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Copyright Statement

PARTAKE

COOPERATIVE DEPARTURES FOR A COMPETITIVE ATM NETWORK SERVICE

This project has received funding from the SESAR Joint Undertaking under grant agreement No 699307 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document is reporting the final results obtained at the end of PARTAKE lifecycle. The report is released as the final deliverable, D8.2: Final Project Results Report within the work package WP8 Project Management.

Starting with the brief Executive Summary, the document makes the comprehensive overview of the project scope and objectives, operational and technical context, as well as a description of the main work performed in each work package. It elaborates the key results achieved with respect to the PARTAKE Concept of Operations and list the technical deliverables whose content has contributed to generation of these results.

The report identifies the corresponding links to the SESAR Programme through its contribution to the current ATM Master Plan and maturity assessment taking into consideration the project Technology Readiness Level, different criteria, rationales and satisfaction levels. In addition, the report draws the relevant conclusions and points to the lessons learned during the project lifetime.

Finally, the document lists all the references related to the project deliverables, project publications and other scientific references used for the development of the PARTAKE tools.

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1 Executive Summary

The main objective of PARTAKE is to implement a tool to provide a deep understanding of airspace traffic dynamics by analysing spatio-temporal interdependencies between trajectories and supporting the implementation of mitigation mechanism that could reduce the probability of air traffic controller tactical interventions while preserving air space user. Towards this goal, tight interdependencies between aircraft trajectories are identified at network level and removed by rescheduling take-off times in such a way that take-off times computed by the network manager are preserved within present CTOT -5 to +10 minutes margin. This can be seen as a short term ATFCM measure that enables to maintain airspace capacity and to reduce the probability to lose separation minima and lessen the conflict resolution controller's task loads.

Computational efficient identification tools for spatio-temporal analysis of a given traffic have been designed and implemented aligned with the concept of operations defined in PARTAKE. To deal with the uncertainty that arises in an operational context with a greater lookahead time, the scope of PARTAKE was aligned with SJU recommendations, towards an application of the methodology in the TMA area. Moving towards a more predictable lookahead time, different realistic scenarios have been tested using the London TMA and validated, including exercises with ATC's and pseudo-pilots in the loop.

The main conclusions that can be drawn is that efficient trajectory mapping tools relying on TBO foundations have been successfully developed, implemented, verified and validated. With the tools an innovative STAM approach has been designed that aims at reducing the probability of ATC interventions without affecting the assigned slots by taking advantage of the CTOT [-5;10] time window. A detailed description of the results obtained can be found in D6.2 "Validation report".

This Final Project Results Report summarizes the qualitative and quantitative performance achieved as a project overview describing the project scope and objectives and the achieved results and main conclusions. Furthermore, it describes the links to the SESAR programme, provides lessons learned at WP level and elaborates the exploitation and follow-up research activities proposed for the next stage of the R&D lifecycle. The document has been prepared by the PARTAKE Consortium Members and recaps the activities performed in each area of the project.

The PARTAKE tools have been tested during the implementation of PARTAKE within Cranfield ATM Lab, during a fast simulation and during a face validation exercise to describe qualitatively and quantitative outcomes.

The maturity assessment is in compliance to the "Introduction to SESAR Maturity Criteria" (edition 1.1.02) and "How to use the Maturity Assessment Tool to Examine SESAR Maturity" (edition1.1.00) and the "Maturity Assessment excel file" as a template.

This Final Project Results Report is based on the Grant Agreement, under number: 699307 – PARTAKE -H2020-SESAR-2015-1, provided by the European Commission. The target audience of the present deliverable are PARTAKE partners, SESER Joint Undertaking and the Academia.

The document is structured as follows:

- The current section gives an overview of the document

- Section **Error! Reference source not found.** presents the project overview including the objectives, the operational and technical context, the work performed in each WP and key project results.
- Section **Error! Reference source not found.** describes links of the PARTAKE project to the SESAR programme and performs a maturity assessment.
- Section **Error! Reference source not found.** gives conclusions and technical lessons learned and suggest a set of further research activities and exploitation activities for the next R&D phase required to push PARTAKE framework for a successful deployment.
- Section **Error! Reference source not found.** provides references to the project deliverables and the project publications and explains the dissemination and communication activities that have been carried out.

2 Project Overview

2.1 Operational/Technical Context

The European Air Traffic Management (ATM) system has to be competitive in the way to support the Airspace User (AU's) demands as for example to satisfy the right time (e.g. departure slots), the right costs (e.g. suitable level of Air Traffic Control (ATC) service), the right place (e.g. AU's preferred trajectories) and the right service quality (e.g. safety) without extra investments, just by removing ATM non-added-value operations that indirectly impact on present ATM capacity.

PARTAKE objectives seeks to improve the air traffic dynamic demand capacity balance. This is achieved by identifying proximate events at network level and mitigate these by the re-adjustment of take-off times within the assigned nominal Calculated-Take-Off-Time (CTOT) margins and the rearrangement of departing sequence of aircraft at the involved airports to minimize the amount of ATC interventions. PARTAKE can be considered as short term Air Traffic Flow and Capacity Management (ATFCM) measures, applied at local level reducing traffic peaks for the whole European airspace.

The PARTAKE approach is based on TBO paradigm that enhances the design of advanced DSTs (Decision Support Tools). DST relies on new airspace demand-capacity balance by re-evaluating the amount of potential controller interventions that can be required in future traffic scenarios ruled by new cutting edge procedures such as free routing (FRA), Airborne Separation Assistance System (ASAS), integration of RPA's or soft flight level capping constraints. PARTAKE contributes to the SESAR JU research topic Trajectory Based Operation (TBO) developing a new DST that could deal with present demand or capacity balance in Air Traffic Management (ATM) relying on a technological framework for information sharing (SWIM). The main TBO challenge PARTAKE is to reach a conflict free robust set of Reference Business Trajectory (RBT) just by introducing small temporal adjustments. PARTAKE is using the TBO approach preserving the 3D components of the Reference Business Trajectories (RBT's) but adjusting the time component by means of small ground delays, providing a new smart mechanism to support conflict resolution (CR) collaborative-competitive tools with minimum ATC interventions.

Aligned with the ATM mission to preserve and even improve the maximum level of safety, while achieving the maximum levels of Efficiency and Resilience it is broadly recognized that these challenges can only be obtained by improving the current levels of Predictability and Flexibility, provided by the ATM planning layers. Furthermore, AU's shall know that any change in their initial intentions is always done in order to maximise the overall system efficiency driven by Fairness and Equity criterion. This can only be understood by the highest level of Transparency.

It has been expected that PARTAKE should be facing the following challenges during its exploratory lifecycle:

- **TBO-FLEXIBILITY:** The introduction of modern communication, navigation and surveillance technologies combined with the development of specific ATM procedures is intended to provide traffic managers with a greater degree of flexibility in dynamically reconfiguring airspace to adapt to changing conditions. PARTAKE will enhance adherence through a flexible synchronization mechanism that will preserve the TTA (Target Time of Arrival) at destination airport by adjusting the CTOT considering the differences between actual take-off times and the planned or calculated take-off times. In those airports with an acceptable predictability of apron taxiway dwell time, PARTAKE will share the information to sequence the departures from the airport parking positions.

- **C2 TBO-PREDICTABILITY:** High predictability would allow a multitude of direct benefits, such as reductions in communication and controller workload. Present A-CDM approaches are by nature more complex than any other airborne enhanced predictability scenario, because it involves the recalculation of the trajectory both for the ground and airborne phases of operation. In PARTAKE the overall predictability of the system will be enhanced; minimizing the ATC interventions with more stable plans preserving the arrival synchronization. The flexible synchronous mechanism will rely on TBO concepts and will be supported by machine-to-machine communication.
- **C3 TBO-TRANSPARENCY:** To create trust between AU's under a fierce competitive trajectory context, the solutions delivered by the different DST's should be transparent to reach win-to-win agreements. PARTAKE increases transparency by preserving as much as possible the local and global AU's preferences through the use of causal rule based models which provides a better understanding of the TBO solutions proposed.
- **C4 TBO-FAIRNESS:** In PARTAKE, fairness is understood as the quality of distributing waypoint's time stamps among a set of individuals in a manner such that each receives a share that fulfils its individual satisfaction threshold. Usually, satisfaction threshold would vary from individual to individual and, therefore, it needs to be taken explicitly into consideration to assign each individual its fair share. Since RBT adherence is a must, in PARTAKE the cost penalties that results from implementing the fine tuning of time stamps by speed control will be measured [1] and compensated among a set of flights preventing "speeding up – slowing down" non-acceptable solutions.
- **C5 TBO-EFFICIENCY:** An accurate estimation of the prediction errors and an accurate understanding of the impact of prediction error accuracy on the performance of the ATFM are crucial to enable the optimisation of the potential cost-efficiency and capacity gains of TBO. Note that lack of proper integration of strategic and tactical decision making processes is tackled by overestimations, which have an impact on the cost-efficiency of the operations. Among the different efficiency metrics, in PARTAKE the freedom gap will be used to measure the cost penalty caused by ATM intervention and is given by the additional operational cost resulting from flying a trajectory that is different from the agreed RBT, and the ANSP efficiency influenced mainly by idleness ATC capacity.
- **C6 TBO-RESILIENCE:** The ability to recover the network. Due to operating condition, changes can impact on the predictability and efficiency of operations. PARTAKE contributes to the resilience of operations by improving the time spacing resilience en-route, the clearance in the departing procedures with a better use of existing airport departure capacities, and avoiding emergent dynamics due to lack of ATC capacity.

2.2 Project Scope and Objectives

The PARTAKE project relates to the topic "Sesar-09-2015: Trajectory Based Operations (TBO)" which relies on the research scope to explore a number of fundamental questions related to TBO as a key element of future ATM operating concepts. A framework is required that can model a system combining trajectories emanating from multiple and diverse airline users and feeding into the different ATM functions at different layers in the network. In this way it should be possible to establish a theoretical optimum and to determine the sensitivity of the system to variations and perturbations to create a robust TBO mechanism. The PARTAKE project scope addresses several key topics and key research objectives which are described in the following.

The project proposes an innovative framework supporting a TBO flexible synchronization mechanism to preserve ATFM constraints. Furthermore, holistic analysis of interdependencies between ATFM, DMAN, AMAN and the agreed RBT in order to generate synergies between AU's while reducing the possibility of an ATC intervention is made to provide a competitive ATM network service. According to this framework, the full use of present resources is foreseen to attend AU's demands, while avoiding resources idleness and saturations that foster poor trajectory adherence (i.e. regulations, holding trajectories, or conservative ATC interventions). This way, an ooptimization model for a fine-tuning management of airspace resources can be deployed.

The project foresees the development of a modelling approach that reduces the probability of separation minima infringement by integrating strategic with tactic and operational decision-making through a causal TBO departure manager, creating a multi-sector planning mechanism. In particular, the approach is based on the application of causal modelling and constraint programming (CP) optimisation techniques, which enable the mitigation of over-saturated scenarios without modifying the RBTs, preserving the TAT and departure slot assigned. The fine-tuning of the Calculated Take-Off Times (CTOTs) allows preserving airports' pre-programmed departure time slots. Furthermore, constraint propagation will lead to a resilience engineering guidance for safety assessment of functional changes in the hot spot sectors in case of unexpected perturbations affects the ATM system

To provide flexible solutions that are in conformity to 4D trajectories agreed at the strategic level, the proposed approach will maximise clearance times in the most conflicted ATM regions without affecting pre-programmed slots by a global coordination of local pre-departure exchange between flights allocated in the same departure slot. The fine-tuning process implemented as a constraint programming model will allow improving the robustness of the en-route trajectories with respect to surrounding traffic in the presence of sources of uncertainty that affect a flight's longitudinal dimension (i.e., wind prediction error).

