D4.2: ARRIVAL, DEPARTURE AND SURFACE MANAGEMENT INTEGRATION AND JOINT SCHEDULING

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EXECUTIVE SUMMARY

Addressing environmental challenges, especially global warming, is more than ever a must for the community. This matter is becoming an increasing priority at regional and global level. Europe has made commitments to reduce the aviation's environment footprint; hence, it is contributing to climate change, increasing noise, affecting local air quality and consequently affecting the health and quality of life of European citizens. Due to Covid-19, the air traffic is drastically reduced and it is expected that it will need five to ten years to recover to 2019 numbers. This offers the chance to rebuild it greener than before. The air traffic in Europe was growing until 2019 and is expected to continue increasing significantly in the future again in order to cope with the growing demand for mobility and connectivity. A long-term effect on the environment from aviation sector, mainly caused by aircraft noise and exhaust gases (especially CO_2, nitrogen oxides NO_x and methane), make it a clear target for mitigation efforts. The future growth of aviation shall go hand in hand with environment sustainability policies. Therefore, studies and research are being conducted in Europe exploring possible optimization of the aircraft technologies as well as Air Traffic Management operations. Given the close interdependency between flight routing and environment impact, optimization in flight trajectory design and ATC operations are an appropriate means to reduce the emissions in short- and medium-term periods.

The international project "Greener Air Traffic Operations" (GreAT) has been launched in line with this perspective. This project will be conducted in cooperation between Chinese and European partners.

In this present document, the work related to the evolution of arrival, departure and surface management tools is presented taking as baseline the description of new ATM principles for airspaces and airports in Europe and China, evaluated in the GreAT main work package 4 document "Environmental-friendly airspace structuring and traffic sequencing".

The new functionalities to be integrated to existing decision support systems (4D-CARMA, DMAN Lite, TraMICS+, MergeStrip) are presented in detail. These improved decision support systems, AMAN, DMAN and SMAN, are able to deal with the new airspace structure and are redesigned and integrated with the goal to minimize the environmental impact (e.g. reduce Distance-To-Go during approaches, use more environmental-friendly procedures such as CDO/CCO). End-users have been deeply involved during both the specification and the validation of the new support tools to guarantee not only greener flight trajectories but also usability of the tools in a potential future operational environment.

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GLOSSARY

Acronym	Signification
AHPV	Approach Horizontal Projection View
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
A/C	Aircraft
CADEO	Controller Assistance for Departure Optimization
CCO	Continuous Climb Operation
CDA	Continuous Descent Approach
CDO	Continuous Descent Operation
DMAN	Departure Manager
DTG	Distance-To-Go
ELDT	Estimated Landing Time
ETA	Estimated Time of Arrival
FHPV	Final Horizontal Projection View
FMS	Flight Management System
HMI	Human Machine Interface
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
MATIAS	Magyar (Hungarian) Automated and Integrated Air Traffic Control System
ML	Machine Learning
MS	MergeStrip
RV	Radar View

RWY	Runway
SMAN	Surface Manager
SOBT	Scheduled Off-block Time
STAR	Standard Arrival Route
THX	Threshold
TOBT	Target Off-block Time
TRACC	Taxi Routes for Aircraft: Creation and Controlling
TTOT	Target Take-off Time
VPV	Vertical Projection View
WP	Waypoint

1. INTRODUCTION

Climate change and global warming is one of today's most serious global challenges that will constitute a significant danger for future generations [Matthews 2017]. This is even amplified by the fact that the climate change is a relatively slow process, which is caused by the accumulation of greenhouse gases over years and decades [Rahmstorf 2007]. When thinking only for the next couple of years in advance, the changes are hardly measurable; this is why economic interests have always been prioritized in the past. The further emission of greenhouse gases by daily traffic, energy production with coal or an outdated technology used in a factory was seen as acceptable, as it provides seemingly only a relatively small contribution to worldwide climate change. In addition, trying to save emissions here would not noticeably change the situation within the near future.

In the last few years, this attitude started to change, as the consequences of the climate change are more and more recognizable to the public. In the same way, also the awareness increases that every emission of greenhouse gas – no matter how small it is – accumulates over the years and decades and makes a difference. The Intergovernmental Panel on Climate Change (IPCC) considers carbon dioxide (CO_2) as the principal greenhouse gas [IPCC 2021]. Aviation represents approximately 2% to 3% of the total annual global CO_2 emissions from human activities and, in addition to CO_2, has impacts on climate from its non-CO_2 emissions (e.g. NO_X, particles) [McCollum 2010]. Uncertainties still exists in the assessment of the impact of the aviation emissions on the environment especially effects associated with non-CO_2. Nonetheless, non-CO_2 impacts cannot be ignored as they potentially represent approximately 60% of total climate impacts that are important in the shorter term[1]. Regarding the Radiative Force (RF) of all aircraft emissions, studies estimate the aviation impact to be within the range 2% to 8%. The wide range of the impact estimations results from the complicated calculations of the altitude depending of all involved emissions [Jungbluth 2018]. The CO_2 and non-CO_2 emissions from aviation are increasing continuously. Nevertheless, CO_2 emissions are becoming of high priority provided its long-term effect. A more precise assessment of the environment impact caused by aviation sector will be performed within GreAT Work Package 7 "Evaluation of Environmental Impact". As a conclusion, it is also worth thinking about how even small gas emissions can be reduced or avoided. Although aviation only contributes to global CO_2 emissions with a low percentage, emissions savings that can be achieved there – even if they are small – are important.

1.1. PURPOSE OF THE DOCUMENT

The purpose of this document is to describe the evolutions implemented for arrival, departure and surface management support tools:

- **4D-CARMA** / **MergeStrip** (AMAN for hub and mid-size airports respectively);
- **TraMICS+** (SMAN); and
- **DMAN Lite** (DMAN).

[1] https://www.easa.europa.eu/eaer/climate-change/aviation-environmental-impacts

1.2. INTENDED READERSHIP

This section describes the intended audience for this document. In general, readers of this document can be:

1) Readers internal to the project, using this document as input for their own activities.
2) Readers of GreAT sister projects (ACACIA, CLIMOP, ALTERNATE), using to follow latest developments and approaches, and to drive scientific exchange between the sister projects. This is for aligning the activities of all four projects and identifying synergy effects.
3) Readers from the GreAT Advisory board, in order to provide input and to follow the developments from a stakeholder point of view.
4) Readers involved in current and future projects dealing with reducing the impact of aviation on climate change and other environmental parameters.
5) Readers from air navigation service providers or other stakeholders not involved in the project but effected from its developments (especially ANSPs, airports, airlines or ATC equipment providers).
6) All other interested members of aviation community.

1.3. STRUCTURE OF THE DOCUMENT

This document contains the following sections:

Chapter 1 Introduction – describes the purpose of the document, the intended audience and the document structure.

Chapter 2 Specification of new functionalities of decision support tools – presents the detailed specifications of the new functionalities to be integrated in the existing tools, also focusing on the expected benefits of each one in terms of environmental impact.

Chapter 3 Integration of new functionalities to existing support tools – describes integration tasks and presents the basic operation of the newly developed functionalities.

Chapter 4 Summary – brief summary of the document content.

Chapter 5 References – contains the references.

2. SPECIFICATION OF NEW FUNCTIONALITIES OF DECISION SUPPORT TOOLS

This chapter presents the list of specifications of all new functionalities implemented within the frame of the GreAT project. These developments target the increase of environmental benefits of existing decision support tools (4D-CARMA, DMAN Lite, TraMICS+ and MergeStrip) during arrival, departure and surface operations.

All requirements are presented by using the following table structure:

ID	TOOL_ID[2]-XX[3]-YYY[4]
Requirement	Brief definition of the requirement
Description	Extended description of the requirement
Priority	• Mandatory • Nice-to-have • Optional
Stability	• Consolidated • Not consolidated

2.1. 4D-CARMA ARRIVAL SUPPORT FUNCTIONALITIES

The support functions of the AMAN used mainly relate to the approach and thus to the last 100 NM before landing. In order to achieve a reduction in kerosene consumption and CO_2 emissions, the airspace structure and thus the spatial organization of approach paths has been reorganized so that it will be possible for almost all approaches to fly an individual optimal approach trajectory without having a negative impact on the overall throughput of an airport. Associated with this is a change in the procedures that air traffic controllers and pilots must follow during this phase of the flight. The basic principle here is the separation and late merging of incoming traffic in terms of their equipment levels, so that there are no conflicts or rescheduling of aircraft to avoid deviations from their optimized trajectory. Functionalities have been developed for both the separation and the merging of traffic flows at the late merging point to assist the controller in this activity. Automatic route and target time negotiation between the FMS on board and the AMAN on the ground was also developed and implemented as a support function for this purpose.

Approach planning systems work time-based, but air traffic controllers distance-based. In order for controllers to be able to translate the AMAN's automatic planning into operational use as usual, visual aids must be provided in the AMAN and the primary display to help transform time-based planning into distance-based planning, in addition

[2] TOOL_ID defines the identifier of the decision support tool (e.g. “MS” for MergeStrip)

[3] XX defines the type of requirement (e.g. “FR” for Functional Requirement)

[4] YYY defines the numeric ID of the requirement

to just organizing the air traffic. These functions include AMAN-DMAN communications, AMAN-FMS communications, Ghosting, TargetWindows, and the Final Distance Indicator.

Other functionality to assist controllers with approach guidance includes tools that are already built into most AMAN today. These include dynamic time lines with labels, target time calculations for significant waypoints, and input screens for given clearances. These are adequately described in the literature and are mentioned in the context of this report only where there have been modifications from the current standard in the context of this project.

DATA EXCHANGE REQUIREMENTS

ID	4DC-DAT-001
Requirement	Storing negotiation parameter in AMAN database
Description	For the AMAN-FMS target time and route negotiation, the AMAN database had to be extended to store process parameter.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-DAT-002
Requirement	Processing negotiation parameter by AMAN
Description	For the AMAN-FMS target time and route negotiation process, functions for data access had to be implemented.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-DAT-003
Requirement	GreAT airspace data for arrival manager
Description	Implementation and organization of the GreAT airspace in arrival manager and traffic simulator. The airspace consists of waypoints, connections, routes and constraints.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-DAT-004
Requirement	Storing AMAN-FMS negotiation status
Description	During the route and target times negotiation process between arrival manager and 4D-FMS equipped aircraft, the actual negotiation status for each direct approach has to be saved.
Priority	• Mandatory

Stability	• Not consolidated

ID	4DC-DAT-005
Requirement	Storing negotiated departure times for each runway
Description	After departure time negotiation, the blocked slots for departures are stored in the database to avoid landing time assignment.
Priority	• Mandatory
Stability	• Not consolidated

FUNCTIONAL REQUIREMENTS

ID	4DC-FR-001
Requirement	Establishing a bidirectional connection from AMAN to FMS
Description	For the target time and the route negotiation process between arrival manager and aircraft, a link between them have to be established and a communication protocol have to be completed.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-002
Requirement	Processing the target time and routing negotiation
Description	After the target time and routing negotiation, arrival sequences for all runways and trajectories for aircraft have to be calculated without shifting already negotiated parameters of other aircraft.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-003
Requirement	Calculating actual separations between aircraft and aircraft placeholders
Description	Calculating actual separations between aircraft and aircraft placeholders like ghosts and TargetWindows on final. The data are needed for the Final Distance Indicator in RadarVision.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-004
Requirement	Additional window in the primary display RadarVision to show actual final separation in nautical miles
Description	Implementation of an additional window in the primary display RadarVision to show actual final separation in nautical miles, which can be activated and deactivated by controller. Visual differentiation between aircraft, ghosts and estimated (optimal) positions of aircraft following the planed trajectory (TargetWindow).
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-005
Requirement	Ghost position calculation functionality
Description	The ghost represents the theoretical position of 4D-FMS equipped aircraft flying CDA-directs on the final approach. To calculated the position, a little 'flight simulator' moves the ghost with speed reduction phases like regular approaches meeting the original aircraft at LMP at the negotiated target time.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-006
Requirement	Ghost visualization on final
Description	Drawing ghost label on the calculated theoretical position on centerline and final.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-007
Requirement	TargetWindow position calculation functionality
Description	The TargetWindow represents the optimal position of non-equipped aircraft flying manually guided on the final approach. Additionally, it indicates the area a non-equipped can use during approach following the minimum wake vortex separations depending on aircraft's weight-classes.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-008
Requirement	TargetWindow visualization in RadarVision (primary display)
Description	Drawing TargetWindows for all manually guided aircraft on each final on the calculated positions on centerline and final.
Priority	• Mandatory
Stability	• Not consolidated

ID	4DC-FR-009
Requirement	Departure slot coordination with DMAN
Description	Function coordinated arrival and departure times with DMAN. Departure times (time windows) are treated as "arrival free intervals".
Priority	• Mandatory
Stability	• Not consolidated

2.2. DMAN LITE DEPARTURE SUPPORT FUNCTIONALITIES

Departure manager (DMAN) are tactical planning tools supporting air traffic controllers by departure scheduling at apron, ground and tower. In GreAT, departure manager functionalities needed in the project were implemented in the arrival manager Maria database, which negotiates and optimizes the take-off sequences at runway threshold with selectable pre-defined different optimization settings. The optimization strategy has an impact on the overall capacity as well as the runway throughput, but it acts on favor of the environment by reducing the amount of unnecessary fuel burn due to reduced runway waiting times and minimizing the number of stoppings with unavoidable breaking and acceleration phases. The acceleration phases in particular drive up kerosene consumption and thus CO_2 emissions during ground operations.

DATA EXCHANGE REQUIREMENTS

ID	DL-DAT-001
Requirement	GreAT airspace and topology data in departure manager
Description	Implementation and organization of the GreAT airspace and airport topology in departure manager DMAN Lite. The airspace consists of waypoints and routes and is needed to determine the minimum separation between two departing aircraft.
Priority	• Mandatory
Stability	• Not consolidated

ID	DL-DAT-002
Requirement	Storing possible and negotiated departure times for each runway
Description	After departure time negotiation, the blocked slots for departures are stored in the database for further planning and visualization.
Priority	• Mandatory
Stability	• Not consolidated

ID	DL-DAT-003
Requirement	Storing actual planned arrival times of aircraft from AMAN
Description	For departure time calculation, DMAN Lite uses actual planned landing times of aircraft to integrate departure slots into the arrival stream with minimal influence on arrival times.
Priority	• Mandatory
Stability	• Not consolidated

FUNCTIONAL REQUIREMENTS

ID	DL-FR-001
Requirement	Importing estimated departure times from flight plans
Description	Import functionality to read estimated departure times from flight plans including aircraft type and weight class, planned runway, and destination.
Priority	• Mandatory
Stability	• Not consolidated

ID	DL-FR-002
Requirement	Importing actual arrival times
Description	Import functionality to read actual arrival times from AMAN. This shave to be done periodically due to the adaptivity of the arrival planning.
Priority	• Mandatory
Stability	• Not consolidated

ID	DL-FR-003
Requirement	Algorithm for searching suited departure slots in the arrival

	stream
Description	Functionality to search for suited departure slots in the actual arrival stream considering the influence on arrival times and given departure slots.
Priority	• Mandatory
Stability	• Not consolidated

ID	DL-FR-004
Requirement	Functionality for transferring scheduled departure times to AMAN and asking for compliance
Description	After selecting departure times in the arrival stream, the planned departure times have to be transferred to the AMAN and it must be queried whether these times are possible for the AMAN.
Priority	• Mandatory
Stability	• Not consolidated

2.3. TRAMICS+ SURFACE OPERATIONS SUPPORT FUNCTIONALITIES

For the organization of taxiing aircraft on the apron, the Traffic Management Intrusion and Compliance System Plus (TraMICS+) surface management system was developed to assist air traffic controllers on the ground with a taxiing trajectory support. TraMICS+ uses a genetic algorithm to plan and adjust taxi trajectories in real time to resolve conflicts between aircraft on the ground, with the goal of reducing waiting time after engine startup and avoidable braking and acceleration due to heavy traffic. The system was validated using a case study at Hamburg Airport, comparing different configuration profiles for generating conflict-free trajectories with TraMICS+. By using a trajectory profile with higher penalties for stops during the taxi phase, it was possible to create more efficient taxi trajectories with 80% fewer stops. Since the acceleration phase on the apron has a significant impact on fuel flow and thus on carbon dioxide emissions, optimal taxiing processes can reduce the local environmental impact.

DATA EXCHANGE REQUIREMENTS

ID	TM-DAT-001
Requirement	Airport topology data in surface manager
Description	Implementation and organization of the airport topology. The topology consists of taxi points, connections, aircraft stands and constraints.
Priority	• Mandatory

Stability	• Not consolidated

ID	TM-DAT-002
Requirement	Trajectory algorithm configuration
Description	Configuration for the genetic algorithm used by TraMICS+ to generate taxi trajectories and solve conflicts.
Priority	• Mandatory
Stability	• Not consolidated

ID	TM-DAT-003
Requirement	Flightplan data
Description	Flightplan data containing information about scheduled off-block times and stands for departures and target stands for arrivals. Data shall conform to NARSIM 'flight' data format.
Priority	• Mandatory
Stability	• Not consolidated

ID	TM-DAT-004
Requirement	Aircraft position data
Description	Position data of moving aircraft to verify conformance to trajectories and enable recalculation of trajectories on deviation. Data shall conform to NARSIM 'aircraft' data format.
Priority	• Mandatory
Stability	• Not consolidated

FUNCTIONAL REQUIREMENTS

ID	TM-FR-001
Requirement	Calculation of conflict-free taxi trajectories
Description	Taxi trajectories are calculated automatically to ensure conflict-freeness and enable continuous taxi operations with minimum number of holds.
Priority	• Mandatory
Stability	• Not consolidated

ID	TM-FR-002
Requirement	Automatic taxi trajectory recalculation on deviation
Description	Taxi trajectories are recalculated automatically when aircraft deviate from the planned route or move faster/slower to ensure conflict-freeness.
Priority	• Mandatory
Stability	• Not consolidated

ID	TM-FR-003
Requirement	Ground situation display
Description	TraMICS-HMI that enables ATCOs to interact with, manually edit and clear the trajectories generated by TraMICS+.
Priority	• Mandatory
Stability	• Not consolidated

ID	TM-FR-004
Requirement	Coordination of taxi trajectories according to TTOTs
Description	If available, TraMICS+ can calculate taxi trajectories backwards according to target takeoff times (TTOT) made available in the flightplan data by the DMAN. Otherwise scheduled or target off block times in the flightplan data are used.
Priority	• Nice-to-have
Stability	• Not consolidated

ID	TM-FR-005
Requirement	Alerting system for non-conformant behavior
Description	TraMICS+ generates visual alerts in the ground situation display to inform the ATCO about deviations from trajectories and indicate when a trajectory had to be recalculated because of these deviations.
Priority	• Nice-to-have
Stability	• Not consolidated

2.4. MERGESTRIP

In this section, all requirements identified and implemented during the execution of the GREAT project are listed and described. All other previously defined requirements are omitted from the list.

