Final Project Report

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Abstract

The objective of P10.2.2 is to specify the Trajectory Prediction and Trajectory Management (TM) related information exchange to improve ground/ground and air/ground interoperability. The trajectory data to be exchanged is intended to be evolving in successive steps from current implementation of TM to the final envisaged TM. This project aims to develop a specification for TM Exchange Format (TMEF). In the specification, it proposed a way to encode and interpret the exchanges. The basic input to the project is all the data and information needed to be exchanged between ATM components, and the output of the project is TMEF covering these needs/requirements. One must also note that this project is more tailored to beyond Step 1, but unfortunately, due to known reasons; it had to be cut at the end of Step 1. What should be done in the future regarding this topic has been covered in section 1.5 Project Conclusion and Recommendations.

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Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
4D	4 Dimensional
ADS-C	Automatic Dependent Surveillance - Contract
AI	Aircraft Intent
AIDL	Aircraft Intent Definition/Description Language
AIRM	ATM Information Reference Model
ASIS	Aircraft intent Synchronisation in support of SESAR
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATS	Air Traffic Services
CDM	Collaborative Decision Making
CHMI	Controller Human Machine Interface
ConOps	Concept of Operations
CPDLC	Controller Pilot Datalink Communications
CTA	Controlled Time of Arrival
DOD	Detailed Operational Description
DST	Decision Support Tool
EA	Enterprise Architecture
ENB	Enabler
EPP	Extended Projected Profile
ER/APP	En-Route / Approach
EUROCAE	European Organisation for Civil Aviation Equipment
EXE	Exercise
FI	Flight Intent
FIXM	Flight Information Exchange Model

FO	Flight Object
FS	Flight Script
HMI	Human Machine Interface
i4D	Initial 4D
IOP	Interoperability
IRS	Interface Requirements Specification
MONA	Monitoring Aids
NM	Network Management
NOP	Network Of Operations
OFA	Operational Focus Area
OI	Operational Improvement
RBT	Reference Business Trajectory
REACT	Requirements Elicitation for an AIDL that supports Consistency across TPs
RMT	Reference Mission Trajectory
SBT	Shared Business Trajectory
SC	Steering Committee
SESAR	Single European Sky ATM Research Programme
SOA	Service Oriented Architecture
SPR	Safety and Performance Requirements
SWIM	System Wide Information Management
TAD	Technical Architecture Document
TM	Trajectory Management
TMA	Terminal Manoeuvring Area
TMEF	Trajectory Management Exchange Formats
TMF	Trajectory Management Framework
TN	Technical Note
TP	Trajectory Prediction/Predictor

WG	Working Group
WP	Work Package

1 Project Overview

The Trajectory Management Exchange Formats (TMEF) whose need and specification have been provided by project P10.02.02 aimed specifying the Trajectory Prediction (TP) and Trajectory Management (TM) related information exchange to improve ground/ground and air/ground interoperability. It provided and interpreted the means to improve the trajectory consistency between systems and supports the improvement of trajectory prediction accuracy.

The trajectory management related data to be exchanged was intended to be evolving in successive steps from current implementation of TM to the final envisaged TM, considering the system needs and capabilities.

The project used requirements received from the partners as input and developed a specification for TMEF, in which it proposed a way to encode/decode and interpret these exchanges, including ATM systems, Aircraft, Airline Operations, Network Operations, Airports and Military.

1.1 Project progress and contribution to the Master Plan

In addition to the projects achievements described in the following section, it contributed to the following areas :

- Co-ordination with relevant projects both in the technical and operational side
- Co-ordination with TMF projects and activities (e.g. 4D Trajectory Study, etc.)
- Co-ordination at WP10 level to ensure consistency and efficient information flow
- Close co-ordination with P10.1.7 regarding
    - Technical Architecture Document (TAD)
    - Functional Block Decomposition
    - Information Flow
    - Requirements Consolidation
- Co-ordination with WP7 for NOP related matters
- Co-ordination with WP9.1 for airborne related matters
- Co-ordination with WP8 & WP16 for Information Management issues
- Co-ordination with WPB for concept and terminology related issues where contributions were provided for :
    - Trajectory Management Concept Document
    - Trajectory Management paper on the use of the RBT
    - WPB Synthetic View
    - Progressing SBT/RBT concepts
    - Use of RBT in ATM systems
    - i4D and CTA co-ordination
    - Trajectory Prediction Issues
- Co-ordination with WP4.2/5.2 for DODs
- Co-ordination with WP4.3 for Validation Roadmap and Release Plans

