E.02.03-STREAM-Concept of Operation

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Abstract

The main objective of the STREAM project is to investigate innovative algorithms, principles and tools to be applied prior to flight execution when user preferred trajectories are under the form of Shared Business Trajectories (according to SESAR ConOps) to early detect and resolve potential conflicts. By applying early de-confliction measures during the SBT negotiation phase, traffic can be successively delivered to ATCOs at a tactical phase already partially de-conflicted, thus reducing the numbers of tactical interventions. This document provides the concept of operations for the STREAM solution, detailing who are the involved actors, what information exchanges are necessary, what are the sequential phases of the process and what is the expected outcome. Also the current context and background in terms of operational procedures and in terms of innovative concepts proposed by recent projects are treated, to allow comparison with the STREAM solution and highlight the main differences.

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TABLE OF CONTENTS

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1 Introduction

Air Traffic Management is a complex process involving many actors with different priorities and objectives and historically dealing with uncertainty. To accommodate unforeseen events while guaranteeing always maximum safety of operations, two main levels of traffic control are applied: the predictive level and the reactive level [1]. The predictive level is set to optimize the traffic management regarding air traffic control system capacities. The main actor in Europe is EUROCONTROL CFMU, the current ATFM authority who will act as Network Manager in the future ATM system, that currently both organizes flights and adjust adequate means of the control system. The mechanisms put in place at a strategic level are aimed at reducing traffic complexity in order to facilitate the traffic control. The reactive part is located in the sector unit at controller level. It is mostly related to the mechanism used to manage traffic complexity induced by planning imprecision.

The major limitation of current ATM system is the loss of effectiveness due to the limited or even null relationship between these two levels. ATFM measures in fact are taken on the base of poor information derived from filed flight plans and augmented with trajectory predictor tools which do not have the necessary information on aircraft performances and Airline priorities to provide precise estimations. This fact, coupled with the lack of formal commitment among all parties to conduct the flight according to the plan, leads to massive reactive actions at tactical level by ATCOs to respond to unforeseen events and to solve conflicts.

One of the fundamental pillars of SESAR is the concept of Business Trajectory, i.e. a 4D trajectory which naturally provides the mean to overcome these limitations, since it represents a formal commitment between Airline, ANSP and Airports to conduct/facilitate the flight according to an agreed and time-based plan. According to SESAR the Reference Business Trajectory (RBT) which the Airspace users agrees to fly and the ANSP and Airport agrees to facilitate, will evolve out of a layered collaborative planning process, going through a long phase of negotiation and refinement. During this phase, running from several months up to few minutes before actual push-back, the Business Trajectory will exist in form of Shared Business Trajectory (SBT).

The main objective of the STREAM project is to investigate innovative strategic trajectory de-confliction algorithms to be applied prior to flight execution, based on the enriched and distributed information potentially available through SBTs. By applying early de-confliction measures during the SBT negotiation phase, traffic can be delivered to ATCOs at a tactical phase already partially de-conflicted thus reducing the numbers of tactical interventions and hence of deviations from the agreed RBT, which is considered always the optimal options for the Aircraft operator given all known constraints. Since these de-confliction actions must be taken for large numbers of flights planned on wide regions of airspace to ensure their effectiveness, new algorithms for conflict detection and resolution that run in linear time with respect to the number of trajectories must be developed. Also since different conflict resolution strategies inevitably imply different impacts on individual users, appropriate metrics for fairness, equity, robustness and efficiency will need to be defined to properly analyze these algorithms.

1.1 Purpose of the document

This document is intended to expose the Concept of Operations behind STREAM, encompassing the description of the working methods and the underlying assumptions allowing the application of the algorithms and tools to operations. This is done as a first exercise to explain to the reader the ideas behind the project development and to establish a common and agreed baseline for project partners to synchronize their work. All the concepts and ideas exposed need to be further assessed and validated before becoming a valid reference for other projects and initiatives.

1.2 Scope of the document

This document focuses on the operational aspects linked with the potential application of strategic de-confliction to European traffic. It focuses hence on the sequential phases of application of the concept, on the actors involved, their responsibilities and interactions etc. Some boundary conditions, technical assumptions and principles behind the algorithms are detailed as well as the logical architecture of the “STREAM solution”. All these technical aspects are specified whenever they imply a direct consequence on the related operational procedures.

2 Background

The Literature review allows to establish the state-of-the-art in the development of methodologies and algorithms related with the STREAM solutions. For a complete analysis the interested reader is referred to the STREAM Milestone 1.1 [2]. In the following section just an overview of the most directly related works is provided.Also in order to fully understand the innovative aspects of the STREAM solution, a brief description of the main strategies and tools currently adopted for conflict detection and resolution in ATM is given. Finally some related concepts investigated by parallel or recent European projects need to be analyzed to capitalize on effort and avoid “reinventing the wheel”.

2.1 Literature review

The current management of air traffic is structured according to different layers of traffic organization and de-confliction, according to the phase of flight [1]. From the strategic predictive measures enforced by the Central Flow Management Unit (CFMU) the aircraft management evolves to the tactical and mainly reactive separation function, under the responsibility of Air Traffic Controllers. Several algorithms and tools have been proposed in literature to support controllers in deciding upon the best strategies and actions to solve conflicts (see e.g. [3,4, 5]). Classical optimization models (e.g. [6,7]) as well as innovative meta heuristics [3] have been investigated for solving CD/CR problems in real-time; however only few of them have been successfully integrated into operational tools, due to the complexity and safety criticality of these functions. The STREAM approach instead is to strategically move CD/CR functions to the pre-departure phase, in order to deliver traffic to the controllers already partially de-conflicted. This concept is enabled by the Shared Business Trajectory (SBT) element proposed by the SESAR, i.e. the 4D trajectory that is shared by the Airspace Users (AUs) for planning and negotiation purposes [8]. The SBT evolves out of a collaborative layered planning process among the involved stakeholders and its ultimate instantiation corresponds with the Reference Business Trajectory (RBT), which the Airspace User agrees to fly and the Airport and ANSP agree to facilitate. The metrics currently available to assess the performances of ATM tools and procedures ([9,10]) will be extended in STREAM and new metrics will be defined according to the work of [11,12], in order to take into account impacts such as fairness and equity of the proposed solution.

2.2 Current operational tools

2.2.1 Conflict Detection Tools

Conflict Detection tools assist the controllers in conflict identification and planning tasks. They provide automated early detection and filtering of potential conflicts, based on trajectories with different look-ahead times depending on the considered controller role, typically from 5 to 20/30 minutes in advance to the conflict.

The set of CD tools currently employed includes a Medium-Term conflict Detection (MTCD), a Tactical Conflict Tool (TCTs) and the What If tools. However a precise classification of the Conflict Detection Tools already in use by the different ANSPs in Europe is not easy to perform as these are locally implemented according to different criteria which are not homogenous (e.g. actor using the tool, parameters setting such as look ahead time). These tools provide automated assistance to the controller, either the Executive or the Planner according to the time horizon.

CD tools currently offer one or several of the following functions:

- The detection and display to the controller of probable loss of the required separation between two (or more) aircraft;
- The detection and notification to the controller of aircraft penetrating segregated or otherwise restricted airspace;
- The detection and display to the controller of aircraft-to-aircraft encounters where, although the required separation will be achieved, each aircraft is predicted to be occupying airspace that might have been used by the other, e.g. in case of pilot request for an alternative level or when resolving a conflict involving one of the aircraft.

2.2.2 Conflict Resolution Tools

CR tools assist the controllers in elaborating solutions to the automatically detected conflicts in a context where the controllers are responsible for the separation assurance. The resolution aid may consist in different types of functions, such as:

- Facilitating the identification of conflict free trajectories and identification of aircraft constraining the resolution of a conflict or occupying a flight level requested by another aircraft;
- Proposing a set of ranked resolutions to the En-Route controllers;
- Visual filtering of the traffic on controllers demand or by conflict filtering logic. This is usually implemented by diminishing the appearance of flights that are not “relevant” with respect to a conflict;
- Probing functions to allow "What If" analysis of solutions proposed by controllers;

Functions such as "What Else" functions may propose solution(s) to a detected conflict (e.g. alternative trajectory or FL changes) which can be evaluated by the controller who may either select (one of) them or prefer to implement one of his/her own resolution.

2.2.3 Main drawbacks of current CD/CR

CD/CR tools are currently used to allow the controller to timely react to potentially dangerous situations (i.e. the conflicts) by detecting them and facilitating the identification of a resolution maneuver by the operator. They are not currently used at a pre-operational phase to proactively de-conflict traffic by imposing trajectory constraints. This is mainly due to the following reasons:

- the quality of pre-departure information available nowadays from AU flight plans is rather poor and would not allow detecting conflicts within meaningful predictability margins;
- the computational complexity implied by the pairwise approach employed in current CD/CR algorithms impose that only a reduced number of trajectories (i.e. less than 60) can be easily managed.