INPUT FLIGHT DATA REQUIREMENTS

ID	MS-DAT-001
Requirement	ASTERIX input flight data source
Description	The system shall support the acquisition of flight data from standard ASTERIX sources (multicast flow)
Priority	Mandatory
Stability	Consolidated

ID	MS-DAT-002
Requirement	ASTERIX categories
Description	The system shall be able to parse the following ASTERIX categories: • CAT021 (ADS-B) • CAT062 (System Track Data)
Priority	Mandatory
Stability	Consolidated

ID	MS-DAT-003
Requirement	Multicast group address and port
Description	The multicast group address and port shall be defined as application configuration parameters
Priority	Mandatory
Stability	Consolidated

ID	MS-DAT-004
Requirement	PildoBox input flight data source
Description	The system shall support the acquisition of flight data from a PildoBox
Priority	Mandatory
Stability	Consolidated

INFRASTRUCTURE REQUIREMENTS

ID	MS-INF-001
Requirement	Installation of multiple instances
Description	Multiple instances of MS shall run in parallel during validation exercises
Priority	Mandatory
Stability	Consolidated

FUNCTIONAL REQUIREMENTS

WHAT-IF

ID	MS-FR-001
Requirement	What-if main objective
Description	What-if functionality shall allow users to preview the effects that a change in speed or next WP for one or multiple flights have to the whole scenario before consolidating the change
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-002
Requirement	What-if preview loading
Description	The preview shall be loaded or updated just after modifying proposed speed or next WP for any flight
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-003
Requirement	What-if preview
Description	Effects of the what-if preview shall be visible in all views: • Radar view (RV) • Approach horizontal projection view (AHPV) • Final horizontal projection view (FHPV) • Vertical projection view (VPV)
Priority	Mandatory

Stability	Consolidated

ID	MS-FR-004
Requirement	What-if preview in RV
Description	When a new next WP is selected for any A/C, a new straight yellow line joining the A/C to the new next WP shall appear on the radar view
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-005
Requirement	What-if preview in AHPV
Description	When a new next WP is selected or a new speed is proposed for any A/C, the new projection must be computed and displayed in the AHPV strip (using a different color)
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-006
Requirement	What-if preview in FHPV
Description	When a new speed is proposed for any A/C located between the THX and the merge point, the new projection must be computed and displayed in the FHPV strip (using a different color)
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-007
Requirement	What-if preview in VPV
Description	When a new next WP is selected or a new speed is proposed for any A/C, the new projection must be computed and displayed in the VPV (using a different color)
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-008

Requirement	Speed change mechanism
Description	The user shall be able to propose new speed values for any A/C based on relative speed modifications (±10kt)
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-009**
Requirement	Speed dynamic probing
Description	The effects of speed modifications shall be automatically loaded to the preview in real time (dynamic probing)
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-010**
Requirement	Preview propagation
Description	A preview generated by a specific user shall be visible by all other users
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-011**
Requirement	Multiple changes in a single preview
Description	A single preview shall display the effects of multiple non-consolidated changes applied to multiple flights
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-012**
Requirement	Changes acceptance mechanism
Description	Speed and next WP changes proposed for one specific A/C shall be consolidated by clicking the “Accept” button in its corresponding operation window
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-013
Requirement	Changes rejection mechanism
Description	Speed and next WP changes proposed for one specific A/C shall be discarded by clicking the "Cancel" button in the operation window
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-014
Requirement	Applicability of manual changes
Description	After a next WP proposal is consolidated for any A/C, the new next WP shall be taken into consideration at the next computation of its corresponding projections
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-015
Requirement	Preview termination mechanism
Description	The preview should automatically disappear from all views after accepting/rejecting the proposed changes
Priority	Mandatory
Stability	Consolidated

ESTIMATED TIME OF ARRIVAL

ID	MS-FR-016
Requirement	Support to multiple ETA computation methods
Description	The system shall allow the use of multiple methods to compute ETA
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-017
Requirement	Selection of ETA computation method
Description	The method to compute ETA shall be selected in the application configuration settings

Priority	Mandatory
Stability	Consolidated

ID	MS-FR-018
Requirement	ML-based estimated time of arrival
Description	A new ML-based method to compute ETA shall be implemented
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-019
Requirement	Type of ML ETA model
Description	The ML ETA model shall be based on the Random Forest regression method (supervised learning algorithm)
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-020
Requirement	Model training settings
Description	The ML ETA model shall be trained by using the following settings: • Number of flights in the dataset: +2000 • Train size: 0.4 • Maximum distance to the airport: 400 km • Flight horizontal efficiency: +0.8
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-021
Requirement	Model independent variables
Description	The ML ETA model must take as input the following independent variables: • Latitude • Longitude • Altitude • Speed • Speed angle • Distance to the T-BAR

	• T-BAR projected speed
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-022
Requirement	Use of ML-based ETA model
Description	ML-based ETA prediction shall be made available to MergeStrip as a totally independent piece of SW by means of a rest API
Priority	Mandatory
Stability	Not consolidated

ID	MS-FR-023
Requirement	Input parameters to be included in the query to the ML-based ETA API
Description	The query to retrieve the ETA value from the ML-based ETA prediction SW shall contain a list of input parameters as per defined in requirement MS-FR-021.
Priority	Mandatory
Stability	Not consolidated

RECOMMENDATION ENGINE

ID	MS-FR-024
Requirement	Main objective of the recommender: conflict resolution
Description	The main objective of the recommender is to propose actions to ATCOs to mitigate existing conflicts.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-025
Requirement	Secondary objective of the recommender: DTG / fuel consumption optimization
Description	The secondary objective of the recommender is to propose actions to reduce overall fuel consumption / DTG in non-conflicting scenarios.
Priority	Nice-to-have

Stability	Consolidated

ID	MS-FR-026
Requirement	Potential actions to be applied for conflict resolution
Description	Two different actions shall be applicable to A/C involved in a conflict: • Increase / reduce speed ○ Two speed changes shall be considered by the recommendation engine: ±50kt (default value) • Change next WP
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-027
Requirement	Conflict resolution: configuration of the relative speed change value
Description	The value of the relative speed change (defined by default as 50kt) shall be editable as a configuration option
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-028
Requirement	Conflict resolution: selection of alternative next WP
Description	All possible next WP are considered for each A/C, considering the current next WP (no STAR change)
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-029
Requirement	Restrictions to the conflict resolution mechanism
Description	Two restrictions shall be applied to the conflict resolution engine: • Resolution actions shall only be applied to A/C involved in a conflict • The recommendation engine shall only be executed when the number of A/C involved in a conflict is equal or less than X (number to be defined after testing).
Priority	Mandatory

Stability	Consolidated

ID	MS-FR-030
Requirement	Selection of optimized scenario
Description	The recommender engine shall select the non-conflicting scenario with the most favorable outcome in terms of overall DTG / fuel consumption.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-031
Requirement	Presentation of proposed actions to resolve conflicts

Description	When the optimum scenario is selected by the conflict resolution engine, a list of proposed actions shall be displayed in the application. Example:
	`Conflict 1 – A/C involved: RYRXXXX, DLHXXXX, WZZXXXX`
	`RYRXXXX – Increase speed +50kt`
	`DLHXXXX – Change next WP: BP844`
	`WZZXXXX – No action required`

Priority	Mandatory
Stability	Consolidated

ID	MS-FR-032
Requirement	Execution of DTG / fuel consumption optimization algorithm
Description	The algorithm shall be executed every X seconds when there are no conflicts in the current scenario. The value X shall be defined in the configuration settings.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-033
Requirement	Potential actions to be applied for DTG / fuel consumption optimization
Description	One single action shall be applicable to A/C: change next WP
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-034
Requirement	DTG / fuel optimization: selection of alternative next WP
Description	The possible next WP shall be restricted to those that reduce the DTG in comparison to the current one
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-035
Requirement	Presentation of proposed actions for DTG / fuel consumption optimization

Description	When the optimum scenario is selected by the recommendation engine, a list of proposed actions shall be displayed in the application. Example:
	`Optimization proposal:`
	`RYRXXXX – Change next WP: NICRA`
	`DLHXXXX – Change next WP: BP844`
	`WZZXXXX – No action required`
	`Change in overall DTG / fuel consumption: X`

Priority	Mandatory
Stability	Consolidated

OTHER

ID	MS-FR-036
Requirement	Conflict lines in the AHPV
Description	Red lines indicating conflict shall be displayed in the AHPV when the minimum distance/time between A/C is not respected at the reference point.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-037
Requirement	Visibility of the conflict lines
Description	The user shall be able to turn on and off the visibility of the conflict lines displayed in the AHPV.
Priority	Mandatory

Stability	Consolidated

ID	**MS-FR-038**
Requirement	Arrival detection mechanism
Description	The system shall support multiple arrival detection mechanisms
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-039**
Requirement	Definition of arrival detection mechanism
Description	The arrival detection mechanism to be used shall be defined in the configuration settings
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-040**
Requirement	Automatic arrival detection based on ECTL B2B
Description	The system shall implement automatic detection of arrivals based on the information provided by EUROCONTROL's B2B services
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-041**
Requirement	Group WPs by STAR
Description	All WPs used to compute distance projections shall be associated to their corresponding STAR
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-042**
Requirement	Next WP selection (manual)
Description	In order to change next WP, the user shall first select the STAR and then select one of the WPs associated to the selected STAR

Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-043**
Requirement	Automatic selection of next WP
Description	The process to automatically select a new next WP is described in the following example: *Consider the following WP sequencing: [A, B, C, D, E, REF_POINT]. Consider that the current next WP is B. When the AC starts moving away from B, use next algorithm:* *IF A/C approaches C → next WP = C* *ELSEIF A/C approaches D → next WP = D* *ELSEIF A/C approaches E → next WP = E* *ELSE → next WP = REF_POINT*
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-044**
Requirement	TMA overlay
Description	The TMA boundaries shall be added to the radar view
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-045**
Requirement	TMA overlay visibility
Description	The user shall be able to show / hide the TMA overlay
Priority	Mandatory
Stability	Consolidated

ID	**MS-FR-046**
Requirement	Runway change procedure
Description	When the user changes the default RWY, the new selected RWY shall be assigned to all A/C (those already in view and those whose first position data is received after the change is applied). If some of the existing flights must keep the original RWY, the

	following procedure shall be applied: 1. Right click on the labels of the A/C that should remain on the original RWY 2. Apply the RWY change through the settings option of MS The color of the selected labels shall be changed to distinguish them from the non-selected ones.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-047
Requirement	Missed approach detection
Description	When an A/C arrives at the THX, it shall be hidden from all views. In case new data from that operation is received after T seconds and the reported height is higher than H, consider it as a missed approach and show the A/C again in all views.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-048
Requirement	Missed approach detection: configuration of T and H
Description	The maximum time allowed for missed approach detection (T) and the minimum height required to classify a flight as a missed approach after crossing the THX (H) shall be defined in the configuration settings.
Priority	Mandatory
Stability	Consolidated

ID	MS-FR-049
Requirement	Use a persistent database
Description	A relational persistent database (e.g. MySQL) shall be used to store user account information and settings.
Priority	Nice-to-have
Stability	Consolidated

3. INTEGRATION OF NEW FUNCTIONALITIES TO EXISTING SUPPORT TOOLS

This chapter describes all integration tasks and presents the basic operation of the newly developed functionalities. Aspects like the how the end-users shall interact with the new functionalities of each decision support tool are covered in this section.

3.1. 4D-CARMA

Integrating manually organized approaches into the direct approach stream of the directs also means integrating different planning strategies into an arrival manager. First, the arrival flows must be separated at the Aircraft Separation Points (ASP). A distinction is made on the basis of the level of equipment: 4D-FMS equipped aircraft are assigned to the direct routes to LMPs selected from the AMAN's airport topology database, all other aircraft are guided to the northern or southern downwind area in dependence of approach direction (Figure 1).

AMAN-FMS TARGET TIME NEGOTIATION

At the LMPs, both streams have to be merged again. The target times of the directs are negotiated and therefore after this process not changeable by AMAN. The AMAN has the task to sort the manually guided aircraft time-based between the directs. Regarding actual speed, altitude, and planned speed reductions, it calculates the optimal turn-to-base point on downwind. If the turn starts before or after the calculated time or does not follow the precalculated turn radius, the AMAN tries to compensate the time divergence be a stronger or a delayed speed reduction on final. If the compensation is not possible on the last miles of approach, conflicts can arise and the controller has to take the decision on missed approach advisories.

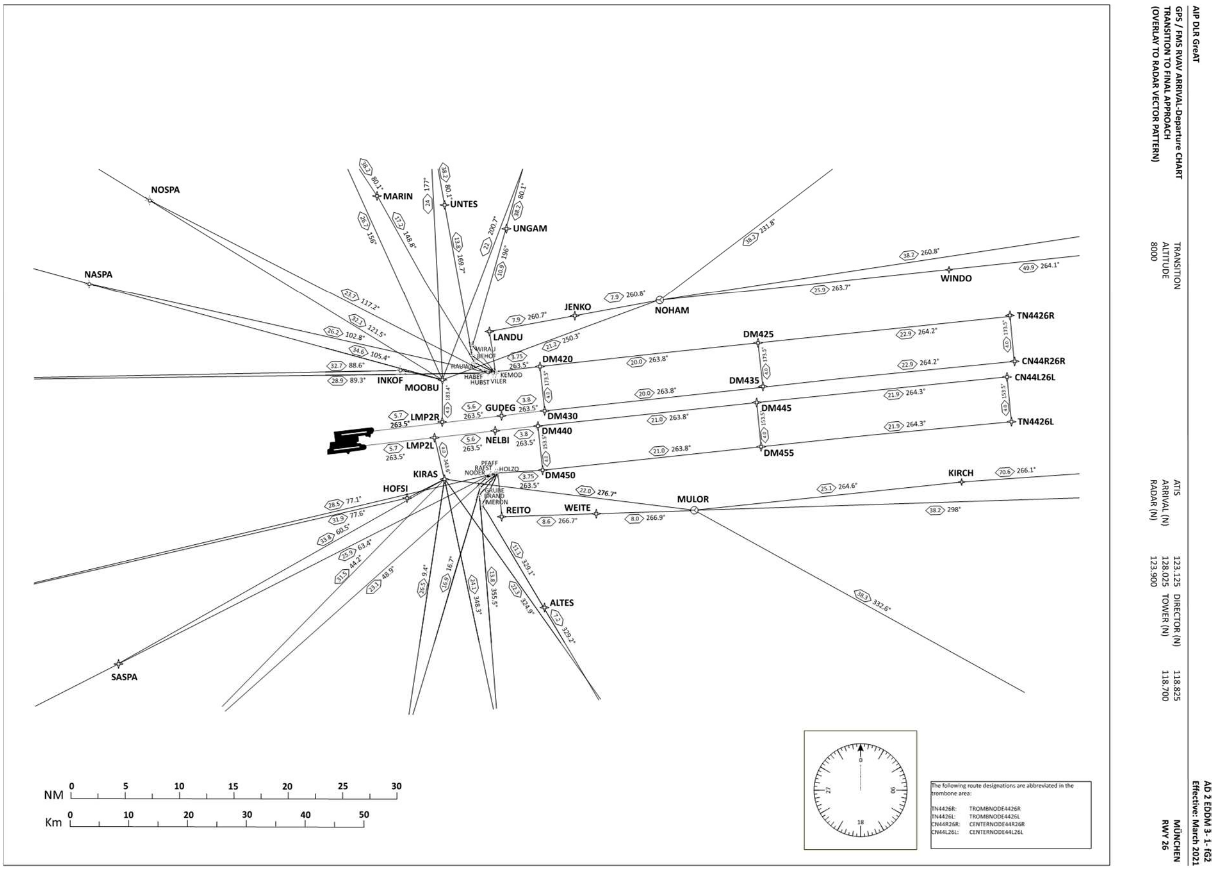

Figure 1: The GreAT airspace structure for approaches. The Aircraft Separation Points (ASP) are slightly out of the picture in the north and in the south. Directs get clearances directly to the LMPs and standard approaches are guided over DM420 or DM450.

The negotiation process between FMS and AMAN begins with the aircraft's first radar contact. As a minimum distance from the runway, 125 nautical miles are recommended, as this distance can ensure that an aircraft can be carried safely and efficiently up to the runway threshold and meets planned target times at significant waypoints.

The AMAN sends an "initial handshake" to the FMS to set up the connection (Figure 2). Once this has been confirmed, an interval request will be sent for a suggested standard approach route (STAR). Usually, the suggested route and runway is found in the flight plan. If the actual approach direction deviates too far from the flight plan, the AMAN may also opt for an alternative runway. The interval should include the earliest and latest possible landing time for an optimal approach from the current position. Both times are sent back to AMAN by FMS. These times are now regarded by the AMAN as a possible landing window. Starting at the earliest possible stage, the AMAN will try to integrate the aircraft into the current approach flow without traffic conflicts. In the event of a conflict with previous aircraft, the aircraft currently under review shall be pushed back until the conflict has been resolved. If the possible landing time is out of the target time window sent by the FMS, either a new target time for another STAR can be requested or the aircraft can be converted into a manually guided standard approach.

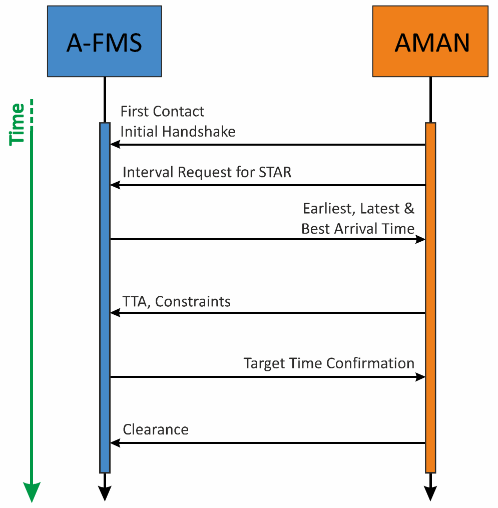

Figure 2: The target time negotiation protocol for the direct approaches between aircraft's 4D-FMS and AMAN. The resulting Target Touchdown Time (TTA) is than fixed until the aircraft passes the LMP.

Once the AMAN has found a suitable landing time for the aircraft under review at the LMP and the runway threshold, it will be sent to FMS as target touchdown time (TTA). If additional marginal conditions need to be considered during the approach (e.g. minimum flight altitudes at significant waypoints), these can be sent here again. The aircraft must then confirm the selected target time to the AMAN. The AMAN then sends a clearance for the entire approach from the current position to the LMP, where the aircraft is usually handed over to the tower controllers. This target time is now marked as unalterable in the AMAN and all other aircraft must be planned around it accordingly. If the traffic context around the aircraft with the negotiated target time changes, there may in theory be major time gaps in the approach flow before or behind that aircraft that may lead to a loss of throughput in the approach capacity. This is accepted as in this mode the AMAN prioritize environment over economy.

GHOSTING

When using ghosting on a primary display, a label of an aircraft is projected onto a different route according to its remaining flight distance to a merging point. In the GreAT airspace structure, the result is a ghost label on the final that must cover the same distance to the threshold (or LMP) as the associated real aircraft on its actual direct route to the LMP. For example, if an aircraft is 25 NM north of the LMP and has to travel 27 NM to the threshold due to a turn and the distance from the LMP to the threshold, its label is additionally mapped to the centerline with a distance of 27 NM to the threshold. The ghost label moves on the final towards the runway with exactly the same speed as it approaches the LMP from the north. This ghosting behavior is called distance-based ghosting.

