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FMP-Met

METEOROLOGICAL UNCERTAINTY MANAGEMENT FOR FLOW MANAGEMENT POSITIONS

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 885919 under European Union's Horizon 2020 research and innovation programme.

Abstract

In the present deliverable, the Technology Readiness Level (TRL) of the FMP-Met concept is assessed. This concept aims at integrating weather uncertainty information into the tools currently used by Flow Management Positions, so that one can obtain an intuitive and interpretable probabilistic assessment of the impact of convective weather on the traffic, up to 8 hours in advance, to allow better-informed decision making. The level of satisfaction of all the maturity assessment criteria evaluated leads to the conclusion that the goal of reaching TRL 1 at the end of the project has been achieved. Moreover, a new Operational Improvement Step is proposed, and the contribution of FMP-Met to increasing its level of maturity is described.

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1 Introduction[1]

1.1 Project context

As indicated in the Project Management Plan [1], the FMP-Met project corresponds to the research topic "Environment & Meteorology for ATM", and is fully aligned with the objectives of the SESAR 2020 Exploratory Research programme of securing

> "*the proper integration of existing and possible new meteorological products into ATM for example to reduce the vulnerability of the ATM system to local weather phenomena and to improve the prediction of 4D Trajectories and network forward planning to enable a minimisation of consequential weather-related delays*",

and also

> "*the incorporation of ensemble weather information into decision-support tools, adapted for different ATM stakeholders*".

Moreover, according to the topic description (Sub Work Area 1.3) described in the SESAR Single Programming Document 2019-2021 [2]:

> "*Research activities will study … how enhanced meteorological capabilities and their integration into ATM planning processes can be utilised for improving ATM efficiency and safety. This requires understanding of the potential of different types of weather-related information that could be used in ATM operations taking into account the inherent uncertainty of meteorological information.*"

In line with the SESAR objectives just mentioned, FMP-Met focusses on the enhancement of Air Traffic Management (ATM) efficiency by integrating meteorological (MET) forecast uncertainty information into the decision-support tools used by Flow Management Positions (FMP), an operational position that monitors the level of traffic in airspace sectors and coordinates flow measures when an excess of demand over capacity is detected.

For completeness, a global summary of the FMP-Met project and of the concept developed is included next.

[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

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1.2 FMP-Met project

FMP-Met deals with the provision of probabilistic traffic forecasts under convective weather for a forecasting horizon of 8 hours.

The key **research challenge** is the analysis of a traffic flow management problem with an extended time horizon, in which the levels of uncertainty are important and, therefore, a probabilistic approach is required. In this analysis different probabilistic weather forecast products have been used, with different lead times and coverage areas (the best products available at each time and location).

The **overall objective** is to provide the FMP with an intuitive and interpretable probabilistic assessment of the impact of convective weather on the traffic, up to 8 hours in advance, to allow better-informed decision making.

The **main outcome** of the project is the development of a probabilistic methodology to forecast traffic congestion and traffic complexity to be used in conjunction with the tools currently employed by FMPs. And three are the **potential benefits** of this development:

- Support to take anticipated, appropriate, and timely tactical flow measures.
- Enhancement of ATM efficiency, which will ultimately reduce flight delays and improve passenger journeys.
- Possibility of conducting what-if analyses, to have a preliminary evaluation of the impact of measures to be taken.

1.3 FMP-Met concept

The FMP-Met concept addresses the problem of how probabilistic forecasts of traffic and acceptable traffic load can be integrated into the FMP procedures. The **aim of the concept** is not to radically change the current FMP procedures, but to seamlessly integrate uncertainty information into the established procedures (see deliverable D2.1 [3]).

Nowadays, the Network Manager supports FMPs with current and anticipated air traffic demand via Eurocontrol's CHMI (Collaboration Human Machine Interface) tool. These predictions are deterministic and based on data received from the flight-plan processing systems, airspace databases, live ATC data from ANSPs, aircraft operator's position reports, and meteorological data from a weather service provider. Thus, the Concept of Operations developed is an evolution of the current practice, switching from deterministic predictions to probabilistic ones.