This implies that the demand/capacity balancing and tactical separation functions are two different and decoupled processes with few or no integration nowadays. As a consequence of this lack of integration between strategic and tactical traffic management, the declared capacity of airspace sectors is always kept below its real capacity, in order to avoid sector overload and to allow ATC and aircrews to safely respond to unexpected levels of traffic at a tactical phase.

2.3 Innovative concepts investigated by European projects

2.3.1 ERASMUS

ERASMUS is an FP6 Project involving as partners EUROCONTROL (leader), DSNA/DTI/SDER (France), HONEYWELL (Czech Republic), University of Linköping (Sweden), Swiss Federal Institute of Technology (Swiss) and SICTA (Italy). It aimed at assessing the technical and operational feasibility as well as the gain in capacity of new separation modes, based on improved 4D trajectory prediction, principally the Trajectory Control by Speed Adjustment (TC-SA).

TC-SA consists in separating the aircraft by up-linking time constraints automatically i.e. with no ATCO involvement in the solution elaboration and application. The time constraints are calculated so that they are achievable through minor speed adjustments of the concerned aircraft (speed variations of about +/- 6% of the current aircraft speeds). It was shown that the controllers are not perturbed by such speed variations and that consequently they can be applied without prior controllers' agreement.

The preliminary results of the first phase feasibility study were promising: 80% decrease in the number of conflicts. However it appeared later that the theoretical results of the feasibility study were obtained under optimistic assumptions. More realistic data values obtained at the very end of the project led to revisit the assumptions of the system parameters.

Hence one of the main outcomes of ERASMUS is that the control and management of uncertainty associated with predicting the trajectory of the aircraft remains the crux of the problem and must be resolved prior to any automation attempts. In particular, it is essential to know the statistical distribution and the tails of distributions of residual errors of trajectory prediction under representative environmental conditions.

Further investigation of the TC-SA is about to start with its pre-operational feasibility in the WP4.7.2 of SESAR.

2.3.2 Episode 3

In anticipation of En-Route validation activities for SESAR and within the context of the European Commission Episode 3 Project (EP3), the En-Route P4.3.4 Prototyping on Queue, Trajectory, and Separation Management was conducted to assess the operability of the 4D trajectory management.

The main aims of the project were to assess the operability, from the controller perspective, of the introduction of the SESAR Reference Business Trajectories and provide initial trends regarding expected benefits in terms of efficiency (e.g. optimised flight profile, better delivery conditions to TMA), predictability (e.g. adherence to pre-defined trajectory) and capacity (e.g. optimised airspace usage and reduced controller workload).

The methodology consisted of a series of three prototyping sessions performed in a SESAR Intermediate Timeframe En-Route Environment (SESAR 2015 traffic forecasts, with all aircraft ADS-C and FMS-4D equipped).

For the full potential benefits of 4D trajectory management to be achieved all controllers strongly felt that the current route structure should be examined and possibly modified, and larger sectors respecting traffic flows be introduced. In addition, to support the 4D trajectory management they requested enhanced and new tools to:

- support conflict detection task
- issue closed loop headings for planning and tactical use
- display the required delivery sequence to TMAs
- provide the time status of the aircraft

2.3.3 SESAR

One of the fundamental elements of the SESAR Target Concept is the 4D Business Trajectory, which evolves out of a collaborative layered planning through 3 main different phases: the Business Development Trajectory - BDT (internal to the airspace user and not shared with the rest of ATM community), the Shared Business Trajectory – SBT (shared for planning and negotiation purposes with the stakeholders) and the Reference Business Trajectory - RBT.

The RBT constitutes the ultimate reference Business Trajectory that the Airspace user agrees to fly and the Airport and ANSP agrees to facilitate. Changes to the RBT must be kept to a minimum, altering it only for reasons of separation and/or safety or in case the Airspace Users' and ATM network goals prevail on the optimisation of an individual flight.

SESAR foresees that for the flights subject to ATFCM regulations, the Network Manager communicates target times of entry in the congested area(s) to the AOC, the relevant Flow Managers, Local Traffic Manager and Airport Operations Centres [13]. The NM notifies the target time entry in the congested area before take-off and, during the execution, the detected deviations between the planned profile and the actual profile phase. This information can be used by the different partners (Flight Crew, Local Traffic Managers, ACC Multi-Sector Planners, ACC/TMA Tactical Controllers) to support adherence to the time of entry in the congested area(s) and/or to be able to monitor the effects of the deviations. Two main types of Target Times are foreseen:

- Target Time of Arrival (TTA)
- Target Time of Overflight (TTO)

Target times are planned times and are used for planning purposes to enable stakeholders coordination, but are not intended as constraints to the trajectory, since they are not inserted in the aircraft system (the FMS). On the other hand controlled times constitute formal constraints for the trajectory since they are allocated by ground systems and inserted into the FMS:

- Controlled Time of Arrival (CTA)
- Controlled Time of Overflight (CTO)

In SESAR Step 1 (2013-2017) CTA is mainly used for arrival traffic sequencing and allocated by ground when the aircraft enters the AMAN horizon, i.e. during the tactical phase. The CTA is allocated within an ETA window previously communicated by the aircraft through datalink, but it is not guaranteed consistency with previously assigned TTA. CTOs are instead used by TC-SA tools of the controlling ATS Unit when a loss of separation is foreseen that can be resolved without “formal de-confliction”. In such a case, there may be a very slight change in speed (3 knots maximum) which has less impact on the user preferred trajectory than a lateral or vertical path stretching.

During the cruise phase the aircraft system continuously monitors the compliance to the RBT/RMT to remain within the required navigational performances. An update of the RBT/RMT is automatically triggered as the trajectory predictions continuously computed by the aircraft system differ from the previously shared trajectory predictions more than the tolerance defined by the ATM System in the Trajectory Management Requirements (TMR). The TMR specifies the lateral, vertical or time parameters that will trigger the update process as well as other event driven and periodic trajectory sharing requirements, the data content required and the allowable tolerances of selected time/speed and altitude.

Hence the STREAM idea of integrating into the RBT all the constraints implied by conflict resolution is compliant with the SESAR Target Concept, but at the same time it is more specific since the objective is to anticipate all the conflict resolution manoeuvres detected for a flight when it is still under its SBT status. It is foreseen that the agreement on the best trajectory amendments which provide conflict resolution can be reached through an iterative and collaborative process between AUs and NM.

Another SESAR concept overlapping with the STREAM solution is the one of Network Operations Plan (NOP): this a collaborative, dynamic and rolling set of plans continuously updated as new or updated information is received, providing a relational image of the state of the European ATM network in that it holds the data of the past, current and future usage of the network. The aim of the NOP is to share information and facilitate the processes needed to reach agreements on demand and capacity, and this constitutes the main link with the STREAM concept. The NOP works with a set of collaborative applications which will allow individual stakeholders to access data in the NOP and enable collaborative agreements which update the rolling NOP.

2.4 Main innovations implied by STREAM solution

The solution proposed by STREAM is to rely on the enriched information about trajectory intentions included in the Shared Business Trajectories to perform early conflict detection and resolution on these same desired trajectories.

This is achieved through new algorithmic solutions that allow to take into account wide airspace portions, in order to guarantee that the conflict resolution manoeuvres enforced into the SBTs (and which later become part of the corresponding RBTs) allow stable plans avoiding the generation of reactionary conflicts. In particular the tools rely on a Spatial Data Structure (SDS) which stores the airspace reservation for different flights according to their SBT and permits to detect conflicts as soon as the reservation is attempted. The Conflict Resolution module relies on the same SDS information to calculate the best SBT amendments guaranteeing fairness, equity, efficiency and robustness of the suggested resolution.

Hence the main difference between the STREAM solution and the ERASMUS solution is that the former is applied before flight execution, when the Business Trajectory is still in the SBT status (i.e. prior to push-back), while the latter takes place during the flight execution phase, when the aircraft has already taken-off. Hence the 2 techniques are complementary and non-overlapping.

Also the SESAR concept for conflict management is significantly different since the detection and resolution of conflicts is mainly performed during flight execution, through the imposition of trajectory constraints (e.g Controlled Times Over/Arrival). The idea behind STREAM solution foresees that the embedding of appropriate constraints at SBTs level can introduce an additional layer of traffic de-confliction thanks to the high quality of information included in SBTs and to the fast and reliable tools working with it. The Spatial Data Structure (SDS) developed by STREAM is foreseen to form part of the NOP, since it will store the spatial and temporal localisation of the trajectories and will be the main enabler for the CD/CR tools.

3 Operational environment

3.1 Area of application

The final goal of STREAM concept is the early detection of conflicts at a pre-departure phase, when 4D trajectories are shared as SBTs with a high degree of precision, and the identification of appropriate de-confliction manoeuvres to be integrated into the final RBT.

