E.02.15-D19-UTOPIA Final Project Report

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Abstract

This final report provides a comprehensive summary of the aim, the research path followed in and the gathered results of the UTOPIA project. It further compiles all produced deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned along the project.

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Publishable Summary

UTOPIA - *Universal Trajectory Synchronization for Highly Predictable Arrivals Enabled by Full Automation* - aimed at integrating new types of airspace users and the consequences arising from the continuous increase in delegating capacity and safety critical traffic management functions to automated systems. The solution proposed in UTOPIA is articulated in three innovative areas:

- Study uncertainty sources and their propagation including the potential of system disruptions by introducing so-called n-dimensional aircraft trajectories to allow consistent data handling.

- Advanced trajectory management algorithms and ground synchronization functions acting as decision support to both systems and users.

- Use of formal language for trajectory data transmission and trajectory synchronization protocols for heterogeneous systems and users in an automated environment.

The UTOPIA project was run in a consortium consisting of Technische Universität Dresden (TUD, Lead), Boeing Research and Technology Europe (BRTE), and Barco Orthogon GmbH (Barco). Its objective was to provide a better understanding of trajectory management functions in the above mentioned areas to efficiently manage heterogeneous traffic considering the increasing presence of autonomous Air Traffic Management (ATM) systems and agents. UTOPIA focused on the design of algorithms allowing the safe and orderly management to merge heterogeneous traffic into a major airport hub (e. g. Frankfurt Main) surrounded by an extended Terminal Manoeuvring Area (TMA). Sequencing and merging was executed by an autonomous arrival management function, which was derived from an operational AMAN. The converging traffic flows into the hub airport consisted of heterogeneous airborne systems, in particular holding both advanced, UTOPIA-type and legacy flight management systems, representing airspace users with different synchronization and protocol capabilities.

The key findings from the UTOPIA project are summarized as follows:

- *Economy*: By increasing the portion of airspace users ready for synchronization, receiving a required time of arrival (RTA) when entering the extended 3 hour horizon TMA, a reduction of fuel consumption of up to 9% could be measured.

- *Transmission*: The required communication bandwidth nearly doubled for the RTA advisory scenarios compared to non-RTA scenarios.

- *Capacity*: The introduction of sophisticated unmanned aerial systems (UAS – light aircraft with automated functions) significantly reduced the sequence changes at UTOPIAs arrival management. But the increasing share of light UAS (up to 50%) caused an expected drop of the runway capacity down to -7%, mainly caused by extended wake vortex separation requirements, which dominates the sequence stabilization of the arrival management.

- *Uncertainty*: The consideration of uncertainties in wind prediction within trajectory management decreased the planning stability of the arrival management (AMAN). The simulated uncertainties caused an increase of arrival sequence changes up to 200%.

- *Synchronization*: Flight path changes due to bad weather cells were simulated within the UTOPIA demonstrator framework. Aircraft performing re-routings notified the AMAN of these flight path changes, effectively implementing air-ground synchronization functions. With these air-ground notifications flights were re-scheduled in an earlier stage and thus avoided detrimental re-sequencings.

- *Aircraft Intent Data Transmission*: Aircraft intent and trajectory information was made available to the ground-based arrival management function by using formal languages to

enhance the ground side trajectory prediction. This function also allows the AMAN to promptly adapt its trajectory prediction as soon as any speed correction is applied by the RTA/CTA instructed flights, leading to a planning stability increase of up to 40%.

- *Vectoring Optimization:* After having left or passed the holding fixes the aircraft received a final vectoring advice by the arrival manager. This advice was optimized using feedback from the aircraft FMS. As a result 95% of the flights touched down with less than 5 seconds deviation from the arrival time scheduled by the AMAN.

Technically, the developed UTOPIA demonstrator proved being a robust test environment to study highly automated air traffic management concepts with emphasis but not limited to arrival management functions, uncertainty source modelling, and heterogeneous traffic configuration analyses. The state of the art operational procedures like holdings and path stretching were extended by studying RTA/CTA approaches.

The effect of relevant sources for uncertainty together with appropriate air-ground synchronization mechanisms could be evaluated in various traffic mix and configuration scenarios against today's ATC concept of traffic operations. We could show that the dynamic exchange of air-ground data significantly improves the performance of the automated arrival management function especially when considering realistic uncertain atmospheric/weather conditions.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and still in progress);
- where appropriate, provide feedback from presentations, and describe exploitation plans;
- provide a comprehensive overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies);
- Analyse the lessons learnt at project level.

