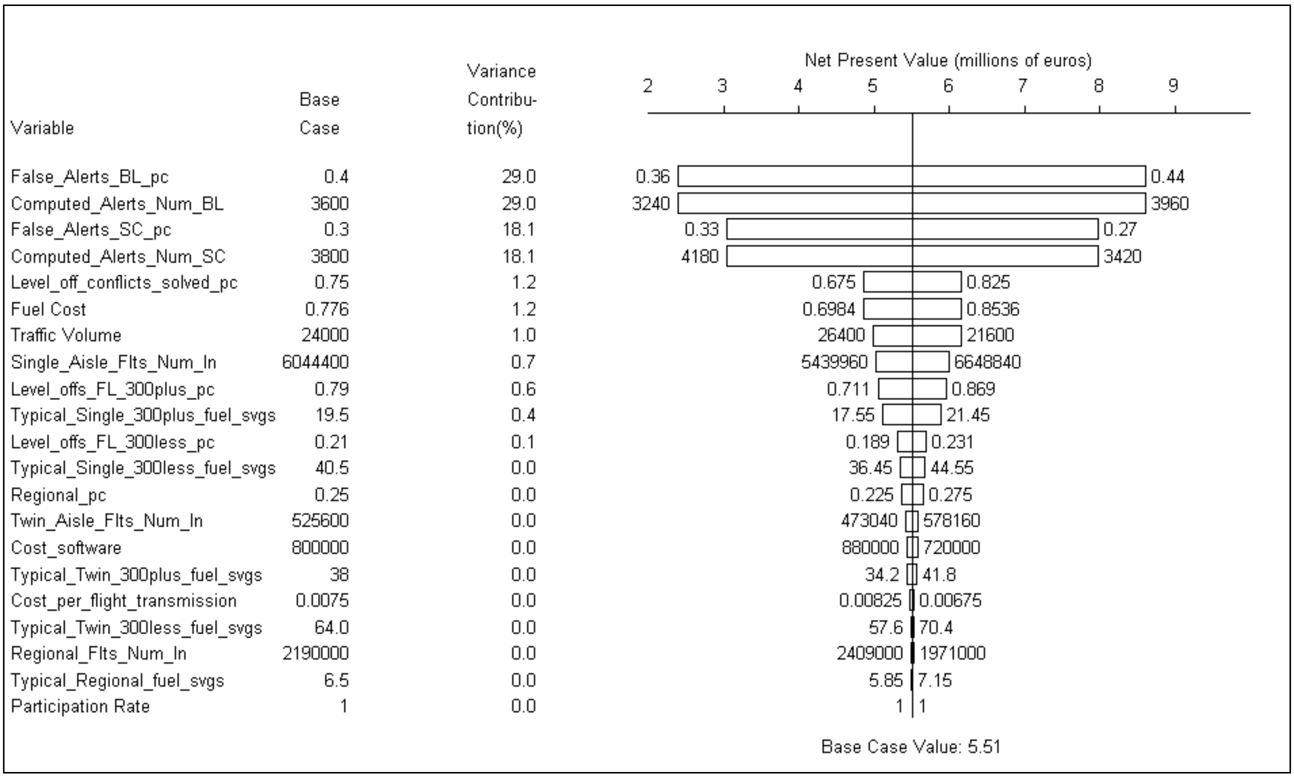

Figure 25: AOC concept Tornado diagram

(Details of the variables can be found in Appendix F.1. The name shown in the tornado diagram can be found in the 'short name' column of the tables.)

The Tornado graph brings attention to the variables that require further attention and should be the focus of any further work. In most real projects, the Pareto rule will happen, as 20% of the variables will typically account for 80% of possible expected value excursion.

Appendix H Probabilistic Analysis for CBA Model

Probabilistic Risk Analysis provides the probability distributions of output magnitudes. The decision-maker can then have a complete picture of all the possible outcomes.

These probability distributions can then be used to perform different assessments:

- Determine a correct range for the results
- Identify probability of occurrence for each possible outcome

As a result, it is easy to get an overview of the risks involved and a feeling for how they should be addressed.

The probabilistic risk analysis is based on Monte Carlo simulation, and that is the reason why the confidence intervals associated with the inputs of the model have to be carefully assessed in order to get the results as reliable as they can be.