- Co-ordination with P10.2.5 for Flight Planning (Flight Object) related matters
- Co-ordination with WP10.7.1 for air/ground exchange related issues
- Co-ordination with WPE (particularly iMET and UTOPIA)
- Co-ordination activities regarding both AIRM and FIXM
- Co-ordination with Airspace Users
- Participation in CP3.1 (Trajectory Prediction and Exchange)
- Participation in CP3.2 (Flight Planning and Dynamic Flight Plan Updates)
- Input provided to standardization and regulatory work
- Co-ordination with EUROCAE WG78 for air/ground TM related exchanges
- Co-ordination with EUROCAE WG59 for architectural issues
- Review of other projects' deliverables
- Participation in the review and update of Operational Improvements(OIs) and Enablers
- Participation in the EPP task force
- Participation in the Validation Exercises (the details are provided in Section 1.4 below)
- Co-ordination with Military
- Co-ordination with Safety and Security Experts
- 4DTrad position paper presented at EUROCAE WG7

Contributions to the OI steps:

Please note that in the below table

- The maturity rated is the OI maturity (and not the enabler maturity)
- Maturity at end of project: we considered maturity today (even if different from what was expected)

1.2 Project achievements

The main objectives/achievements of this project were:

To achieve projects' objective, it was proposed to come up with a means of encoding and interpreting the information exchanges, while covering all the data and information needed to be exchanged between:

- ATC Systems
- Aircraft
- Airline Operations
- Network Operations
- Airports
- Military Systems

To support the TP and TM processes. The trajectory data exchanged were evolved in successive steps from the current implementation of TM to the final envisaged TM.

The project contributes to AIRM/FIXM which are also linked to WP08, this is how the projects are indirectly connected. As a result of the interaction between some WP08 projects (e.g. P8.1.3) with P10.2.2, there were changes implemented in new versions of both AIRM and FIXM. These changes were documented in the reports on Step 1 activities (e.g. see section 2.4 in D76).

The following table lists the Enablers the project has contributed to together with the nature of contribution:

ENABLER	ENABLER TITLE	CONTRIBUTION
ER APP ATC 14 a/b/c/d/e/f	Controller Tools to Use Aircraft-Derived 4d Data	The project contributed to the definition and improvement of the data exchange required as a basis for these two enablers for the exchange of aircraft data between air and ground. In this respect the project works in co-ordination with WP9.1 for airborne related matters, with EUROCAE WG78 for air/ground TM related exchanges standardisation, with P10.7.1 for air/ground exchange related issues. The participation of the project to the EPP task forces also contributes to these enablers. From FDPS point of view, the trajectory will be calculated using ADD when available. Merging all ADD related enablers in one will mean this enabler to be validated as a whole. As ADD can be received by different ways (Mode S, ADS-B, ADS-C) and the data used for improvement of ground TP , Safety nets, Conflict Management and Monitoring aids are not necessarily the same and also as these topics are addressed by different WP10 projects, it seems relevant to keep four enablers (ground TP, Safety Nets, Conflict Management and Monitoring Aids). It does not seem necessary to differentiate ER and APP.
ER APP ATC 70b/d	Manage ADD from A/C for FDP and Tools	The project contributed to the definition and improvement of the data exchange required as a basis for these two enablers for the exchange of aircraft data between air and ground. In this respect the project works in co-ordination with WP9.1 for airborne related matters, with EUROCAE WG78 for air/ground TM related exchanges standardisation, with WP10.7.1 for air/ground exchange related issues. The participation of the project to the EPP task forces also contributes to these enablers. From FDPS point of view, the trajectory will be calculated using ADD when available. Some use of ADD is foreseen for step 1 (aircraft weight and vertical profile) for the P10.2.1 prototype. Step 2 objective was to extend the use of ADD to speed schedule and other data available through EPP. In step 1, prototype(s) will already use some ADD data derived from EPP (e.g. TOD) and times to update ground trajectory prediction. It was recommended to check the potential