In particular, the proposed approach will generate robust schedules that incorporate uncertainties with alternatives or buffer bottleneck points to prevent significant ATM capacity losses. A causal modelling approach will be used to formalize the different events, to simulate and validate the departure-time-bounded adjustment process that preserves the scheduled slots, while relaxing tight 4D interactions (for instance, reducing or solving demand-capacity imbalances). The causal model will be extended and implemented as a constraint programming model to automate solving large and congested scenarios interfacing with SWIM through service-oriented architecture (SOA) applications. Validation scenarios will rely on fast-time simulators and humans in the loop scenarios and face validations to identify the clearances and overlaps predicted by the causal model using realistic traffic data.

To address the above challenges which currently limit the benefits that could be obtained by a proper deployment of DST's relying on TBO concepts, the following key research objectives are defined in the project:

Objective	Work carried out for objectives' achievement
To Achieve ATC Minimum Tactical Interventions: Reference Business Trajectories provide an excellent source of information to	✓ Implementation of the TBO mapping tools ✓ Adjustment of TBO mapping tools

identify long time in advance situations in which 2 or more aircraft could require ATC directives to maintain the required separation minima.	toward TMA environment ✓ Identification of concurrence and coupling interdependencies allow to define metrics that could lead to greater clearance time.
To identify TBO interdependencies: Traffic complexity is inherent to the scalability problem of cause effect reactions between different actors sharing a common resource.	✓ Implementation of TBO mapping tools ✓ Graph based analysis ✓ Identification of Concurrence and Coupling Interdependencies
To determine feasible departure configurations: Constraint programming (CP) is an emergent software technology for declarative description and effective solving of large, particularly combinatorial, problems especially involving scheduling, resource allocation, placement and planning.	✓ Development of the CP model to determine feasible departure configurations ✓ Implementation of the optimization model
To develop a TBO Service Oriented "Information Management" Platform: To address the challenge of transparency, the project will rely on using SWIM to enable more cost and time efficient exchange of information between AU's and ATM stakeholders.	✓ Implementation of an Information System giving access to traffic real data and enabling the definition of scenarios for traffic analysis and mitigation. ✓ Implementation of web services supporting the main PARTAKE functionalities (mapping, detection and filtering, analysis and mitigation)
To maximize trajectory adherence at key waypoints: RBT relying only on deterministic assumptions will generate a weak and lack of robust predictability system. Time trajectory adherence can be improved by computing the speed change combinations to improve clearance robustness at identified TBO interdependencies supporting a fine-tuning algorithm to tackle stochastic problems while mitigating an important source of some emergent dynamics.	✓ Identification of concurrence and coupling interdependencies allow to define metrics that could lead to greater clearance times
To verify and validate the implemented Tools: A cultural change from fierce competition to a friendly competition through cooperation requires some evidences of the benefits that can be achieved by the different stakeholders	✓ Verification Concept ✓ Verification of TBO mapping tools, Analysis Tool and Mitigation Tool ✓ Fast simulation exercises ✓ Simulation exercise considering the

supporting each particular business model.	human-in-the-loop ✓ Face validation session with ATM experts

Table 1: Objectives of the PARTAKE Project

Finally, the applied objectives considering the ATM stakeholder interests are:

- **Reduction of the probability of separation minima infringement**: Preliminary results shows that implemented fine-tuning algorithms could be easily parameterized to provide robust clearances at hotspots for a certain rate of predicted conflicts. Thus, instead of minimizing the ATC interventions in a high sensible scenario that could generate cascade effects on downstream conflicts, PARTAKE tools could be used to provide a robust traffic in which a reduced amount of ATC interventions are considered as part of the solution.
- **Enhancement of airport A-CDM processes:** PARTAKE tools will contribute to a smooth integration of the different DST's implemented at airport level in the ATM system, in which information about turnaround and taxi-out delays could be used for a better use of airspace resources.
- **To improve ANSP predictive workload:** The implemented TBO mapping tools provides a more accurate traffic information to Flight Management Position in which task load at sector level could be estimated at micro-level.

2.3 Work Performed

The work performed during the project lifecycle is elaborated through eight Work Packages (WP). Each WP describes the main content developed by the Project Team.

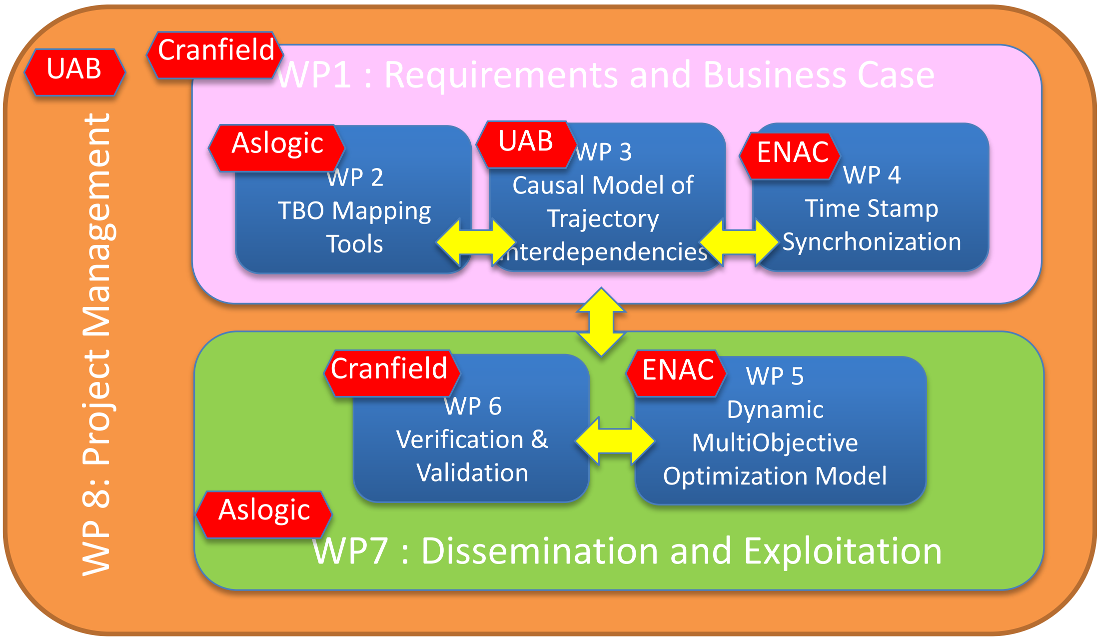

Figure 1: WP distribution

2.3.1 Work Package 1

Requirements and Business Case		
Task	Leader	Contributors
T1.1 TBO requirements	CU	UAB, ENAC
T1.2 Evaluation strategy	ENAC	CU
T1.3 Stakeholder satisfaction	Aslogic	UAB
T1.4 Business case	CU	ENAC, UAB

Table 2: Tasks of WP1

WP1 focuses on specifying functional and non-functional requirements of the PARTAKE software, as well as the definition of evaluation criterions and questionnaires. WP1 will be used as the basis for the tools design and as a reference for development and validation stages.

The objectives achieved in this Work Package (WP1) during this reporting period are the following:

- ✓ It has been designed a Technology Acceptance Model (TMA) questionnaire in order to evaluate the acceptability of the implemented method by different stakeholders.
- ✓ It has been produced a Business Case that overviews the project, identifies PARTAKE's major stakeholders including their needs and concerns. It has been created a business case assessment criteria based on scenarios and assumptions.

2.3.2 Work Package 2

TBO Mapping Tools		
Task	Leader	Contributors
T2.1 TBO Mapping Tools Design	UAB	UAB, ENAC
T2.2 SWIM connector	Aslogic	
T2.3 Macro- and micro-mapping modules	Aslogic	UAB
T2.4 Intelligent filter for determining the temporal looseness	Aslogic	CU

Table 3: Tasks of WP2

The work developed in this WP could be divided in two main pillars:

- The design principles of the four functional PARTAKE tool (detection, analysis, mitigation and information management) were set in order to satisfy the functional requirement. This specification was done using a black box approach, in which each module is seen as a separate module that maps certain inputs to outputs, remaining the underlying structure and implementation hidden. The design structure was also represented and main results of these tasks were presented in Deliverable D2.1.

- In deliverable D2.2 the working principle of the mapping tool, together with technological framework was presented. In order to be able to detect conflicts trajectories are discretized in macro and micro cells. After this initial process, the entry and exit time of those cells that have been shared for more than one aircraft are studied (filtering process). Together with the fundamental basis of the tool a user manual was released.

2.3.3 Work Package 3

Causal Model of Trajectory Interdependencies		
Task	Leader	Contributors
T3.1 Definition and Modelling of Requirements	CU	UAB, ENAC, Aslogic
T3.2 Coloured Petri Net specification of trajectory time-dependency dynamics	UAB	Aslogic
T3.3 State Space Analysis of time stamp interdependencies	UAB	Aslogic
T3.4 Sensitivity Analysis	ENAC	UAB, CU
T3.5 Automatic generation of Operational Constraints	Aslogic	UAB

Table 4: Tasks of WP3

The objective of this work package is to develop a model suitable for a better understanding of the different interdependencies between trajectories that might require an ATC directive to preserve separation minima. The identification of the interdependencies between trajectories and a measure of concurrence and coupling interdependencies is a key requirement to determine how much control should be applied to the flow of traffic and at what point in the flow it should be applied.

This objective of the WP was to specify in Coloured Petri Net formalism a discrete event model of the different interdependencies between trajectories. This objective was complemented by graph theory analysis to take advantage of better scalability possibilities. Furthermore, the objective of providing sensitivity measures of the interdependencies to describe the dynamics between concurrence and coupling interdependencies were generated using graph theory. This supports the development of a better understanding of a flexible synchronization mechanism to preserve TTA while capitalizing the CTOT gap. Finally, the prediction of the effects of any change in the time stamp through the full trajectory to support a collaborative time stamp re-assignment was accessed in this ask. The objectives have been implemented within the scope of the Analytics tool.

2.3.4 Work Package 4

Time Stamp Flexible Synchronization Mechanism		
Task	Leader	Contributors

T4.1 Time Stamp Synchronization	ENAC	UAB, CU
T4.2 Robustness Improvement	UAB	Aslogic, ENAC, CU, ENAC

Table 5: Tasks of WP4

Based on the trajectories mapping and analysis modules from work packages 2 and 3, the tasks in WP4 consisted in developing the mitigation module of the PARTAKE solution. The objective of this module is to fine-tune the take-off times (within the CTOT provided by the Network Manager) in order to increase the clearance time at identified trajectory interdependencies, which in turn reduces the probability of future ATC intervention.

This specification corresponds to a constraint satisfaction problem (CSP), which can be efficiently solved using constraint programming (CP), a recent and powerful programming paradigm. The CSP was mathematically modelled, taking into account the constraints identified in previous work packages, and implemented using an efficient CP software library.