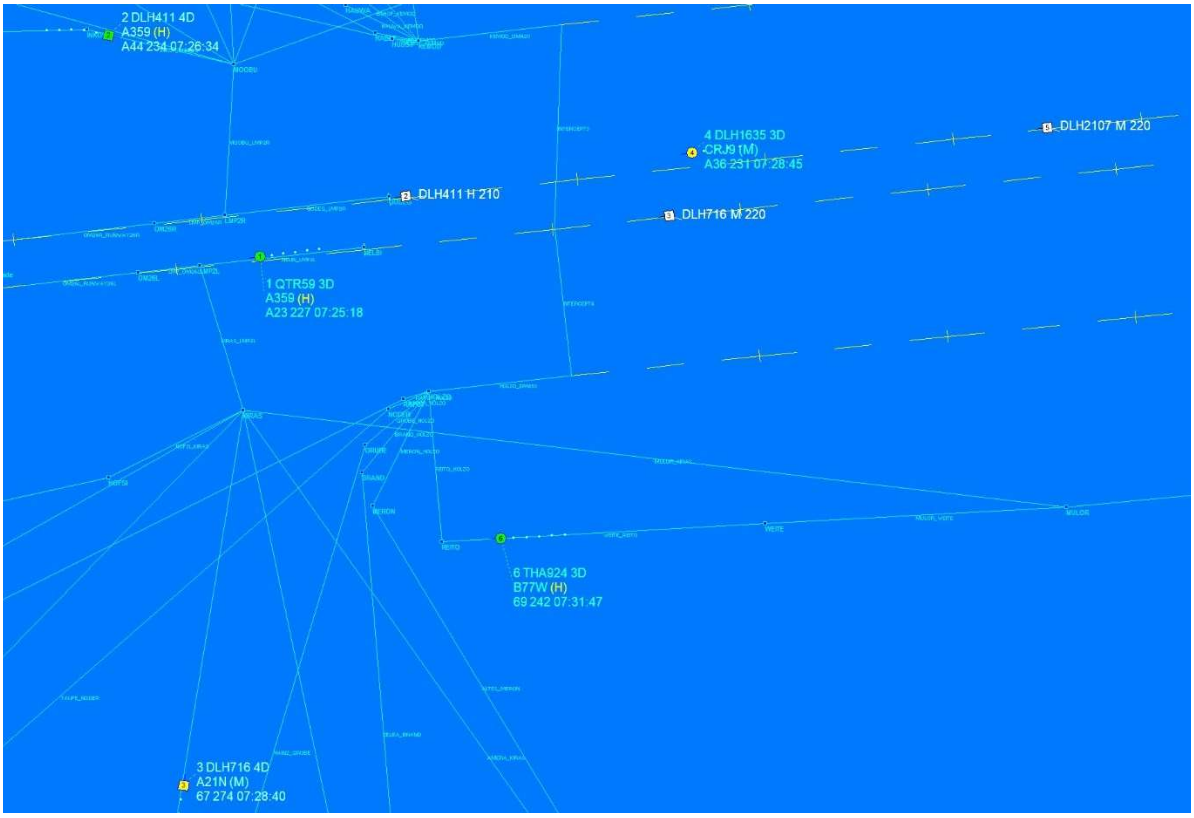

Figure 3: Display with three ghost labels on the final. The light grey squares with the numbers two, three, and five represent direct approaches of 4D-FMS equipped aircraft with the actual sequence numbers two, three, and five in the landing sequence (green square with the two and yellow square with the three; green indicates weight class heavy and green medium). The green and yellow circles show aircraft already flying on the final. Screenshot from RadarVision with changed colors to improve readability.

However, with distance-based ghosting, a controller cannot guide a conventionally guided aircraft directly in front of or behind the projected aircraft and be sure that it is now staggered correctly up to the LMP or threshold. The 4D-FMS equipped aircraft changes speed at a different rate than a conventionally guided aircraft due to the procedure during the final approach phase. As a result, the two aircraft may become too close at the LMP or create an unacceptably large gap.

TIME-BASED GHOSTING

For the time-based ghosting the applied distance $d_{ghost}(t)$ between ghost and LMP is based on the remaining flight time t_{rem} of the equipped aircraft to the LMP. The remaining time t_{rem} (i.e., the difference of LMP-target time and actual time) is multiplied with a constant speed v_{const} to calculate the distance $d_{ghost}(t)$ between LMP and the visualized ghost position. As a result, the ghost label moves with constant speed on the centerline, provided that the negotiated target time of the equipped aircraft stays fixed. The value for the parameter v_{const} is chosen close to the average speed of unequipped aircraft during the turn from the downwind over base-leg on the centerline (e.g. v_{const}=230 kts groundspeed). The constant speed makes the ghost an easily predictable reference for the relative guidance of unequipped aircraft. However, it represents neither the exact speed profile and flight distance of the associated equipped aircraft nor an ideal reference for the deceleration profile of the real unequipped aircraft, which has to decelerate to a lower speed before the LMP.

THREE-SEGMENT GHOSTING

The three-segment ghosting is an extended version of the time-based ghosting method. As for the time-based ghosting the distance $d_{ghost}(t)$ is also based on the remaining flight time t_{rem} of the equipped aircraft to the LMP. However, instead of assuming a ghost movement at a constant speed v_{const} independent of the distance to the LMP, the three-segment ghosting calculates with 1) a segment at constant speed in the area of the trombone, 2) a segment with constant deceleration in the middle part of the final, and 3) a segment at constant speed the last miles before overflying the LMP (Figure 4).

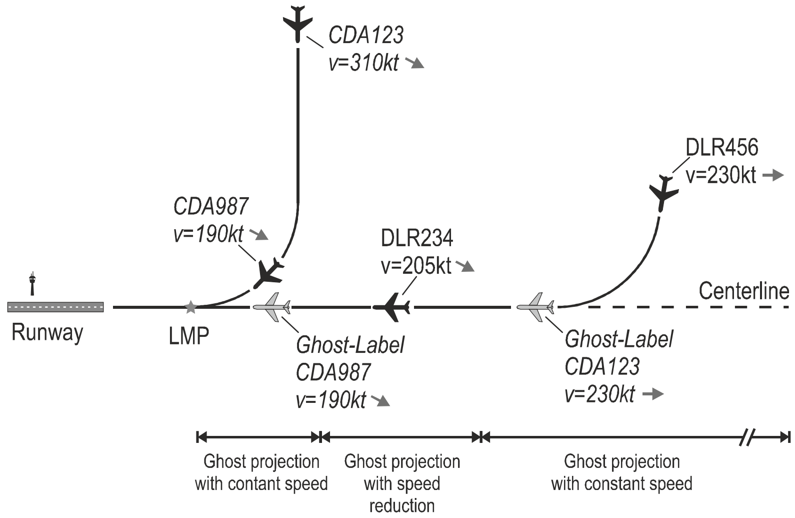

Figure 4: Schematic illustration of ghost labels (grey) and labels of real aircraft (black) on centerline and final.

The first segment with constant speed (e.g. 220-230 kts) allows that the ghosts move at a similar speed to the unequipped aircraft in the area where unequipped aircraft intercept the localizer and present a predictable reference to establish the correct spacing initially.

The second segment with the deceleration of the ghost imitates the deceleration profile of the real unequipped aircraft when approaching on the final. At the LMP, all aircraft have to have a speed below 185 kts. During standard approach, this target speed is usually achieved a few miles before the position of LMP and the pilots moves the aircraft with a constant speed in this phase of final approach.

Using the three-segment approach, once an appropriate spacing is established between unequipped aircraft and ghosts, it should be easier to keep this stable during final approach. Furthermore, the three-segment ghosting permits that equipped aircraft and associated ghost label meet at the LMP not only at the same time, but also at the same speed.

In this way, ghost labels are projected in the intercept area of the final, which move towards the LMP at a constant speed and thus provide controllers with a good orientation as to where the 4D-FMS aircraft are in relation to the manually guided aircraft in terms of time and space. On the other hand, this allows the speed transition in the area of the LMP where the ghost and real label of the 4D-FMS aircraft meet to be mapped without jumps or significant speed shifts and thus realistically.

However, a prerequisite for the operational capability of this procedure is that controllers, when guiding the aircraft on the final, adhere to the airspeeds assumed for the 4D-FMS-equipped aircraft and that these assumed airspeeds are selected beforehand in an appropriate and realistic manner. This applies until approximately two minutes before reaching the LMP. Thus, this assumed constant speed should correspond to the approach speed reached by an aircraft in the intercept area and in the first section of the final - and thus on the last level segment. The speed reduction profile from an 4D-FMS aircraft and thus a CDA approach differs only slightly from that of a standard approach in the final segment before the threshold, since both aircraft ultimately touch down at nearly the same speed. From the LMP onwards, the position of the aircraft and the associated ghost coincide, so that the ghost-label display is switched off from the LMP onwards.

The time-based distance calculation for a ghost label is performed accordingly using the following equations. The remaining flight time Δt from the current position to the LMP is obtained with

$$\Delta t = t_{LMP} - t_{current}$$

Δt: Remaining flight time to the LMP

t_{LMP}: Planned or negotiated time at LMP

$t_{current}$: Current time (system time)

Accordingly, the speed difference Δv between the assumed final speed and the overflight speed at the LMP is calculated:

$$\Delta v = v_{const} - v_{LMP}$$

Δv: Velocity difference between constant flight on the final and the flyover velocity at the LMP.

v_{const}: Ground speed on the final assumed for the ghost label.

v_{LMP}: Overflight speed at the LMP

For the distance calculation, the time required for an aircraft ghost to reduce its constant speed on the final to the overflight speed over the LMP is used. Assuming a constant speed reduction rate of a_{const}=0.6 kn/sec on the final, this results in

$$t_{red} = \frac{\Delta v}{a_{const}}$$

t_{red}: Time needed for a ghost label to decelerate from v_{const} to v_{LMP}

a_{const}: Assumed velocity reduction rate of aircraft on the last section of the final

When calculating the sought time-dependent distance d_{LMP}between ghost label and LMP, a case distinction is now made for the constant-flight and speed-reduction phases ($\Delta t < t_{red}$):

a) The remaining flight time to the LMP is shorter than the last constant phase (t_{const}): Distance d_1.
b) The remaining flight time is shorter than the last constant phase and the speed reduction phase (t_{red}): Distance d_2.
c) The remaining flight time is longer than the first two phases: Distance d_3.

For this reason, the distances of these three phases are calculated separately and then added together.

$$d_{LMP} = \sum_{n=1}^{3} d_n$$

The parameters Δt for the remaining flight time to the LMP and the time t_{red} a ghost label takes to decelerate from v_{const} to v_{LMP} are calculated as described above. Thus, d_1 is calculated from:

$$d_1 = \begin{cases} \Delta t < t_{const} \rightarrow v_{LMP} \cdot \Delta t \\ else \rightarrow v_{LMP} \cdot t_{const} \end{cases}$$

And d_2 accordingly:

$$d_2 = \begin{cases} \Delta t \leq t_{const} \rightarrow 0 \\ \Delta t > t_{const} \cup \Delta t \leq t_{const} + t_{red} \rightarrow \frac{1}{2} \cdot a_{const} (\Delta t - t_{const})^2 + v_{LMP} (\Delta t - t_{const}) \\ else \rightarrow \frac{1}{2} \cdot a_{const} \cdot {t_{red}}^2 + v_{LMP} \cdot t_{red} \end{cases}$$

The calculation for d_3 is again according to a constant velocity motion:

$$d_3 = \begin{cases} \Delta t > t_{const} + t_{red} \rightarrow v_{const}(\Delta t - t_{const} - t_{red}) \\ else \rightarrow 0 \end{cases}$$

The speed calculation for the 3-segment ghost is divided in three parts. First, the constant flight phase directly in front of the LMP, then the phase with the velocity reduction and finally the constant velocity phase in the Trombone segment:

$$v_{Ghost} = \begin{cases} \Delta t < t_{const} \rightarrow v_{LMP} \\ \Delta t > t_{const} \cup \Delta t < t_{const} + t_{red} \rightarrow v_{LMP} + a_{const} \cdot \Delta t \\ else \rightarrow v_{const} \end{cases}$$

v_{Ghost}: Ground speed at which the ghost label of an equipped aircraft is moved on the final.

v_{LMP}: Constant ground speed at which the ghost label approaches the LMP.

v_{const}: Constant Ground Speed at which the Ghost label moves in the area of the Trombonen segments.

For the validations in the GreAT project, the speed at the LMP was v_{LMP}*=180 kn*, the mean reduction rate a_{const}*=0.6 kn/s* and for the time with constant airspeed in front of the LMP the time was set to t_{const}*=50 s*.

TARGETWINDOWS

Since 4D trajectories are calculated in GreAT for all non-equipped aircraft, ghosting can also be supplemented by targets to support conventional radar vectoring. Unlike ghosting, a target does not perform a projection of an aircraft for the surrounding traffic, but for the considered aircraft itself. In this visualization, the remaining planned flight path on the final is "rolled out" for all non-equipped aircraft located on the downwind or a base leg: The TargetWindows thus indicate where the aircraft would be on the final if they flew a direct approach based on its AMAN-planned trajectory. The TargetWindow is a dashed semicircle with the opening facing the direction from which the proposed aircraft is to turn from downwind to final (Figure 5). The opening moves along the final and thus always marks the best position in the sequence of the corresponding aircraft.

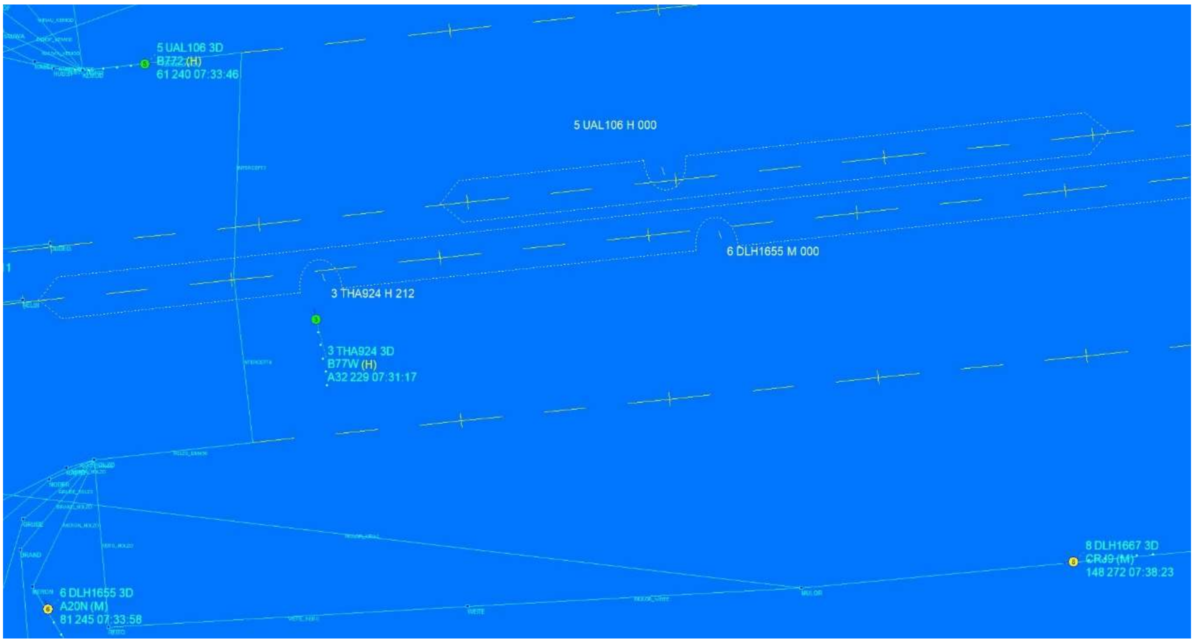

Figure 5: TargetWindows for the two finals of the independent parallel runway used in GreAT The dotted lines indicates the safe area for positions of the manually guided aircraft. As soon an associated aircraft reaches the final, the half circle disappears. Screenshot from RadarVision with changed colors to improve readability.

The air traffic controller's aim is to turn the actual aircraft onto the final so that it is congruent with its TargetWindow. If the controller misses the turn in time (the TargetWindow is already uncatchable away), a new TargetWindow results from a newly generated trajectory, which is generated on the basis of an adjusted target time at LMP and threshold. The TargetWindow thus also represents an indicator of the compliance accuracy of the aircraft to be guided with respect to the AMAN planning. If the associated TargetWindow of an aircraft is in front of the aircraft under consideration, the aircraft is behind its planning in terms of time. If, on the other hand, it is moving behind, it is currently behind its planned time. Similar to ghosting, this variant of targeting also transfers the time-based planning into a distance-based display, thus enabling the controller to perform approach guidance with the usual indicators.

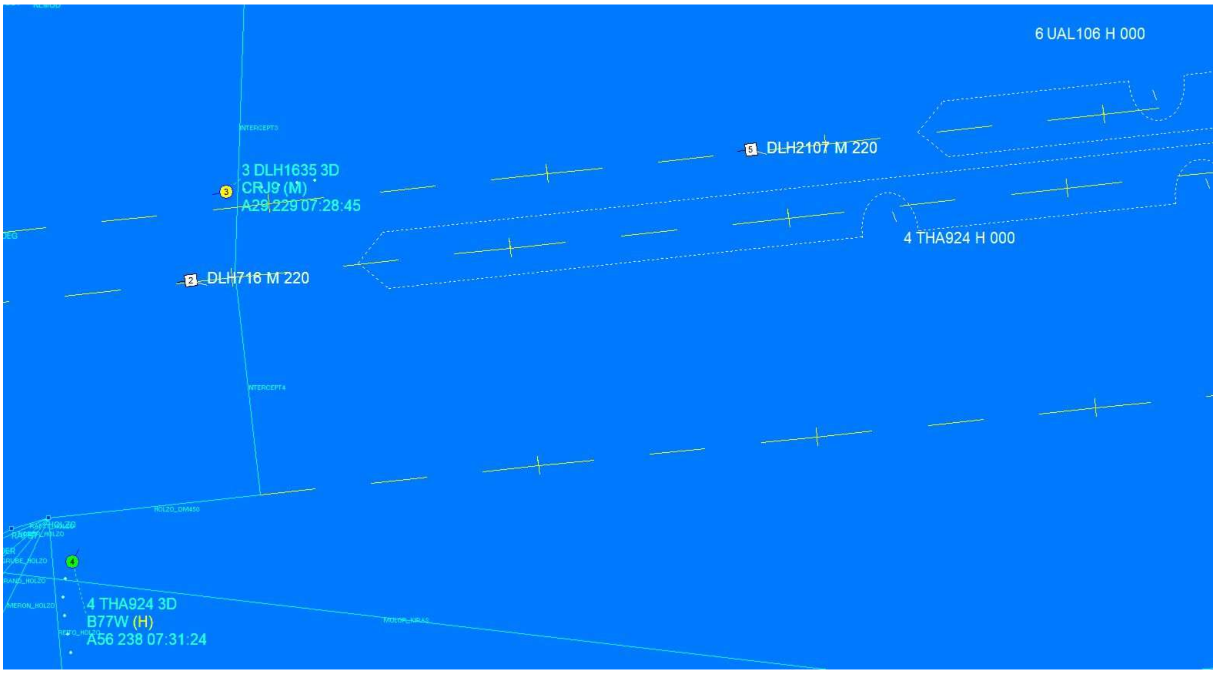

Figure 6: The safe area marked by dotted lines considers real aircraft as well as ghosts. Screenshot from RadarVision with changed colors to improve readability.

In addition, the TargetWindows still indicate by a dashed line the area that can be considered a safe area on the Final based on AMAN planning and the current traffic situation. The area classified as safe considers not only the real aircraft on the Final, but also the Ghosts, as these represent planned positions of aircraft that they will take in the near future (Figure 6).