1.2 Intended readership

This document is intended to readers wishing to get a comprehensive overview about the UTOPIA project at technical and commercial management level. In addition to the technical summary and derived project conclusions (see also UTOPIA deliverable D5.3), this document gives an overview of the technical project performance as well as the dissemination activities along the course of the project. Furthermore, a breakdown of the eligible project costs for all project participants and lessons learnt during the project run are condensed.

1.3 Inputs from other projects

- Not applicable -

1.4 Glossary of terms

All terms are explained and referenced in the corresponding work packages deliverables, see especially UTOPIAs final deliverable D5.3.

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D1.1	Review and Gap Analysis of automation development included in SESAR	Deliverable D1.1 gives an overview about the technologies that will be deployed to implement the SESAR operational concepts by the year 2020 (as stated in the Air Traffic Management Master Plan). Therefore, the most significant concepts are presented accompanied by the technologies needed to implement those concepts. Additionally, concepts of higher levels of automation that may be introduced beyond the timeframe of 2020 are reviewed and analysed to identify gaps between the necessary and the available technologies.	Approved
D1.2	Concept specification for mixed traffic operations in the terminal area	Deliverable D1.2 lays out the anticipated principles to integrate heterogeneous traffic with different performance, technical and operational capabilities into a complex and dense airspace such as an Extended Terminal Manoeuvring Area (E-TMA) and explains how these principles allow the implementation of the UTOPIA concept of Operation based on newly defined Capability Levels (CL).	Approved
D2.1	Definition of trajectory information for air-ground synchronization	Deliverable D2.1 introduces the trajectory prediction process in the UTOPIA project. It points out the interfaces to exchange trajectory information and describes the proposed ways to specify the information. Finally the expected results of WP2 are given.	Approved
D2.2	Specification of a formal structure to express the trajectory information	Deliverable D2.2 defines the formal structure for the expression of the trajectory information within the UTOPIA project, which will be a combination of the two formal languages Flight Intent Description Language (FIDL) and Aircraft Intent Description Language (AIDL). The different XML schemas that will be required are described and examples are given.	Approved
D2.3	Design of formal translators from the on-board native trajectory data structure to the formal structure from the on-board native trajectory data structure to the formal structure	Deliverable D2.3 describes the translator designs for the UTOPIA entities that will be used to generate and consume UTOPIA XML messages to be distributed within the UTOPIA demonstrator.	Approved

D2.4	Translator Prototypes	Deliverable D2.4 describes the status of the software development of the translator prototypes. Here, it rather focuses on demonstrating the capabilities of these translators than delivering plain source code.	Approved
D3.1	Identification of stochastic parameters	Deliverable D3.1 identifies stochastic factors that influence trajectory synchronization between ATM ground and air segment. The document also names and specifies the sources of uncertainty, and states the package of shared trajectory information among the participants. The sources of uncertainty have been allocated, identified and sorted into classes in this document. Furthermore, the relevant data for synchronization have been fixed and listed.	Approved
D3.2	Stochastic modelling	Deliverable D3.2 provides an introduction into the procedures and algorithms of stochastic modelling within the UTOPIA project. The document also defines sources and dedicated stochastic factors that have the greatest effect on trajectory synchronization between ATM ground and air segment.	Approved
D3.3	Design scheme for virtual system environment and description of derived agent capabilities	Deliverable D3.3 describes the general design of the virtual ATM system environment, which will be used for the UTOPIA demonstrator phase. It defines agents acting inside an extended TMA and their necessary capabilities to synchronize trajectory data between air and ground systems.	Approved
D3.4	Disruption Scenarios	Deliverable D3.4 provides a systematic methodology for developing scenarios that hold the potential to influence and, potentially disrupt the trajectory synchronization process between the ATM ground and air segment. Along the methodological scenario development, background information related to scenario building, expert knowledge on weather and relevant findings as presented in the UTOPIA deliverables D3.1 to D3.3 on uncertainty sources were considered.	Approved
D4.1	Architecture design of simulation test bed	Deliverable D4.1 describes the architecture, components, configuration, communication protocols and information schemes that will shape the UTOPIA demonstrator.	Approved
D4.2	Functional implementation environment	Deliverable D4.2 provides an overview of the inputs that are required to conduct simulation runs with the developed UTOPIA simulation environment.	Approved
D4.3	Prototype of the simulation test bed	Deliverable D4.3 gives a summary of the prototype of the simulation test bed: the UTOPIA Demonstrator. It provides details on the single entities and information about the simulation setup and traffic generation. It furthermore elaborates on the implemented weather modelling, the calculation of the Corridor of Uncertainty and the disruption modelling.	Approved