		overlap with ER APP ATC 14 (they could be merged).
ER APP ATC 82a	FDP to Use SBT/SMT, RBT/RMT	The project contributed to the modelling of the trajectory data required by the FDP for trajectory prediction purpose. This activity was co-ordinated with WP8 & WP16 ensuring alignment with AIRM. Our input to CP3.1 and CP3.2 in this matter, contributed to the evolution of the successive versions of FIXM. The project also worked together with P10.02.05 and with EUROCAE WG59 contributing to the definition of the ATC-ATC IOP. This is necessary to ensure a consistent and coherent view on the SBT/SMT, RBT/RMT by the FPD's. From FDPS point of view, FDP: System shall accept creation and revision of the RBT/RMT. However, implementation not foreseen for Step 1. It was recommended that a new Ground-Ground IOP is created (for Flight Object).
ER APP ATC 86	FDP To Use Locally-Related Parts of 4d Trajectory	Reviewed the enabler and recommended that the enabler description should be improved because it is not clear enough.
ER APP ATC 100a/b/c	4D Trajectory in Step 1 - FDP/HMI/MONA	Reviewed the enabler and recommended that the enabler description should be improved and link to TS-0103, CM-0604, IS-0305 is removed and enabler should focus on the receipt of EPP, checking compliance with planned trajectory, updating ground trajectory with estimates from EPP, up-linking route clearances, receiving downlinked requests. From FDPS point of view, the trajectory is refined using the EPP obtained through ADS-C when available. (TOD position and decent vertical profile used to improve ground TP accuracy). Via i4D + CTA exercise(s), P10.2.1/P10.2.2 contributes to this by means of using EPP in the ground ATM system) For Step 1, the ground FDPS system uses information from the EPP to update the ground prediction. However, it is not foreseen that EPP will replace FDPS trajectory.
ER APP ATC 121a	Mgt & Delivery of ATC Enr & App Clearance Using D/L	Reviewed the enabler and recommended that the link to AUO-0302-A is either removed or made optional. Eventually it was removed.
ER APP ATC 136	Safety Nets for TMA	Reviewed the enabler (the title should only address STCA) and recommended that the link to AO-0309 is either removed (a new enabler should be created if necessary). This enabler does not seem to be R3 but R2 - there is nothing in Release 3 Plan V0.3 related to it. There is EXE-04.08.01-VP-239 that will address STCA improvement (use of DAP) in En-Route and TMA but this relates more to ER APP ATC 14 c/f

		enablers.
ER APP ATC 139a/b	FDP + Tools Enable CTO For Seq At Intermediate Merge Points	Reviewed the enabler and ask for clarification because the text neither clearly explains it nor justifies its existence. Eventually it was removed.
ER APP ATC 141a/b	Cruise Climb	Requirements (operational intentions) were not clear, redrafting of the text describing the enabler/requirements was requested. P10.2.1 contributes to this by providing a TP&TM capability to predict cruise climb profiles with the accuracy required to implement them across traffic (Note: this was envisaged for Step 2)
ER APP ATC 143	OAT	From FDPS point of view, the system manages the dialogue to agree a CTA with the aircraft and the consequent RBT/RMT amendment. AMAN tool uses ETA and ETA min/max to provide the CTA to be up linked. It also provides tolerance and TTL/TTG to support ATCO decision on CTA implementation. Via i4D + CTA exercise(s), P10.2.1/P10.2.2 supports CTA operations from step 1.
ER APP ATC 148	AMAN Support CTA	
ER APP ATC 149	AGDL for i4D Including CTA Between ATSUs	
ER APP ATC 94a	ATC Tools in Support of RNP.1 in App	From FDPS point of view, the trajectory will be calculated using ADD when available. Some use of ADD is foreseen for step 1 (aircraft weight and vertical profile) for the P10.2.1 prototype. Step 2 objective was to extend the use of ADD to speed schedule and other data available through EPP. In step 1, prototype(s) will already use some ADD data derived from EPP (e.g. TOD) and times to update ground trajectory prediction. Having said that, it was recommended to remove the link to IS-0302.
ER APP ATC 93	Resource Mgt & Pln Tools to Use Complexity	This enabler relates to the tools for complexity assessment. It is recommended to keep it as is. In P10.1.7 TAD, G/G datalink function refers to a new enabler ER APP ATC 18 that would support "exchanges between ATC stakeholders to manage the coordination related to the dynamic sectorisation". Enabler "GGSWIM 26b" could be a candidate to do that but probably in a later release.
GG SWIM 26b	Use of Ground-ground data SWIM enabled services for Network Operations Planning	The work done by the project in the trajectory data modelling has to be considered as valuable input contributing to the possible improvement of the performance of SWIM enabled services by proposing efficient way of representing aircraft intent. P10.1.7 TAD shows a link from GGSWIM-26 to CM-0103 and not GGSWIM-26b to CM-0103 A - GGSWIM-26 (including the provision and use of the service) has been split into GGSWIM-26a (provision of the service) and GGSWIM26b (use of the service). It is not necessary to differentiate; as if the service is used it is necessarily provided. Anyway, R3 exercises related to complexity