The integration of probabilistic information in the decision process is based on a decision support tool. In this project a **tool concept** is devised, which aims at giving a concise airspace overview to raise awareness for possible imbalances in demand and capacity. In addition, this tool will allow to test the impact of FMP measures informing the decision maker on the cost and effectiveness before taking the measure.

The **context of use** of the concept is the FMP process under adverse weather (thunderstorms), for en-route + Terminal Control Area (TMA) traffic, for a time horizon of 8 hours (tactical phase).

Given the forecast look-ahead time of 8 hours, and the stochastic evolution of the atmosphere, the FMP predictions on sector demand and traffic complexity are affected by MET forecast uncertainty, so that a **probabilistic approach** becomes the appropriate one. The proposed tool is derived from existing concepts. The **novelty** in FMP-Met is that the weather impact is included in the traffic forecast used by the tool; in addition, since the forecast is probabilistic, it also includes uncertainty information.

A schematic description of the FMP-Met project, including the input/output and the main tasks carried out, is given in Figure 1.

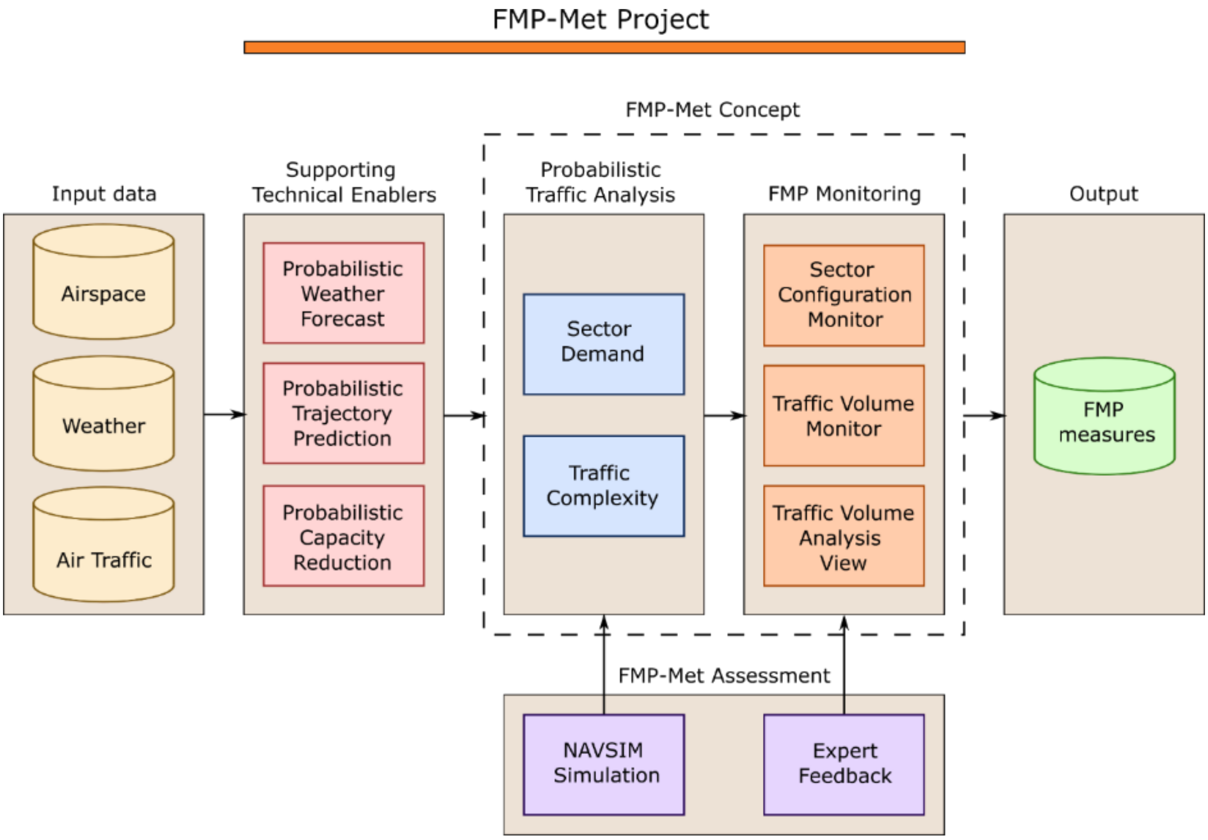

Figure 1. Structure of FMP-Met project

The FMP-Met concept relies on the availability of the following three **supporting technical enablers**:

- Probabilistic weather forecasts. In this project (see deliverable D3.1 [4]), MET uncertainty is quantified by a probabilistic prediction technique called Ensemble Weather Forecasting. Three types of forecasts are considered: ensemble nowcasts, and limited-area and global Ensemble Prediction Systems (EPS).
- A probabilistic trajectory predictor, providing 4D trajectories with a measure of uncertainty. The trajectory predictor developed in the project (see deliverable D4.1 [5]) is capable of avoiding the storm cells and captures not only the meteorological uncertainties, but also the uncertainty in the storm avoidance strategy and the uncertainty in the departure time for those aircraft that are still on ground.

- A probabilistic predictor of capacity reduction caused by thunderstorms, that is a probabilistic measure of the Available Sector Capacity, given, for example, as the ratio of the sector capacity under the given weather constraints to the maximum possible capacity of the sector without weather systems (see deliverable D6.1 [6]).

Two probabilistic methodologies have been developed for traffic analysis under adverse weather: sector demand and traffic complexity (see deliverables D5.1 [7] and D6.1 [6], respectively), on which the tool concept for FMP monitoring is based. This tool is composed of 3 layers: Sector Configuration Monitor, Traffic Volume Monitor and Traffic Volume Analysis View.

Note that the analysis of the FMP Measures to be taken based on the probabilistic predictions generated using the FMP-Met concept is beyond the scope of this project.

1.4 Deliverable scope

In this document (see the Grant Agreement [8]) an assessment of the Technology Readiness Level (TRL) of the FMP-Met concept is presented. Moreover, a new Operational Improvement (OI) Step is proposed, and the contribution of FMP-Met to increasing its level of maturity is described.

The assessment is included in Section 2, and the contribution to the proposed OI Step and the level of satisfaction of each TRL criteria is provided in Section 3.

1.5 Acronyms and Terminology

Acronym	Description
ACC	Area Control Centre
ANSP	Air Navigation Services Provider
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
CHMI	Collaboration Human Machine Interface
CIFLO	CHMI for Flow Management Positions
DCB	Demand-Capacity Balance
EPS	Ensemble Prediction System
FMP	Flow Management Position
MET	Meteorology
MV	Monitoring Value
OI	Operational Improvement

PRU	Performance Review Unit
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level

1.6 FMP-Met Consortium

Acronym	Description
USE	Universidad de Sevilla
AEMET	Agencia Estatal de Meteorología
ACG	Austro Control GmbH
CCL	Croatia Control Limited
LiU	Linköping University
MetSol	MeteoSolutions GmbH
PLUS	Paris-Lodron Universität Salzburg
UC3M	Universidad Carlos III de Madrid
ZFOT	University of Zagreb

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2 TRL assessment

The TRL assessment performed in this document follows the layout proposed for ER Fund / AO Research Maturity Assessment described in the ER Final Project Results Report template.

TRL-1.1

Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?

The ATM problem addressed in this project is the enhancement of the decision-making process for Flow Management Positions (FMP) under adverse weather, by integrating meteorological forecast uncertainty information in their currently used procedures.

Because the time window of interest in this traffic flow management problem is 8 hours, the **main challenge** is the need to analyse an extended time horizon in which the levels of uncertainty are important and, therefore, a probabilistic approach is required.

TRL-1.2

Has the ATM problem/challenge/need(s) been quantified?

In the concept assessment provided by FMP experts (see TRL-1.12), they have indicated that in some Area Control Centres (ACC) convective weather is one of major challenges in Operations, especially in summer when their capacities and also Network capacities are exhausted. “Adverse weather will always increase Air Traffic Flow and Capacity Management (ATFCM) delays, and Air Traffic Control Officer (ATCO) workload as well.”