After a first version of this mitigation module was successfully tested, the robustness of the solutions issued by the model has been assessed. Experiments showed that the solutions proposed by the mitigation module are stable with respect to the variability of the traffic, which is a key aspect for an operational application. Then, a feedback loop scheme was set up for the mitigation module. The principle is to have the model solve successive subsets of the input traffic (e.g. traffic in the next half-hour) every few minutes, to be able to handle small uncertainties on the predicted trajectories. This feedback loop has been implemented, and models for uncertainties on take-off times and for along-track errors due to wind prediction uncertainties have been proposed.

Finally, the whole model, initially set up for an en-route application, was adapted and tested to a TMA environment. One of the main adaptations was a reduction of the amplitude allowed for take-off times fine tuning, as the operational setting is more dynamic than for en-route. Following a large set of fast-time simulations and analysis, recommendations have been provided for the choice of the feedback loop parameters, both for en-route and TMA environments.

2.3.5 Work Package 5

Dynamic Multiobjective Optimization Model		
Task	**Leader**	**Contributors**
T5.1 Cost Assessment of Time Stamps Modifications	ENAC	UAB, CU, Aslogic
T5.2 Optimization towards AU's Preference	CU	UAB, ENAC, Aslogic

Table 6: Tasks of WP5

The mitigation module developed in work package 4 has been modified in WP5 into a multi-objective optimisation process, taking into account the induced costs and preferences of the various PARTAKE stakeholders.

In a first phase, the costs incurred by the PARTAKE solution has been assessed and compared to the costs of the current ATM system in a similar context. PARTAKE costs are essentially due to the short delay that might occur at take-off for a subset of flights. A mathematical model of these costs has been formulated, taking into account ground fuel consumption, maintenance cost, crew costs, passenger cost and the effect of a single delay on the network, also known as reactionary delay. As a comparison, the current cost of ATC manoeuvres has been estimated using the BADA model combined with a measure of en-route manoeuvres produced by control instructors and student controllers on a realistic traffic scenario. These estimations are used as an input to define the optimisation objectives of the PARTAKE mitigation module.

In a second phase, a strategy for optimisation has been set up. As multiple stakeholders are involved in the mitigation process, with multiple interests, various objectives have been defined and mathematically modelled. These objectives are related to the robustness of PARTAKE solutions, airline costs, airspace users' preferences and airports' preferences with respect to departure and arrival sequences. A literature review has been conducted to determine the most adapted approach to multi-objective optimisation in the context of PARTAKE mitigation, among classical schemes such as Pareto frontier determination, lexicographic ordering or linear scalarisation. The choice was made to use linear scalarisation due to its efficiency and its a priori approach. In this scheme, the resulting optimisation objective is parametrised by weights impacting every single objective, so that the decision maker can set the system according to the operational context, traffic, potentially by involving stakeholders in a collaborative decision process.

While developing the multi-objective approach, a few performance issues have been identified. Those issues where caused by the default strategy used in the optimisation algorithm to find solutions. A review of typical search heuristics used in constraint programming was conducted, leading to the implementation of a much more efficient strategy, thus reducing the computation time of the mitigation module.

Experiments have been carried out using fast time simulations for a large set of parameters for the multi-objective optimisation process. The analysis of the outcomes of these simulations proved that the variations on the weights for each objective has the expected influence on the mitigation results and exhibited the main interactions between objectives. Despite the antagonism of some objectives, it was shown that acceptable values are reached for all measured parameters, no matter the distribution of the weights for objectives.

2.3.6 Work Package 6

Verification and Validation		
Task	Leader	Contributors
T6.1 Tools verification	CU	UAB, ENAC, Aslogic
T6.2 Validation Scenarios	CU	UAB, ENAC, Aslogic

Table 7: Tasks of WP6

WP6 focuses on verification and validation of PARTAKE. The verification tasks provides a quality assessment in order to check if the requirements proposed in the concept of operations have been achieved. PARTAKE is a multi-modular system capable to 1-Detect, 2-Analyze and 3-Mitigate concurrence events in the airspace. The verification tasks take advantage of this modular structure in order to test each part of the software while considering the integration problems associated to a stand-alone application. The results of the verification tasks are documented and shared with the intended readership through the release of deliverable D6.1.

Once the software is verified and the project achieves a target maturity level, a set of validation tasks are completed. First, it is carried out fast simulation exercises, that compare baseline situations (w/o PARTAKE) with ideal PARTAKE scenarios in order to demonstrate the features, flexibility and capabilities of the software developed. Secondly, it is carried out a main simulation exercise considering the human-in-the-loop and the most relevant uncertainties detected during the project development. In this case, ATCs & Pilots are incorporated into a virtual scenario in which PARTAKE provides the Air Traffic Controllers with a suggested *optimal departure sequence* through the use of a Decision Support Tool.

The results of these exercises are then used to perform a *face validation* session, in which ATM Experts, Members of the PARTAKE Advisory Board and representatives of different stakeholders provide their opinions about the project objectives in order to find enough evidence that the project objectives have been achieved. The feedback will be provided based on a previously defined questionnaire that could be customized depending of the category of the different stakeholders (e.g. airports, ATC, airlines, etc.)

2.3.7 Work Package 7

Dissemination and Exploitation		
Task	**Leader**	**Contributors**
T7.1 Elaboration of a Dissemination and Communication Strategy and Impact assessment	Aslogic	UAB, ENAC, CU
T7.2 Graphical identity, website and communication material	Aslogic	UAB, ENAC, CU
T7.3 Dissemination events for awareness raising	UAB	ENAC, CU, Aslogic
T7.4 Sustainability and Exploitation Strategy & Actions	CU	UAB, ENAC, Aslogic

Table 8: Tasks of WP7

The tasks in the WP7 have been dedicated to the project communication and dissemination policy and strategy, definition objectives for that, target groups, timeline, metrics, resources and roles, key messages and actions and channels for dissemination. Moreover, some efforts have been made towards development of the project website with all its attributes.

The tasks have also considered the exploitation activities, through definition of the exploitation plan (EP), that had gathered the objectives of the project, the main outcomes (results), to whom the project was directed and what activities should had been developed according to that view. In addition, it established the control mechanisms to ensure that the pursued objectives of the EP are accomplished. There had been also defined the Intellectual Property Rights Management (IPRM) and the actions to be carried out with regard. The initial steps for establishing the IP Directory had been carried out. This document has been updated during the lifetime of the project to include the IP Directory at the end.

Finally, the EP has established the exploitation strategy for this project and the exploitation objectives. It defined exploitation activities to reach those objectives, and in addition, quantitative and qualitative monitor metrics. The analysis of the impact of the different activities had been carried out. The market identification complementing the one conducted in the EP has been also conducted. This extension of the market identification aimed at recognizing potential markets that might directly benefit from an application of the PARTAKE Concept, augmenting the visibility and sustainability of the project.

2.3.8 Work Package 8

WP8 has been active during the project lifetime. The objective is to ensure an efficient and active coordination of the project through administrative and organizational tasks, and monitoring of the financial project components. Performed activities have included:

- General project administration;
- Preparing and post-processing of European commission reviews from the consortium-side including support in the implementation of recommendations from SJU;
- Preparing, executing, and post-processing of scheduled project meetings;
- Preparation and submission of the management related parts of the reports to SJU.
- Management of financial management platform;
- Preparation of the financial reports to the SJU;
- Controlling of the overall budget;
- Maintenance of the project intranet and data repository for the consortium (Nebula platform), which has been continuously updated, containing all important documents.

2.3.9 Work Package 9

WP9 is active throughout the entire project lifetime. The objective of the WP is to ensure compliance with the ‘ethics requirements’ set out in this work package which in particular refers to the following three requirements, see Table 9.

Ethics Issue Category	Ethics Requirement Description
Humans	Detailed information must be provided on the informed consent procedures that will be implemented
Protection of personal data	Detailed information must be provided on the informed consent procedures that will be implemented.
Protection of personal data	Detailed information must be provided on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation

Table 9: Ethic requirements

From the innovation perspective, one of the main drivers of PARTAKE project is to contribute with a feasible tool to support the Airspace User (AU's). However, acceptability of a new proposal by the different stakeholders in a conservative sector is always seen as a barrier to deploy innovative ideas in the market. Thus, in PARTAKE it is envisaged to involve stakeholders during the first part of the project to collect their opinions through different questionnaires (D1.3) in order to decrease the risk of acceptability of the PARTAKE solutions at later stages of the project.

Despite individuals will not be "identifiable", to ensure that no problems will arise due to protection of personal data, a detailed plan for procedures is developed that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation.

2.4 Key Project Results

At the beginning of its lifecycle, the Project was aiming to achieve some of the SESAR Key Performance Indicators (KPIs). The deliverable D1.2: *2 Report on the tools evaluation strategy* [2] had elaborated the PARTAKE expected results and its KPIs that had been aligned with some SESAR KPIs. In summary, all the PARTAKE benefits will positively reflect to the ATM stakeholders in the following aspects:

1. AU's can preserve their preferred trajectories and minimize the probability of manoeuvres due to ATC interventions.
2. By reducing the probability of ATC interventions an extra airspace capacity can be generated to manage efficiently an increment in the demand.
3. Baseline for the spatial and temporal digitalization of the airspace that provides the right support for the design of new metrics.
4. A framework to manage the trajectory uncertainties generated at airport level.

One of the project objectives has been an improvement of the airspace capacity by means of a traffic synchronization approach. This KPI has been only initialized thought the analysis of spatio-temporal interdependencies between reference business trajectories, especially in terms of its metrics definition. The capacity itself should comprise the ATC position as well, which has not been fully established within the project timeline, and the integration of PARTAKE with other operational functionalities such a A-CDM and E-AMAN for a more robust trajectory synchronization solution.

PARTAKE original proposal focus on the spatio-temporal analysis of the full European ATM system, however, lack of trust on TBO and poor predictability encouraged to apply PARTAKE framework to other scenarios in which uncertainties could be bounded in time and space. Thus, PARTAKE tools have been tailored to TMA with evolving traffic and over-flights arriving from other sectors providing a separation of 3Nm minimum at horizontal level and 1000 ft at vertical level. Nevertheless, the verification and validation tasks confirmed the friendly approach to parameterize PARTAKE to different airspace volumes and discretization of the TMA into cells of a particular size. Thus, it is relevant to mention the possibility to tailor PARTAKE spatio-temporal digitalization to different airspace operational conditions such as for example UTM in which preliminary satisfactory results beyond the scope of the project has been achieved.

As described in the previous sections, and further detailed in the projected deliverables, the PARTAKE computation of departure PTOT time instants can be subject of uncertainties in the pushback initial time and the control on the taxiway. The integration of the airport information system with the PARTAKE framework could provide an important step forward to extend PARATKE functionalities with UDPP in such a way that the departure sequence has no negative impact on the runway performance. Furthermore, the airport decision support tools and its information system could provide an excellent source of information to PARTAKE to extend the amount of control variables while absorbing ground uncertainties that could impact on the proposed PARTAKE departure sequence. According to the face validation exercises, it is also worthwhile to mention that for those airports in which runway is used in shared mode in which arrivals and departures coexists, the information provided by the E-AMAN is a requirement.