Figure 26 shows the AOC concept (ECAC level) cumulative probabilistic distribution:

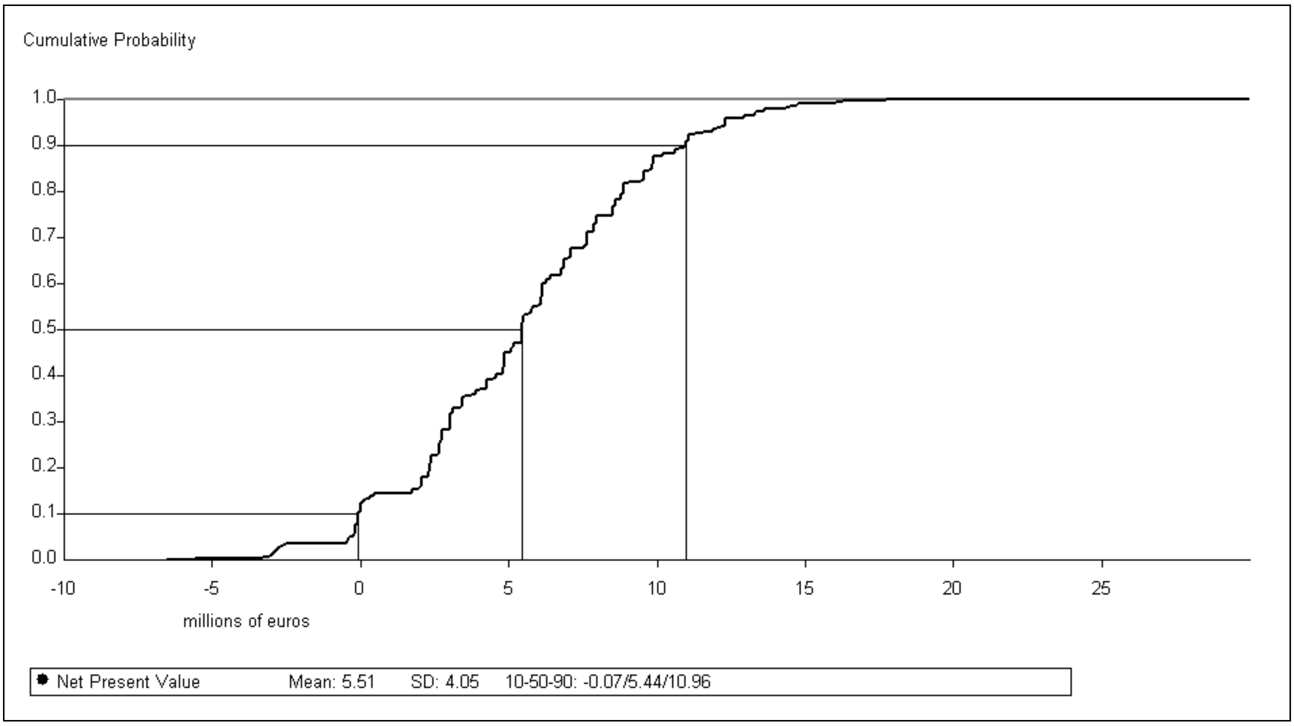

Figure 26: AOC Concept Cumulative Probability Curve

The diagram shows the probability of having a result equal or higher to a defined value. SD is the standard variation and measures the spread of the data about the mean value.

