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iFly

Safety, Complexity and Responsibility based design and validation of highly automated Air Traffic Management

Specific Targeted Research Projects (STREP)

Thematic Priority 1.3.1.4.g Aeronautics and Space

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Executive Summary

The iFly project is aimed at developing an Advanced Autonomous Aircraft (A^3) concept and evaluating the traffic levels that allow safe operations in the Self-Separation enroute airspace. The development of an Air Traffic Flow Management (ATFM) concept for Self-Separation en-route airspace makes part of this, and is addressed in this report.

This ATFM concept is aimed at working in an environment with user-preferred routing, and self-separation operations without tactical ground support. The ATFM concept is aimed at giving the airspace users the greatest possible freedom to choose the best route from a business point-of-view from TMA to TMA. It is assumed that short and medium term conflict resolution is able to handle most traffic situations encoutered within self-separation airspace. Only in certain areas within self-separation airspace ATFM will assist in limiting demand to keep tactical operations in these areas efficient. These areas where ATFM can be active are (1) the transition areas between self-separation airspace and managed airspace, (2) at the boundaries of airspace restrictions, and (3) in between closely spaced airspace restrictions.

The demand in these ATFM areas is limited by applying a novel flexible scheduling method. The scheduling method can handle the uncertainties that exist at the long term view of flow management. It can be applied fluently from the strategic flow management time frame well before the actual departure till the tactical flow management time frame around half an hour before the actual arrival to flow constraint airspace.

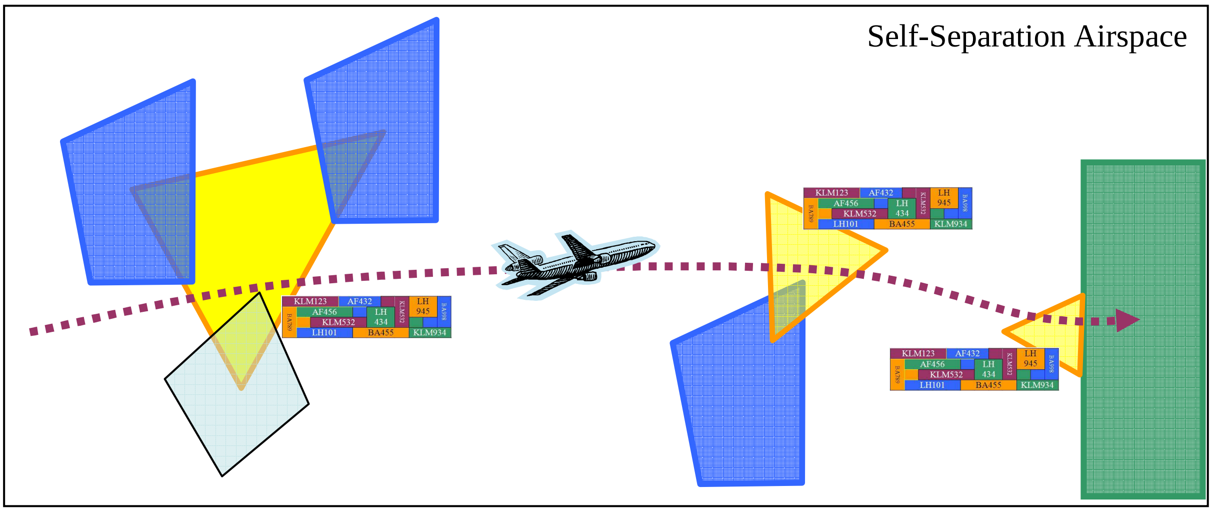


Table of Contents

1 Introduction

Air Traffic Flow Management (ATFM) ensures that user demand does not overload the capacities offered by the air traffic infrastructure. ATFM does this by viewing air traffic centrally from a regional perspective, and restricting the traffic movements based on relevant information.

The problem ATFM is facing is the limited availability of capacity to handle traffic in air traffic control sectors and TMA's (Terminal Manoeuvring Area). Furthermore, making the right choices in restricting traffic is not easy as the traffic flow is only predictable within limits.