If an aircraft turns onto the final with a delay or too fast and misses its ideal intercept, the controller can immediately see whether he has to correct the approach of the aircraft to avoid a conflict with a direct approach or other standard approaches, or whether the approach can be continued as started without any implications with other traffic.

FINAL DISTANCE INDICATOR

The Final Distance Indicator (FDI) is an additional window which can be displayed by the controller at the bottom of the primary display. Every (extended) final is displayed as a line on which the aircraft are dynamically lined up. In addition, the current separation between the aircraft is displayed in nautical miles with one decimal place, so that controllers can directly read the current separation at any time (Figure 7). The color scheme of the FDI automatically adapts to the color scheme of the primary display.

Figure 7: Final Distance Indictor (FDI) of RadarVision with aircraft label (triangle), Ghost label (square), and TargetWindow label (half circle). The numbers between the symbols indicate the current separation in nautical miles.

The symbols and their colors for the aircraft differ depending on their equipment level (4D-FMS or standard FMS) and position (Figure 8). Standard approaches are displayed as a triangle standing on its tip, ghosts as squares and the positions of the TargetWindows planned by the AMAN as semicircles. White symbols correspond to aircraft of the Light weight class, yellow to the Medium weight class and green to Heavy.

Figure 8: Detail extract of the Final Distance Indicator with the actual separation between aircraft on a final.

Additionally, a trend display can be added. Two small arrows in front of and behind the current distance value indicate whether the separation between two aircraft is currently increasing (<5.0>) or decreasing (>5.0<). If the separation just remains constant, no additional symbols are displayed.

The positions of the aircraft, which are on the final or on the centerline, are taken directly from the radar data. The positions of the ghosts on the primary radar are used for separation measuring, not the distances (rack miles) of the associated 4D-FMS aircraft to the runway threshold. The TargetWindows positions result from the planned trajectory of the respective aircraft. Thus, the separations displayed in the FDI are not the actual separations that exist between the aircraft at any given time, but rather the separations that result if the aircraft continue to move along their planned or negotiated trajectories.

COORDINATION WITH DMAN

For coordinated planning of take-offs and landings on a runway, an arrival manager (AMAN) must be able to work with a departure planning system (DMAN). In particular, the exchange of information is important, as well as the ability of the planning systems not only to adapt to a changing traffic situation and controller input, but also to respond to requests and requirements from other planning systems. In GreAT, a light version of a departure planning system was developed and deployed, which independently incorporates flight plan data for departures, generates a timed departure plan, coordinates this with the AMAN for the respective runway, and can respond to changing traffic if necessary (Section 3.2).

During traffic organization, the AMAN receives requests from the DMAN for departure times on a specific runway, if required. The AMAN examines the current landing sequence to see if it causes a separation conflict with the landing scheduled before the departing aircraft. If this is not the case, a check is made to see if the following landing aircraft has a conflict with the take-off. If there is no conflict, the slot of the planned take-off is entered in the AMAN as a blocked landing time (Arrival Free Interval).

However, if there is a conflict with a previous landing, the AMAN will send a new, slightly delayed proposed take-off time to the DMAN to resolve the conflict. If the take-off causes a conflict with a subsequent landing, the first attempt shall be to move the landing behind the take-off slot. If the approaching aircraft has sufficient distance to the runway threshold, this is usually not a problem. The entire landing sequence is then simply delayed by a few seconds and an appropriate Arrival Free Interval (AFI) is scheduled at the departure time suggested by the DMAN. However, if the traffic situation makes it impossible to move the arrivals back, the departure slot will be denied by the AMAN.

This also happens when departure requests conflict with 4D-FMS aircraft whose landing time may not be adjusted after successful target time negotiation. For these departures, the DMAN must generate completely new departure times and negotiate them with the AMAN. If the arrival times of the flights are shifted slightly so that the departures are affected, the DMAN can also shift the departures slightly. However, it is not possible to reschedule a departure before its Earliest Take-off Time (ETOT). A complete rescheduling of a departure is also necessary if it has to be scheduled behind its EUROCONTROL departure slot due to too many arrivals.

3.2. DMAN LITE

One of the aims of GreAT was the developing of an automatic coordination between AMAN and DMAN to enable an efficient cooperative use of runways for take-offs and landings (mixed mode operation). One of the constraints on coordination were the negotiated and therefore unadjustable landing times of the direct approaches conducting continuous descent operations (CDO), since any adjustment would mean a deviation from the optimal approach trajectory. To solve the task, it was necessary to adapt the way the system manages its aircraft departures with consideration of arrivals with adaptable and non-adaptable touchdown times. The originally envisage DMAN-SMAN system TraMICS+, which allows dynamic adjustment and a coordination of the start times with the AMAN, was not used in the same simulation runs, because only very few functionalities were required from the departure manager and the adjustment of the overall system would have far exceeded the benefit in the validations. Instead, a DMAN Lite functionality was implemented directly in the AMAN’s database MariaDB, which provides the same functionalities for the AMAN via internal interfaces as a complete system solution with DMAN and SMAN would provide. In this way, the cooperation between AMAN, DMAN, and SMAN could be simulated and thus validated with much less effort. The validations of the DMAN-SMAN System TraMICS+ were thus carried out technically independently in separate runs.

When developing the DMAN Lite, the first step was to transmit the departure times before each start of a simulation run. This was initially done manually by inserting them into the simulation database containing the flight plans and did not allow for manual adjustment of the times during runtime. The adjustment of the departure times was then done as a function of the changing arrival times as scheduled by the AMAN and written to the shared database.

In a first step, the different constraints regarding the scheduling were extracted. The fundamental condition hereby was that only the departure times should be adapted by the departure manager.

At first, the used runway should be considered. Since the used runway topology consists of two independent runways, only aircrafts on the same runway needed to be considered. The second constraint concerned flight scheduling. Here, it had to be considered that arrivals and departures did not have a fixed schedule with respect to each other, which meant that a delay of one arrival flight could lead to an adjacent departure flight being scheduled before the next arrival flight in order to condense the staggering. This was implemented to make the DMAN behavior more realistic, as similar scheduling is used at a commercial airport.

On the other hand, regarding the inner-departure schedule on each runway respectively, a fixed schedule was used, to keep the order of the departures the same. To further implement the security features used in air traffic, the departure manager should also comply to specific separation rules. To ensure the wake vortices do not infer with other aircrafts, a time separation in regards to the weight classes of the current and following aircraft have to be calculated. For example, between two aircrafts, both with a medium weight, there should be at least a 75 second time separation.

Finally, the departure times previously used as fixed times were used as base values, as well as earliest take off times, meaning an earlier departure was not possible and would in turn not be scheduled.

To implement those functionalities, the first step consisted in deciding about the way the DMAN should be introduced into the simulation environment. In the traditional solution, the functionalities of the DMAN were implemented as a separate tool, resulting in additional dependencies and the need for interfaces between other parts of the planning systems, for example the database containing the flight plan.

Therefore, the functionalities of the DMAN were directly integrated in the database. This could be achieved with the use of different features of the flight plan database, which was implemented in the relational database language MariaDB. Two different tools were utilized to implement the functionalities, triggers and functions. A trigger can monitor a database and wait for specific conditions to arise, while functions offer possibilities to dynamically read and write on the database.

With regards to the functionalities of the DMAN Lite, at first a decision had to be made about which triggering events should start the calculations of the support system. Since the given flight plan in the database of the AMAN does not contain the departure times at simulation start, a first trigger had to be implemented that submit once the departures' flight plan data to the AMAN. To write the departure times into the database, a function was introduced, which can be invoked by the above-mentioned trigger (Figure 9). After getting called, the function would determine the currently running scenario and choose the correct set of departure times to insert into the database. This trigger is activated every time new departures have to be scheduled and coordinated with the inbounds.

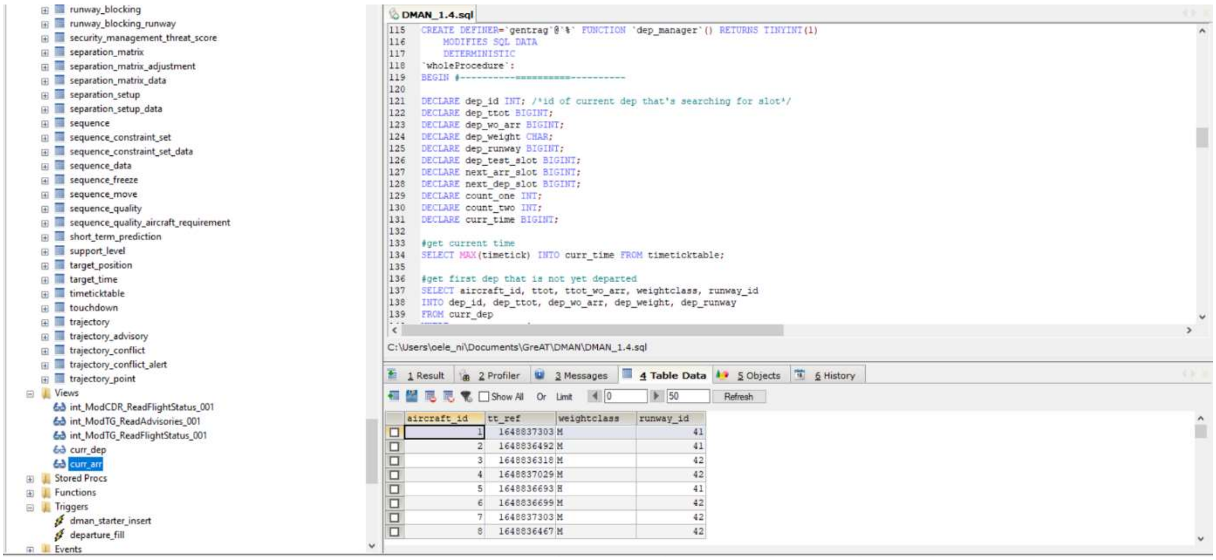

Figure 9: The DMAN-SMAN functionalities required by the AMAN during the validations were implemented directly in the underlying MariaDB. RadarVision was extended as the user interface and used accordingly by the controllers in the tests.

Additionally, a second trigger was needed to start the adaptation of the departure times. Since every change of arrivals could interfere with departures, this trigger would detect all time changes of those flights. This functionality starts every five seconds to adapt the departures.

With compliance to all the above-mentioned constraints, this implementation revalues the scheduling of the departure flights. To prepare for this, the function uses the database to read all the current arrival and departure times. Afterwards, the manager works in iterations to reschedule all the departures one by one, starting with the earliest. For each of those flights, a few possible slots will be determined and then tested. With the use of another function the separation of the previous and next planes will be checked, as well as the internal order of the departures. DMAN Lite must follow the scheduled runways of the flight plan and it had no possibility to induce runway changes. After the earliest slot that is meeting all the constraints is found, the flight plan gets updated and the departure will be marked as recalculated before resuming with the next flight.

Figure 10: Arrivals and departures in the GreAT airspace with target time scheduling. In the timeline on the right, blue labels represent departures and other colored label are arrivals. The arrival color depends on aircraft's weight class. Screenshot of validation trials from September 2022 in Braunschweig with additionally visualization of planned trajectories (yellow lines with red dots).

With this implementation in the database itself, the DMAN Lite can be used without external tools or the need to transmit the flight plan over interfaces. Furthermore, no external preparation is needed at the beginning of planning and supporting. Departures are shown on the timeline from the RadarVision primary display so that approach controllers are always aware of the planning and coordination of arrivals and departures (Figure 10).

3.3. TRAMICS+

TraMICS+ provides an algorithm to calculate conflict-free taxi trajectories as well as an interface to visualize taxi trajectories in a ground situation display, to support ATCOs when handling ground traffic. In a first step, TraMICS+ calculates the shortest route from an aircraft's designated stand to the designated runway entry (or runway exit for arrivals, respectively), using a multi-objective A*-algorithm. This algorithm optimizes the initial route for distance and sharpness of turns, preferring routes with fewer and less sharp turns. In a second step, the initial routes are used to generate initial trajectories, by computing the necessary taxi times assuming a standard speed of 15 kt as well as considering available planning times in the flight plan.

These planning times are either Estimated Landing Times (ELDT) for arrivals, or SOBTs for departures that are made available in the flight plan data. If paired with a DMAN, the calculated TTOTs are instead used to calculate the trajectories in reverse. This generates a TOBT and suitable taxi trajectory for each aircraft, so that the TTOTs can be achieved.

Lastly, all generated trajectories are checked for conflicts with other trajectories. If a conflict is found, a genetic algorithm is used to generate new modified trajectories based on the initial trajectory to solve conflicts. Modifications for new trajectories can include holds, route changes, or speed advisories for certain taxiways. Holds can be inserted in the trajectory at the gate before engine startup, in front of intersections or at certain points on taxiways to enable pushback operations. The speed advisories include fast taxiing (about 20 kt), slow taxiing (about 10 kt) or use the default speed of 15 kt. Lastly, changes to the initial taxi route can be made to avoid conflicts (Figure 11).

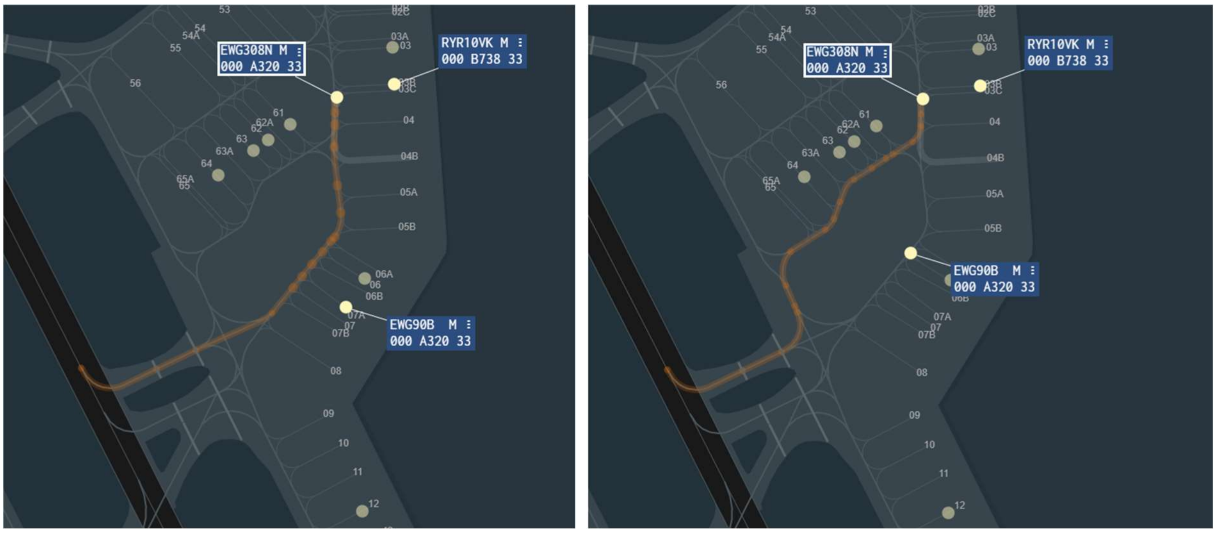

Figure 11 Trajectories are automatically recalculated when a conflict is detected. In this example, a conflict because of an unplanned pushback (EWG90B) has been detected. Therefore, the trajectory of EWG308N has been recalculated to use another taxiway.

The new trajectories are then evaluated using a penalty function to find the best trajectory. This penalty function uses different parameters that can be configured, thus enabling the creation of different trajectory profiles. TraMICS+ achieves an average calculation time per trajectory of under 0.5 seconds on standard consumer hardware, allowing the software to solve most conflicts in real time.

ATCOs can use TraMICS+ with a suitable ground situation display in the ATS360 simulator at DLR. This enables visualization, editing, and confirming of the generated trajectories.

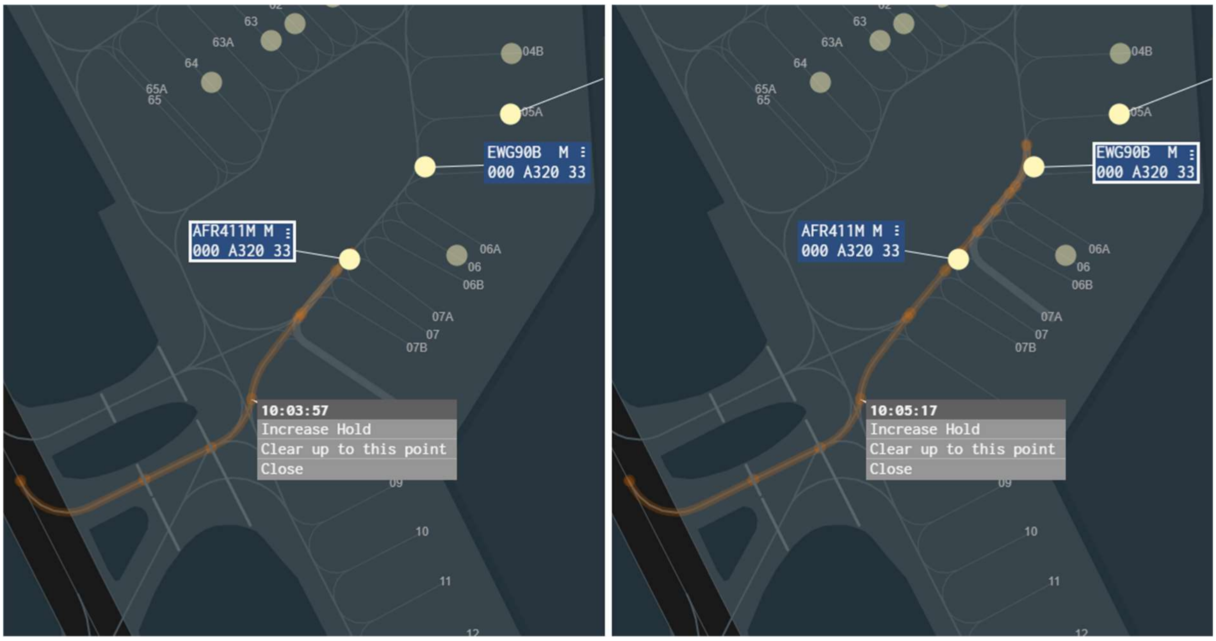

Figure 12 Trajectory information with calculated arrival times at taxi points can be displayed along the route. Aircraft on the same route are separated in time.

Whenever a label of an aircraft is selected, the taxi trajectory for this aircraft will be visualized. The ATCO can interact with the trajectory by clicking on the highlighted points. This opens a menu containing the planned arrival time of the aircraft at this point, as well as options to clear the trajectory until this point or insert a hold. The example in Figure 12 shows the taxi trajectories of two aircraft. While both trajectories contain the same taxiway segment, the ATCO is able to confirm conflict freeness by clicking on one of the points along the trajectory. This shows the trajectory menu with calculated arrival times, indicating that there is enough time spacing between the aircraft to remain conflict-free.

It is also possible to configure visual indicators that will highlight aircraft that need special attention, e.g. because a new trajectory has been generated or to show if an aircraft is early or late.

3.4. MERGESTRIP

WHAT-IF

The What-if functionality provides ATCOs with a mechanism to analyze the effects that potential changes in speed or next WP would have to the sequencing of arriving aircraft. Then, according to these effects, the ATCOs may decide to accept or discard the proposed changes.