The PARTAKE functional and non-funtional requirements [1] was established with a clear vision to integrate the pre-flight information as a control variable to identify the hotspots and the time-stamp gaps to mitigate tight interdependencies between trajectories. Furthermore, the tool to identify the hotspots provides extended information that could be used to enable other mitigation mechanisms such as rerouting that could be used not only to preserve the safety distance between aircraft but also to provide extra separation without introducing latent capacity.

According to the ConOps, the original or preferred user trajectory is preserved introducing only a time shifting inside the CTOT which if is properly coordinated with the pushback operation should not introduce any extra cost regarding the fuel consumption. The PARTAKE framework can be extended also with en-route flight speed changes to relax some time interdependencies that could over-constraint the combination of CTOT departures between PARATKE airports. Furthermore, since PARTAKE is running in a continuous cycle approach, the flight speed changes could provide an extra control variable to preserve the safety distance and the preferred business trajectories in those interdependencies that arise due to time-stamp uncertainties.

Different validation scenarios have been implemented. The goal was to check the PARTAKE performance in a high dense and complex airspace with evolving traffic and over-flights: The London Terminal Area in which they coexist 5 airports and over-flight traffic from Bristol and Manchester airport. Furthermore, the traffic in the Compton area was stressed to check if in the nominal scenario it could be possible to reduce the probability of ATC interventions. The same experiments were also repeated in a virtual scenario with ATC's and pseudo-pilots to check the acceptability of the results and identify the main sources of uncertainties that could affect the quality of the results.

Regarding the spatio-temporal interdependencies analysis tools, its validation was performed by means of an innovative ATM dashboard (see Figure 2) in which the main relevant data is constantly updated according to the cycle parameters:

- **Spatial information**. It is presented in the left side of the dashboard as a *thermogram* on the map where the color relates to the number of potential concurrence events identified in a cell.
- **Temporal information**, from current simulation time to the look ahead. Three complementary views are provided:
    - *Entry counts*: both the estimated (according to RBT's as defined in the so6 file) and the most up-to-date (according to current time during the simulation) are represented. The entry count has been aggregated by the execution period P. In the nominal case, the most up-to-date count should be equal to the estimated unless it is affected by mitigation measure in a

given period. This will not be case in the validation exercises where different sources of disturbances are introduced.

- ○ *Occupancy vs. concurrence event* graphs. Prediction of the occupancy evolution is plotted along with the predicted concurrence events. In the later, several plots can be selected to see concurrence events involving any flight in the sector and/or just the ones involving the flights departing from the coordinated airports.
- ○ *Concurrence event timeline.* This graph shows the time instant when concurrence event takes place as well as its duration. Additionally, the involved flights can be checked. Two views can be selected to see concurrence events involving any flight in the sector or just the ones involving the flights departing from the coordinated airports.

- **Parameter window** shows the different parameters that have been specified for the simulation.

Figure 2: ATM Dashboard

Regarding the virtual scenario, realistic traffic was used (see Figure 3) with 3 experiments, the first one provided the baseline while the other 2 experiments provided relevant information about the importance of the adherence to the sequencing proposed by PARTAKE and the effects of the uncertainties on the spatio-temporal interdependencies.

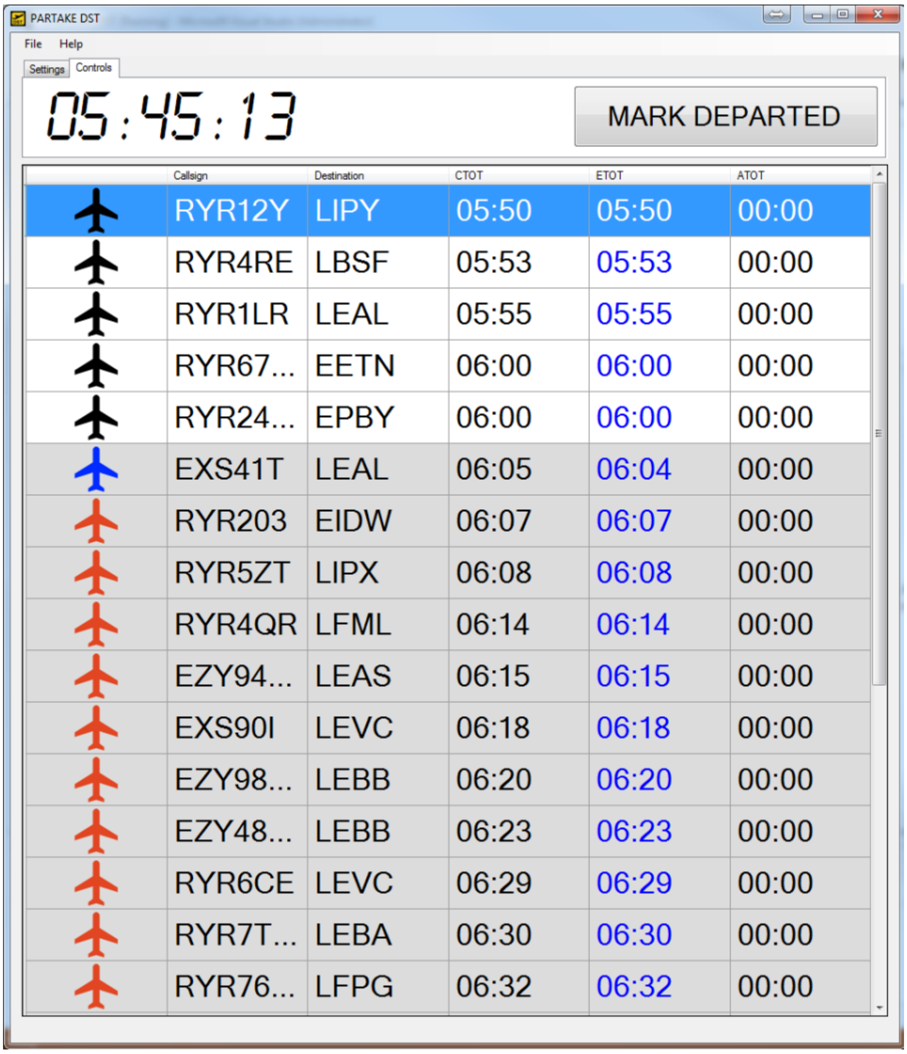

Figure 3: Desion Support Tool

Finally, the applied objectives considering the ATM stakeholder interests are:

- **Reduction of the probability of separation minima infringement**: Preliminary results shows that implemented fine-tuning algorithms could be easily parameterized to provide robust clearances at hotspots for a certain rate of predicted conflicts. Thus, instead of minimizing the ATC interventions in a high sensible scenario that could generate cascade effects on downstream conflicts, PARTAKE tools could be used to provide a robust traffic in which a reduced amount of ATC interventions are considered as part of the solution.

- **Enhancement of airport A-CDM processes**: PARTAKE tools will contribute to a smooth integration of the different DST's implemented at airport level in the ATM system, in which information about turnaround and taxi-out delays could be used for a better use of airspace resources.

- **To improve ANSP predictive workload**: The implemented TBO mapping tools provides a more accurate traffic information to Flight Management Position in which task load at sector level could be estimated at micro-level.

2.5 Technical Deliverables

Deliverable ID	Deliverable name	WP number	Lead participant	Dissemination level	Delivery date of latest edition
D1.1	Report on PARTAKE functional and non-functional requirements	WP1	CU	Public	30th June 2016
D1.2	Report on the tools evaluation strategy	WP1	ENAC	Confidential	20st January 2017
D1.3	Technology Acceptance Model questionnaire	WP1	ASL	Public	31st October 2016
D1.4	TBO Business Case	WP1	CU	Confidential	8st February 2016
D2.1	Report on the tools design	WP2	ASL	Public	31st October 2016
D2.2	Release of mapping tools	WP2	ASL	Public	15th March 2017
D3.1	Modelling Requirements	WP3	CU	Public	20st January 2017
D3.2	CPN model	WP3	UAB	Confidential	29st December 2016
D3.3	State Space Analysis	WP3	UAB	Public	15th March 2017
D3.4	Sensitivity Analysis	WP3	ENAC	Public	16th October 2017
D3.5	Operational Constraints	WP3	ASL	Confidential	16th October 2017
D4.1	Time stamp computation	WP4	ENAC	Public	18th December 2017
D4.2	Robustness	WP4	ENAC	Public	16th November 2017
D5.1	Fuel consumption assessment	WP5	ENAC	Public	2nd November 2017
D5.2	Multiobjective Optimization	WP5	ENAC	Public	8th February 2018
D6.1	Verification Report	WP6	CU	Confidential	21st November 2017

D6.2	Validation Report	WP6	CU	Public	28th February 2018
D7.1	Set-up of a communication and dissemination strategy and plan	WP7	ASL	Confidential	12th January 2016
D7.2	Exploitation Plan	WP7	CU	Confidential	15th March 2017
D7.3	Report on Exploitation Impact Assessment	WP7	CU	Confidential	2nd September 2017
D7.4	Project website	WP7	ASL	Public	5th February 2017
D8.1	Project Management Plan	WP8	UAB	Confidential	12th January 2017
D8.2	Final Project Results Report	WP8	UAB	Public	28th February 2018
D9.1	POPD - Requirement No. 3	WP9	UAB	Confidential	29th April 2017
D9.2	POPD - Requirement No. 2	WP9	UAB	Confidential	29th April 2017
D9.3	H- Requirement nº 1	WP9	UAB	Confidential	29th April 2017

Table 10: Project deliverables

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

Traffic flow management was originated in the 70s in USA to tackle air traffic scenarios where the ATC reached high levels of stress, leading to dangerous situations. The research efforts, led by the MIT, looked for a suitable metric able to predict those expected air traffic concentrations in given airspace volumes.

Such a metric was the "entry count". The entry count, measured as flow of aircraft entering these volumes per hour, was considered the best "gross" value damping the impact of the existing uncertainty contained in the flight plans. The volume (an ATC sector or airport) and the time frame (one hour) were big enough to provide reasonable estimates although not accurate. The entry count enables the evaluation of the general expected situation for a given traffic volume.

Integrated ATFM in the European airspace started much later (in 1996) than in US and it was developed driven by the necessity for a change on how ATFM was conducted. The incorporation of an integrated management of Flight Plans and main flows crossing sectors pointed to the introduction of metrics containing higher granularity (in time, not in space). *Occupancy,* as a measure of air traffic density, was a good candidate with improved depiction of the airspace volume situation. However, it was partially rejected, as the values, considering the flight plans uncertainty, might provide misleading information to flow managers. Thus, the entry count was still maintained as the basic metric driving to decisions about ATFM measures in the European airspace.

The SESAR ATM Master plan recognised that the modernisation of the European ATM system "should look for a better knowledge of the flights as a whole, as part of a flow within a network". This aim conceals the need for tailored metrics able to characterise different physical scenarios at different time horizons. All the above underpinned by the TBO concept.

Improved predictability would allow the introduction of more effective metrics for ATFM measures and, as reflected in the ATM Master Plan, enabling that "flexibility is also key to ensuring a resilient system that is able to deliver to maximum capacity in all situations".

One of the PARTAKE main contributions is the effective definition and implementation of the *parametrisable spatiotemporal interdependencies* metric able to characterise the traffic flow from the ATM perspective. PARTAKE has defined a framework that allows operational experts to tailor which is the best level of granularity for each *spatiotemporal* environment in a flexible manner, and then, to have a better knowledge about the required management or control mitigation measures.