D5.1	Operational Scenario Design	Deliverable D5.1 describes the design of the simulation scenarios, which will be executed in the UTOPIA demonstrator to simulate automated arrival management in the extended TMA of the Frankfurt/Main airport. The scenario traffic generated is based on CFMU flight plan data and varied to investigate the influence of different parameters like traffic density, WTC distribution etc. The baseline traffic scenarios are then extended by simulating uncertainty related effects as well as by analysing possible benefits of air-ground trajectory synchronization.	Approved
D5.2	Scenario Definition and Documentation	Deliverable D5.2 describes the specific configurations of the simulation scenarios, which will be executed in the UTOPIA demonstrator to simulate automated arrival management in the extended TMA of the Frankfurt/Main airport. Furthermore, the document explains how the scenarios are set up, configured, executed and analysed within the UTOPIA demonstrator environment.	Approved
D5.3	Summary and Results	Deliverable D5.3 combines a summary of the UTOPIA project with the presentation of the results obtained from the UTOPIA demonstrator simulations. The summary revisits and sums up the past project deliverables allowing the reader to understand the concepts developed in the UTOPIA project. The second document part presents the simulations, explaining the chosen variations of the parameters and presents and discusses the lessons learned from the UTOPIA demonstrator runs.	Approved

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

The UTOPIA consortium participated to the workshops of *complexWorld* and *HALA!* research network to provide UTOPIAs expertise to the scientific community.

- "Uncertainty in ATM: Definitions, Sources, Scales, Challenges", Naples, Italy, 27th May 2013
- "Resilience and Robustness in ATM" in Toulouse, 10th July 2013

All seven publications generated inside the UTOPIA project are publicly accessible at the website of TU Dresden (www.ifl.tu-dresden.de) and were presented to an international auditorium. All chosen conferences hereto comprised a peer-review process by at least two experienced evaluators.

2013 - Eurocontrol SESAR Innovation Days (SID), Stockholm, Sweden

M. Schultz, H. Fricke, T. Kunze, T. Gerbothe, C. Grabow, J. De Prins, M. Wimmer, P. Kappertz.
Modelling and Evaluation of Automated Arrival Management considering Air Traffic Demands

This publication points out the capabilities of the developed UTOPIA methods while using the UTOPIA demonstration environment. All UTOPIA scenarios and the corresponding simulation results are presented, focussing onto the impact of stochastic input parameters operationally caused by instable local wind fields and adverse weather conditions to the achievable synchronization capability.

2013 - International Conference on Application and Theory of Automation in Command and Control Systems (ATACCS), Naples, Italy

T. Pabst, T. Kunze, M. Schultz, and H. Fricke.
Modeling external disturbances for aircraft in flight to build reliable 4D trajectories

This paper presents a model to generate 4D trajectories based on stochastic disturbances acting on the aircraft in flight. Definitions for momentary position uncertainty and its projection over time as a corridor of uncertainty are presented in this paper paving the way for a model transferring external disturbances into position uncertainty adhering to the trajectory.

2012 - Eurocontrol SESAR Innovation Days (SID), Braunschweig, Germany

M. Schultz, H. Fricke, T.Kunze, J. Mund, J. López Leonés, C. Grabow, J. De Prins, M. Wimmer, and P. Kappertz.
Uncertainty Handling and Trajectory Synchronization for the Automated Arrival Management

During the UTOPIA project lifecycle, scientific and operational fundamentals were comprehensively studied and implemented at mature prototype level to provide a functional proof of concept. The fundamental research areas cover an initiating review and gap analysis, a detailed concept specification, followed by the identification of stochastic parameters, the development of a stochastic model, and finally the design scheme for the virtual environment.

2012 - International Conference on Application and Theory of Automation in Command and Control Systems (ATACCS), London, UK

M. Kaiser, J. Rosenow, H. Fricke, and M. Schultz.
Trade-off between optimum altitude and contrail layer to ensure maximum ecological en-route performance using the Enhanced Trajectory Prediction Model (ETPM)

This paper provides a comprehensive introduction into the Enhanced Trajectory Prediction Model (ETPM) and a hydrodynamic model of contrail evolution, both developed at TU Dresden, the application and data trial for an automated 4D cruise optimization with regard to ecological objectives.