The final objective is to help ATCOs in the process of finding the optimum solution to deal with conflicting scenarios, in which the minimum separation distance/time between aircraft at the reference point is not respected,. Thus, reducing the late application of non-efficient strategies (e.g. holding patterns), the overall fuel consumption and CO2 emissions during the descent and approach phases will be also minimized.

SPEED PROBING

The speed probing consists of analyzing the effect that an A/C speed change would have on its horizontal projections displayed in MergeStrip (AHPV and FHPV).

The speed probing selector is available in the A/C operation window, which is displayed after clicking its corresponding label in any view (see Figure 13).

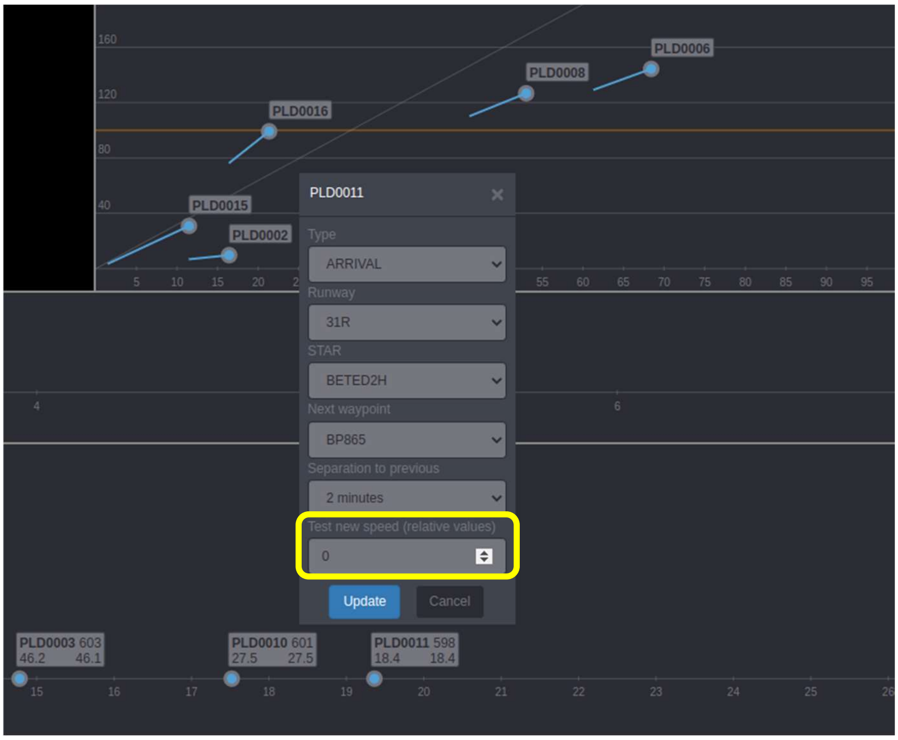

Figure 13. Speed probing selector in the operation window

The up/down arrows located on the right of the speed selector allow the ATCO to apply relative speed changes to the selected A/C. When a new speed change is selected, the effects on the horizontal projections are automatically displayed in the preview (see Figure 14).

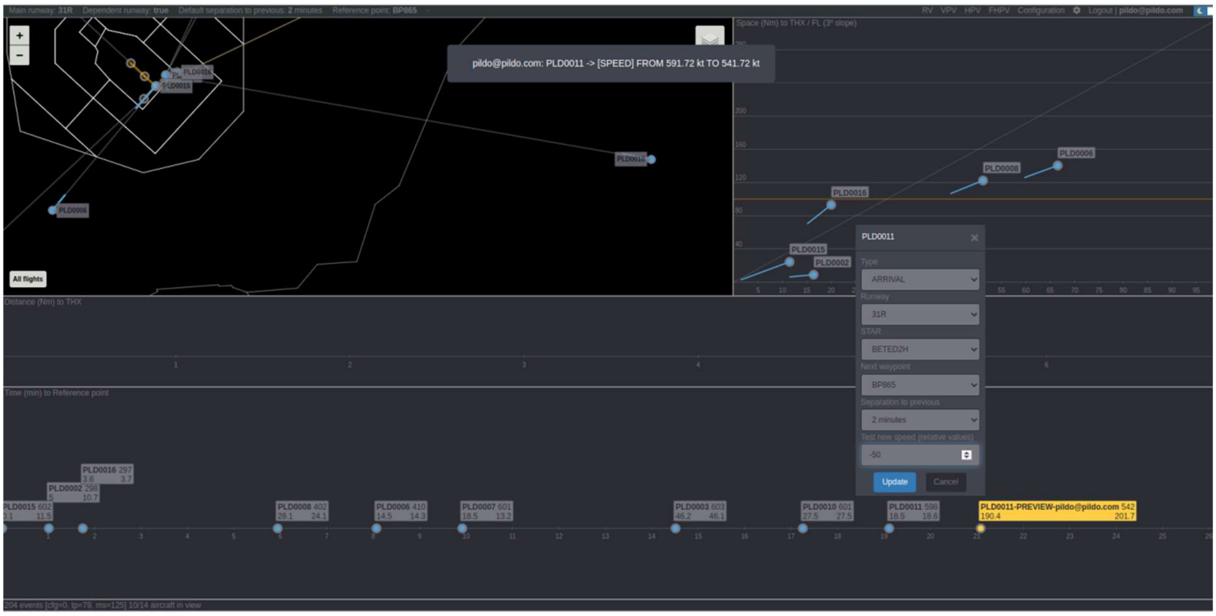

Figure 14. Visualization of speed probing effects in the preview mode (1)

In the example displayed in Figure 14, a relative speed change of -50 kt has been applied to the current A/C speed. As a consequence, the time to the reference point is increased, so the A/C moves backwards in the AHPV strip (see Figure 15).

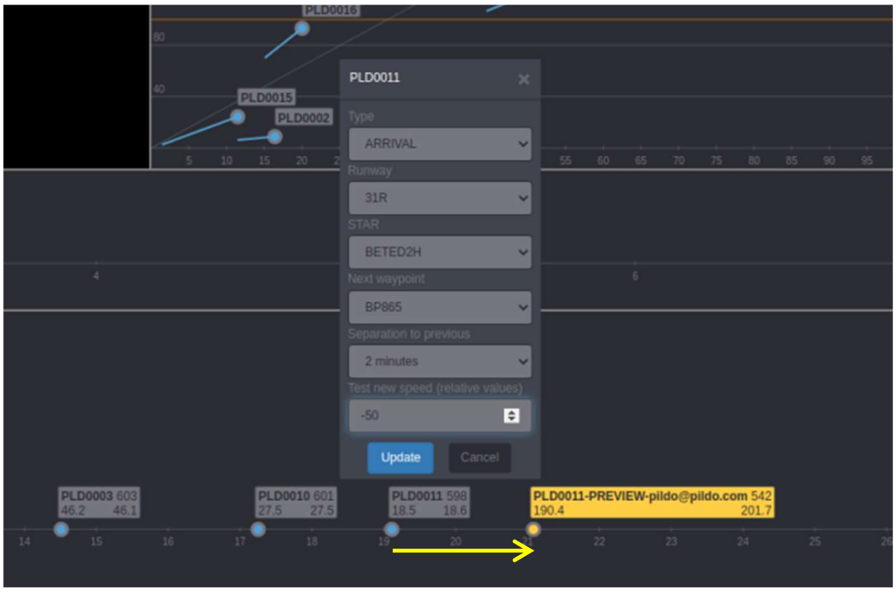

Figure 15. Visualization of speed probing effects in the preview mode (2)

If the ATCO keeps changing the value of the speed selector, the preview will be automatically updated considering the new values.

A change of speed cannot be applied nor discarded in MergeStrip, since the real value of the time to reference point just depends on the current A/C speed (its real value). As a consequence, if the ATCO decides to apply a speed change for a specific A/C, the new speed value must be communicated to the pilots. As the aircraft adapts its speed to that required by the ATCO, the real A/C indicator in the projection view will approach the temporary one created for the preview (see Figure 15).

CHANGE OF NEXT WP

The change of next WP consists of analyzing the effect that a potential change of the WP towards which the A/C is directed would have on its horizontal projections displayed in MergeStrip (AHPV and FHPV).

The next WP selector is available in the A/C operation window, which is displayed after clicking its corresponding label in any view (see Figure 16).

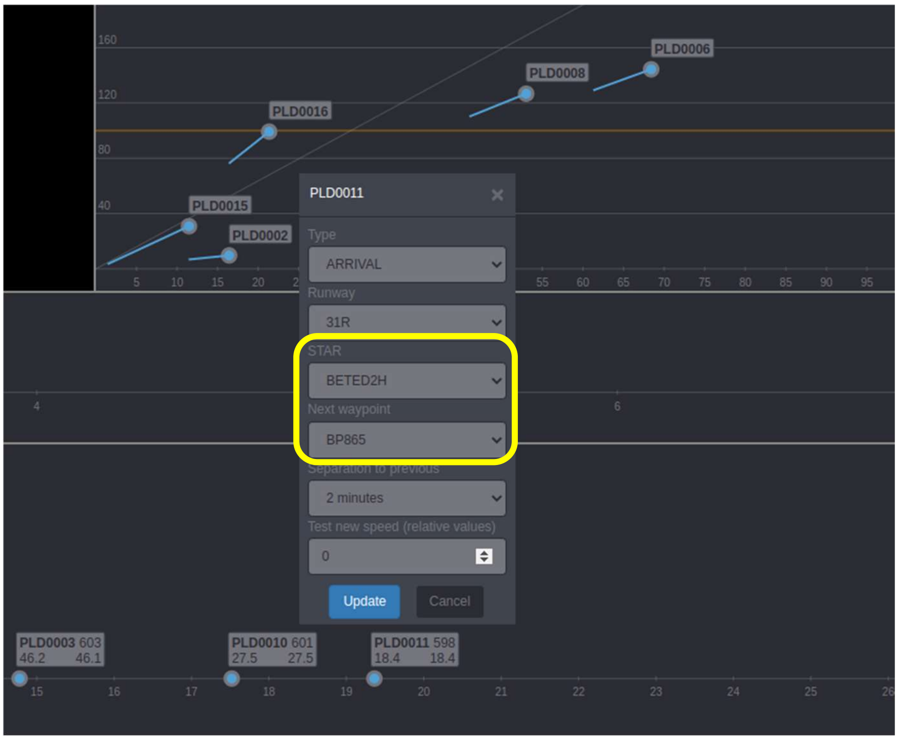

Figure 16. STAR and next WP selectors in the operation window

As specified by the requirements, all WPs are grouped by STARs. If the ATCO wants to set a new next WP included in the same STAR as the current next WP, it must be selected from the "Next waypoint" dropdown list. On the other hand, if the A/C is to be directed to a WP contained within a different STAR, the ATCO must firstly select the STAR in the "STAR" dropdown list. When the STAR is changed, the options contained in the "Next waypoint" dropdown list are updated accordingly.

When a new next WP is selected, the effects on the horizontal projections are automatically displayed in the preview (see Figure 17).

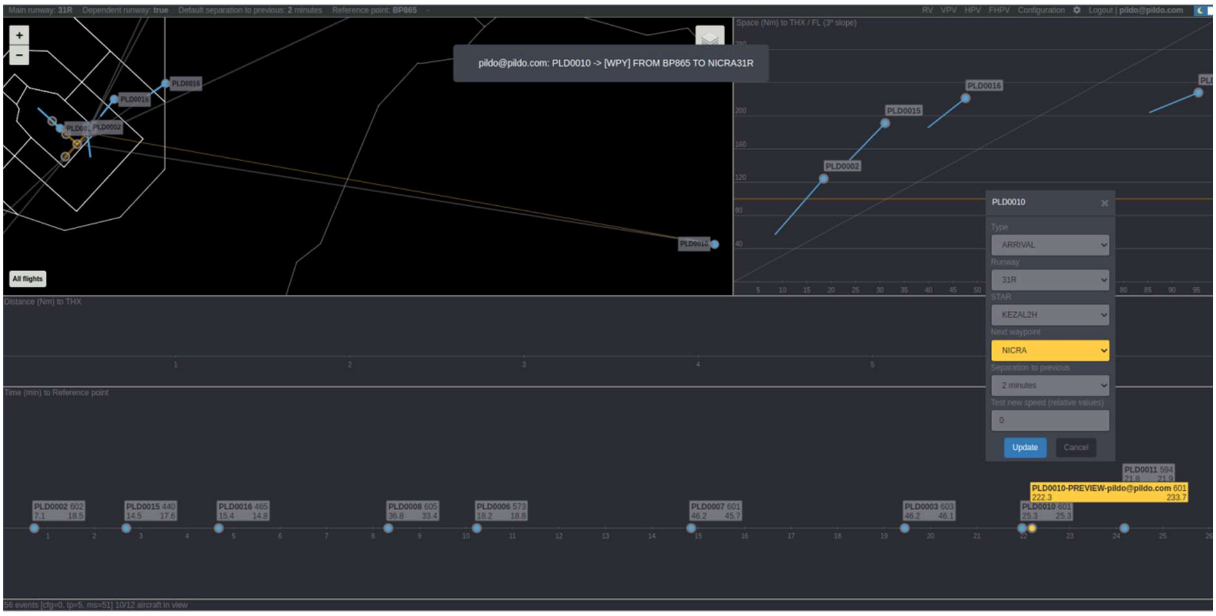

Figure 17. Visualization of next WP changes in the preview mode

A part from the effects on the computed projections, visible in the AHPV, a yellow line joining the current position of the A/C and the new proposed next WP is also displayed in the RV (see Figure 18).

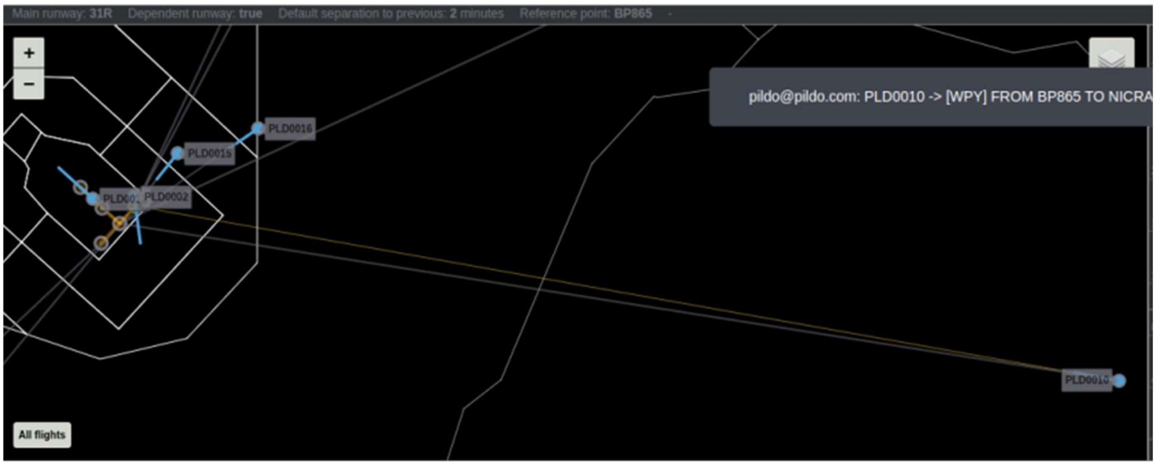

Figure 18. Visualization of next WP change in the RV

The next WP change can be applied or discarded by the ATCO.

- The proposed change can be **applied** by clicking the button "Update" in the A/C operation view. In this case, the proposed change disappears from the preview and the new next WP is taken into account for future projection computations.
- The proposed change can be **discarded** by clicking the button "Cancel" in the A/C operation view. In this case, the proposed change disappears from the preview and the original next WP is taken into account for future projection computations.

MULTIPLE CHANGES

Multiple speed and next WP changes can be displayed in a single preview, as shown in Figure 19.

Figure 19. Multiple changes in the preview mode

All changes included in the preview are listed at the top of MergeStrip's main window. The following pattern is used to describe the changes in view:

USER: **CALLSIGN** -> [**TYPE**] FROM **X** TO **Y**

Where:

- **USER:** user identifier
- **CALLSIGN:** identifier of the affected A/C
- **TYPE:** type of change (WPY / SPEED)
- **X:** old value of WP/speed
- **Y:** new value of WP/speed

The examples from Figure 19 are:

pildo@pildo.com: PLD0010 -> [WPY] FROM BP865 TO NICRA31R

pildo@pildo.com: PLD0007 -> [SPEED] FROM 600.85 kt TO 560.85 kt

ESTIMATED TIME OF ARRIVAL

The current method to calculate the ETA is based on multiplying the A/C current speed by the distance from the A/C current position to the reference point. Even if this method introduces an important error in the estimations, especially at the early stage of the descent (no accelerations are taken into account), it has proven to be quite useful in MergeStrip's environment, in which the users are more interested in relative separations between A/C than in absolute time of arrival values.

The improvement in the calculation of the ETA is based on the use of a machine learning algorithm. This algorithm provides a more accurate estimation of the time of arrival taking a number of parameters as input (e.g. position, speed, speed direction).

In this section, both the ML-based algorithm and the main obtained results are presented.

THE ALGORITHM: RANDOM FOREST REGRESSOR

The new ETA prediction algorithm is based on the Random Forest regression method (supervised learning algorithm that uses ensemble learning). It combines predictions from multiple machine learning algorithms to make a more accurate prediction than a single model.

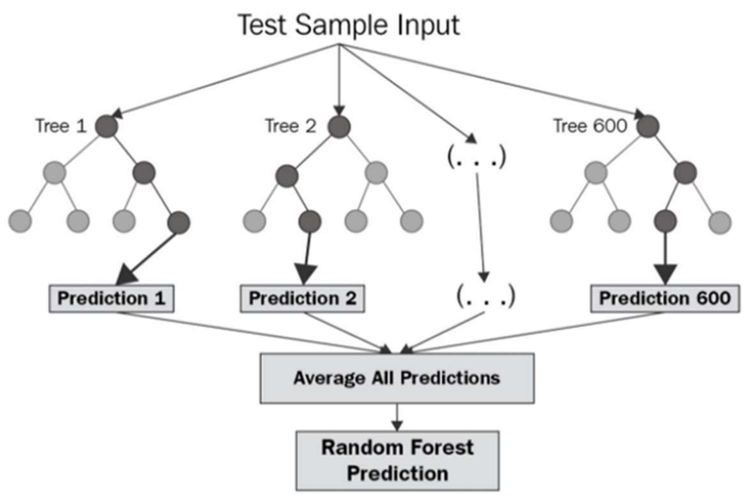

Figure 20. Random Forest prediction tree

The implemented ETA prediction module is based on Python's sklearn module, specifically the RandomForestRegressor function.

During the construction of the model, different adjustments have been performed in order to achieve 2 main objectives:

- Minimize the prediction error
- Simplify the model (use as few independent variables as possible)

DATA PREPROCESSING

All built models were trained and tested by using a single dataset containing information of almost 7000 flights (7.3M of data points). These data was collected by a PildoBox installed at HungaroControl premises.