Moreover, they have identified some drawbacks of the current process:

- Today, FMP’s and ACC Supervisors tasked with Configuration Management brief themselves of relevant meteorological conditions on various separate (from CIFLO - CHMI for Flow Management Positions) MET-briefing systems, and they must convert this information into impact on sector Monitoring Value (MV) and integrate it manually into the current Collaboration Human Machine Interface (CHMI). Risks here are many, from FMP officer not understanding the potential negative impact and causing an overload/overdelivery on sector to overregulating weather with very low intensity.
- Today, FMP actions on weather are often reactionary and too-late, considered as the last-option but with the best intentions applied when most airborne flights are no longer subject to ATFCM measures but Air Traffic Control (ATC).
- In different ACCs different methods are used by FMPs to ascertain the impact of predicted (forecasted) weather to sector capacities, and in turn to choosing the optimal configuration.

As a quantitative indicator of the expected impact, taking into account that a large percentage of the en-route air traffic delays are attributed to weather (21.2% in 2019, 3.6 million minutes, according to

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Eurocontrol's Performance Review Report 2019 [9]), if the methodologies developed in this project help to reduce the weather dependent delays just by 5%, and if we consider that 1 minute of delay costs the ATM network roughly 100€, then savings of 18M€ per year could be achieved for the European air traffic system.

TRL-1.3

Are potential weaknesses and constraints identified related to the exploratory topic/solution under research?

- The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.

The following weaknesses have been identified for the FMP-Met concept:

- Only one use case has been analysed; more cases would be required to build trust in the concept.
- The analysis is very demanding computationally (hence, some simplifications have been made: sampling, clustering).

The FMP-Met concept is bound by the following constraints:

- The concept is valid for en-route and approach phases.
- The applicability of the concept is constrained to geographical areas where nowcast and local area model weather products are available.

TRL-1.4

Has the concept/technology under research defined, described, analysed and reported?

The FMP-Met concept has been defined and thoroughly described, including the required graphical displays, in deliverable D2.1 [3], and the corresponding assessment in deliverable D7.1 [10]. The concept has been summarised in Section 1.2.

The probabilistic methodologies developed to forecast traffic congestion and traffic complexity, including all the mathematical details, are described and tested in deliverables D5.1 [7] (probabilistic traffic demand and congestion) and D6.1 [6] (probabilistic traffic complexity).

The 3 underlying technical enablers considered in this project are described in deliverables D3.1 [4] (probabilistic weather forecast), D4.1 [5] (probabilistic trajectory predictor) and D6.1 [6] (probabilistic weather-induced capacity reduction).

TRL-1.5

Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?

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The potential use of the tool concept developed in FMP-Met shows a main contribution to the following SESAR goal:

- **Improvement of the overall ATM system efficiency.** An enhanced (better-informed) FMP process under adverse weather can lead the Air Navigation Services Providers (ANSP) to a better identification of the ATFCM measures to be implemented, thus improving the traffic throughput, and reducing delays.

This contribution is in line with the description of the topic "Environment and Meteorology for ATM" (Sub Work Area 1.3) of the SESAR Single Programming Document 2019-2021 [2]:

> "Research activities will study … how enhanced meteorological capabilities and their integration into ATM planning processes can be utilised for improving ATM efficiency and safety. This requires understanding of the potential of different types of weather-related information that could be used in ATM operations taking into account the inherent uncertainty of meteorological information."

TRL-1.6

Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities?

- What are these new capabilities?

- Can they be technically implemented?

The new capabilities offered by the FMP-Met concept are that it integrates

- weather information into the FMP tools, and
- uncertainty information into the FMP decision-making process.

This concept also facilitates the consideration of other sources of uncertainty in addition to the meteorological one, such as the uncertainty in the take-off time and the uncertainty linked to the storm avoidance strategy.

The concept has been developed so that the new features can be easily implemented, in the form of a new tool layer, added to the layers currently in use.

TRL-1.7

Are physical laws and assumptions used in the innovative concept/technology defined?

The main assumptions used in the development of the FMP-Met concept are the following:

- The ensemble approach to quantify uncertainty (based on scenarios) is the right approach to integrate uncertainty information into the FMP process (this is the base for the statistical analysis).