		management (VP-002, VP522 and VP632) as described in Release 3 Plan V0.3 do not refer to any SWIM enabler for data exchanges.

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
D04	Safety and security report for step 1	This Safety and security report for Step 1 has been limited to the analysis of the extensions of existing legacy systems needed to support i4D. SESAR safety and security requirements when available will be used as an input and the deliverable will identify the requirements on safety and security the formatting method(s) used for Step 1 needs to satisfy. As Step 1 relies mainly on legacy systems, only extensions to existing formats or new ones where required will be considered. As it has been identified in the different OSEDs and other documents that have served as input to this document, we can list the following areas as to be part of Step1: • i4D • CTA operations • PRNAV/ADD • ATFCM/FUA • Efficient and Green Terminal Airspace Operations – CDA • Airborne Spacing and Separation: ASPA S&M.
D08	Draft technical standards to support ongoing standardisation bodies in step1	Based on the experience of Step 1 P10.2.1/P10.2.2 SESAR activities, this document contains a set of change proposals for the update of data exchange standards used for TM purposes. The purpose of this document is not to propose a new standard or a new revision of an existing standard, but instead is intended as a document to support the standardisation bodies making those revisions/standards.

		The SJU is responsible to submit the SESAR results/recommendations to the standardisation bodies and ultimately it is the standardisation body that will update the standard if deemed applicable.
D10	Consolidated Specification of SESAR Trajectory Management Exchange Formats and TM process modelling and design for step 2	This document contains TM exchange formats and TM process design and modelling. It provides the means to improve trajectory consistency between systems and support the improvement of trajectory prediction accuracy.
D71	Preliminary assessment of needs and feasibility study for step 2	In order to prepare step 2, this preliminary assessment and feasibility study has two objectives. First to clarify the different concepts and terminology of potential application in the definition of exchange formats (section 2). And secondly a preliminary survey of late Step 1 and early Step 2 use cases potentially requiring TM exchange formats along a gap analysis in comparison with the existing Air-Ground and Ground-Ground exchange formats.
D139	Updated Needs Assessment and Feasibility Study for step 1	This document is complementary to D01-Assessment of needs and feasibility study for step 1. It includes Step 1 requirements which arrived later than originally expected.
D140	Specification of TM Exchange Formats and TM process design and modelling for Step 1	This document contains the specifications for late arriving Step 1 requirements which were captured in the Updated Needs Assessment deliverable.

1.4 Contribution to Standardisation

This project provided a set of change proposals with relevant standardisation bodies (e.g. EUROCAE WG78). To realize what is proposed, a common agreement on the way forward would be essential as well as the follow-up work that needs to be conducted by the associated standardisation body.

It contributed to standardizations activities in several ways (details can be found in the deliverable D08):

- Proposed changes to the OLDI standard version 4.1
- Proposed changes to the ADEXP standard version 3.1
- Considering the CPDLC, changes were proposed regarding Safety and Performance Requirements (SPR) for Advanced ATS Data Communication version I
- Considering ADS-C, changes were proposed regarding Safety and Performance Requirements (SPR) for Advanced ATS Data Communication version I

EUROCAE WG78:

The following was reported in the list of standardisation activities :

- New SPR for PM ADS-C services i4D
    - Downlink of trajectory data according to contract terms (Enabler A/C-37) – proposed modifications on ADS-C.
- New SPR for data link exchange of instructions or clearances related to CTA allocation (4DTRAD)
    - Downlink of trajectory data according to contract terms (Enabler A/C-37) – proposed modifications on CPDLC.
- The standard has been finalized. The version 1.0 of the standards includes some P10.2.2 change proposals.