1516
Appendix I Overview of Validation Objectives Status for P 05.05.02

1517

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0010.0010	Sensitivity to AOC data accuracy / Trajectory accuracy improvement	CRT-05.05.02-VALP-0010.0010	The accuracy of a predicted trajectory is improved considerably when AOC data is used in the prediction when compared to the accuracy without the use of AOC data.	There are a number of cases where accuracy improved: 1. AOC mass for climbed aircraft. 2. AOC speed for climbed aircraft. 3. AOC mass and speed for climbed aircraft. AOC mass for decent aircraft.	OK
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0010.0010	Sensitivity to AOC data accuracy / Trajectory accuracy improvement	CRT-05.05.02-VALP-0010.0010	The accuracy of a predicted trajectory is improved considerably when AOC data is used in the prediction when compared to the accuracy without the use of AOC data.	There are a number of cases where accuracy improved: 1. AOC mass for climbed aircraft. 2. AOC speed for climbed aircraft. 3. AOC mass and speed for climbed aircraft. AOC mass for decent aircraft.	OK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0050.0010	Ability to apply concept to current TP systems	CRT-05.05.02-VALP-0050.0010	The TP algorithm used in the test is representative of current or near term TP systems.	Minor modification introduced to iFACTS TP algorithms that allowed the use of AOC data in the iFACTS system.	OK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0050.0110	Ability to apply concept to ATC tools that use TP	CRT-05.05.02-VALP-0050.0110	AOC data is used in a demonstration using current or near-term	The sample data used is a mixed of AOC supported and non-supported aircraft.	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		systems		operational ATC tools.		
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0050.0110	Ability to apply concept to ATC tools that use TP systems	CRT-05.05.02-VALP-0050.0110	AOC data is used in a demonstration using current or near-term operational ATC tools.	AOC data successfully demonstrated in a near-term operational ATC toolset (iFACTS).	OK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	CRT-05.05.02-VALP-0010.0110	A variation limit on the AOC parameters can be established that ensures accuracy equal or greater than the stability without AOC data..	The effect of modification introduced to reported AOC data investigated and stability of the ATC system using TP with AOC data validated.	OK
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0010.0110	Sensitivity to AOC data accuracy	CRT-05.05.02-VALP-0010.0110	A variation limit on the AOC parameters can be established that ensures accuracy equal or greater than the stability without AOC data.	There is a noticeable improvement in the TP accuracy as a result of using AOC data.	OK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0020.0010	CDnR tool performance improvement / CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance	CRT-05.05.02-VALP-0020.0010	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	There is a benefit in using AOC data for CDnR tool performance. Highest benefit is obtained by using AOC mass and speed data combined. See detailed objectives results below.	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		without the use of AOC data.				
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0020.0010	CDnR tool performance improvement / CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	CRT-05.05.02-VALP-0020.0010	CDnR tool performance for Area Control improves when the underlying TP is supported by AOC data when compared to performance without the use of AOC data.	Noticeable improvements in the performance of CDnR when the underlying TP is supported by AOC data.	OK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0030.0010	ATM system performance improvement through AMAN	CRT-05.05.02-VALP-0030.0010	The reliability and stability of a proposed AMAN sequence is improved considerably.		NOK
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0030.0110	ATM system performance improvement through CDnR	CRT-05.05.02-VALP-0030.0110	The rates of false and missed alerts of CDnR tool are reduced.	(ECAC and high density core area results are similar) Compared to performance without the use of AOC Data, Missed conflicts alert rates due to TP errors, reduces by 10% (look-ahead 8-18 minutes) using Mass and Speed AOC data combined, for conflicts with at least one aircraft in climb. The reduction is about 12% for look-ahead 5-8 minutes.	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					Benefits for conflicts missed alerts cruise/cruise are small. False conflicts alert rates due to TP errors, reduces from 5% (cruise/cruise) to 10% (cruise/climb) (look-ahead 8-18 minutes) using Mass and Speed AOC data combined, depending in conflict type. The reduction numbers are similar for look-ahead times 5-8 minutes. -The increase in continuous climb is related to the false alert rate reduction for conflicts (involving at least on aircraft in climb): The false alert rates decreasing by 10%, the rate of continuous climb stopped unnecessary due to a false alert will reduce at most by 10%.	