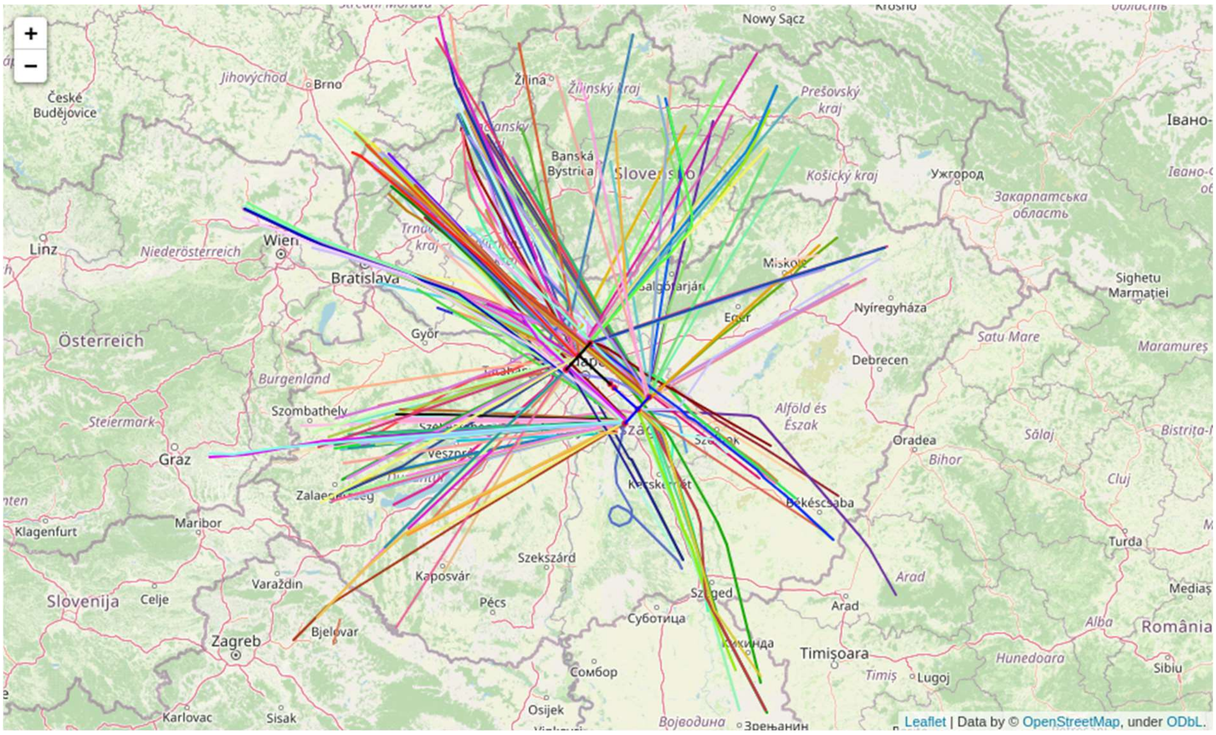

Figure 21. Sample of positions included in the dataset

The most relevant fields included in the original dataset are:

- **ID:** flight identifier, numerical value
- **TIMESTAMP:** time in milliseconds since the UNIX epoch (January 1, 1970 00:00:00 UTC)
- **CALLSIGN:** flight callsign
- **LATITUDE:** latitude value, in degrees
- **LONGITUDE:** longitude value, in degrees
- **ALTITUDE:** altitude value, in feet
- **ACC_DISTANCE:** accumulated distance covered since the first detected position, in nautical miles
- **ACC_ALTITUDE:** accumulated altitude change since the first detected position, in feet
- **DIST_TO_AIRPORT:** distance from the current position to the airport reference point, in nautical miles
- **VELOCITY_EW:** true East-West airspeed, in knots
- **VELOCITY_NS:** true North-South airspeed, in knots
- **VERTICAL_RATE:** vertical speed, in feet per minute
- **WIND_EW:** component of the wind speed in the East-West direction, in knots
- **WIND_NS:** component of the wind speed in the North-South direction, in knots

During the data preprocessing phase, the values of some additional variables were computed and added to the dataset:

- **ANGLE_V:** track angle, in degrees
- **DIST_TBAR:** distance from the current position to the T-BAR entry point, in nautical miles
- **HOR_EFFICIENCY:** horizontal efficiency, defined as the ratio between the distance to go (DTG) and the distance to the T-BAR entry point (DIST_TBAR)
- **V_PROJ_TBAR:** component of the speed vector pointing to the T-BAR entry point

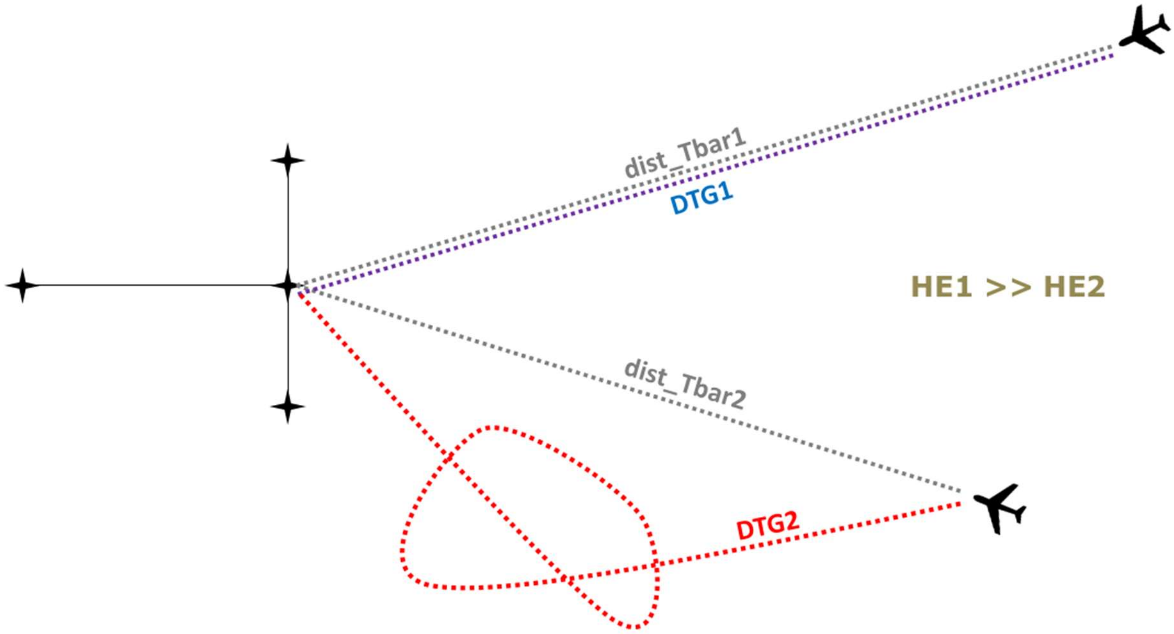

Figure 22. Graphical representation of the horizontal efficiency concept

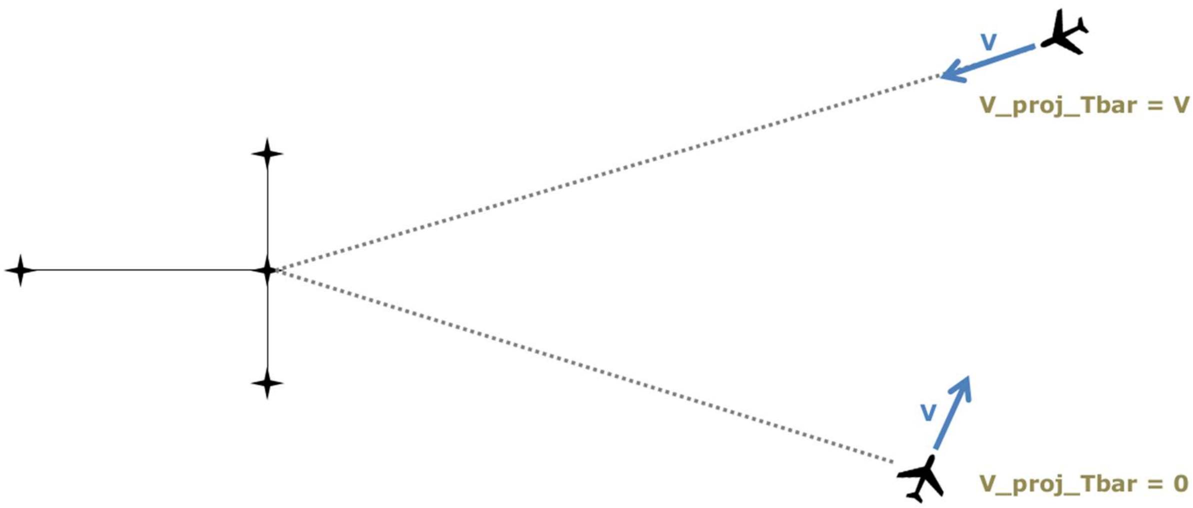

Figure 23. Graphical representation of the T-BAR speed projection concept

Finally, the value **TARGET_SEC** was also added to each data sample. This value corresponds to the real value of the ETA, indicated as the number of seconds that the A/C needs to travel from the current position to the reference point. This variable is the one used as the true reference to compute the ETA prediction error.

MODEL BUILDING

Different models were built and tested during this phase. From simpler to more complex, the proposed models had the following characteristics (independent variables):

- **Base**
  - LATITUDE
  - LONGITUDE
  - VELOCITY
  - ANGLE_V
  - DIST_TBAR
- **Extended**
  - **Base** characteristics
  - ALTITUDE
  - V_PROJ_TBAR
- **Wind**
  - **Extended** characteristics
  - WIND_EW
  - WIND_NS

In addition, for each one of these 3 models, two versions were tested: one using all available data points (no horizontal efficiency filter) and another using only filtered points (HE ≥ 0.8). The objective of applying an horizontal efficiency filter to the input data was to remove non-standard descending trajectories which might had a negative impact on the final prediction error.

RESULTS

The obtained results are summarized in the following table.

Model type	HE ≥ 0.8 filter	Mean Error [s] (Train)	Mean Error [s] (Test)
Speed (current)	NO	**105.36**	**105.56**
Speed (current)	YES	**101.43**	**104.28**
Base	NO	20.07	24.97
Base	YES	13.70	18.74
Extended	NO	**16.70**	**23.86**
Extended	YES	**11.91**	**17.46**
Wind	NO	15.96	24.58
Wind	YES	11.44	17.64

Table 1. Mean prediction error of different ETA models

The column "Train" corresponds to the mean prediction error obtained by using the same data used to train the model as input. On the other hand, the column "Test" corresponds to the mean prediction error obtained by using a different set of data as input.

The following figures present the main results in terms of prediction error.

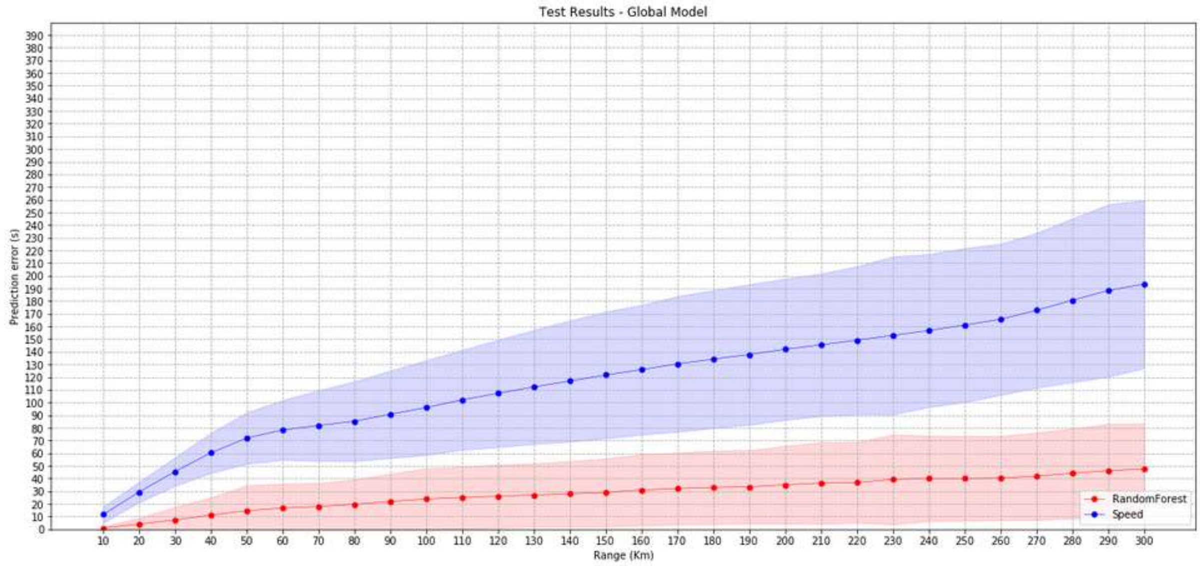

Figure 24. Prediction error – Base model without HE filter

Figure 25. Prediction error – Base model with HE filter

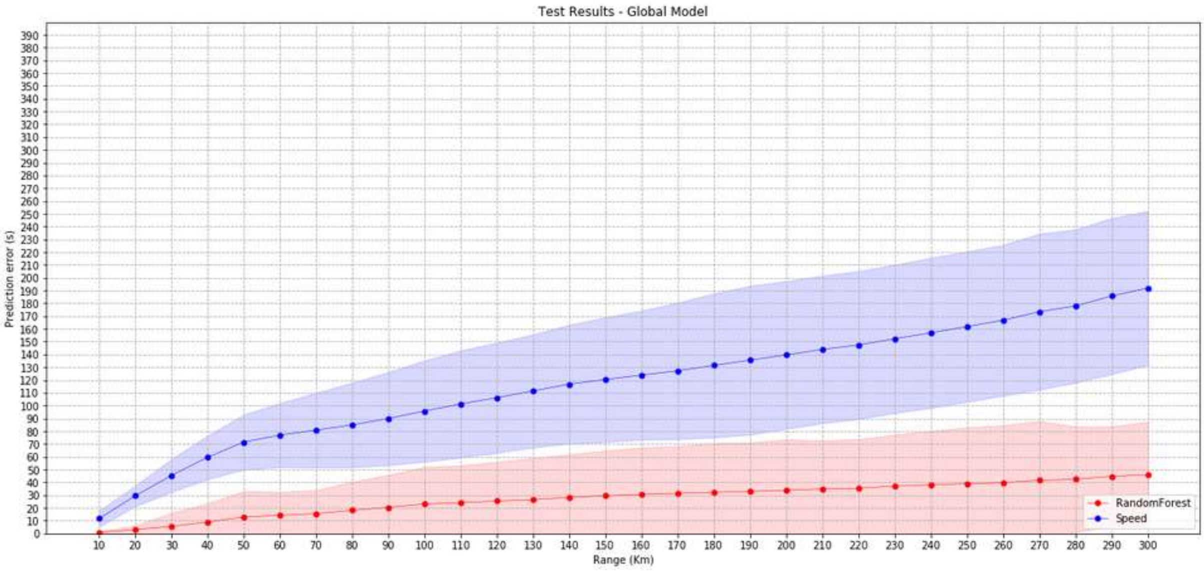

Figure 26. Prediction error – Extended model without HE filter

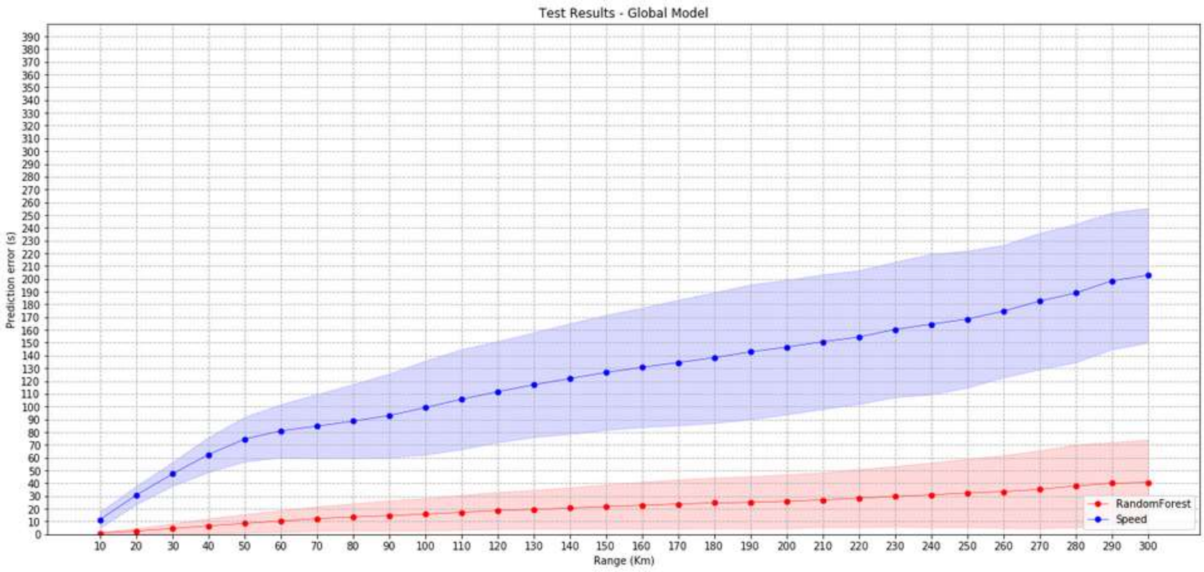

Figure 27. Prediction error – Extended model with HE filter

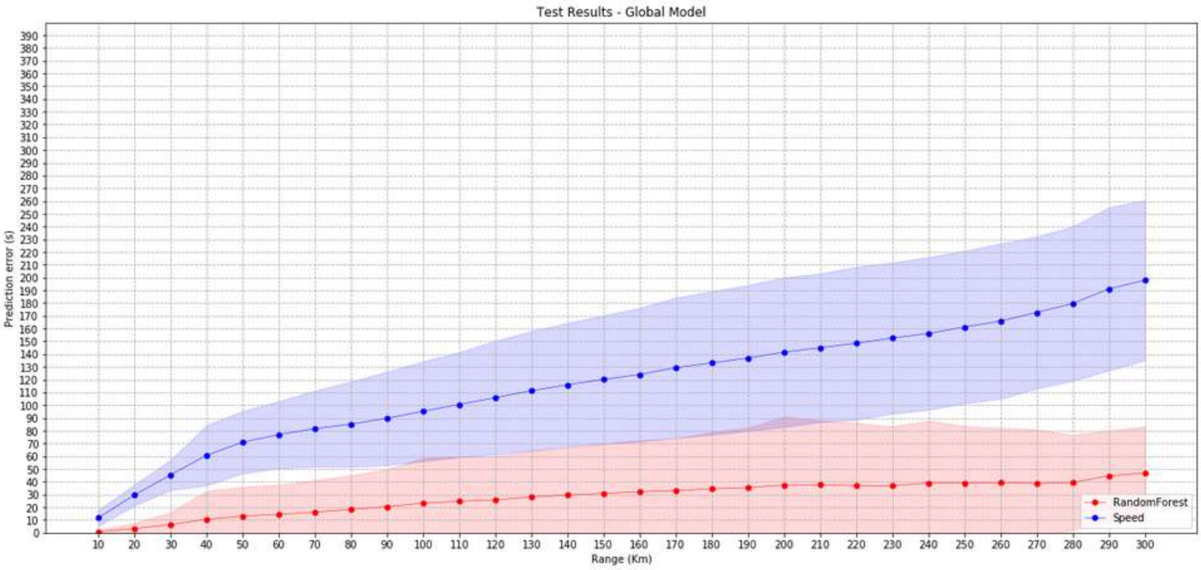

Figure 28. Prediction error – Wind model without HE filter

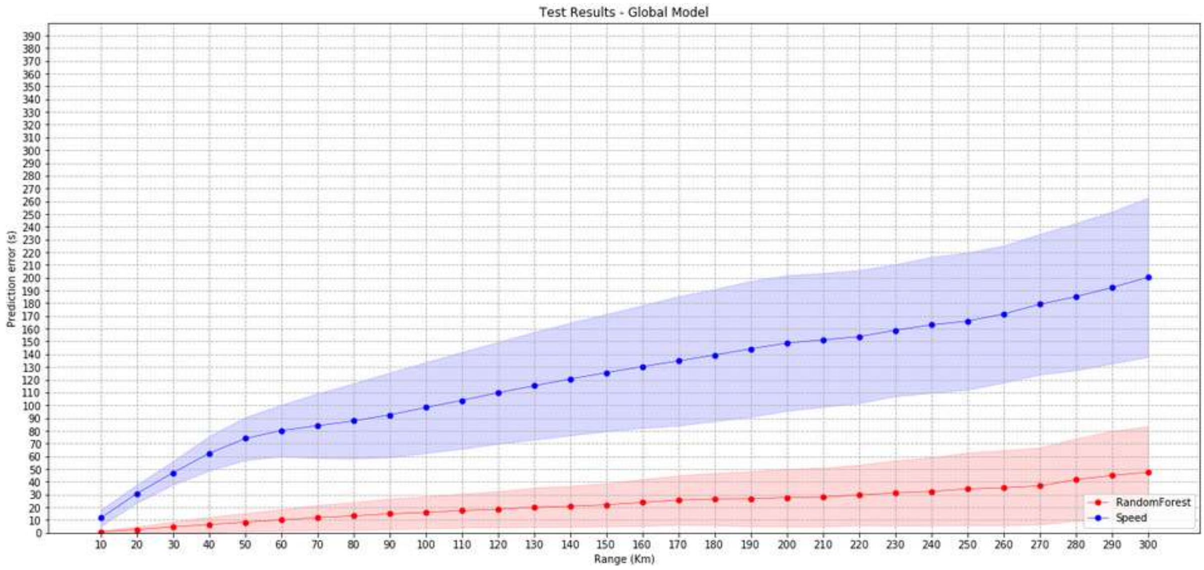

Figure 29. Prediction error – Wind model with HE filter

After analyzing the obtained results, the **Extended model with HE filter** was chosen as the candidate for the final validation tests (integration to MergeStrip). As it can be seen in Table 1, adding wind data to the model did not bring any significant benefit in terms of ETA prediction error.