2012 - International Conference on Research in Airport Transportation (ICRAT), Berkeley, US

M. Kaiser, M. Schultz, and H. Fricke (2012).
Automated 4D Descent Path Optimization using the Enhanced Trajectory Prediction Model (ETPM)

The paper proves that the Enhanced Trajectory Prediction Model (ETPM) provides a significant improvement in both accuracy and prediction speed compared to other existing trajectory prediction or Aircraft Performance Models (APM). The ETPM extends the trajectory logic of the UTOPIA project towards using a dynamic adaptation of the essential sampling points of the trajectory grid. The model was applied to automated 4D descent path optimization to reach minimum fuel conditions (maximum specific range) and the strict use of an existing standard arrival route considering all types of today's air traffic control restrictions.

2011 - Eurocontrol SESAR Innovation Days (SID), Toulouse, France

M. Schultz, H. Fricke, M. Kaiser, T. Kunze, J. L. Leonés, M. Wimmer, and P. Kappertz.
Universal Trajectory Synchronization for Highly Predictable Arrivals Enabled by Full Automation

This publication introduces UTOPIA, the proposed targets of the project and the fundamentals of the project work packages: Three innovative key elements and the necessary steps to reach the ambitious project targets are explained in detail: (1) formal models of trajectory data and trajectory synchronization protocols for heterogeneous systems in an automated environment, (2) study uncertainty sources and their propagation in the aircraft n-dimensional trajectories (nDT), considering also system disruptions, and (3) advanced trajectory management algorithms and ground synchronization functions based on the formal n-dimensional trajectory data and uncertainty models.

2011 - International Conference on Application and Theory of Automation in Command and Control Systems (ATACCS), Barcelona, Spain

M. Kaiser, H. Fricke, and M. Schultz.
Enhanced Jet Performance Model for High Precision 4D Flight Path Prediction

The presented enhanced jet performance model provides a significant improvement over currently applied trajectory prediction methods. The use of analytical methods allows a high level of adoption of the real physical aircraft environment. This paper presents an analytical model of the aircraft performance and applies the findings to precisely predict fuel flow characteristics as fundamental parameter for trajectory planning.

3.2 Presentations/publications at other conferences/journals

- Not applicable -

3.3 Demonstrations

A limited technical demonstration was given at the Close-out meeting at EEC premises in October 2013. It covered the simulation of a heavy traffic scenario sequenced with the UTOPIA ground management function and assuming uncertainty sources (instable wind fields).

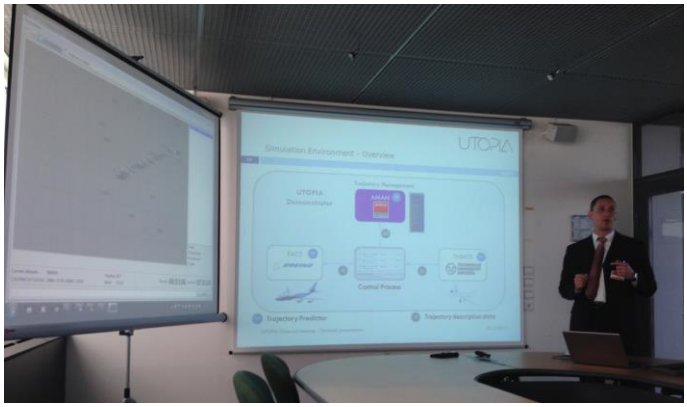

Figure 1: UTOPIA Demonstration at EEC premises in October 2013

3.4 Exploitation plans

The Institute of Logistics and Aviation at TU Dresden is an internationally settled research institute focussing as one pillar onto innovative ATM concepts with emphasis onto trajectory optimization and high precision flight performance analysis. The results reached in UTOPIA project promise the usefulness of handling heterogeneous areal systems while considering uncertainty inside the aircraft trajectory description. Uncertainty impacts clearly system performance in terms of punctuality and ecology of flight as automated functions have to increasingly iterate advisories leading to re-sequencing and profile adaptation at short notice. At the extreme end however, there is the risk of reaching system disruption, meaning that excessive uncertainty may lead to non-functioning of the developed stochastic algorithms. Even though, this effect could not be observed for the selected UTOPIA scenarios, the institute will use the project results to further investigate the influence of external and hardly predictable input factors to the performance of the ATM system. The UTOPIA project provides a solid basis for these upcoming investigations. TU Dresden together with its project partners so intends to make use of the project outcome to raising additional research funding allowing a continuation of that fascinating research domain.