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0030.0110	ATM system performance improvement through CDnR	CRT-05.05.02-VALP-0030.0120	The number of continuous climbs available through the CDnR tool is increased.	(ECAC and high density core area results are similar) Compared to performance without the use of AOC Data, Missed conflicts alert rates due to TP errors, reduces by 10% (look-ahead 8-18 minutes) using Mass and Speed AOC data combined, for conflicts with at least one aircraft in climb. The reduction is about 12% for look-ahead 5-8 minutes. Benefits for conflicts missed alerts cruise/cruise are small. False conflicts alert rates due to TP errors,	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					reduces from 5% (cruise/cruise) to 10% (cruise/climb) (look-ahead 8-18 minutes) using Mass and Speed AOC data combined, depending in conflict type. The reduction numbers are similar for look-ahead times 5-8 minutes. -The increase in continuous climb is related to the false alert rate reduction for conflicts (involving at least on aircraft in climb): The false alert rates decreasing by 10%, the rate of continuous climb stopped unnecessary due to a false alert will reduce at most by 10%.	
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	CRT-05.05.02-VALP-0040.0010	Demonstrated that grossly incorrect values for AOC data parameters can be detected.	Investigated during system test prior to simulation activity.	OK
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0040.0010	Rejection of invalid data	CRT-05.05.02-VALP-0040.0010	Demonstrated that grossly incorrect values for AOC data parameters can be detected.	Investigated during system test prior to simulation activity.	OK
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0040.0020	Baseline operation without AOC data	CRT-05.05.02-VALP-0040.0020	An operational system is demonstrated to use AOC data in a subset of the flights it handles	AOC data successfully applied for a subset of flights.	OK
EXE-	OBJ-05.05.02-	Baseline	CRT-05.05.02-	An operational system	AOC data successfully applied for a subset	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
05.05.02-VP-301	VALP-0040.0020	operation without AOC data	VALP-0040.0020	is demonstrated to use AOC data in a subset of the flights it handles	of flights.	
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0040.0210	Unconditional data acceptance	CRT-05.05.02-VALP-0040.0210	AOC data with grossly incorrect values is taken into the system. (Note that OBJ-05.05.02-VALP-0040.0010 prevents this data from subsequently being used)	Investigated during system test prior to simulation activity.	OK
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0040.0210	Unconditional data acceptance	CRT-05.05.02-VALP-0040.0210	AOC data with grossly incorrect values is taken into the system. (Note that OBJ-05.05.02-VALP-0040.0010 prevents this data from subsequently being used)	The system successfully switched to current base line using the default BADA values.	OK
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0040.0310	Correct fall back to baseline operation	CRT-05.05.02-VALP-0040.0310	TP system generates usable trajectory based on the baseline algorithm for aircraft for which grossly incorrect AOC data is supplied.	Investigated during system test prior to simulation activity.	OK
EXE-	OBJ-05.05.02-	Correct fall back	CRT-05.05.02-	TP system generates	Investigated during system test prior to	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
05.05.02-VP-301	VALP-0040.0310	to baseline operation	VALP-0040.0310	usable trajectory based on the baseline algorithm for aircraft for which grossly incorrect AOC data is supplied.	simulation activity.	
EXE-05.05.02-VP-069	OBJ-05.05.02-VALP-0060.0110	Some benefit achieved without full AOC data support	CRT-05.05.02-VALP-0060.0110	Benefit is available in a mixed-mode scenario	AOC data successfully applied for a subset of flights and accuracy improvements achieved in computed TP.	OK
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0060.0010	Demonstrate use of AOC data in TP in operational system.	CRT-05.05.02-VALP-0060.0010	A representative operational system uses AOC data to improve TP accuracy.	AOC data successfully demonstrated in a near-term operational ATC toolset (iFACTS).	OK
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0060.0010	Demonstrate use of AOC data in TP in operational system.	CRT-05.05.02-VALP-0060.0010	A representative operational system uses AOC data to improve TP accuracy.	AOC data successfully demonstrated in a near-term operational ATC toolset (iFACTS).	OK
EXE-05.05.02-VP-300	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode / Prototype concept demonstration	CRT-05.05.02-VALP-0070.0010	AOC data provided to iFACTS system that received it and demonstrated the ability to handle it.	AOC data successfully provided, received and handled by a near-term operational ATC toolset (iFACTS).	OK
EXE-05.05.02-VP-301	OBJ-05.05.02-VALP-0070.0010	Demonstrate use of AOC data in mixed mode / Prototype concept demonstration	CRT-05.05.02-VALP-0070.0010	AOC data provided to iFACTS system that received it and demonstrated the ability to handle it.	AOC data successfully provided, received and handled by a near-term operational ATC toolset (iFACTS).	OK

Table 42: Overview: Validation Objectives, Exercises Results and Validation Objectives Analysis Status for P 05.05.02

- **END OF DCUMENT –**