In order for the conflict resolution manoeuvres to be effective, the complex interactions among different traffic flows must be taken into account which may imply the reactive creation of a new conflict when another one is resolved. Due to the high degree of connectivity of the European ATM Network it is foreseen that only by considering the whole ECAC Airspace one could ensure that all potential interactions are identified.

The average daily number of flights in 2010 in Europe was around 26000 [15] with peak days of up to 36800 as on July 1st. Considering the typical distribution of take-offs in Europe, as showed in Figure 3 below, and taking into account that the average flight duration is 1h23' (according to EUROCONTROL PRR), it means that a two-hour sliding time window could be employed to filter insertion into the SDS, which will imply to easily have between 5000 and 6000 flights active at the same time. This amount of flights will have to be managed in real time by the algorithms, and this represents a very demanding technical requirement on the performances of the algorithms and of the SDS.

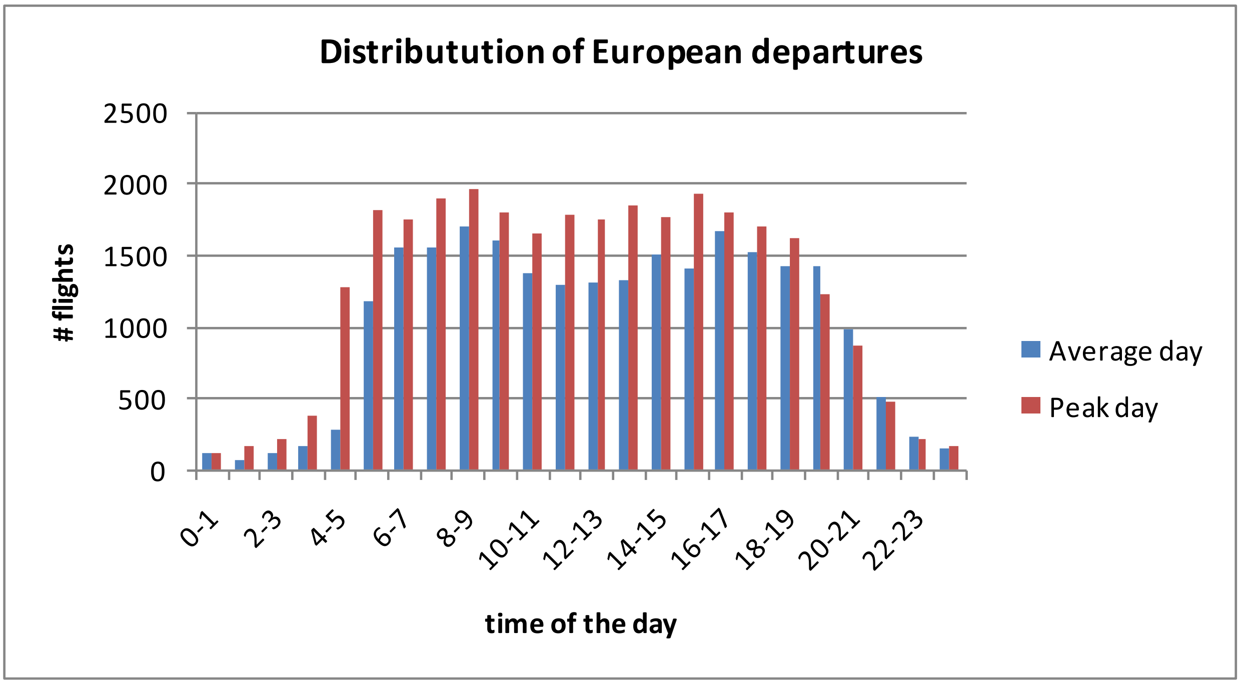

Figure 3: Daily distribution of take offs in Europe (Average day: 09/11/2010, Peak day: 01/07/2010). Source: EUROCONTROL ALL_FT data.

Hence the most appropriate solutions will be investigated by the project to comply with the computational burden required by the STREAM operational solution. These will include:

- The application of advanced techniques for the reduction of quantity of data stored in the SDS (temporal filtering, relational data bases, etc.);
- The design and implementation of a scalable distributed SDS, capable of supporting different airspace configurations (ACC, FAB’s, Sectors);
- The identification of disconnected clusters of interfering traffic allowing the separation of the general problem into several smaller sub-problems.

3.2 Roles and Responsibilities

The relationships among different stakeholders involved in the operation of the STREAM solution are represented in figure below, while more details about different roles and responsibilities are given in the next sub-sections.

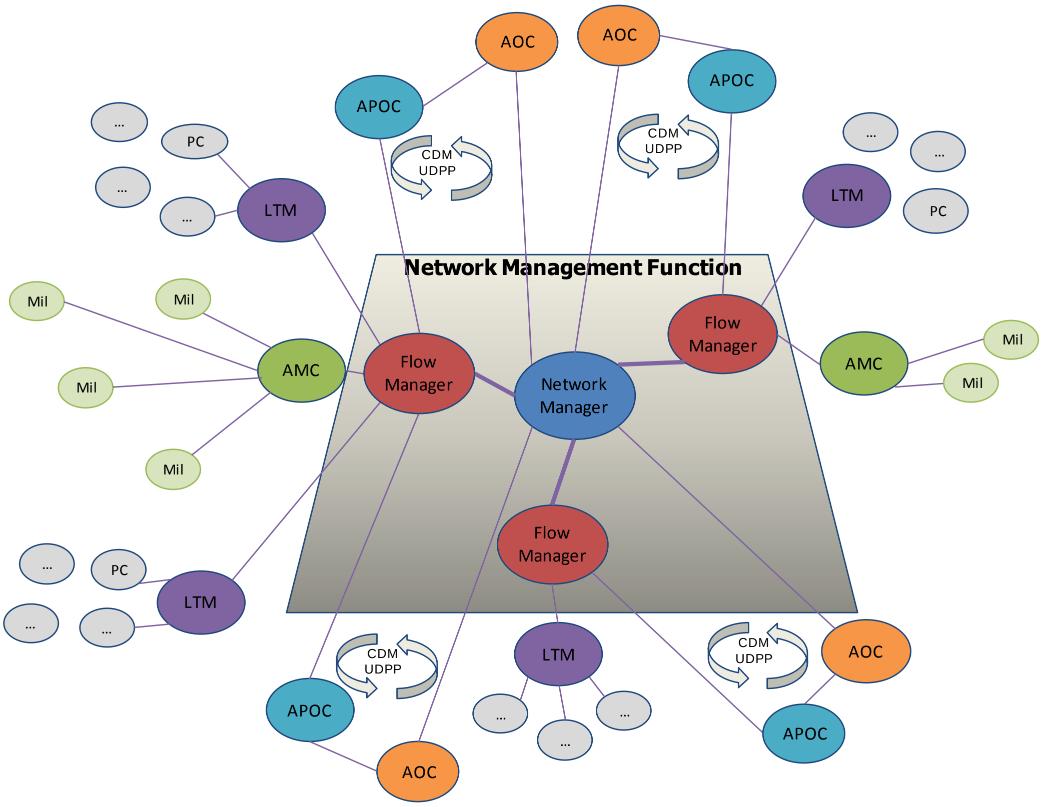

Figure 4: Stakeholder relationships for the implementation of STREAM solution

3.2.1 Network Manager

During the long-term planning phase, when the Business Development Trajectory is still not shared by AOC with the rest of the world, the NM function performs long-term demand/capacity analysis, preparation of seasonal plans and plans for special events, participation to airspace design activities, and simulation activities to improve the overall DCB process.

During the Planning when AUs share their flight intentions under the form of SBT, the NM closely co-ordinates with the Flow Managers in order to assess regional decisions for unexpected network effects, to coordinate inter-regional actions and to oversee negotiations.

The role of the Network Manager includes:

- the compilation of the NOP
- the successive integration of SBTs
- the collection and dissemination of known ATM constraints
- the identification of conflicts between (accepted and agreed) Reference Business Trajectories and (newly published) Shared Business Trajectories
- the communication of these conflicts to the corresponding Airspace User

In the Execution Phase the Network Manager has to assure the stability of the NOP, reacting to unexpected events, which impact on overall network performance, such as unusual meteorological conditions are loss of significant assets (e.g. runways, airports).

In the STREAM concept the Network Manager will be in charge of collecting SBTs from AUs, check their validity, processing them in order to store in the SDS and allow conflict detection and resolution. This implies that the Network Manager has the responsibility to implement, run and maintain the CD/CR tools based on the common SDS structure. The NM function has the relevant authority to impose most appropriate resolution manoeuvres (as computed by the conflict resolution module) to the RBTs previous to the take-off of the flight.