Along the course of the UTOPIA project, our partner Barco Orthogon did extend and refine its software suite used to analyse arrival management processes. The investigation metrics and methods developed within UTOPIA are candidates for the inclusion within relevant company products. Furthermore, it is likely that the developed software will be used in public research projects, Barco Orthogon takes part in. The lessons learnt from conducting a complex multi-site software development and integration project complement the knowledge Barco Orthogon has gained from similar commercial projects. Within UTOPIA Barco Orthogon has e.g. investigated and implemented a new way of transmitting XML ATC data over a computer network. This is a technology becoming increasingly important in the future European ATM network integration (SESAR SWIM).

Boeing Research and Technology Europe's fast-time traffic simulation tool was extended through the UTOPIA project with new features and functionalities, like real-time execution, distributed ATM simulation setup, coherent dynamic wind disturbances and aircraft intent sharing. The new simulation capabilities open new scopes for future research projects.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
27.03.2012	D0.1, D0.2, D0.3, D1.1, D3.1	78,181.60 €	3,927.13 €	Paid
25.10.2012	D0.4, D0.5, D1.2, D2.1, D3.2, D3.3	98,749.21 €	3,555.58 €	Paid
08.03.2013	D0.6, D0.7, D2.2, D2.3, D2.4, D3.2, D3.4, D4.1	135,458.18 €	4,268.57 €	Paid
05.08.2013	D0.8, D4.2, D4.3, D5.1	87,472.29 €	751.82 €	Billed
To be billed	D0.9, D0.10, D5.2, D5.3	121,748.03 €[1]	1,696.06 €[1]	To be billed
GRAND TOTAL	D0.1, D0.2, D0.3, D0.4, D0.5, D0.6, D0.7, D0.8, D0.9, D0.10, D1.1, D1.2, D2.1, D2.2, D2.3, D2.4, D3.1, D3.2, D3.3, D3.4, D4.1, D4.2, D4.3, D5.1, D5.2, D5.3	522,609.30 €	14,199.17 €	

[1] … estimated costs for 5th invoice are based on **preliminary** cost breakdown forms of all partners (will be finalized in 12/2013)

Table 2 - Overview of Billing

Company	Planned man-days[2]	Actual man-days[3]	Total Cost	Total Contribution	Reason for Deviation
TUD	865	918	228,340.80 €	228,340.80 €	*
Barco	395	529	285,338.58 €	142,669.29 €	*
Boeing	501	430	329,596.77 €	164,798.39 €	*
GRAND TOTAL	1,761	1,878	843,276.15 €	535,808.47 €	*The additional effort is caused by the cost-neutral project extension and does not exceed the original price of the contract.

[2] … person days according to updated work plan (dated 02.08.2013)
[3] … person days calculated from man-hours (one workday has: 8 man-hours (TUD, BARCO) or 7.5 hours (Boeing))

Table 3 - Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
Clear and transparent communication between all partners during the project. This prevented possible road blocks on early stage and resulted in an appropriate collaborative decision-making procedure.
Each **partner was responsible** for a set of UTOPIAs deliverables, as predefined and communicated through the project plan. These responsibilities lead to a clear hierarchy referred to the deliverable output and assured a continuous on time performance during the project duration.
Very efficient **distributed implementation** of developed models using decentralized revision control and source code management. Each partner could bring in his own expertise in his own branch. These branches were merged on a regular basis. These shared responsibilities were a key enabler for UTOPIAs performance.
The **SJU/Eurocontrol project officer** excellently guided the UTOPIA management team at all phases of the project with respect to administrative tasks. His domain expertise and critical reviews of the project outcomes consequently resulted in high quality UTOPIA deliverables.
Continuous dissemination ensured the project visibility within the scientific community and did set out additional targets besides the project deliverables. These additional targets lead to a further clarification of project goals and smart presentations of the individual project progress.
What should be improved?
The **communication to other SESAR WP projects (all E and 1 to 16, B etc.)** at administrative and technical level was too limited. Technical solutions from other projects could not be used to their full extent to improve project performance at an early stage and avoid duplication of efforts.
The development of **common data platform** for (available) European data sets (traffic, weather, performance, etc.) should be focussed during the next projects (however based on the lessons learnt from the perhaps less successful Eurocontrol VDR project). Gathering relevant data, cleaning and processing that data should become a standardized process facilitating follow-up projects in using it along verification and validation activities.. This very costly and time-consuming process so should be replaced by granting access to already processed European data sets or at least a set of reliable reference data for several (future) scenarios.

Table 4 - Project Lessons Learnt