PARTAKE identifies the management and control variables which can be used to improve the air traffic behaviour in the airspace. PARTAKE's initial aim only covered the use of estimated take-off times as control variables for mitigating concurrence events (*i.e. a spatiotemporal interdependence*) at STAM level in the whole European airspace. It has been initially materialised by targeting concurrence events in environments where management and control variables are closer in time, i.e. climbing segments in Multi-Airport systems, such as the London TMA, which is underlined in green in **Error! Reference source not found.**.

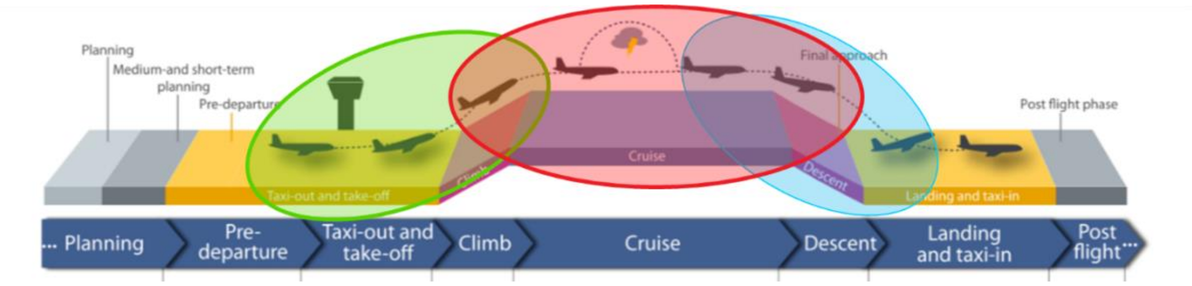

Figure 4: PARTAKE concept areas of application

Figure 2 also includes potentially usages of the PARTAKE in other operational environments. The blue area would represent the potential applicability of PARTAKE in an E-AMAN context. The PARTAKE application in the E-AMAN solution would try to mitigate concurrence events (holding in a stack) by applying tailored clearances to involved aircraft on the en-cruise phase.

The red area, finally, shows the application of PARTAKE in an en-route context, where local clearances may create concurrence events downstream. PARTAKE concept could be applied to advise which locally applied solutions may mitigate concurrence events at network level.

In summary, PARTAKE solution develops on top of the automation principles of: when is the best time to take a decision; where is the best place to take it; and who is the best player for doing so in an ATM context. PARTAKE solution provides a parametrisable tool tailored to these criteria for identifying the problem that should be mitigated and the analysis mechanisms to provide the best solution.

3.2 Maturity Assessment

OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	Achieved	PARTAKE concept pivots around the concept of *parametrisable spatiotemporal interdependency,* or concurrence event. This concept habilitates the parametrisation of desired metrics for their application in different operational contexts and environments. The PARTAKE framework has relied on the application of the STAM methodology developed in the P07.06.05 of SESAR 1. PARTAKE has implemented a methodology including the detection, analysis and mitigation phases, incorporating novelties in the different phases. Thus, the deployment of the PARTAKE framework in an operational use case resulted in the development of a Concept of Operations placed on the boundary between ATFCM and ATC, and tailored to the London TMA operational framework. On the detection phase, PARTAKE has implemented a high-performing concurrence level identification process, going to high-level programming to fast identification of aircraft potentially involved in concurrence events. On the analysis phase, PARTAKE has incorporated graph theory principles to isolate flights which are very sensitive to any change, inducing problems downwards. On the mitigation phase, the same graph theory principles have been applied to determine what is the best solution ensuring an overall increased network performance, given a set of concurrence events and a given operational environment.
OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	Achieved	The basic idea is built around the concurrence event concept. The introduction of the parametrisation element on the identification process enables tailoring the tool for different operational contexts and environments. The basic scientific principles for this process, together with the basic principles of the mitigation one, have been published in leading conferences in the ATM field, such as the ATM Seminar. The paper *"A Constraint Programming Model with Time Uncertainty for Cooperative Flight Departures"* received the best paper award in the separation track in the 12th ATM

			R&D Seminar, in Seattle. In addition, the paper *"An efficient constraint programming for cooperative flight departures"* won the *best paper award* 2016 at the 13th International Multidisciplinary Modeling & Simulation Multiconference, celebrated at Larnaca (Cyprus).
OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	Achieved	The PARTAKE ConOps D1.1 analyses the position of the project within the envisaged future ATM system. In addition, the concept / need is also covered within the ATM Master Plan. The use case of PARTAKE within the London TMA responds to an identified need in the *Essential Operational Change* "AMAN / DMAN Integration Including Multiple Airports". Some relevant OIs targeting this operational change are: 1. TS-0302-A, B Departure Management Information from Multiple Airports 2. TS-0307 — Integrated Arrival Departure Management for traffic optimisation within the TMA Airspace In addition, PARTAKE developments and conclusions could affect the following OIs: 3. DCB-0208 – DCB in a trajectory management context 4. DCB-0308 – Advanced Short Term ATFCM 5. CM-0206 – Conflict Detection and Resolution in the TMA using trajectory data
OPS.ER.4	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?	Achieved	The Project has reported during its lifetime the background and development of the concept. The initial distribution of workpackages has covered the identification of the need and its materialisation in a Concept of Operations (WP1), the identification phase tailored to TBO (WP2), interdependency analysis (WP3), the mitigation phase (WP4), optimisation (WP5). PARTAKE solution describes a new capability, which is a flexible adaptation of metrics used in different operational contexts for decision-making. This capability has been developed and deployed by applying this concept for an operational context with a high-predictability level, where the control actions are closer in time to the concurrence events to be mitigated. Specifically, the adaptation of the *parametrised spatiotemporal interdependence* concept to the London TMA environment provides a new type of STAM solution to be deployed in this

			high-complexity environment.
OPS.ER.5	Are the relevant stakeholders and their expectations identified?	Achieved	The main stakeholders have been identified is the Exploitation Plan. In this sense, it is likely that expectations of the stakeholders are covered, as the project is completely aligned with the ATM Master Plan, which is covering the expectations within the aviation community. The final dissemination workshop of PARTAKE was conducted at Cranfield University on the 20th of February of 2018. Representatives of NATS, INDRA, Rolls-Royce, Luton Airport, Cranfield Airport attended. The panel of experts identified that the solution can be benchmarked against nowadays solutions that are being used within the London TMA, such as the Minimum Departure Intervals (MDI) at Birmingham airport, which is the current norm for flow synchronisation and demand control at the London TMA. The stakeholders also identified that PARTAKE provides a baseline for the design of new metrics which are essential for a better efficiency of the overall ATM system.
OPS.ER.6	Are there potential (sub) operating environments identified where, if deployed, the concept would bring performance benefits?	Achieved	The PARTAKE solution is adaptable to its application in different operational environments. The use case of the PARTAKE framework was deployed for simulation in the London TMA environment, which is a high-complex TMA scenario.
SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	Partially Achieved	The real-time simulation exercise counted on ATCo and pilots that identified main areas where PARTAKE can impact. In the airport operational environment, PARTAKE should be integrated within the airport A-CDM. It is also required an integration within AMAN solutions for enabling a higher adherence to the PARTAKE target take-off times. In addition, the operational implementation

			of PARTAKE would require procedures to be put in place on the airport operations, to prioritise taxi for some aircraft in case a PARTAKE clearance is issued. PARTAKE shall be implemented integrated within systems providing information about airborne and on-ground aircraft. Therefore, PARTAKE should be implemented at region level or ATC Unit level, for delivering its solutions to impacted airports in the surrounding area.
SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?	Partially Achieved	Automation is supporting the three main functional areas of the project, identification, analysis and mitigation. These needs have not been described as "automation needs", but as technical developments for providing solutions to deploy the concept.
SYS.ER.3	Have initial functional requirements been documented?	Achieved	The functional requirements of the tool have been listed in the Deliverable 1.1 (ConOps).
PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	Partial, non-blocking.	Validation activities carried out a proof-of-concept testing, by integrating PARTAKE within the ATM simulator at Cranfield University. The results from this proof-of-concept can be consulted on D6.2. The ATM Experts identified that the solution as a baseline from which evolve in the creation of new metrics for managing the airspace. In addition, SJU experts identified that the PARTAKE solution can be benchmarked against current MDI measures to test the feasibility of the solution. The assessment concludes that it is Partial Non-blocking due to the feasibility study has not formally covered all the ramifications of the project, and it has not involved the participation of TMA controllers. However, the PARTAKE solution was placed within an operational environment, and potential benchmark scenarios (MDI) were identified. A comprehensive feasibility study could be carried out for potential stakeholders and decision-makers, based on the methodology and technical implementations of the PARTAKE

			solution. The prototype is already integrated in a simulation environment, where realistic scenarios may be reproduced.
PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	Partially	A BIM (Benefits Impact Mechanism) analysis was carried out, which could be consulted on D1.4, in addition to associated influence factors.
PER.ER.3	Has an initial cost/benefit assessment been produced?	No, but non-blocking.	Partially. An initial cost-benefit anaysis was carried out, which could be consulted on D1.4, in addition to associated influence factors.
PER.ER.4	Have the conceptual safety benefits and risks been identified?	Achieved	Deliverable 1.2 covered a conceptual safety case, identifying conceptual safety benefits and risks. The validation activities have demonstrated that PARTAKE tool helps to synchronise traffic, by providing clearances that would remove planned concurrence events without inducing new ones.
PER.ER.5	Have the conceptual security risks and benefits been identified?	No, but non-blocking.	The solution will rely on the overall security mechanisms to be deployed by the system.
PER.ER.6	Have the conceptual environmental impacts been identified?	No, but non-blocking.	The concept, once applied in the TMA environment, would allow aircraft flying their RBTs during the climb phase. This would have a positive impact regarding the most optimum trajectories from the airspace users, increasing the horizontal and vertical flight efficiency.
PER.ER.7	Have the conceptual Human Performance aspects been identified?	Achieved	The PARTAKE solution has been subject to a proof-of-concept testing. A real-time simulation was carried out, where ATC ground roles were simulated by rated Air Traffic Controllers. The application of PARTAKE impacts on the taskload of the ground and local controllers, as it is required more adherence to targeted take-off times. Nonetheless, the ground controller participating in the validation remarked that current flow measures at airports create a

			similar taskload, due to the departure times shall be also managed. The mitigation of the taskload of the controller in the sector of interest was conceptually proved, as the concurrence events leading to PARTAKE clearances were removed, incrementing the minimum distances among pair of aircraft.
VAL.ER.8	Are the relevant R&D needs identified and documented?	Achieved	The dissemination event helped to identify main R&D activities which could extend the current PARTAKE solution. The main R&D needs are listed in the Conclusions section of Deliverable 6.2. These needs reflect the need for introduce Departure Time windows in the PARTAKE solution, an enhanced understanding of current procedures such as Minimum Departure Intervals. The impact on the system architecture shall be object of further research as well as its integration with other solution such as E-AMAN. Finally, the PARTAKE solution has been tested with planned trajectories. There is a gap between planned and actual trajectories, that may lead to lack of effectiveness of applied PARTAKE measures. Machine learning may help to bridge the gap between plan and reality, tailoring the identification and mitigation tools to represent which actually is occurring in the airspace.
TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	Achieved	PARTAKE have successfully performed several validation exercises both in a digital simulation environment and in a virtual environment with ATC's and pseudo-pilots. Results achieved seem to confirm that the technology concept is well formulated and TRL-2 has been achieved.