In the following figures, a comparison between the prediction error obtained by using the new ML-based ETA prediction model and the one obtained with the old ETA prediction method (based on the current airspeed) is presented in a per-flight basis:

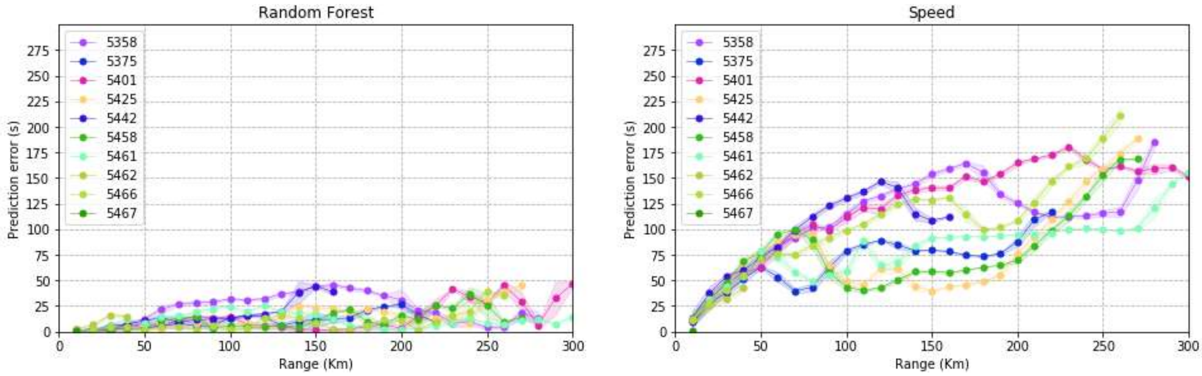

Figure 30. ETA prediction error: Random Forest vs current airspeed (1)

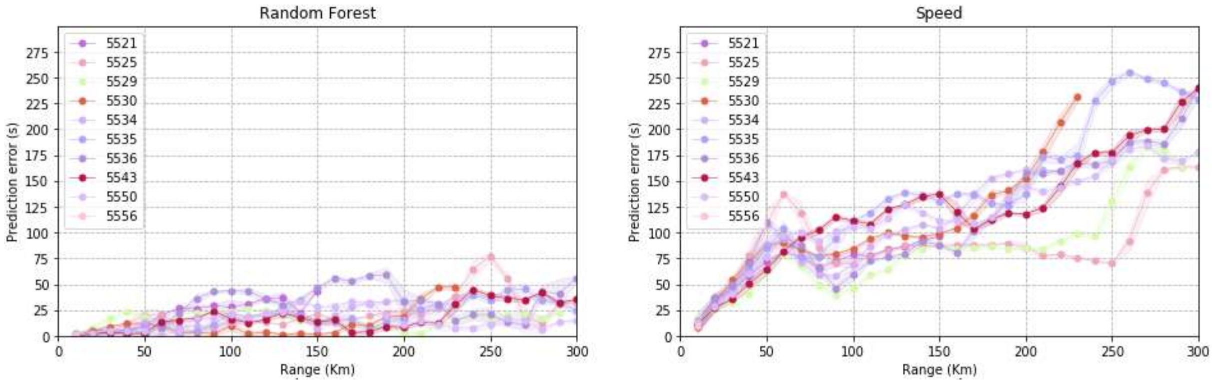

Figure 31. ETA prediction error: Random Forest vs current airspeed (2)

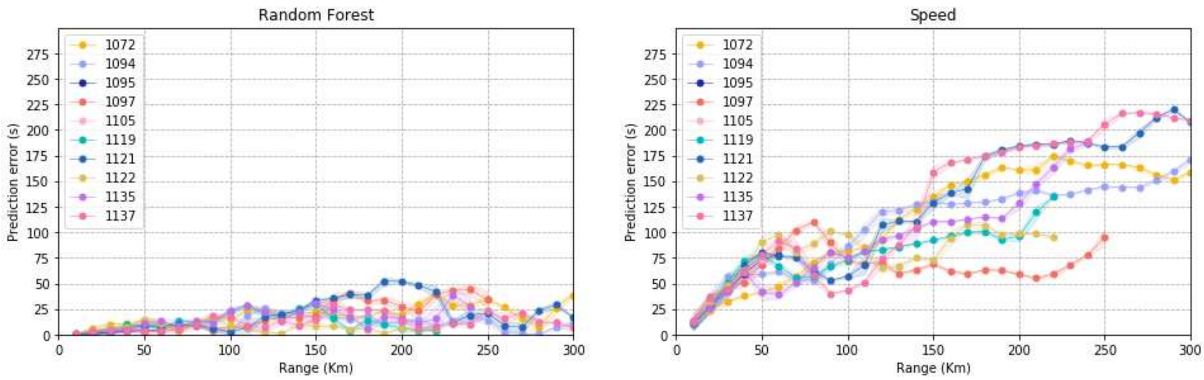

Figure 32. ETA prediction error: Random Forest vs current airspeed (3)

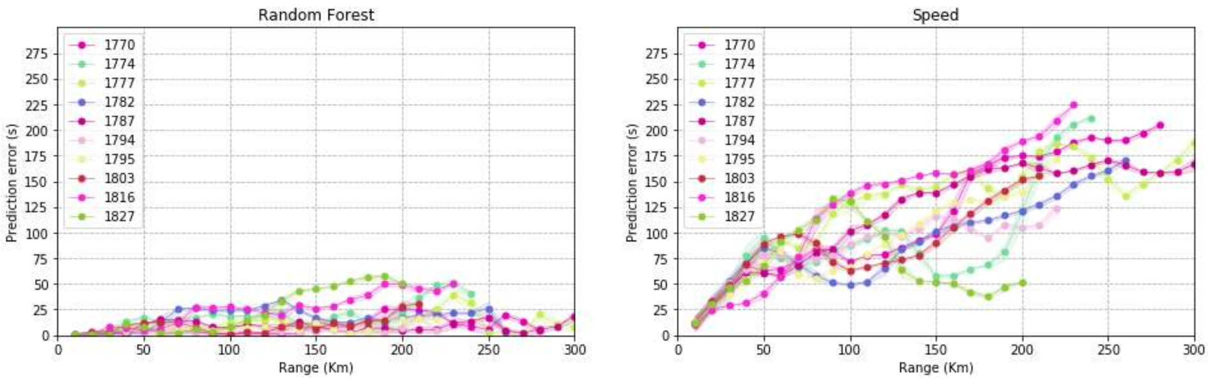

Figure 33. ETA prediction error: Random Forest vs current airspeed (4)

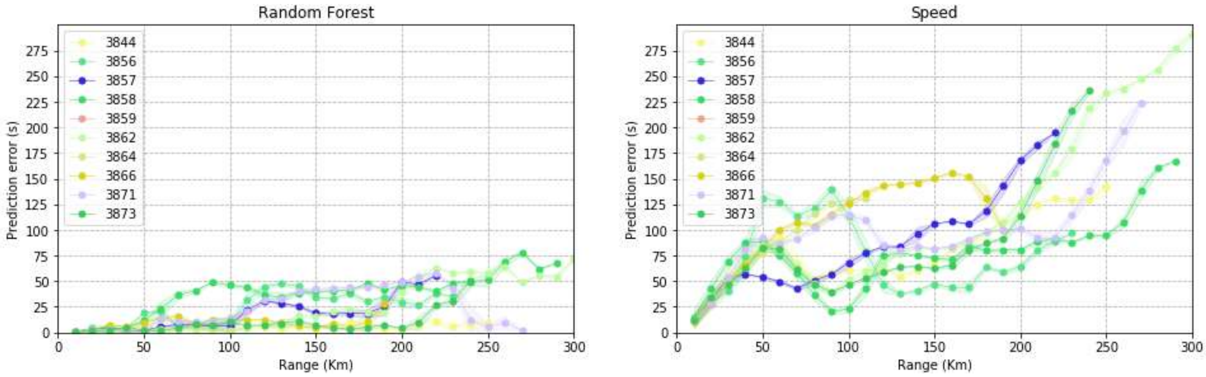

Figure 34. ETA prediction error: Random Forest vs current airspeed (5)

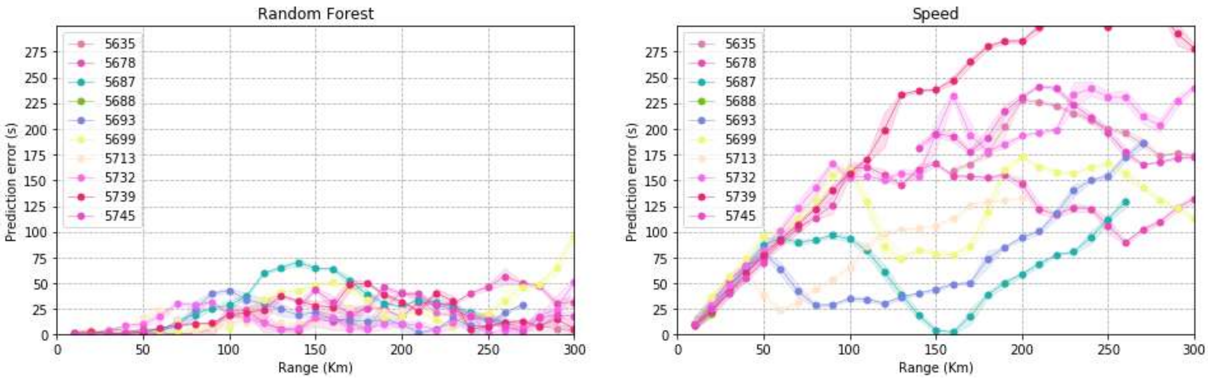

Figure 35. ETA prediction error: Random Forest vs current airspeed (6)

CONCLUSIONS

The following conclusions were extracted from the process:

- The mean error is ~100 seconds less than the error obtained with the current ETA computation approach (method based in the current airspeed value)
- The less the distance to the T-BAR entry point, the less the ETA prediction error (the same happens with the method based in the current airspeed)
- Large non-efficiencies (e.g. holding patterns) were discarded from the input data used to build the model. As a consequence, their time deviations will not be taken into account when performing ETA predictions at early points of the descending trajectories.

RECOMMENDATION ENGINE

The recommendation engine is a feature that runs in the background during the execution of MergeStrip. The engine does not disturb any other functionality. The recommender is divided into two enhancements. The first one only works in case of conflicts, its goal is to resolve existing conflicts. The second one only works in case of no conflicts, its goal is to find a new optimum route for an operation to decrease the DTG or time to the RWY.

CONFLICT RESOLUTION

For conflict resolution the engine tries all combinations between all WPs of the current STAR, and speed increments/decrements. The engine compares all possible combinations and selects the best one. It only considers combinations affecting aircraft involved in the conflict. This method is executed every certain time (selected by the user). If the engine finds a solution it highlights the labels of the affected operations in green (see Figure 36).

Figure 36. Operations with conflicts that can be resolved by the engine

The calculated combination of new WP and new speed is displayed in green under each field.

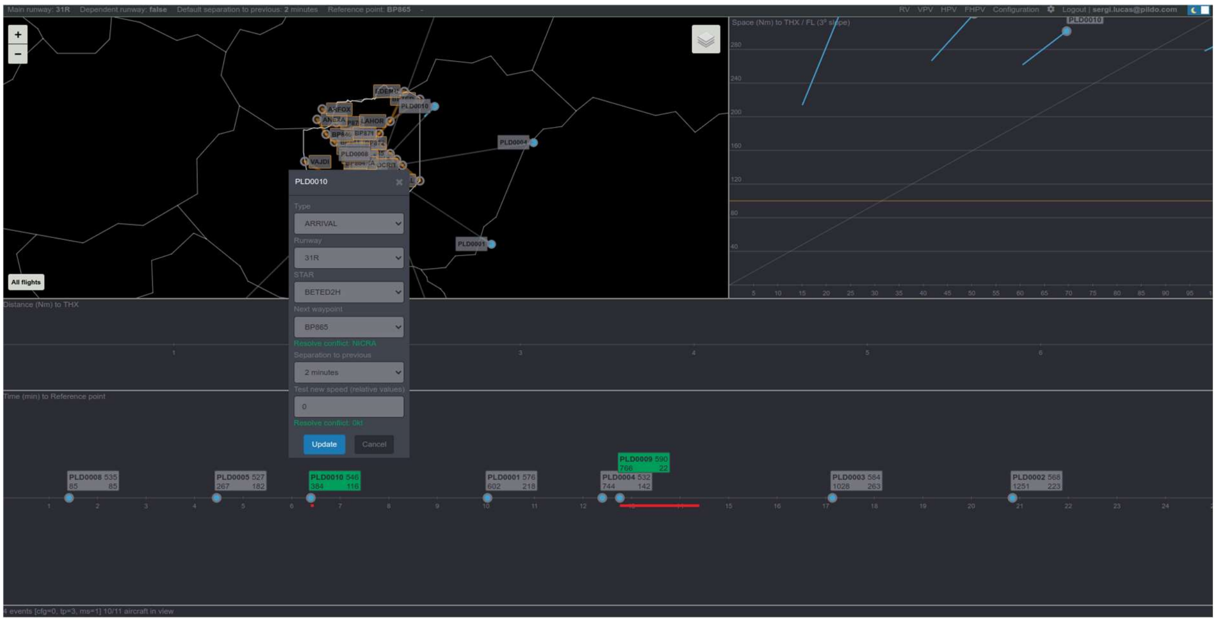

Figure 37. Computed combination displayed in the edit operation display

To accept the proposed changes, the user must click the button "Update". Next WP will be automatically updated. The new speed value shall be communicated to the A/C.

Figure 38. Conflict solved after implementing of changes proposed by engine

OPTIMIZER

The aim of the second branch of the recommender is to find more optimum routes for A/C which are not involved in conflicts. To find the optimum route for a specific A/C, the engine checks all possible next WPs (taking into account only those assigned to the current STAR) and compares the results to select the best option. This method is executed periodically (frequency selected by the user) and the results are presented to the user in the same way as the previous functionality. If the engine finds a more optimum solution, the label of the operation is highlighted green as shown in Figure 39.

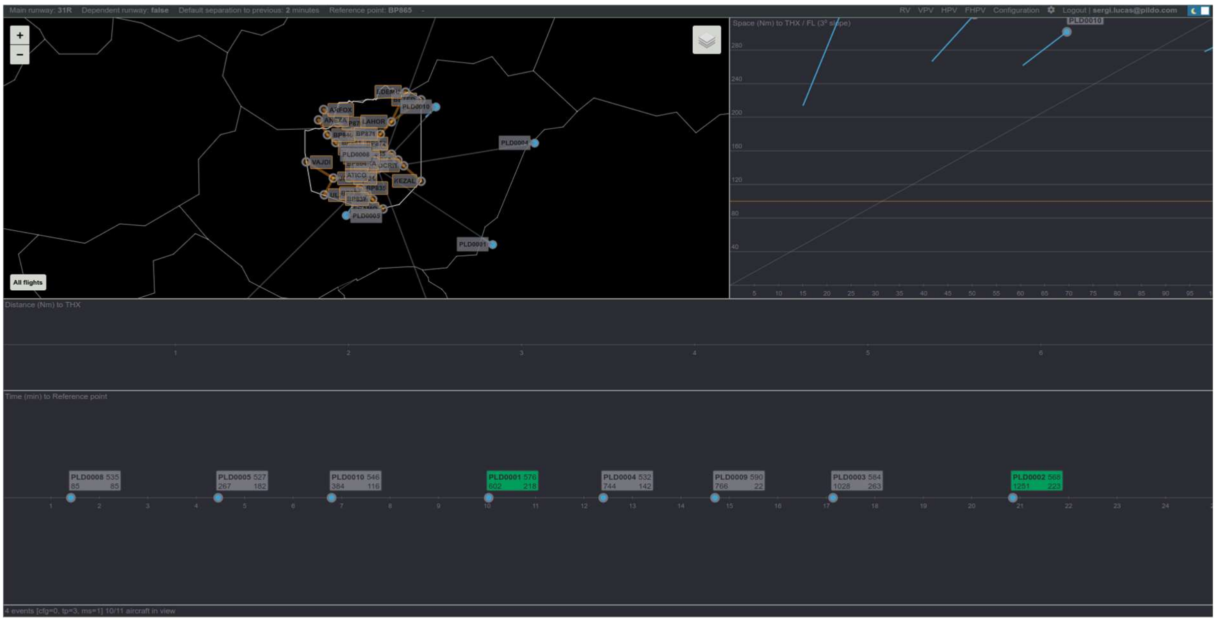

Figure 39. Operations in green are those where the engine found a solution

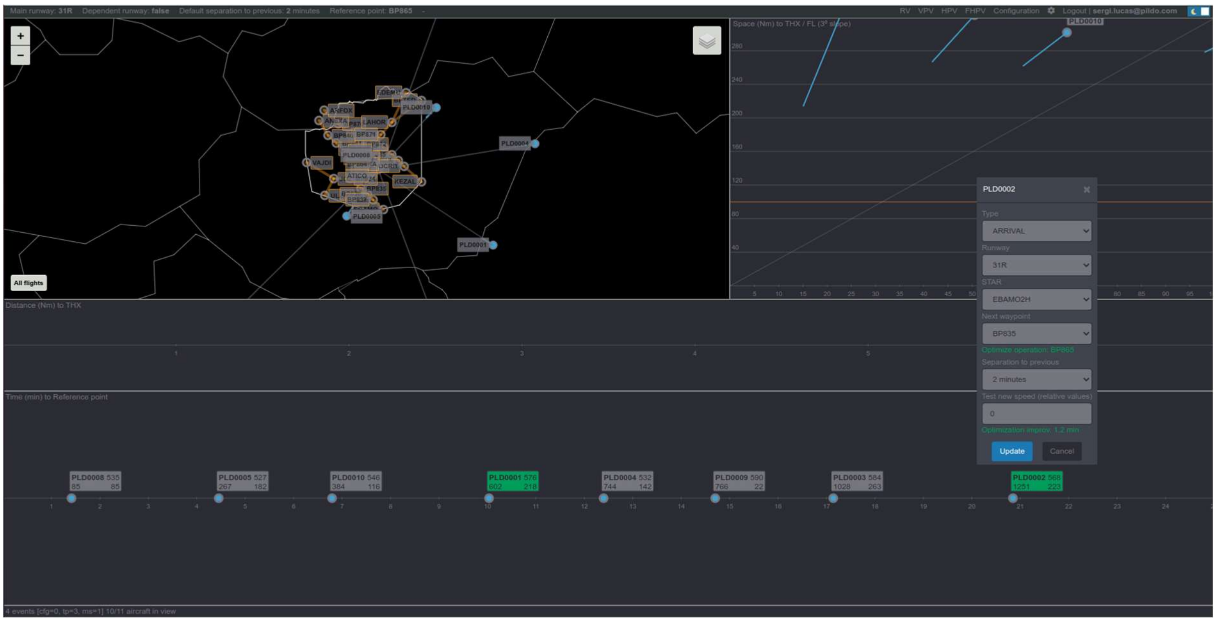

Figure 40. Edit operation display with the recommended Waypoint in green

As in the previous case, to accept the proposed changes the user must click the button "Update". Next WP will be automatically updated. The new speed value shall be communicated to the A/C.