3.2.2 Flow Manager

The Flow Manager is the point of contact at regional level (i.e. within a FAB) for coordination on DCB matters and acts as the interface to the Network Manager and to the local ACC Supervisor as well as with the Military Airspace Management Cell. He ensures that the ACC is up to date with the demand and capacity situation.

The tasks of the Flow Manager are carried out mainly in the Planning Phase and in the Execution Phase. In the Planning Phase these are the confirmation of capacity values and associated sector configurations for the day of operations as well as the fine-tuning of the scenario with the Network Manager.

In the Execution Phase the Flow Manager monitors the FAB sector loads and compares demand with critical sector capacities, advises the Network Manager on DCB measures if demand exceeds capacities and monitors the implementation of DCB measures.

In the STREAM concept the Flow Manager will be in charge of supporting the Network Manager to early detect congested areas in his area of responsibility and to coordinate in liaison with the NM and the Local Traffic Manager the conflict resolution actions to be imposed as constraints on RBTs after assessment of their impact on the whole traffic in the region.

3.2.3 Local Traffic Manager

The Local Traffic Manager (LTM) functionally lies between the Flow Manager and the sector planning and takes a view over a group of multi sector areas and/or sectors. Accordingly, he may subsume the Flow Management Position (FMP) in some ANSPs. In others the LTM may be complementary to the FMP. Either way, he acts as the coordinating link between the ANSP and regional flow management.

The LTM is concerned with the developing forecast of traffic patterns, taking a ‘helicopter’ view of complexity and key constraints to traffic flow in the area. He looks at traffic flows covering the period of the Network Operations Plan using all available data. Hence during the planning phase he will be in charge of assessing the level of uncertainty of traffic predictions and to support the NM by providing the necessary information on local constraints and detecting imbalances between demand and declared capacity in the NOP.

In the execution phase he monitors the actual congestion and detects workload limits requiring new control measures.

In the STREAM concept the LTM will be in charge of determining the local conditions and applicable constraints causing trajectory modifications at a strategic phase, to monitor the evolution of capacity, congestion and traffic flows with respect to previous forecasts and to ensure that his Flow Manager is always in possess of the most updated local information. Also in the case that the CR module identifies beneficial to modify a specific RBT to resolve a conflict, this action will be channelled through the LTM down to the responsible ATCO.

3.2.4 Airport Operations Centre

The Airport Operations Centre (APOC) is the central organisational unit responsible for airport airside operations. It provides the roles of Resource Management, Flight Operations Management and Environment Management and is responsible for CDM with all relevant stakeholders

Airport Resources are planned and allocated iteratively and fed into the NOP through a specific Airport Operations Plan (AOP). On the day of operation this plan is consolidated through the balanced mapping of Business Trajectories demand on the various airport resources, e.g. allocation of aircraft stands, gates and de-icing facilities and check-in areas for passengers within the terminals. Also complexity management of taxiways needs to be performed. If demand exceeds capacity the Resources Manager has to revise the plan through a collaborative process. He will be supported by the Flight Operations

Manager who is aware of all the dependencies within the daily operations plan. (Aircraft turn-round, transfer data, etc.)

The APOC hosts the function of the Airport CDM Cell. This unit is responsible for ensuring and improving communication between all stakeholders, including data-management of CDM relevant data. This includes the dissemination of airport information like landing time, constraints, turn-round time, "Departure Planning Information" and received "Flight Update Messages", etc.

In the STREAM concept the APOC has a central role in ensuring visibility of the most-updated conditions and constraints affecting the airport and as consequence the RBTs, in order to reduce the uncertainty and to enable more informed decisions on the trajectories modifications to be calculated by the CR module. The APOC is hence responsible for providing specific capacity figures that can be used as input by the algorithms to detect and resolve situations of congestion and potential conflict.

3.2.5 Airline Operations Centre

The Airline Operations and Control Centre (AOC) is an organisational unit of an airline and is normally run by a variety of professionals from different areas. It is hosting the roles of Flight Dispatch, Slot Management and Strategic & CDM Management thereby managing the operations of the Airline and implementing the flight programme.

The overall responsibility of the AOC is to maintain the integrity of the scheduled Flight Programme and to take in real time the necessary decisions in order to manage all the flights within the airline network.

The main tasks of the AOC concern the pre-tactical planning phase and the execution phase of flights. The AOC is the point of contact within the Airspace User Operations for all subjects related to CDM.

The AOC is responsible for improving airline network performance (integrity) and optimization of the SBT (prior to departure) and RBT (execution phase) to ensure the users’ business objectives for a flight are met. It devises solutions for constraints arising from the NOP. The AOC is also responsible for "arrival and departure priority proposals” (define preferences, slot swapping and inbound priority sequencing) and decision are taken in the frame of a CDM process. In general it will make proposals for delay allocation and flight prioritization as part of the User Preferred Prioritization Process (UDPP).

In the STREAM concept the AOC will be in charge of providing the requested SBT to the NM and of implementing the modifications required by the NM according to the strategic conflict resolution process. Also the AOC will constitute the AU interface and unique “spokesman” with the NM during the negotiation processes that may instantiate following the revisions of submitted SBT.

3.3 Current vs. future working method

Under the current system the predictive part of air traffic flow management mainly formalizes through time constraints on the take-off of affected flights, i.e. the ATFM slots. These constraints are intended to modify the temporal demand path to comply with the available capacity at airports and airspace levels. However on the execution phase the actual evolution of traffic is often very different with respect to the planned one, due to the lack of time/speed constraints to be met by flights. This implies that when an ATFM slot introduces a delay to the flight, during execution phase speed is increased to reduce delays, thus causing in general poor traffic predictions and high uncertainty on traffic evolution.

STREAM solution will rely on the SBTs component, currently investigated by SESAR, which will introduce higher predictability of flight operations through 4D trajectories at the pre-departure phase. The negotiation and agreement of SBTs ultimately leading to the correspondent RBTs will be a process already put in place to comply with the SESAR ConOps, while the STREAM solution will require one additional control dimension on the top of it, since it will imply some additional constraints to be agreed and imposed on RBTs to prevent potential conflicts.

ATCOs working method will be modified since both planning and executive controllers will have to comply with specific 4D constraints to guarantee that the flight meets its agreed RBT. This shall not necessarily increase their workload, since they will be provided with clear targets to be met by flights, suggesting priorities and maneuvers when resolving conflicts and this increasing situational awareness [16]. On the other hand the Network Manager will have available a new tool to assess traffic complexity through the use of the SDS and hence base its decisions on richer information.

The necessary data for executing CD and CR will in general be already available through NOP or specific trajectory information communicated by the AU to the NM. From the currently available definition of SBT in SESAR it is not clear if AOCs will provide some specific data enabling precise trajectory prediction, such as actual aircraft mass or cost index. Obviously these parameters will be very important to allow precise conflict detection and appropriate conflict resolution maneuvers but they could be considered as private information by Airlines. In this case STREAM solution foresees that AUs would be requested to provide 4D estimations for their flights in specific points along the trajectory (identified as hot-spots by the NM) and to attach confidence intervals to them. A natural incentive for AUs to provide good estimates will be to receive targeted constraints for their flights causing less disruptions to schedules.

4 STREAM Assumptions

The main assumptions on which the STREAM solution for conflict detection and conflict resolution at a pre-departure phase relies are:

- Airspace Users (AUs) are capable of submitting a Shared Business Trajectory compliant with the standard format and information content foreseen by SESAR, for all the flights they are planning to operate within ECAC airspace, with at least 2 hours of advance with respect to take-off time;

- The NM has the technical capability of receiving the SBT requests from AUs, performing the data pre-processing necessary to data parsing and insertion into the SDS;

- Airspace Users and the NM have all the systems in place enabling the iterative negotiation of 4D Trajectories from the strategic phase up to the execution one (i.e. from SBT to the definition and agreement of the RBT).

- The information content and format of the SBT facilitates the prototyping and analysis of the STREAM solution. In this sense the project will define an SBT model consistent with SESAR and tailored to be integrated in the simulation platform.

- Different levels of weather forecast accuracy are achievable according to the time horizon and the variable forecasted. The STREAM solution will be tested under several different conditions, to explore the potential performance of the algorithms. In particular the project will assume different levels of Trajectory Prediction (TP) performance to study the feasibility and potential benefits of STREAM, with weather forecasts (mainly wind and temperature) being a key factor for TP performance;

- The information in the SDS is maintained updated by the NM, by periodically reflecting the status of the RBTs already on execution, registering their deviations and allowing compare SBTs of flights still on the ground with the most updated picture of current and estimated future traffic in the SDS.

Additionally a number of assumptions are relevant, although not directly impacting the STREAM implementation, but rather for guaranteeing that the trajectory amendments proposed at pre-departure phase by the conflict resolution module are later achievable during the execution phase:

- 4-D Trajectory Datalink Services (4DTRAD) are fully implemented and usable by ground and airborne systems. This allows data exchange and coordination between air and ground during the execution phase, permitting ATCOs to assess the compliance of aircraft with agreed RBTs and to react to changes according to TMR.