Allowing user-preferred routing makes it possible for airlines to choose the most effective route from airport to airport. This saves fuel and improves predictability for the airlines. For the passengers the delays can be reduced and comfort can be improved. Overall costs for providing air traffic management can be reduced.

The objective is to describe an Air Traffic Flow Management concept for Self-Separation Airspace, which builds upon the philosophy behind autonomous aircraft operations and breaks away from the centralized doctrine of current day ATFM. The concept will aim to minimally intrude on the user-preferred routing. It will keep the responsibility for separation assurance with the autonomous aircraft crew. There where it is likely that inefficiencies resulting from interactions of autonomous aircraft can be more efficiently solved by flow management than by the autonomous aircraft collaboratively the FMSSA function will intervene.

1.1 Deliverable D8.2 Scope

The Air Traffic Flow Management concept for Self-Separation Airspace (FMSSA) will build on relevant work within iFly work packages 3, 4 and 5 and will align with the SESAR concept (Single European Sky ATM Research) for flow management as has been available at the beginning of 2009. The FMSSA concept will focus on the en-route phase of flight as this is also the scope of the overall iFly project.

Before the concept for FMSSA is developed the current centralized ATFM system is described based on available literature. This helps identifying the ATM (Air Traffic Management) problems ATFM is focussed on. After that, underlying principles for an ATFM concept and the actual concept for ATFM in Self-Separation Airspace are defined.

1.2 Document Layout

First of all, the document starts with a description of the current centralized flow management concept in section 2. Based on this description, the ATM problems with the current centralized flow management are identified in section 3. Section 4 gives a short technical overview of the underlying principles for the proposed ATFM concept for self-separation airspace. The actual concept for ATFM in self-separation airspace is given in section 5. Operational scenario's for ATFM in self-separation airspace are provided in section 6. Finally, section 7 gives concluding remarks on the presented concept for ATFM in self-separation airspace.

2 Centralized ATFM with ground-based Air Traffic Control

The objective of Air Traffic Flow Management is to allocate the available resources, like airport and sector capacity, and to maintain an efficient traffic flow consistent with controller workload restrictions. The reason that ATFM is necessary is that available capacity and demand are not always in balance due to various reasons. For instance the weather can have a large influence on short term changes in the availability of capacity [Sridhar 2007].

In the Air Traffic Flow Management problem the aim is to redistribute the delays in the traffic system in such a way that controller workload is not exceeded, that fuel and time related costs are minimised, that flow management measures are shared equitable, and that banks of flights into and out of hubs are kept intact [Bertsimas 1998].

To alleviate the flow through sectors and terminal areas several methods have been developed over the years. An effective technique is to adjust the release times of traffic into the airborne network. Furthermore, the spacing of flights passing through specific sectors can be adjusted (e.g. metering). Also rerouting flights around bad weather areas is commonly used [Bertsimas 1998].

In the following sub-sections a short description of current ATFM aimed at ground-based centralized Air Traffic Control (ATC) is given by addressing the ATFM responsibilities, the operational phases, the information streams, and systems. Furthermore, a summary of methods for optimizing traffic flow management problems is given as used for centralized ATFM.

2.1 C-ATFM Responsibilities

The main objective of ATFM is to support ATC in preventing any system overloading and ensuring an expedited flow of air traffic during times when demand exceeds, or is expected to exceed, the available capacity of the ATC system.

It is the responsibility of the ANSP (Air Navigation Service Provider) regarding ATFM to provide good estimates on declared capacity of their sectors or airports, and to comply with the allocated takeoff slots. It is the responsibility of the airspace users to provide to the ATFM stable flight plans of sufficient quality, comply with the allocated takeoff slots, and execute the flights according to the agreed flight plans. It is the responsibility of ATFM to manage the flight plan data, to monitor the actual traffic situation and update the expected demand data based on potential and actual changes to the planned profiles of individual flights, and to allocate flow management measures to alleviate mismatches between expected demand and declared capacity [ATFCM Evolution Plan] (Air Traffic Flow and Capacity Management).