Table 11: Maturity assessment

4 Conclusion and Lessons Learned

4.1 Conclusions

An overall conclusion is that: Spatio-temporal interdependency analysis tools implemented in PARTAKE provides a baseline for the design of new metrics, which are essential for a better efficiency of the overall ATM system, and contributes to:

- A better integration of present fragmented layered planning processes,
- Mitigate lack of efficiency due to mismatch between planned and flown trajectories.
- Provides a common understanding along the criteria and time of the triggering trajectory management relevant events.
- ATM digitalization providing relevant information to identify the causes of "emergent dynamics" which will be the basics for a better understanding of the "un-modelled dynamics".
- Facilitate the transition from the current "airspace based operations" towards the proposed "trajectory based operations".
- To identify the existing gaps, enablers and barriers for the implementation of a new ATM operational architecture based on the spatio-temporal interdependency analysis that could become in more specific exploratory research actions.
- A STAM dynamic capacity demand balance by means of a fine tuning algorithm to compute the departure time without affecting the ATFCM pre-flight assignments.

The validation exercises allows to confirm the following achievements:

- Trajectory compatibilities can be analysed in a common picture supporting different look ahead times, and the analysis based on measuring the trajectories compatibility characteristics by the common metric.
- The analysis of the Spatio-Temporal picture is a valuable information to predict the expected required SM interventions. Furthermore the concepts of looseness and its computation in the interdependencies provides also a relevant information about the sensitivity and robustness of the spatio-temporal picture.
- PARTAKE allows a continuous rolling-up horizon to predict SM interventions due to trajectory uncertainties.
- ATM digitalization in discretized cells could be extended considering different granularity levels according to trajectory uncertainty which it is assumed is time dependent.
- The mitigation tools implemented provides an excellent baseline to move separation management functionalities toward trajectory management services in which efficiency can be improved while preserving the same safety levels.

4.2 Technical Lessons Learned

The work done in PARTAKE Project has produced lessons learned, which are summarised below for each technical Work packages. One main lesson is the importance of creating the right mechanisms for a mutual learning during the ConOps elaboration in which the different competencies of the members should be seen as the most important asset to create a common understanding of the objectives together with the methods and tools to be adapted/implemented. The collaborative working platform "Nebula" was a true support to foster the collaboration within the team. Also, another important lesson is that active involvement of an Advisory Board without financial support is difficult.

From WP 1	**Lessons Learned from Requirements and Business Case**
	The Work Package 1 formulates the Concept of Operations of PARTAKE and provided the roadmap that was used for the project development. In a low TRL project, in which basic principles are observed and a technology concept is formulated, the definition of requirements should aim at defining a general idea of the system.
	The functional requirements of PARTAKE were based on the project proposal and maintained high levels of flexibility for the defined tasks. This aspect was a key to successfully achieve the project objectives. We had a clear idea of the PARTAKE system from a very early stage of the project, but we obtained the required flexibility to discuss different ideas related to the concept of operations that did not changed the original definition of the system.
	The definition of Cost-Benefit Analysis in early stages is a challenging task that requires realistic quantitative information, which is not easily estimable in TRL1 or TRL2 projects. Consequently, the use of a more qualitative approach like the Benefit Impact Mechanism (BIM) provided more suitable estimations of the project in defined Key Performance Areas (KPA).
	The evaluation plan developed in deliverable D1.2 provided the baseline for the validation strategy. The definition of key performance indicators represent the matter of discussions during the validation exercises performed as part of the V&V tasks.
From WP2	**Lessons learned from TBO Mapping Tools**
	The successful implementation of the PARTAKE tool was based on a solid specification of PARTAKE different modules requirements, together with the use of black box approach that allowed the verification of each of them independently.
From WP3	**Lessons learned from Causal Model of Trajectory Interdependencies**
	Graph theory represents a good framework to identify trajectory interdependencies on a large scale.

	Due to its design, the tools could be adopted to the study of wind forecast and delay recovering capabilities
From WP4	**Lessons learned from Time Stamp Flexible Synchronization Mechanism**
	Although the operational settings are quite different for en-route and TMA, PARTAKE can be easily adapted to work in both environments, with very few changes.
	In order to increase the robustness of the PARTAKE mitigation towards uncertainties on take-off times and along-track errors, it is recommended to use PARTAKE within a feedback loop. The horizon and refresh time parameters of this loop depend on the operational context PARTAKE is used in (en-route or TMA).
From WP5	**Lessons learned from Dynamic Multiobjective Optimization Model**
	A multi-objective optimisation approach is possible for the PARTAKE mitigation module, although the computation time for finding solutions is slightly increased.
	The proposed approach provides an intuitive way of adapting the optimisation criterion depending on the context of use and based on a negotiation between all involved stakeholders. Even with extreme values for configuration, the associated costs stay within a reasonable margin, below the estimated current costs of ATC.
	The baseline for this optimisation scheme must be calibrated on realistic data (possibly recent traffic) before parametrisation and usage in a given operational context.
From WP6	**Lessons learned from Verification and Validation**
	Given the software-oriented nature of the PARTAKE project, the verification tasks focused on testing the technical components of the tools based on the functional requirements of the project. Initially, the project required a set of stand-alone tools that represented the modules of Detection, Analysis and Mitigation. A key decision of PARTAKE was the integration of these three modules in a single executable bundle. The result was a technical deployment of the PARTAKE solution executable in a recurrent process. It also improved the test and verification activities by allowing us to perform fast simulations using different scenarios. The simulations were used, among other purposes, to empirically analyse the sensibility of different parameters such as the cell size, execution period or vertical separation minima.
	The concept of operations described in the first work package was defined as a theoretical approach of a problem. However, we decided to orientate the validation activities towards a *Proof of Concept*, by carrying out real-time simulations of a conceptual TBO scenario containing the PARTAKE integrated solution. Additionally, the orientation of PARTAKE to solve a realistic problem in a local airspace with the support and continuous feedback of operational experts (ATCs and Pilots), provided us with key aspects that could have been neglected in a more theoretical approach.

	The validation strategy that was adopted in the WP6 and the Validation Workshop, definitely supported the exploitation and dissemination activities by increasing the level of acceptability and understanding of stakeholders and decision makers.
From WP7	**Lessons Learned from Dissemination and Exploitation**
	The production of quality work was the basis of PARTAKE dissemination. Consortium members participated in 5 international conferences and published 3 scientific papers. Additionally, PARTAKE won the best paper award of the 12th ATM R&D Seminar and 13th International Multidisciplinary Modelling and simulation multiconference. Additionally, a workshop was hold at Cranfield University presenting the adaptation of PARTAKE tool to London TMA to relevant AMT stakeholders.
From WP8	**Lessons Learned from Project Management**
	Small consortiums with all the consortium members fully engaged in the successful implementation of research objectives creates a friendly atmosphere during brainstorming sessions that foster the identification of most prominent solutions to academic problems.
From WP9	**Lessons Learned from Ethics Requirements**
	The preparation and preparation of the ethic requirements deliverables supported to educate the consortium towards the right behaviour during the validation scenarios.

4.3 Plan for next R&D phase (Next steps)

The implementation and validation of PARTAKE framework has unveiled several operational conditions that requires extra research to extend the applicability of PARTAKE to London TMA and other multi-airport configurations enlarging the scope to the full European ATM system. On the other hand, there are several research and innovation topics that were out of the scope of the PARTAKE proposal and should be considered in future research to reach higher TRLs. Bellow are summarized both future research topics.

4.3.1 Next Steps for PARTAKE Tools:

1. *Sequencing Departures computing Time windows* : Present implementation of Partake computation of departure take-off time provides the right time instant at which each aircraft should take-off to preserve separation minima at the different tight spatio-temporal interdependencies. To get a better acceptability of the proposed technology the mitigation tool should compute feasible departure take-off time domains that would guarantee also separation minima at the different tight spatio-temporal interdependencies. Thus, initial CTOT time window domain allows from -5 to +10

minutes take-off and it is proposed to compute the lowest and highest bound inside the original domain (ie. CTOT assigned slot) that preserve the separation minima with all the other trajectories in the look-a-head time.

Validation exercises unveiled that the airport taxi-out pathways status and the dynamics of landing aircraft in a shared mode runway requires a time window take-off time instead of a particular time instant. Furthermore the use of time windows could avoid an increment of pressure at the runway threshold while avoiding any negative impact on the runway performance.

2. *Classification :* As a consequence of improving the Constraint Logic Programming model to compute the take-off time domain, a relevant qualitative information is provided about the priority to be given to each departure. Thus, a narrow time window means that a flight has a very tight trajectory and an effort to fit the take-off in the proposed time-window will avoid several potential ATC interventions.

   Thus, a classification of departure aircraft in each airport could contribute to a better monitoring of the turnaround and taxi-out processes that could affect those aircraft that has a tight take-off time.

3. *Integration with the UDPP*: As it was reported in the PARTAKE Conops [1], the implemented services are fully compatible with UDPP implemented at airports. At present, UDPP is seen as a boundary condition to PARTAKE, however, the analysis of the spatio-temporal interdependencies considering the potential swapped trajectories could provide an extra control variable for a more robust mitigation of the tight interdependencies. Thus, in case that a particular aircraft is not ready for the assigned CTOT due to delays (ie. turnaround delay for example), it is identified other aircraft that could take profit of the slot according to UDPP business rules, however PARTAKE could provide a value for the convenience to prioritize the swapping according to the impact of the trajectory in the air side.

4. *Last minute departure coordination*: The application of PARTAKE to multi-airport planning should require a coordination tool in which any delay introduced in the take-off of an aircraft in a nearby airport should be informed to those departures that could be affected in order to compute the extra delay. The identified spatio-temporal interdependencies can be used to determine the right aircraft that should be slightly delayed. It is expected that this functionality could provide some benefits only for those airports sharing the same TMA with tight interdependencies between the trajectories.

5. *Uncertainty models for the mitigation mechanisms*: Present implementation of PARTAKE tools, assumes the adherence of the aircraft to a trajectory. Despite it is used the RBT, it could be used other trajectory specifications such as ones elaborated by a Machine Learning model relying on historical data. The mitigation mechanisms try to maximize all the looseness at the tight interdependencies to minimize ATC interventions. According to ATM community feedback, PARTAKE could be improved by considering in the constraint logic programming model different weight to the

interdependencies such that those trajectories with more uncertainty should receive a bigger looseness. Somehow, instead of using an equity criteria, PARTAKE could be extended considering a fairness criteria.

4.3.2 Next Steps for PARTAKE Framework

1. *Integration with A-CDM architecture*: Results achieved during the implementation of collaborative decision-making tools in airports show the benefits of a better predictability of airport processes to mitigate the free propagation of perturbations. PARTAKE framework was conceived to determine the take-off time of aircraft holding in the runway feeder, but for a better acceptability the departure sequence should be considered from the parking position, thus, an estimation of the end of turnaround tasks together with an estimation of the taxi-out will allow PARTAKE to sequence the departures from the taxi position.

   A proper integration of PARTAKE with A-CDM will enhance the capacity to preserve or improve the runway performance, reduce the runway threshold pressure and reduce the probability of ATC interventions.