- All aircraft are FMS equipped thus being able to receive and automatically load in onboard navigation system multiple constraints;

- P-RNAV operations are available at ECAC level and all aircraft have RNP-1 navigation capabilities. However it may also be interesting to consider mixed equipage in order to assess the applicability of the STREAM concept in a shorter time frame.

5 Description of the STREAM operational solution

The solution proposed by STREAM to overcome the main limitations described in 2.2.3, is based on the early identification of potential conflicts from the trajectory information available at the strategic phase (SBT) and their early resolution by imposition of most appropriate trajectory modifications to be integrated into RBT and respected during execution.

This basically implies that traffic is synchronized through formal agreements for each flight and this intends to enhance predictability of the entire ATM system, thus closing the gap between its predictive and adaptive parts.

5.1 Medium-term planning phase

During the medium-term planning phase (from few months up to few days before flight) the SBT will be provided by the Airspace Users to inform other ATM actors of their flight intentions and their preferred trajectory. Compared to today, the SBT is expected to be shared with ATM actors earlier than current ATC flight plans: typically, several weeks ahead for early planned flights, the SBT description will contain limited trajectory description with statistical estimates.

Progressively more and more information from AUs and regional flow managers will be available to the Network Manager in order to plan traffic evolution, to identify major capacity shortfalls and develop Demand-Capacity Balancing (DCB) scenarios based on the historical traffic demand, enriched with early communication of SBTs for repetitive flights.

SBT is expected to be progressively detailed and updated during the successive iterations of the planning process, as more complete and reliable information about the planned operational situation becomes available. As the planning horizon comes closer to operations (from a few days before operations), the SBT will contain more detailed 4D trajectory description, reflecting the latest available forecasts and compatible with the latest known ATM constraints.

From few days before operations, the SBT will contain a detailed estimated 4D profile and all the applicable ATM constraints, to support the agreement process and the promulgation of the RBT.

The Network Manager will check SBT against the latest known ATM constraints will be triggered not only prior to the SBT publication but also regularly after, in order to make sure that the SBT remains valid towards dynamic changes in ATM constraints. Invalid cases will generate alerts to the originating AUs asking them to update and send a new edition of the SBT.

STREAM solution could already be applied during this phase to perform early conflict detection, contributing to give a better awareness of future congestion by considering different uncertainty buffers.

Through this iterative planning process, AUs and service providers agree on the 4 D trajectory to be flown. This includes, in particular the 2D route, the cruise level (plus any planned en-route level changes) and planned speed, and the constraints with which the aircraft must comply.

5.2 Short-term planning phase

During the few days before flight the enriched information attached to each flight request will progressively be refined, thanks to higher degree of reliability of the operational and technical constraints applying on the day of operations. The Airline Operation Centres (AOCs) will submit their latest modifications to SBTs to the Network Manager through a suitable data communications infrastructure, i.e. the System-Wide Information Management (SWIM) infrastructure. The trajectories generated by the different AOC planning tools must be expressed in the appropriate standard format and must include the most updated information in possess of the Airspace User regarding flight intentions. This information shall include quantitative estimation regarding specific aircraft parameters that enable precise trajectory predictions by ground tools (i.e. the flight script).

SBT in this phase will contain a detailed estimated 4D profile and all the applicable ATM constraints, to support the agreement process and the promulgation of the RBT. The latest instantiation of the SBT should correspond to an Operational Flight Plan, with the detailed sequence of way points (published) and pseudo way points (computed to build the lateral transitions and vertical profiles), associated altitude/time/speed and applicable ATM constraints.

STREAM solution will apply on the day of operations, in the time horizon from 2 hours before take-off and the final agreement of the RBT (i.e. few minutes before push back).

During this time frame in fact the most reliable information will be available regarding the main factors contributing to uncertainty in traffic evolution:

- The actual operational and technical status of the aircraft fleet (from AU)
- The specific aircraft to be used for each flight (from AU)
- The availability of airport resources, in terms of runway capacity, airport configuration, stand availability and special factors (strikes, runway closures, etc.) – from Airport Operator. Even if these different aspects are not explicitly considered by STREAM algorithms, the Airport will provide capacity figures based on them that will be taken into account for conflict detection in the TMA. Thus, a LVR would be modeled in the SDS by a higher time window occupancy of the runway cells.
- Weather forecasts (from Weather Forecast Service Provider)

- The availability of airspace resources in terms of airspace structure, airspace capacity and availability of ATCO manpower and the resulting constraints for AUs. (from Flow ANSPs and NM). Even if these aspects are not explicitly considered by STREAM algorithms, they will be analyzed by the NM to anticipate disruptions.

The SBT will then be processed in order to allow its insertion and storage into the SDS. This will be done at NM level, by applying a trajectory prediction process that will determine the trajectory evolution in space and time according to the structure of the SDS and will estimate the uncertainty buffer to be padded to the SBT, according to the quality and quantity of the information provided.

The computation of precise trajectory predictions is fundamental for reliable CD/CR. To that end, a highly flexible Trajectory Prediction Infrastructure, based on BADA4.0, will be used in STREAM to generate the trajectories that will be fed into the CD/CR tool. Precise trajectory calculation (aircraft model and weather model) and accurate knowledge of the future aircraft behaviour and airline preferences will increase the reliability and robustness of the CD/CR tool results. It is expected that air-ground and ground-ground synchronization during the flight execution will be based on real data feeds (e.g. aircraft derived data) and will provide precise trajectory profiles shared among all involved actors and augmenting the system predictability. Even if the execution phase is not directly managed by the STREAM solution, it is closely related since STREAM conflicts might be detected between SBTs and RBTs, thus possibly implying also RBTs modifications. This is considered to be a special case, which however should be left open to assess its impact on the system and on users.

Based on the overall information gathered from the different stakeholders involved, the NM will then obtain support from the STREAM tools in order to:

1. Generate 4D Trajectories based on flight intent information obtained from the latest SBT;

2. Store the 4D Trajectories in the SDS and detect conflicts depending on the defined certainty levels, since the robustness of the resulting conflict-free trajectories will depend on precision of the trajectory prediction upon which the CD function is based. This task will allow the 4D representation of traffic in the network at European level for the next 2-3 hours. Consequently it will be possible to:

    a. Identify potential conflicts, likely violations of separation minima, e.g. two aircraft at the same level over the same geographical area at the same time.

    b. Identify hot spots and congested areas.

3. The Conflict Detection phase will occur in parallel with the insertion of the pre-processed SBT information into the SDS. Every data stored into the SDS can be interpreted as a reservation (or “booking”) of an aircraft, which intends to use a spatial resource (the coordinate) for a certain period of time. Thus, minimum information to be stored is the aircraft id (which is the object that

occupies the discrete coordinate of the SDS) and the time at which the coordinate will be occupied by the aircraft. If two or more aircrafts want to use the same coordinate at the same time (or during overlapped time-windows), then it means there is a conflict between their trajectories.

4. Propose amendments/constraints to the 4D Trajectories to de-conflict traffic. Whenever a potential conflict is detected, the CR module is invoked to propose resolution measures. Since CR works on the same SDS, it adds visibility of the aircraft involved and of all the auxiliary information stored. Hence it will be able to calculate the most suitable manoeuvre to de-conflict trajectory, in terms of trajectory amendments for one or more aircraft involved in the conflict. The amendments will then be converted into appropriate constraints (in terms of changes to the flight script, such as modified 2D route, speed and altitude changes which can eventually be translated into 4D windows to be met by aircraft at specific points).