EUROCAE WG59:

Participation to the EUROCAE WG59 for the first revision of the ED133 standard. A set of issues to be solved in this revision has been identified and agreed. Each issue has been allocated to a member of the EUROCAE WG59 for analysis and proposition of solutions. The kinds of issues are:

- Issues related to problems discovered during the IOP validation exercise.
- Inclusion of NM in the IOP: adaptation of the role management, inclusion of NM data in existing and new FO clusters, service request for NM, ECAC wide trajectory in FO.
- Clean-up of the FO model
- Analysis of the inclusion of EPP data in FO

1.5 Project Conclusion and Recommendations

To facilitate TBO, there is a need to encode and interpret the necessary exchanges of trajectory management related information. This could include Flight Intent (in a way, a subset of AI), Aircraft Intent, the 4D Trajectory, TM requirements as well as Airline Preferences. The way forward to achieve this is through analysis of the information required to be exchanged, production of a syntactic and semantic definition of the exchange format and any associated requirements of how to interpret these exchanges and verification and validation of the established exchange format through platforms (industrial-based prototype) which could lead into a standard that addresses the needs of all the stakeholders. TMEF is a very important part of this process.

The TMEF could be a language that comprises a reduced set of instructions that capture primitive aircraft behaviour together with a set of grammatical rules that govern the valid combinations of those instructions to formally and univocally determine any possible aircraft motion. The TMEF could provide an unambiguous tool to describe any possible aircraft trajectory with arbitrary levels of detail and could serve as a means to achieve reliable interoperability among disparate systems and tools that rely on trajectory prediction. Initial experiments (e.g. REACT, ASIS projects) have already demonstrated that the TMEF concept can be used with Trajectory Predictors supporting operational airborne and ground-based systems.

AI expressed in TMEF could meet key interoperability requirements for system-wide trajectory synchronization, including the ability to support the integration of airborne and ground-based automation systems. Therefore, TMEF is an essential step required to achieve system-wide TBO. TMEF is a potential mechanism to allow disparate airborne and ground-based automation systems to interoperate on the basis of consistent definitions of how the aircraft intends to fly its Business/Mission trajectory. This will facilitate conflict detection and resolution and dynamic negotiation of aircraft trajectories to accommodate user preferences and optimize airspace resources.

The expression of AI information in TMEF is fully compatible with the Flight Object concept approach. The adaptation of the FO data structures required to meet system-wide trajectory synchronization demands some adaptation of the contents of the Flight Script. However, this can be achieved without changing the basic concept. There are also strong indications that the expression of aircraft intent in TMEF can significantly reduce the bandwidth requirements for SWIM when performing trajectory synchronization.

In order to achieve final validation of a proof-of-concept for system-wide trajectory synchronization in support of TBO based on the TMEF, representative key stakeholders of airborne and ground-based automation systems should be involved in the development, verification and validation of such a concept through prototypes (e.g. industry-based prototypes).

P10.2.2, in its nature, is more suited to Step 2 rather than Step 1. The goal of the project was to produce a means of exchanging trajectory management related information between the ATM components. The content of this exchange is identified by partners in SESAR. P10.2.2 achieved its goals for Step 1 given the amount of information it received by producing a specification for exchange of TM related data. Unfortunately, even though during the project, it became obvious that to improve both the Trajectory Prediction and Trajectory Management, more information needed to be exchanged, the decision to not to go ahead with Step 2 prevented further development of this specification. This, as it was mentioned in section 1.5 is highly recommended based on the experience in this project. Of course, one can also interpret the recommendations, and these recommendations would not be made if they were not justified, as a wish list. However, one also should not forget that this wish list is basically a collection of requirements expressed by SESAR partners but not achieved due to constraints that we are all aware of.

2 References

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[2] European ATM Master Plan

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[4] SESAR D3 The ATM Target Concept

[5] SESAR PMP V2.0 – for the definition of roles & responsibilities

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[8] European Air Traffic Management Master Plan, (revision of March 2010)

[9] Integrated Roadmap Dataset (DS15)

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[13] SESAR P10.02.02 D04 - Safety and security report for step 1, v00.01.01

[14] SESAR P10.02.02 D05 - THALES Testing platform and tools specification for release 1, v00.01.01

[15] SESAR P10.02.02 D07 - INDRA Test reports for step 1, v00.01.01

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[25] SESAR P10.02.02 D78 - Report on Step 1 Activities 2015-2016, v00.01.00

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[38] SESAR P5.5.1, Step 1 TMA Trajectory Management Framework, Initial INTEROP, 00.01.00, February 2011

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