- The interaction-based PRU (Performance Review Unit) methodology to quantify traffic complexity is the right approach to account for the adverse effects of weather on complexity, through the addition of a new indicator for the aircraft-storm interaction.

TRL-1.8

Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified?

- Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.

The following strengths, benefits and limitations have been identified:

Strengths:

- The concept developed considers
  - an extended time horizon (8 hours), using different probabilistic weather forecast products (with different lead times and coverage areas),
  - several sources of uncertainty (weather, take-off time, storm cell avoidance),
  - multi-sector scenarios,
  - 4-D trajectories and 4-D storms (Cloud Top Height, non-static meteorology with forecasts evolving over time).
- The overall methodology is very versatile, capable of using different implementations of the three underlying technical enablers.

Potential benefits:

- Improved (better-informed) decision-making process for FMP under adverse weather.
- Possibility of conducting what-if analyses, to have a preliminary evaluation of the impact of measures to be taken.

Limitations:

- Accuracy/reliability of the supporting technical enablers in capturing the real uncertainty, in particular the following factors:
  - The inherent variability of the forecasts, which may overestimate or underestimate the presence of the storm.
  - The limitation of the high-resolution EPS, which does not provide convective areas to avoid, and, linked to this, the lack of lateral deviations in the long-term trajectory predictor.
- The positive assessment of the FMP-Met concept is limited by the fact that only one use case has been analyzed, although the concept potential has been clearly identified.

TRL-1.9

Have Initial scientific observations been reported in technical reports (or journals/conference papers)?

The following papers have been produced during the timeframe of the project:

Conference papers:

- Eduardo Andrés, Javier García-Heras, Daniel González, Manuel Soler, Alfonso Valenzuela, Antonio Franco, Juan Nunez-Portillo, Damián Rivas, Tomislav Radišić and Petar Andraši "Probabilistic Analysis of Air Traffic in Adverse Weather Scenarios", International Conference on Research in Air Transportation (ICRAT) 2022, June 2022, pp. 1-8.
- Anastasia Lemetti, Tatiana Polishchuk, Valentin Polishchuk, Alfonso Valenzuela, Antonio Franco, Juan Nunez-Portillo and Damián Rivas "Probabilistic Analysis of Airspace Capacity in Adverse Weather Scenarios", SESAR Innovation Days (SID) Conference 2022 (to be submitted in September).

Journal papers:

- Alfonso Valenzuela, Antonio Franco, Juan Nunez-Portillo and Damián Rivas, "Probabilistic Analysis of Tactical Flow Management under Adverse Weather", Transportation Research Part C: Emerging Technologies (to be submitted in October).

TRL-1.10

Have the research hypothesis been formulated and documented?

The following hypotheses have been formulated:

- The FMP process under adverse weather can be improved.
- Information about weather uncertainty can improve current FMP decision-making process.
- New features can be integrated into the tools currently used by FMPs.

These hypotheses frame the FMP-Met concept (as described in deliverable D2.1 [3]) and are the base for the concept validation performed via FMPs' feedback (as shown in deliverable D7.1 [10]).

TRL-1.11

Is there further scientific research possible and necessary in the future?

The following actions have been identified as possible future developments to improve the accuracy of the predictions:

- Post-processing of high-resolution EPS to determine convective areas to be avoided (that is, to define no-fly zones).

- Enhancement of the long-term trajectory predictor with lateral deviations, to avoid no-fly zones.

The following actions have been identified (by the experts consulted) as possible future developments to improve the tool performance:

- Addition of a Map View functionality, to have a better perception of the weather status and evolution.
- Addition of What-If functionality, to evaluate before adopting a measure its possible impact.

TRL-1.12

Are stakeholder's interested about the technology (customer, funding source, etc.)?

The FMP-Met concept has been assessed positively by FMPs from ACG and CCL, by means of a validation exercise. This validation was based on FMPs' feedback (expert opinion) via questionnaires.

The FMPs recognized that the FMP process under adverse weather can be operationally improved and that the FMP-Met concept developed in this project is a good first step, which deserves to be explored further. The experts consulted were comfortable using the graphical displays selected for the tool concept developed. They also suggested improvements for future development (see TRL-1.11).