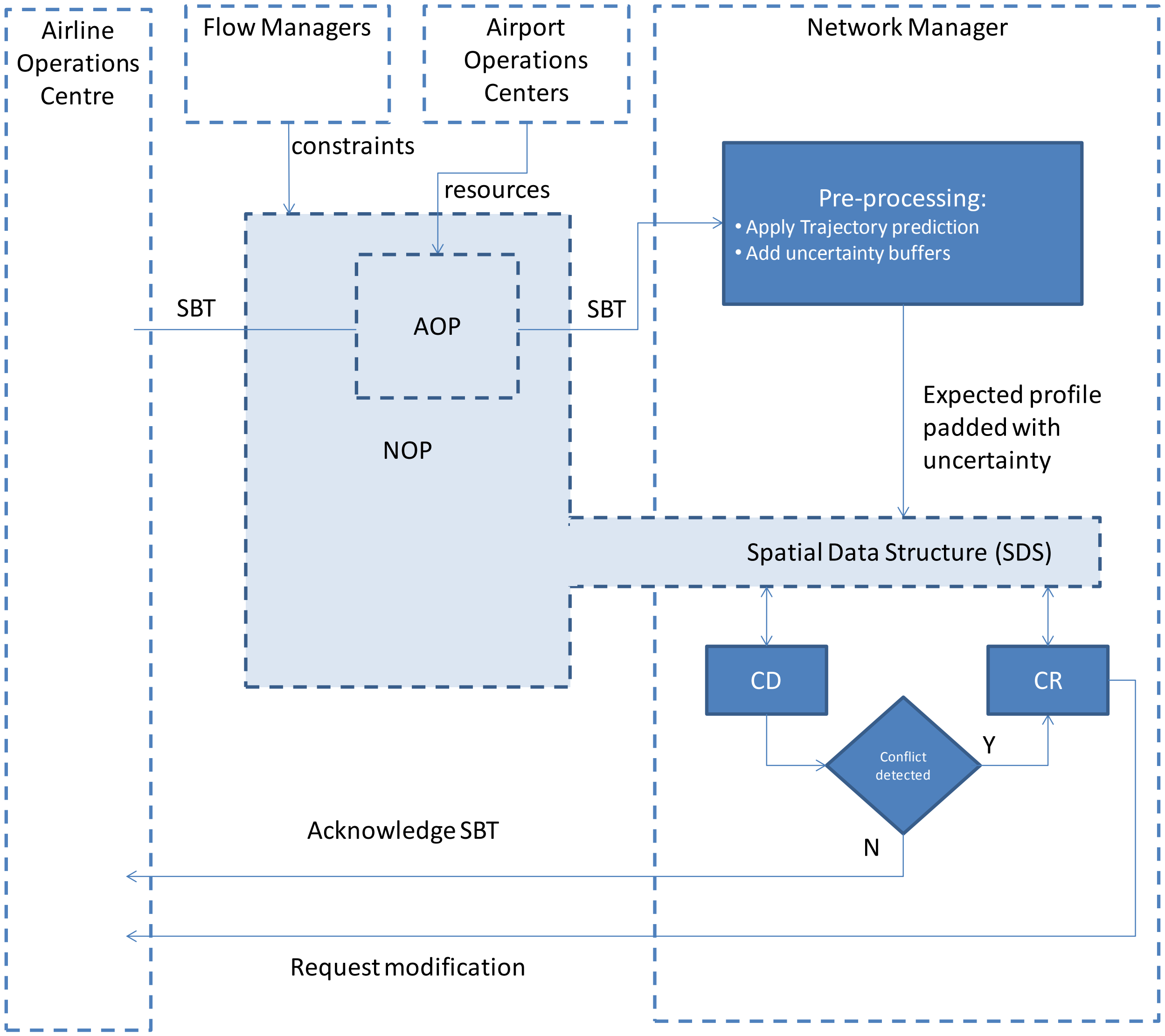

Figure 1: Main components of the STREAM solution

The Airspace Users will have the possibility to express their preferences over different solutions to comply with constraints, thus engaging in a sort of iterative negotiation process, according to which the AUs communicates their preferences and the NM calculates the most preferred maneuvers, associated with specific constraints.

Since each detected conflict may have several possible trajectory amendments to be solved, each one implying in general a different impact on users, either the AUs communicates their priorities (e.g. in terms of cost index for each flight) to the NM who can then assess and impose the best solution or the NM proposes a set of possible resolutions to the users which then will have to provide the ranked order of preferred ones to the NM. With these weights then the NM will then be able to select the one generally preferred. The trajectory amendments communicated to users shall just specify the actions on the aircraft operated by them, in order not to leave possibility of a resolution chosen just to penalize a competitor. This method could be more complicated to be implemented but could guarantee the collaborative agreement of a fair solution, without requiring AUs to explicitly declare aircraft priorities.

It is foreseen that the final STREAM solution will enable this Collaborative Decision Making process, although it will not be explicitly simulated in this project but just emulated to provide the final agreement on a de-conflicted SBT (which would become the RBT).

5.3 Data content, availability and accuracy

The increased quantity and quality of information made available in the couple of hours before flight execution to the actors in the European ATM system will enable new methods for strategic conflict management and traffic synchronisation.

Airspace users will have the possibility to specify earlier in time their flight intentions and through a richer description, indicating the desired 4D trajectory and also their preferences and constraints —either in absolute terms (*e.g.* acceptable tolerances) or in relative terms (*e.g.* a set of 4D trajectories ranked from the most to the least preferred), to support the trajectory negotiation.

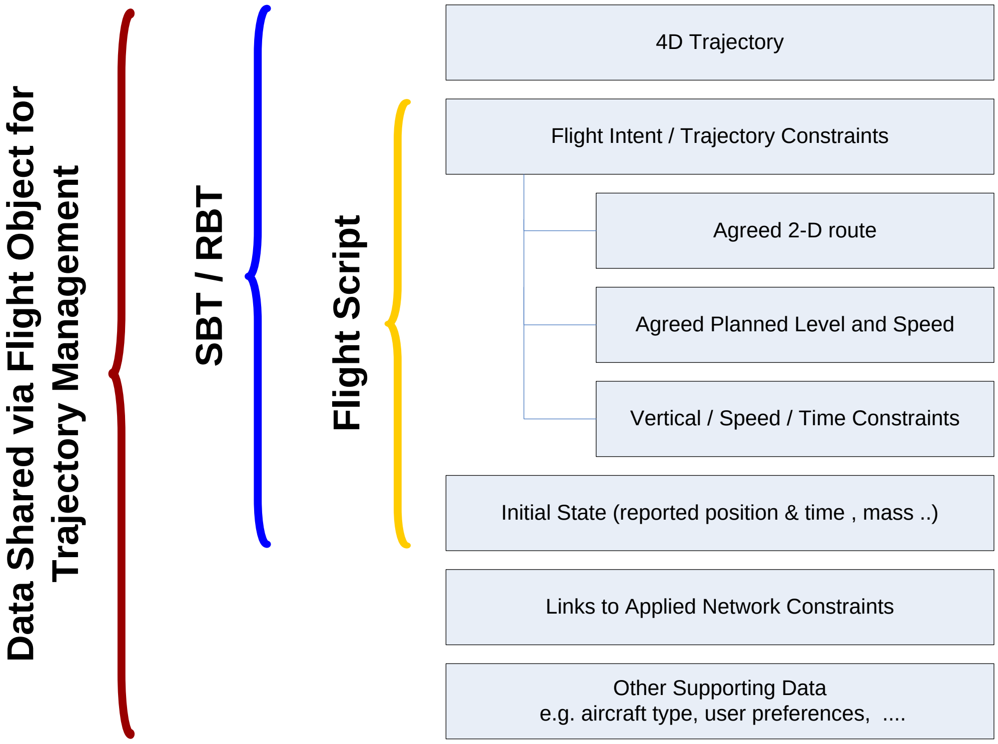

Figure 2: SBT/RBT data content and ancillary data (SESAR B4.2)

Specific data from the Airspace Users that the STREAM solution will require in order to calculate precise trajectory predictions for performing CD/CR during the short-term planning phase are:

- Aircraft type
- Meteo forecast (wind velocity and temperature)
- Initial aircraft state, including TOW, position, speed, altitude, time, ..
- Waypoints 2D and their type
- Preferences and Constraints applicable to the trajectory, such as:
    - User preferences
    - Desired Cruise Altitude
    - Desired Cruise Speed
    - Planned Climb and Descent speeds
    - Operational Context
    - Airspace structure (routes, WPs, SIDs, STARs,…)

The result will be a predicted sequence of aircraft states including position, times, speeds, weights (i.e. fuel consumed), etc

Lack of quality input information would degrade TP performance, thus sensitivity analysis will be performed considering some reference true trajectories and different TP errors (different “degradation modes” of the TP due to modelling errors, lack/errors of input data, etc). Such a study would also be useful to inform SESAR on what information should be included in the SBT (flight script) to make the STREAM concept work to an acceptable level of performance. The modelling of uncertainty is outside the scope of STREAM, however it has direct impact on the benefits implied by its solution. On the other hand the *UTOPIA* WP-E project focuses on this topic, thus it is expected that its main results could be integrated in the design of STREAM tools.

In addition to the input data for TP, additional information should be made available by the relevant stakeholders to assess the confidence associated to predictions and to anticipate disruption such as:

- The actual operational and technical status of the aircraft fleet (from AU): this information is intended to provide early indication of schedules which are likely to be disrupted due to unavailability of an airframe for technical reasons.
- The specific airframe to be used for each flight leg (from AU): this information will allow the system to logically connect successive flights to be performed by the same airframe, in order to anticipate delays.
- The AUs preferences regarding trajectory modifications: these can be either specified as a quantitative indicator attached to each trajectory (e.g. the cost index) or as a relative preferences over different trajectory modifications as offered by the NM.
- The availability of airport resources, in terms of runway capacity, airport configuration, stand availability and special factors (strikes, runway closures, LVR, etc.) (from Airport Operator): this information allows to precisely estimate airport capacity and to detect potential disruptions to scheduled ground processes that could affect TMA trajectory changes in the TMA.
- Weather forecasts (from Weather service provider) allow to anticipate effects on airport capacity and traffic patterns.
- The availability of airspace resources in terms of airspace structure, airspace capacity and availability of ATCO manpower and the resulting constraints for AUs (from ANSPs & NM): this information allows to anticipate the effect of ATM constraints on the traffic.