2. *Integration with E-AMAN architecture:* For those airports with one runway operating in shared mode, the landing aircraft are blocking the use of the runway for departure purposes during certain time periods. The information about the time the runway will be blocked by an arrival is a requirement for PARTAKE framework. Note that the lack of this information is a source of uncertainties for the take-off time that can easily generate a take-off delay with respect to the take-off time computed by PARTAKE impacting negatively on the mitigation mechanisms.

   A proper integration of PARTAKE with E-AMAN will enhance the capacity to preserve the proposed take-off times in shared mode runways, to improve the runway performance, reduce the runway threshold pressure and reduce the probability of ATC interventions.

3. Minimum Departure Interval: According to the operational conditions in the airport there are some constraints regarding the minimum departure interval. The factors that influence this value should be considered also in PARTAKE framework to guarantee the safety factors.

   Extending the Constraint Logic Programming model with the rules that define the minimum departure interval will provide a better understanding of the constraints that affect the departure while it will contribute to improve the runway performance (ie. avoid latent capacity), reduce the runway threshold pressure and reduce the probability of ATC interventions.

4. *Design a valuable traffic complexity metric*: Within Today's "airspace based operations" balance between the demand and the system resources relies on the hourly entry count* (complemented by the occupancy) of the "expected traffic" into the ATC

sectors or airports. The spatio-temporal interdependency analysis tools implemented in PARTAKE, support the design of more smart metrics to better understand traffic dynamics.

Partake framework can support the design of new metrics which are sector independent enhancing the concept of airspace based operations principle and allows different granularities to encompass uncertainties' growth with look ahead time.

5. *Model Aircraft Performance*: Considering PARTAKE proposal as a ER project with low TRL, the implemented framework has not considered different aircraft performance, instead all the modules consider just 1 type of medium aircraft performance. To tackle more realistic scenarios PARTAKE framework should be enhanced with the performance of a mix of medium and heavy aircraft to evaluate if proposed take-off times are sensible to the mix of aircraft in the multi-airport system, in which case the mitigation mechanism functionalities should be extended.

6. *Machine Learning*: A barrier identified during the validation exercises is the lack of adherence between the trajectories used in PARTAKE (RBT's) with respect the flown trajectories. Machine learning models provide an excellent baseline to identify aircraft flow patterns and propose a more realistic trajectory to be analysed by Partake.

   Extending PARTAKE framework with Machine Learning functionalities will provide a better identification of the real future spatio-temporal interdependencies, and in consequence the mitigation mechanism will generate more robust looseness. For these airports that lacks A-CDM or a proper control of the taxi-out pathways, ML could improve the right sequencing from the Parking position.

7. *Spatial Mitigation Mechanisms:* Present PARTAKE mitigation mechanism rely on preserving AU's trajectory preferences (ie. RBT's) and introducing a slight take-off time shifting inside the assigned slot. The digitalization of the airspace by means of discretized cells, enhance PARTAKE to explore the possibility to introduce an extra traffic synchronization control variable by means of path stretching/path shortening trajectory changes.

   Extending PARTAKE framework with extra traffic synchronization control variables will provide the capacity to increase the looseness values at the identified interdependencies as a trajectory management mechanism that could contribute to lessen the ATC task load

8. UTM application: PARATKE provides an excellent opportunity to validate the airspace spatio-temporal digitalization functionalities in the drone architecture. The main differences regarding aircraft performance, very short linear segments, and the business model, introduces some important changes in the services that properly adapted and validated could contribute to the deployment of a decentralized conflict resolution system.

9. *ATC position*: It is of high relevance importance to consider the ATC position in the PARTAKE framework. The limited time and resources in ER projects made it difficult to consider the role of ATC in PARTAKE, except for the validation exercises. Despite it has

been considered that the situational awareness of ATC is maintained and that a dashboard can support ANSP management tasks, the project should be extended considering the ATC human factors to take benefit from the control variables.

10. *Airspace Users*: Airlines should be involved to check the acceptability of PARTAKE framework that somehow can affect by providing priority to other aircraft waiting also in the runway threshold. Thus, despite the benefits of a trajectory with less ATC interventions and the possibility to fly the preferred trajectory, there are several business model aspects that should be crosschecked to identify potential barriers.

11. *Training Material*: An important aspect to leverage the functionalities implemented to be used as a reference framework by the ATM community is the preparation of training materials to get used to the spatio-temporal interdependency analysis information, and allow them to take an active role in the future improvements of the framework.

5 References

5.1 Dissemination and Communication activities

The communication and dissemination activities can be divided in the next three different blocks:

1. **Set-up of a communication and dissemination strategy**

During the first three months of the Project, Aslogic created a corporative image to be used during the life cycle of the project. It was composed of: logotype, corporate colour scheme, concept icons, corporate typeface and corporate stationary (see Figure 5)

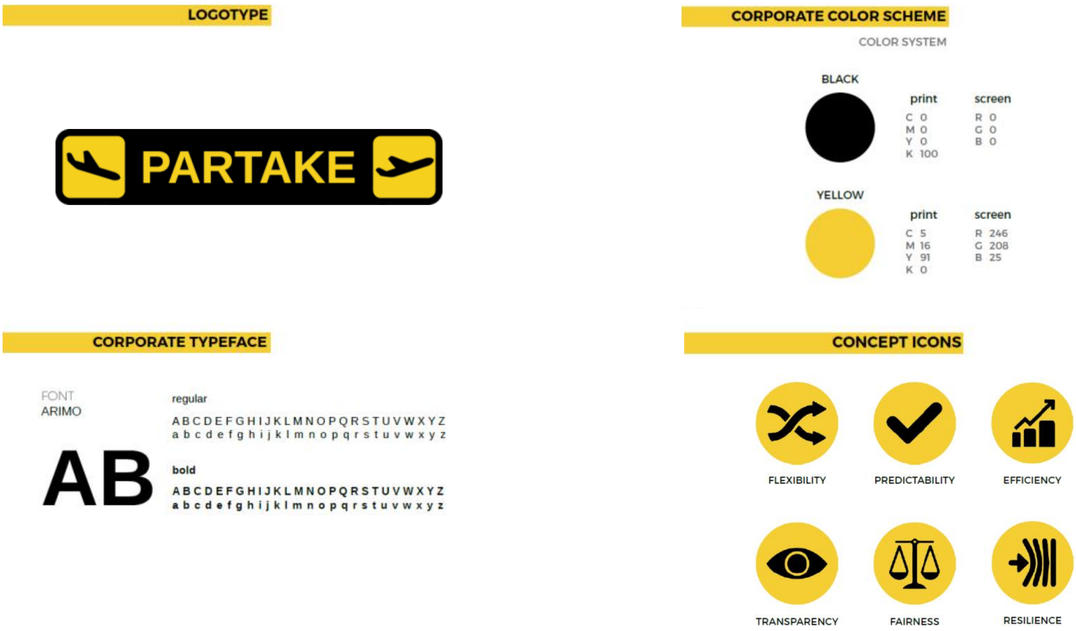

Figure 5: ***PARTAKE Branding***

Additionally, a promotional material leaflets, roll-up and poster for PARTAKE dissemination/promotion events and meeting were created during the first stage of the project (see Figure 6)

Figure 6: ***PARTAKE leaflet promotional material***

A website (http://www.partake-aero.eu) and a Linkedin profile (https://www.linkedin.com/company/10913811/) was created in order to publish news, public documents and update relevant information about the Project (see figure 3 and 4).

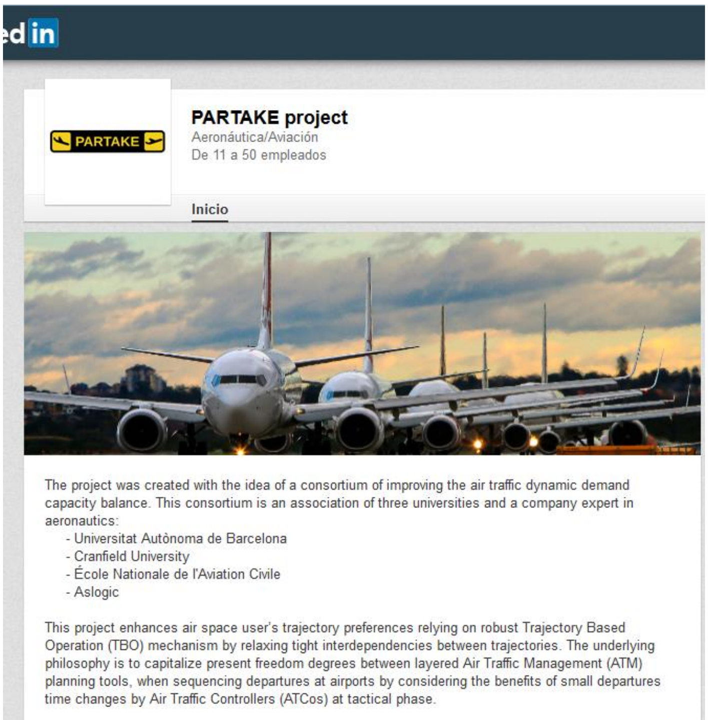

Figure 7: *PARTAKE LinkedIn page main view*

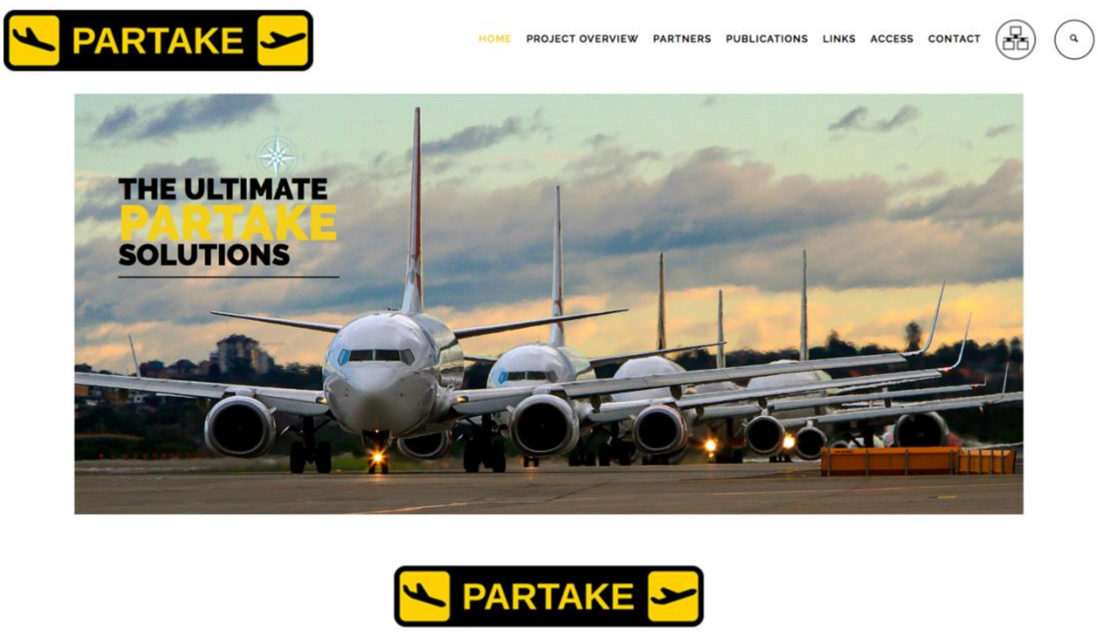

Figure 8: *Website main window*

2. Communication & dissemination activities during the project funding period.

As a result of the work developed during PARTAKE funding period 6 different papers were published in international journals or conference special issues journals:

- *Schefers, N., Piera, M. A., Ramos, J. J., & Nosedal, J. (2017). Causal Analysis of Airline Trajectory Preferences to Improve Airspace Capacity. Procedia Computer Science, 104, 321-328.*
- Schefers N., Ramos, J. J., Nosedal-Sánchez J. ; **“***A case of a modelled saturation level for cooperative flight departures”* (International Journal of Simulation and Process Modelling)
- F.J. Saez Nieto “Hot spot identification and mitigation at strategic level by subliminal changes in aircraft time of arrival at Junction” (6th SESAR Innovation Days, 8 – 10 November 2016, Delft)
- Nina Schefers, Juan José Ramos González, Jenaro Nosedal-Sánchez; *“An effiicient constraint programming model for cooperative flight departures”* (13th International Multidisciplinary Modelling & Simulation Multiconference, I3M 2016, 26 – 28 September 2016, Cyprus). **Best Paper Award winner.**
- Juan J.Ramos, Nina Schefers, Marko Radanovic, Miquel A. Piera, Pau Folch; *“A Constraint Programming Model with Time Uncertainty for Cooperative Flight Departures”* (12th USA/Europe ATM R&D Seminar, ATM2017, 26-30 June 2017, Seattle). **Best Paper Award winner.**
- Nina Schefers, Juan José Ramos González, Pau Folch; *“A decision support tool for strategic conflict management through assignment of calculated take-off times”* (HMS 2017 (I3M): The 19th International Conference on Harbour, Maritime & Multimodal Logistics Modelling and Simulation, 18-20 September 2017, Barcelona)

Additionally, PARTAKE team participated in 5 international conferences focused on ATM and modelling & simulation, obtaining the best paper award in two of them (see figure 5):

- 12th ATM Seminars 2017**. Best Paper Award winner**.
- International Multidisciplinary Modelling & Simulation Multi conference (I3M 2016). **Best Paper Award winner.**
- International Multidisciplinary Modelling & Simulation Multi conference (I3M 2017).
- SESAR Innovation days 2016
- SESAR Innovation days 2017

Figure 9: ***PARTAKE best paper award***

In order to present the results obtained during the project a PARTAKE proof of concept workshop was hold at Cranfield University ATM Laboratory (IDEAS Area, Aerospace Integration Research Centre, AIRC) (see figure 6). In this event PARTAKE framework was applied to a multi-airport system improving the airspace throughput by identifying trajectory interdependencies to synchronise departures. London TMA operations was simulated in real-time to apply PARTAKE for managing departures at London Luton Airport and London Stansted Airport to mitigate the impact of regulations of TC Capital on airports' throughput.

Figure 10: *PARTAKE workshop at Cranfield facilities*

Thanks to this event, a direct positive industrial feedback was provided thanks to the participation of relevant stakeholders like NATS, INDRA, Rolls-Royce, Flight Operations Manager of Luton Airport. Additionally, different commercial meetings were held in order to find synergies with companies that commercializing ATM product (INDRA, Everis) and companies and institutes interested in the future deployment of the U-space (Vodafone, INTA, DronSystems, Everis).

Moreover, aiming to reach general public. 5 articles were public in newspapers (La Vanguardia (with an average circulation of 136.508 daily copies over the past year) or ABC (with an average circulation of 132.794 copies per day over the past year)) and 2 radio interviews.

3. **Communication & dissemination monitoring**

During PARTAKE funding period a constant monitoring of the webpage and the LinkedIn profile were done in order to measure the impact of the project. One week before Cranfield workshop:

- Mass Media: 5 articles and 2 radio interviews
- Scientific publications: 6 published papers, 12 search engines referrals
- Conferences & events: 5 conferences, each with 200 assistants aprox.
- LinkedIn: 5 professional recommendations
- Website: 1069 page views, 28 deliverables downloaded
- News-letters: 5 professional subscribers, 21 downloads at website

It is expected that the monitoring values will be increased after Cranfield workshop and an updated version of the values will be submitted in the final project report.

5.2 Project Deliverables

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[2] PARTAKE Consortium. *D1.2 Report on the tools evaluation strategy, Edition 01.00.00,* 31st August 2016, Toulouse.

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5.3 Project Publications

[1] N Schefers, MA Piera, JJ Ramos, J Nosedal, "Causal Analysis of Airline Trajectory Preferences to Improve Airspace Capacity", Procedia Computer Science 104, 321-328.

[2] N Schefers, JJ Ramos, J Nosedal, "AN EFFICIENT CONSTRAINT PROGRAMMING MODEL FOR COOPERATIVE FLIGHT DEPARTURES", 2016,The International Conference on Harbour, Maritime & Multimodal Logistics M&S – HMS.

[3] Juan J Ramos, Nina Schefers, Marko Radanovic, Miquel A Piera, Pau Folch, "A Constraint Programming Model with Time Uncertainty for Cooperative Flight Departures", ATM Seminar Seattle 2017.

[4] Nina Schefers, Juan José Ramos González, Pau Folch, "A DECISION SUPPORT TOOL FOR STRATEGIC CONFLICT MANAGEMENT THROUGH ASSIGNMENT OF CALCULATED TAKE-OFF TIMES", 2017,The International Conference on Harbour, Maritime & Multimodal Logistics M&S – HMS.

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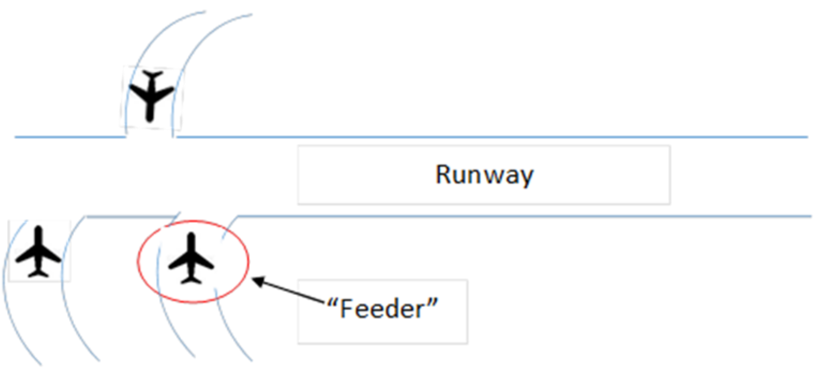
Appendix A

A.1 Glossary of terms

In most cases, the definitions of Eurocontrol were used because they are widely used by the ATM community and are always used in the same way for operational purposes. In some cases, definitions were adopted towards the PARTAKE environment.

Term:	***Definition:***
Conflict	Event in which a loss of separation minima occurs. For PARTAKE usage, a conflict occurs when two or more aircraft share the same cell or neighbouring cells with loss of defined separation minima.
Clearance	Clearance is a statement provided by the ATC indicating that a requested action can be taken so that none of the AU's involves could be implicated in a safety issue. For PARTAKE a clearance furthermore mean that no more than 1 aircraft is in a cell (including neighbouring cells with loss of separation minima).
Discretization (cell and route)	A discretization of a route is transferring the information that defines the route into discrete counterparts with a defined structure (such as cells). In PARTAKE discretized trajectories (time-equidistant waypoints) are required to map them to the grid.
Hotspot	A hotspot is an airspace volume where two or more proximate aircraft are facing a safety event. In PARTAKE hotspot are contiguous cells where a set of spatiotemporal interdependences take place during a time interval. This concept should obey to a complexity metric.
Overlap	Two or more aircraft positions are located within the same cell (or neighbouring cells with loss of separation minima) during the same time interval.
Predictability	A measure of delay variance from the current ac position until the successive planned waypoint.
Robustness	Robustness means that the system is capable to perform a required task while overcoming the effects of many perturbations. In PARTAKE a robustness measure has been defined over concurrence and coupling interdependencies in D4.2.
Runway feeder	It refers to the last segment of a taxiway that is used to access to the active runway to perform a line-up and take-off operation. The aircraft must stop at the runway holding position / stand-by point until authorized by ATC. 
Sensitivity	Sensitivity refers to the capability of a system to react/respond to a given

	input. In the particular case of PARTAKE, sensitivity could refer to the capability to perform a change in a given Key Performance Area.
Slot	Slot refers to an interval of time in which the aircraft must perform a required action.
Uncertainty	An uncertainty is a situation that causes unknown information and triggers a vertical, cross-track or along-track deviation with respect to the planned trajectory.

A.2 Acronyms and Terminology

Term	Definition
A/C	Aircraft
A-MAN	Arrival Manager
ACC	Air-Traffic Control Centre
A-CDM	Achieved Through Collaborative Decision Making
AOBT	Arrival Off-Block Time
AOP	Airport Operations Plan
ARN	Air Routes Network
ARN	ATS Routes Network
ASBU	Aviation System Block Upgrades
ASM	Air Space Management
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
CA	Collision Avoidance
CASA	Computer Assisted Slot Allocation
CDM	Collaborative Decision Making
CHMI	CFMU Human Machine Interface
ConOps	Concept of Operations
CLP	Constraint Logic Programming
CP	Constraint Programming
CSP	Constraint Satisfaction Problems
CTOT	Controlled Time Of Take-off
CU	Cranfield University

D-MAN	Departure Manager
DPI	Departure Planning Information
ECAC	European Civil Aviation Conference
ENAC	École Nationale de l'Aviation Civile
EOBT	Estimated Off-Block Time
ETOT	Estimated Take-Off Time
FABS	Functional Airspace Blocks
FCFS	Based On The First-Come-First-Served
FFAS	Free Flight Airspace
FIR	Flight Information Regions
FL	Flight Level
FMP	Flow Management Position
FOC	Flight Operations Centre
FRA	Free Route Airspace
FUM	Flight Updates Messages
GAT	General Air Traffic
ICAO	International Civil Aviation Organization
IFPS	Initial Flight Processing System
IFR	Instrument Flight Rules
LTM	Local Traffic Management
MAS	Managed Airspace
MSP	Multisector Planner
NM	Nautical Mile
NMOC	Network Management Operations Centre
NOP	Network Operations Plan
OAT	Operational Air Traffic
PARTAKE	cooPerative depArtuRes for a compeTitive ATM networK sErvice
PDS	Pre-Departure Sequence
PIA	Performance Improvement Areas
RBT	Reference Business Trajectory

RDP	Requirements Development Process
RNP	Required Navigation Performance
SA	Separation Assurance
SA	Simulated Annealing
SBT	Shared Business Trajectory
SES	European Sky Initiative
SESAR	Single European Sky ATM Research
SM	Separation Management
SOA	Service-based Architectures
STAM	Short-Term ATFCM Measures
SWIM	System Wide Information Management
TA	Time of Arrival
TBO	Trajectory Based Operations
TM	Trajectory Management
TMA	Trajectory Manoeuvring Area
TOBT	Target Off-Block Time
TOS	Trajectory Option Set
TS	Tabu Search
TT	Target Time
TTA	Target Time Of Arrival
TTO	Time to Over-fly
TTOT	Target Take-Off Time
UAB	Universitat Autònoma de Barcelona
UDPP	User Driven Prioritization Process
UMAS	Unmanaged Airspace
VFR	Visual Flight Rules
WP	Work Package