3 Conclusions

For the maturity assessment of the FMP-Met concept, a new OI Step is proposed:

DCB-xx01: Use of probabilistic weather forecasts to enhance FMP process.

The aim of this OI is to enhance the decision-making process for FMPs under adverse weather, by integrating meteorological forecast uncertainty information into their currently used procedures.

The contribution of FMP-Met to this OI is the definition of a concept to integrate MET forecast uncertainty information into the procedures currently used by FMPs. The core of the new features to be incorporated into FMP tools is a probabilistic methodology to forecast sector congestion and traffic complexity under adverse weather in a time horizon of 8 hours.

The potential use of the tool concept developed in FMP-Met shows a main contribution to the following SESAR goal:

Improvement of the overall ATM system efficiency. An enhanced (better-informed) FMP process under adverse weather can lead the Air Navigation Services Providers (ANSP) to a better identification of the ATFCM measures to be implemented, thus improving the traffic throughput, and reducing delays.

The level of satisfaction of all the maturity assessment criteria is evaluated in Table 1 according to the answers given in the previous section to the questions posed.

TRL-criteria ID	Status
1	**Achieved**
2	**Achieved**
3	**Achieved**
4	**Achieved**
5	**Achieved**
6	**Achieved**
7	**Achieved**
8	**Achieved**
9	**Achieved**
10	**Achieved**
11	**Achieved**
12	**Achieved**

Table 1: Level of satisfaction of the maturity assessment criteria

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At the start of the project the positioning was Pre-TRL 1. In our previous work we had carried out research showing this level of achievement, as described in the Appendix B of the Project Handbook of SESAR 2020 Exploratory Research [11]: "*Fundamental exploratory scientific research investigating relevant scientific subjects and conducting feasibility studies looking for potential application areas in ATM, concentrating both on out-reach to other disciplines as well as educating within.*" Indeed, the application area found was FMP decision-making process when subject to the effects of convective weather.

Our goal was to reach TRL 1 at the end of this project. To achieve this level and the corresponding maturity we needed [11] "to explore the transition from scientific research to applied research by bringing together a wide range of stakeholders to investigate the essential characteristics and behaviours of applications, systems and architectures. Descriptive tools are mathematical formulations or algorithms." In FMP-Met we have worked closely with stakeholders (FMP experts from ACG and CCL) and have delivered a concept tool that could enhance FMP decision-making process under adverse weather, providing support to take anticipated, appropriate, and timely tactical flow measures.

The level of satisfaction of all the maturity assessment criteria evaluated leads to the conclusion that the assessment is positive, and, therefore, we can claim that the goal of reaching TRL 1 at the end of the project has been achieved.

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4 References

[1] "FMP-Met Deliverable D1.1, FMP-Met Project Management Plan," Edition 00.02.01, July 2021.

[2] SESAR Single Programming Document 2019-2021 (SPD), 2019.

[3] "FMP-Met Deliverable D2.1, Concept of Operations for Weather-Dependent Probabilistic Flow Management," Edition 00.02.00, December 2020.

[4] "FMP-Met Deliverable D3.1, Nowcast and EPS Forecast Products," Edition 00.02.00, December 2020.

[5] "FMP-Met Deliverable D4.1, Trajectory prediction under adverse weather scenarios," Edition 00.01.00, May 2020.

[6] "FMP-Met Deliverable D6.1, Forecast of sector complexity and airspace capacity reduction in multi-sector scenarios," Edition 00.01.00, November 2021.

[7] "FMP-Met Deliverable D5.1, Forecast of sector demand in multi-sector scenarios," Edition 00.01.00, November 2021.

[8] Grant Agreement number: 885919 — FMPMet — H2020-SESAR-2019-2, 2020.

[9] Eurocontrol, Performance Review Report 2019, Performance Review Commission, 2019.

[10] "FMP-Met Deliverable 7.1, Evaluation and assessment of proposed methodologies," Edition 00.01.00, May 2022.

[11] Project Handbook of SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4) (Programme Execution Guidance), Edition 03.00.00, March 2019.