Appropriate mechanisms shall be put in place to stimulate stakeholders to provide the information. This could include regulatory approach, which is likely to been acceptable for institutional stakeholders (weather service providers, Airports and ANSPs) but less for the Airspace Users. For them specific incentive mechanisms should be foreseen, which guarantee to minimize the impact of de-confliction measures whenever accurate information is provided. This could be rather straightforward, since RBTs agreed on the base of a full set of flight information provided by the AU will contain specific target times to be matched during execution. On the contrary the flights with less or no target times will be selected as best candidates at the time of applying de-confliction measures at a tactical level.

Uncertainty will always be part of the system due to the fact that the look-ahead horizon will imply a certain variability of the evolution of the flight and of the boundary conditions. The uncertainty will need to be quantified and translated in the space and time reservation in the SDS: TP inaccuracies will result in uncertainties around predicted 4D points along the trajectory. The higher the uncertainty the larger the bubble around the position of the aircraft in space and time hence the higher the probability of possible potential conflicts.

On the other hand each potential conflict identified by the CD module will result in a new constraint calculated by the CR module to the 4D trajectories involved, thus allowing:

1. To provide visibility to the AU of the Network congestion levels in particular regions where constraints are imposed

2. To give incentive to the AUs to provide all the necessary data to capture precisely the evolution of the trajectory, in order to diminish the probability of detecting a conflict and thus a resolving maneuver.

Assuming that with a high level of predictability (which depends on stakeholders providing information) conflicts can be avoided already on pre-departure, the simulation will analyze the benefits (e.g. in fuel consumed) of constraining the RBT at pre-departure phase (and then flying it accurately and avoiding the anticipated conflict) with respect to not reacting to the detected conflict and then conduct avoidance maneuvers tactically.

The SDS will naturally provide a tool to detect critical areas for congestion or hot-spots. In fact by computing the available buffers (in space and time) that each trajectory has at different SDS reservation volumes, it will be possible to determine the degree of flexibility/variability acceptable for each of them. In turn the identification of the more sensitive trajectories (i.e. the ones with higher number of time constraints crossing a higher number of critical areas) will permit to decide on prioritization criteria when it comes to tactically solve conflicts or vectoring traffic.

The trajectories with less uncertainty in the prediction will have tighter volumes reserved in the SDS and hence will be considered of higher priority than a flight with a wider reservation. This will naturally derive from the inclusion of robustness criteria into the conflict resolution maneuver computation, which will be properly weighted (in conjunction with fairness, equity and efficiency) in order to give AUs a clear incentive to provide accurate information to be used by the trajectory prediction process.

5.4 Logical architecture of the STREAM solution

5.4.1 Data pre-processing module

The data pre-processing module will constitute the interface between raw SBT data as transmitted by AUs and the CD/CR tools within the NM system. It will be in charge of reading the information included in the SBT and to make it usable for being stored in the SDS by:

- receiving SBT from the AUs systems and generate accurate trajectory predictions from the information contained in it (i.e. the flight script)
- check validity and be processed by the CD/CR modules
- To complement SBT transmitted data with:
    - Trajectory prediction, based on the input information included in the SBT and enabling the identification of which input information (intent) can be changed to resolve potential conflicts (what-if probing), such as 2D route, speed/altitude constraints, etc.
    - Estimation of uncertainty by comparing with the rest of data from other sources and appending this uncertainty to the given estimation.

The SBT data are then filtered according to the estimated take-off time and only the ones complying with the current active time scope of the SDS are passed on and immediately stored into SDS, while others will be automatically pre-filtered and introduced at the right time. At a certain time t, the flights that will be inserted into the SDS will be the ones taking-off in the time interval *[t; t+120minutes]*, with appropriate refreshing time (i.e. rolling base), to guarantee effective catching of updates. As soon as a flight lands, its trajectory data are eliminated from the SDS and possibly passed to the NOP for post-flight analysis. This rolling horizon thus constitutes a temporal filter to limit the amount of stored data only to flights which are at the final stage of SBT negotiation and whose 4D trajectory can be precisely described. The RBT of flights already in execution phase will be maintained continuously updated in the SDS through the NOP.

The specific architecture of the data pre-processing module and of its functional sub-blocks is out of the scope of STREAM project.

5.4.2 Conflict detection module

All SBTs trajectories are sequentially inserted into the SDS according to their space and time evolution. This implies a formal booking of a series of discrete space/time volumes into the data base, corresponding with the samplings of 4D envelop that can be built around the aircraft, which takes into account the estimated aircraft path plus the margins implied by wake vortex, minima separations and level of uncertainty.

The radius of the tube will then depend on the uncertainty attached to the trajectory data and to boundary conditions (wind, ATM constraints,...). The sampling rate of the 4D-tube will in turn define the granularity of the information stored, while the spatial distance between successive reserved positions in the SDS depends on the speed of the aircraft, whereas the relative positions of the waypoints depend on the direction of the aircraft.

The resolution of the SDS is the distance between discrete points of the SDS. Several factors are considered to determine the granularity of the SDS, such as:

- Modelled objects:
    - the size of the physical airspace to model,
    - the size of the tubes to be stored in the database,
    - the aircraft speed
- Technological factors:
    - the quantity of memory available in the computer,
    - the speed of execution of the algorithms,
- Operational needs:
    - The expected congestion levels and required accuracy

Note that the excess of resolution may lead to a loss of computer performance as well as to an inoperable amount of memory requirements, whereas a lack of resolution may lead to lose some important objects of the space. Hence the right trade-off needs to be evaluated, depending on the specific operational needs and technical capability levels.

At the moment of storing a tube-point in the SDS, a conflict is detected. In the case that no other flight has reserved the same space volume, no conflict is detected so the spatial resource can be booked without conflict. In the case of detecting a previous booking of the same space volume by another flight, then the algorithm compares their time windows. If their time-windows are overlapping, then a conflict is detected and the CR system is informed. If the time windows are not in conflicting, it means that the coordinate might be booked for a different time window.

Therefore, the number of actual comparisons performed by the algorithm is considerably limited only to aircraft reserving the same spatial volumes, thus acting like a natural “spatial prune” avoiding the pairwise strategy and linearizing the temporal performance of the algorithm.

Additionally all relevant information to be successively exploited by the CR module, can be stored in the SDS and attached to the flight, such as state space information, times, type of aircraft involved, priorities, etc.

A conflict can be detected either between different SBTs or between an SBT and an RBT already on execution. In this latter case there might be situations in which it could be more beneficial to modify an already agreed RBT than a number of different SBTs, even if this may imply a stronger coordination effort to be achieved. In fact the change proposal should be triggered by the NM, channeled through the Flow Manager, to the Local Traffic Manager and then the RBT revision executed by the responsible ATCO. A specific case might be a congested TMA around a hub airport in which a predominant carrier operates and one of its RBTs is in conflict with several SBTs. It would be in the very interest of the carrier to slightly modify the one RBT to leave all other SBTs unchanged. This case should be assessed by simulations to derive feasibility and benefits.

5.4.3 Conflict resolution module

The maneuvers calculated and suggested by the CR module will be based on the impact of the maneuver on the user preferred profiles, measured according to specific indicators for

- Fairness: balancing conflicting interests by means of a just procedure that takes into account the acceptance levels of the users and their individual satisfaction.

- Equity: Treating all users equally without taking into account their specific identity, but rather their ability to facilitate trajectory management process.

- Robustness: taking into account the ability of the aircraft to keep its planned trajectory in response to the occurrence of a disturbance

- Efficiency: including

    - time efficiency: additional flight duration implied by the maneuver;

    - fuel efficiency: additional fuel consumption implied by the maneuver;

    - flow efficiency: considering the number of impacted flights in the traffic flow;

The relevant indicators will be developed by WP3 during the course of the project and they will be weighted in order to evaluate the overall impact of conflict resolution maneuvers on individual users as well as on the system. This implies that the best trade-off will be searched between local impact and global impact imposed by the maneuver.

A set of possible resolution scenarios could be available for each conflict. In this case the tool would clearly indicate the different options which should made available, together with the causing constraints to AUs for selecting the preferred one. Under all circumstances the final agreement between the involved service providers and the impacted Airspace Users will be necessary in order to close the SBT negotiation and to instantiate an RBT for each flight. This agreement may be achieved immediately upon AU request of its desired trajectory, in case that no ATM constraints are violated and no conflict are detected, or may be the result of several proposals and negotiation iterations.