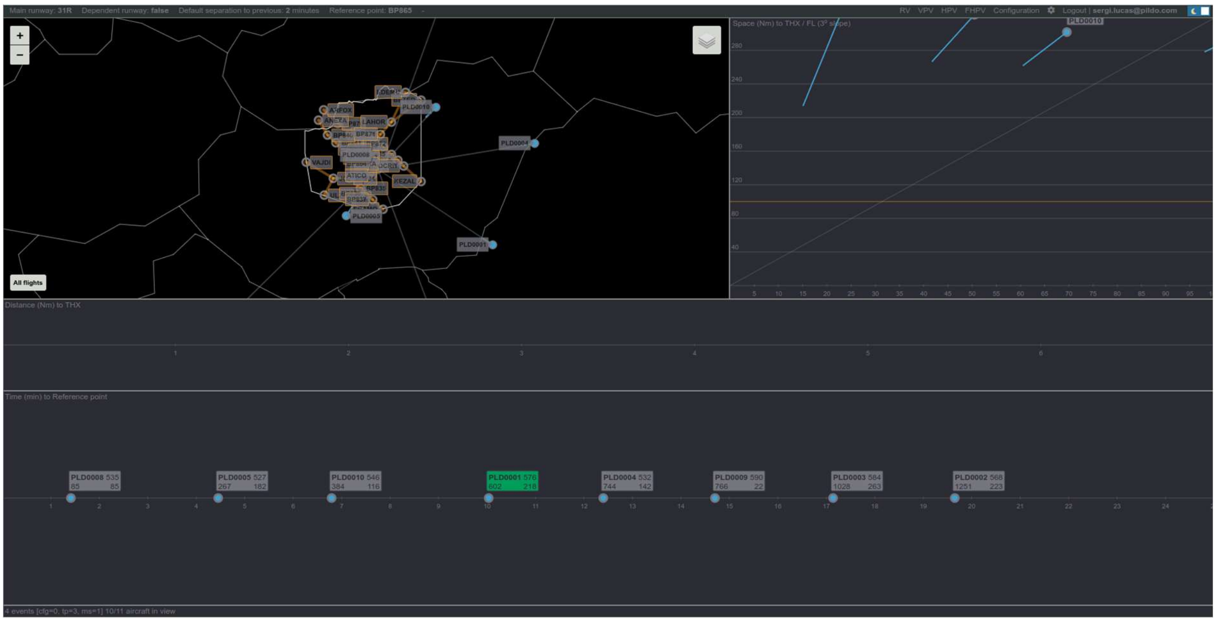

Figure 41. Operation decrease time after applying change proposed by engine

OTHER

CONFLICT LINES

A conflict is defined as a situation involving two or more A/C in which the minimum distance/time between them at the reference (or merging) point is not respected. The conflict lines are used in the AHPV to help ATCOs to detect potential conflicts at an early stage.

Figure 42 shows a scenario with two conflicts.

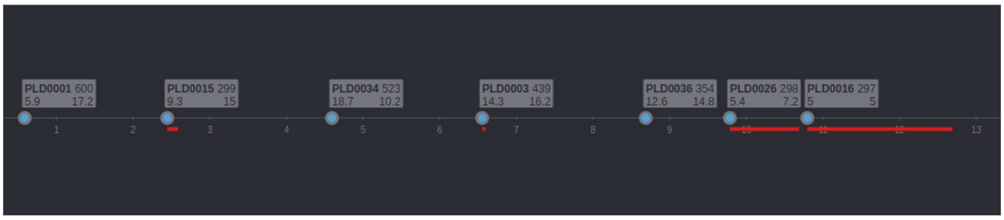

Figure 42. Conflict lines in the AHPV

The first conflict involves PLD0001 and PLD0015. This conflict could be solved by applying a slight delay to PLD0015, which can be achieved either by reducing its speed or by directing the aircraft to another WP to increase its DTG. Another possibility would be to increase speed for PLD0001.

The second conflict involves three A/C: PLD0036, PLD0026 and PLD0016. Multiple combinations of speed and next WP changes could be analyzed by means of the what-if function to solve the conflict.

As shown in Figure 42, the length of the red conflict lines is directly proportional to the delay that must be applied in order to solve it.

The visibility of the conflict lines can be activated or deactivated from the Horizontal Projection View settings window (see Figure 43).

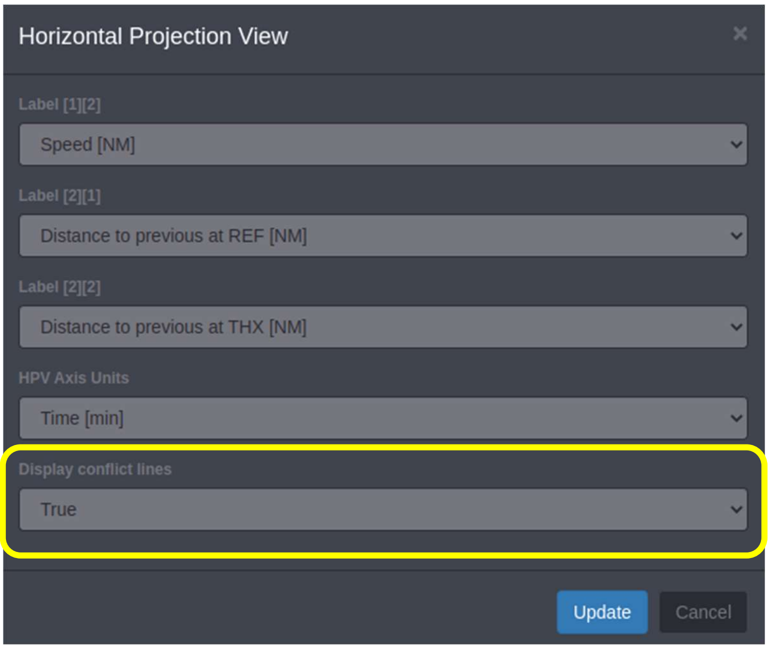

Figure 43. Show/hide conflict lines from the AHPV

TMA/FIR OVERLAY

As requested by the ATCOs, by default the RV's background is black and two information layers are displayed:

- Terminal Maneuvering Area (TMA)
- Flight Information Regions (FIR)

As shown in the following figures, the user can decide to show/hide both layers from the map options menu, located at the top-right corner of the RV.

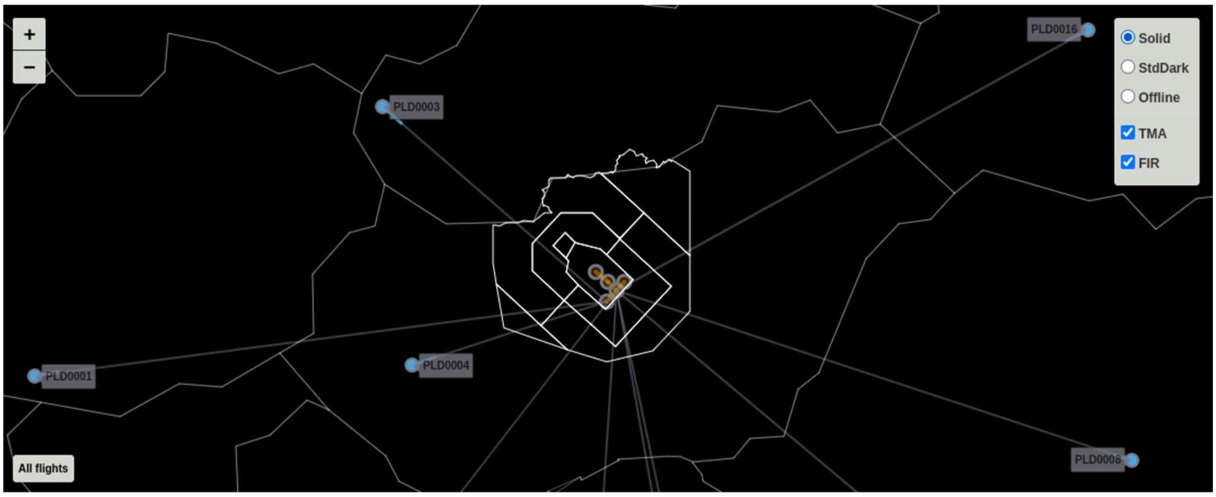

Figure 44. RV - TMA and FIR visible

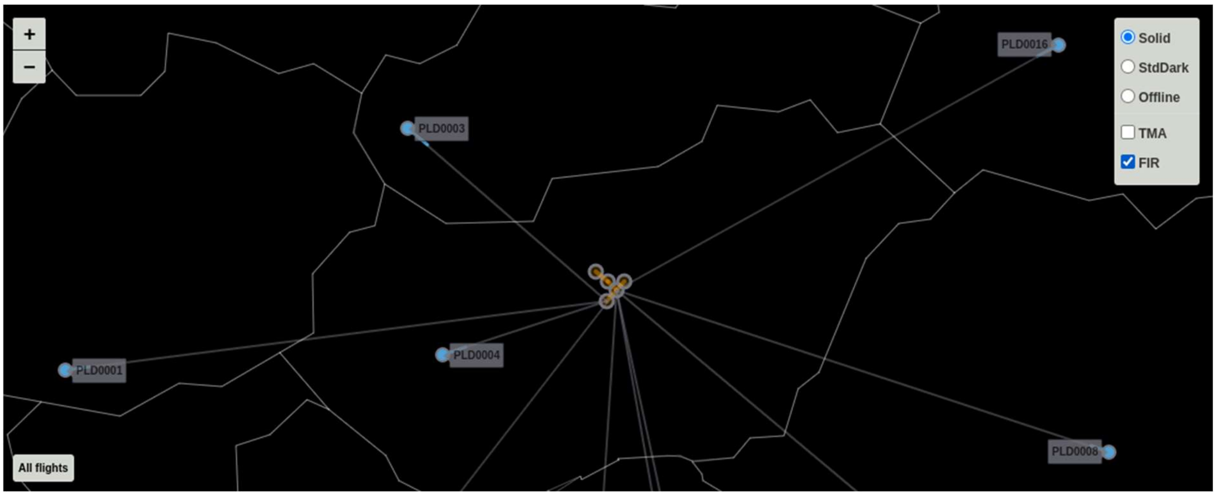

Figure 45. RV – TMA hidden and FIR visible

RUNWAY CHANGE PROCEDURE

When the user changes the default RWY, the new selected RWY shall be assigned to all A/C (those already in view and those whose first position data is received after the change is applied). If the original RWY of some of the existing flights must be kept, the following procedure must be applied:

1. Right click on the labels of the A/C that should remain on their original RWY
2. Apply the RWY change through the settings option of MS

The border color of the selected labels is changed in all views to distinguish them from the non-selected ones (see Figure 46).

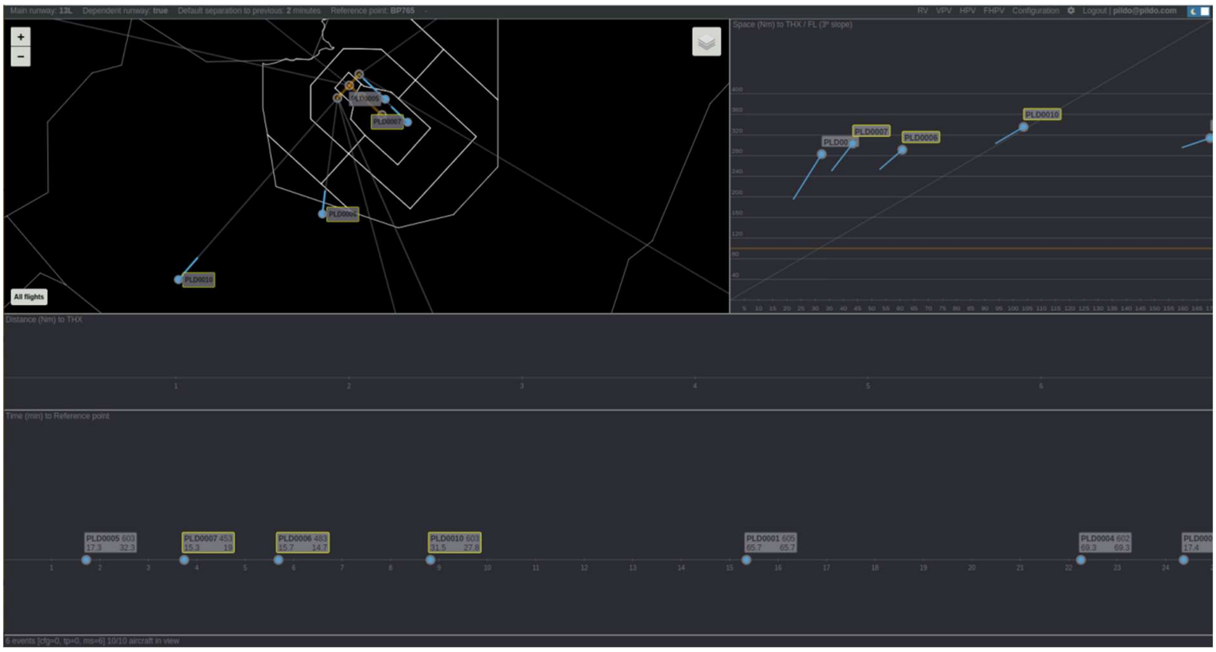

Figure 46. Runway change procedure – Excluded A/C selection

In the previous example, the RWY change will be applied to all A/C in view except PLD0006, PLD0007 and PLD0010.

Once the excluded A/C are selected, the RWY can be changed from the main configuration window, available by clicking the "Configuration" option in the top-right menu.

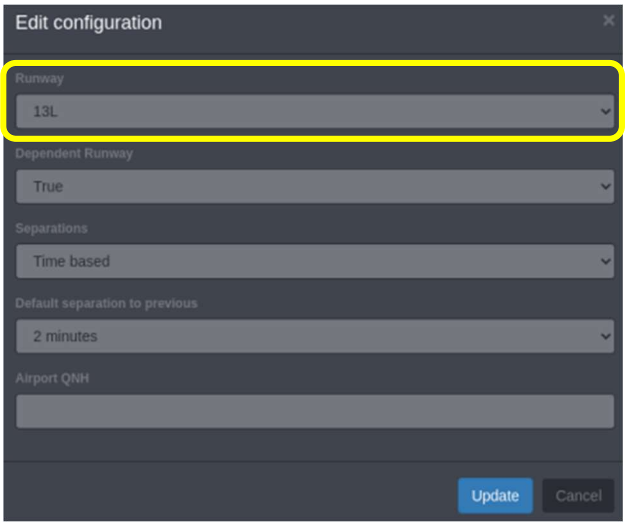

Figure 47. MS main configuration window

4. SUMMARY

To save kerosene and the associated reduction of climate-impacting emissions, there is no one big solution that will transform air traffic into a completely environmentally friendly and sustainable transport medium in one fell swoop. Instead, many small steps are needed that, taken together, will reduce greenhouse gas emissions from aircraft. This concept presents a wide variety of solutions, each of which can only provide a small component, but which, taken together, will make an important and tangible contribution to making this transport segment more environmentally friendly. To this end, solutions were presented, some of which can be implemented immediately, but some of which require further research and development until they can be seamlessly and safely integrated into air traffic and its control.

The solutions relate in particular to the areas of airspace organization, its design and efficient use, and to support systems for air traffic controllers and pilots that will help them to optimally manage traffic both in the air and on the ground without increasing ATCOs' workload. The MergeStrip System allows ATCOs to continuously inform flight crews with track miles information, enabling them to fly fuel- and noise-optimal approach procedures. These procedures make it possible to reduce both noise pollution and CO_2 emissions, especially in the vicinity of airports, which will benefit the residents of these traffic hubs in particular. Another approach procedure that enables smooth and thus efficient traffic flow, especially at highly congested airports, is the point merge procedure. It has already proven at various airports that by efficiently shaping the approaching traffic, holding patterns and delay procedures can be reduced through equalizing traffic peaks that are otherwise responsible for additional fuel consumption and thus increased CO_2 emissions.

Metroplex airport constellations present another challenge for efficient air traffic management. Metroplex refers to areas where several airports are located so close together that their approach and departure areas overlap. These overlaps impose continuous constraints on the management of traffic, since the arrivals and departures of each airport must be coordinated not only with each other but also with the corresponding movements of neighboring airports. These arrangements cost time and it is not always possible for controllers and pilots to find optimal sequences and distributions to guide traffic. The associated delays inevitably lead to additional consumption of kerosene and increased CO_2 emissions.

At these points, the use of planning support systems for air traffic controllers lends itself to helping not only air traffic control, but also flight crews and airlines. Systems such as AMAN, DMAN and SMAN can not only help controllers with general coordination, but also calculate solutions to guide traffic flows on approach, departure and on the ground in such a way as to minimize delays, which always mean increased fuel consumption and thus CO_2 emissions. Some of these systems with general support functions are already available on the market. Therefore, the GreAT project focuses on the coordinated cooperation of these planning systems. It has been shown that local optimizations for one aviation sector are more often associated with disadvantages for other sectors. However, to find global optima in flight control, these systems must coordinate with each other. This concept shows that this is possible in some places in a simple master-slave procedure, but for optimal traffic flows, procedures from the field of AI should also be applied.

The GreAT project shows that there are solutions for the interaction of airspace design, procedures for pilots and air traffic controllers, and the use of planning systems specially and individually tailored to airports and their surroundings, which enable near-optimal guidance and control of air traffic. In this way, we will be able to reduce the environmental impact to an absolutely necessary minimum already in the near future.

5. REFERENCES

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