In the cases when negotiation process does not converge to a feasible solution within a certain time limit, the ATM authority (i.e. the NM at the strategic phase or ATCO during the execution phase) will have the right to impose the most indicated conflict resolution measure.

5.4.4 Final Agreement

Since each detected conflict may have several possible trajectory amendments to be solved, each one implying in general a different impact on users, either the AUs are able to attach a specific priority coefficient to each trajectory, in order for the NM to assess and impose the best solution, or the NM communicates to the users the set of possible resolutions suggested by CR module and they in turn respond with the ranked order. The NM will be then be able to select the most preferred solution, i.e. the one whose sum of individual rankings is the higher. The trajectory amendments communicated to users shall just specify the actions on the aircraft operated by them, in order not to leave possibility of a ranking conceived just to penalize a competitor. This method could be more complicated to be implemented but could guarantee the collaborative agreement of a fair solution, without requiring AUs to explicitly declare aircraft priorities.

The result of this process will be to have pre-synchronized traffic in the regions that are foreseen to be more congested. This synchronization will be agreed by involved actors (AUs, ANSPs and Airports) and formalized through the RBT, which will include the constraints in path and time derived by the strategic de-confliction measures. Different types of constraints will need to be defined to better cope with the flexibility required by the system:

1. Soft constraints: those constraints that admit certain flexibility since they are coupled with other constraints along the trajectory.
2. Hard constraints: those constraints that must be imperiously respected since they have an impact on other constraints imposed along the trajectory in different areas.

These constraints will be clearly identified in the RBT and will provide a commitment from the stakeholders to conduct/facilitate the flight accordingly. This means that the aircraft will not be automatically cleared through these constraints, since unexpected events could still occur imposing tactical interventions and the explicit ATCO clearance will continue to be needed. However the overall predictability of the system will be enhanced, thus implying less tactical interventions and more stable plans.

The constraints resulting from STREAM early de-confliction maneuvers should be diversified from other type of constraints resulting from other interventions (e.g. sequencing through CTO/CTA). The concept of Target Window proposed by CATS project [14] represents a good candidate to easily represent the resulting constraints and their degree of looseness: they are 4D windows (i.e. in space and time) located on sensitive points along the trajectory, depending on airspace configuration and ATM needs.

The size of the window inherently represents the tightness of the constraint in space and time to be respected in order to avoid the conflict. The sizes and location of the windows could be negotiated and changed until the final RBT agreement, when they are freeze. This allows to build an overall stable plan for aircraft already in the air and to take this plan as reference to negotiate and agree trajectories with aircraft still on the ground (i.e. during the SBT phase).

On the other hand the flexibility of the system will be guaranteed by allowing a tactical revision of the RBT in whatever moment and for whatever reason during flight execution. This implies a formal RBT change, thus causing a new or modified aircraft booking volume in the SDS to maintain the picture updated and at the same time to detect new potential conflicts as well as the corresponding resolving maneuvers by the CR. Due to the time constraints on the computational time that can exist in the execution phase the CD/CR processes need to be fast and reliable and this will be ensured by the specific design of STREAM algorithms.

6 Expected benefits

The main benefits for which STREAM solution is conceived and the tools are developed can be resumed according to 3 ICAO Key Performance Areas: Predictability, Capacity and Environmental Impact. The concerned indicators will be quantitatively assessed through simulations within project activities. In the following a rational is provided that justify the performance expectations in each area.

6.1 Improved Predictability

Higher predictability will be induced by closer integration between the global predictive part of the ATM, performed by ATFCM function previously to flight take-off, and the local reactive part, performed by tactical controllers. These 2 phases are currently poorly synchronized due to the scarcity of information on precise desired 4D profiles at the strategic phase and to the lack of computationally efficient tools to tackle complex Conflict Detection and Resolution problems involving up to several thousands of flights. STREAM solution will develop algorithms and models that can perform Conflict Detection and Resolution in the pre-departure phase, i.e. based on the richer information available in the SBT and on the contractual leverage offered by the RBT to integrate appropriate de-confliction measures.

Moreover the constraints imposed on the strategically de-conflicted RBTs will give visibility to the different involved actors of the level of sensitivity of each trajectory to tactical modifications. This will help controllers in assigning priorities to different flights when it comes to tactically vectoring traffic (for whatever need), in order to minimize network impact by picking the less constrained trajectories.

At the same time the traffic stored in the SDS will represent a reliable picture of the traffic in the next 2-3 hours, thus allowing the NM to identify congested areas and hot spots and to plan necessary actions.

6.2 Capacity Increase

The early de-confliction of flights will allow to reduce tactical interventions by controllers and thus to decrease the workload. This will allow them to handle more flights at the same time, while guaranteeing the same situational awareness and thus safety. This in turn implies an increase of the real sector capacity.

At the same time the fact of knowing in advance that part of the traffic will arrive to the airspace sector already de-conflicted, will help reduce the “safety buffer” which today is applied by local traffic managers when declaring capacity. This implies that the declared capacity will increase more than the true capacity, as indicated in the following diagram.

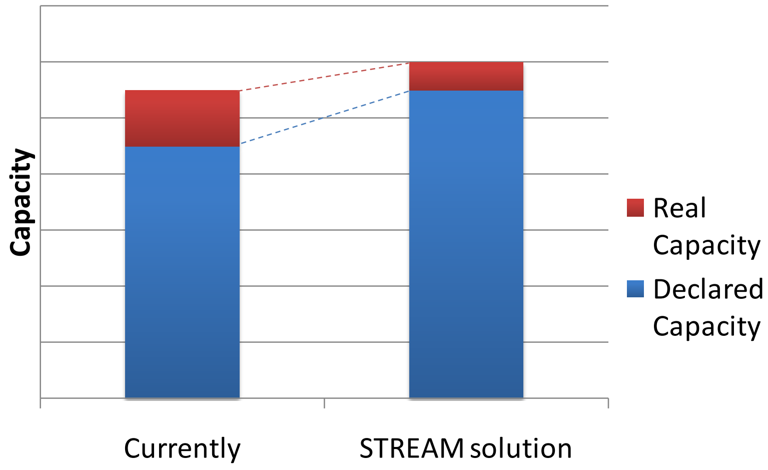

Figure 5: Qualitative increase in real and declared capacities implied by STREAM

6.3 Environmental Impact

Thanks to the enhanced efficiency of ATM operations and the opportunity for airspace users to fly trajectories which are as close as it is possible to their optimal ones, while minimising the need for tactical modifications due to conflict resolution tasks the STREAM solution will reduce fuel consumption and hence gaseous emissions.

7 Conclusions

The operational solution proposed and investigated by STREAM is intended to close the gap between the predictive and reactive parts of ATM. This can be achieved by performing conflict detection and resolution during pre-departure phase, based on the enhanced information that will be available to ATM stakeholders through the SESAR Shared Business Trajectory.

Assuming that the quality of information available from SBT is good enough to precisely predict the evolution of trajectories during execution, new algorithmic approach to conflict detection and resolution with respect to the classical pairwise strategy is necessary to guarantee effectiveness of the imposed trajectory amendments.

The conflict detection and resolution modules developed by STREAM are then based on a Spatial Data Structure which allows to perform conflict detection in linear time with respect to the number of trajectories and to propose trajectory modifications that take into account fairness, equity, robustness and efficiency of the proposed solution. Specific constraints are then derived and imposed on the final instantiation of the SBT for a flight, i.e. its RBT which guarantee avoidance of conflicts if respected during flight execution.

The STREAM concept is pretty simple and straightforward but relies on a series of assumptions that will be accurately investigated and assessed during the course of the project, mainly through simulations:

- That the airspace users are keen to communicate their precise flight intentions and parameters (flight script) enabling accurate trajectory prediction. The STREAM solution is designed to incentivize AUs to provide this, since the narrower their estimations, the lower the probability of detecting a potential conflict and hence to receive a trajectory amendment.

- Different levels of weather forecast accuracy are achievable according to the time horizon and the variable forecasted. The STREAM solution will be tested under several different conditions, to explore the potential performance of the algorithms. In particular the project will assume different levels of Trajectory Prediction (TP) performance to study the feasibility and potential benefits of STREAM, with weather forecasts (mainly wind and temperature) being a key factor for TP performance;

- The mechanisms for 4D Trajectory management as well as all the relevant technologies both on the ground and in the air are available according to the SESAR roadmap, thus ensuring the necessary enable for the STREAM solution to be efficiently operated.

It is foreseen that the implementation of the STREAM solution could positively affect Predictability, Capacity and Environmental Impact. The concerned indicators will be developed by WP3 and then quantitatively assessed through simulations in WP4.

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