2.2 C-ATFM Phases

The ATFM process can be divided into three phases: strategic flow & capacity planning, optimised capacity management, and tactical flow & capacity management [Eurocontrol OCD Vol. 1] (Operational Concept Description).

In the strategic flow & capacity planning phase the airports and air traffic service providers declare initial estimates for the available capacity. Furthermore, the airspace users indicate the expected demand. This process can start up to 18 months before the day of operation and continue until a week before the actual operations.

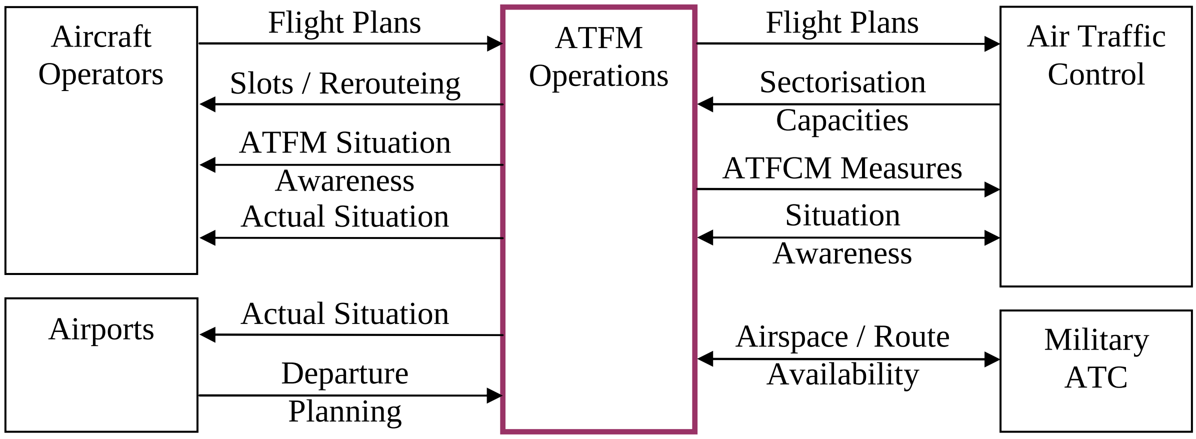


Figure 1 Operational Structure with ATFM [Source: CFMU Handbook] (Central Flow Management Unit)

In the optimised capacity management phase better demand information and user capability data becomes available. This is used to create an Operations Plan. The projected trajectories, airspace organisation, and allocation of entry/exit times for airspace and airports are determined. This phase is started a week before the actual operations.

On the day of operations the tactical flow and capacity management phase is started. The aim is to minimise disruptions due to last changes like significant weather phenomena, but also take benefit of opportunities like increased sector capacities.

2.3 C-ATFM Information streams

The ATFM process has connections to the aircraft operators, airports, air traffic control, and military air traffic control. In Figure 1 a context description of ATFM is given.

The aircraft operators provide flight plans to ATFM. The flight plans are passed on to the ANSPs. The Military ATC will indicate airspace and route availability to ATFM. The ANSPs will indicate sector and airport capacities to ATFM. The ANSP is also informed about Military airspace and route availability. ATFM can determine restrictions applicable for the flights and will inform both the aircraft operators and the ANSPs about the applicable restrictions, slots and reroutes. The airport operators inform ATFM about the departure planning. The airport operator is informed by ATFM about the slots.

2.4 C-ATFM systems

A short description of the ATFM system elements is given in [Figure 2] and as a summary below:

- The ATS Environment Database (Air Traffic Services) contains the details on the ATFM area organisation, ATS routes, and routeing systems, airfields, standard instrument departures, standard arrival routes, navigation aids, ATC sectorisation, etc.
- The Flight Plan Processing System processes and distributes flight plan data.
- The Tactical Flow Management System presents the planned and actual traffic situation, provides the slot allocation, and assesses rerouting.
- The Archive system contains performance data and quality indicators for assessment of ATFM measures.
- The Pre-tactical Flow Management System is used to assess the impact of proposed flow management measures before implementation.

Within the AIS Database information about the environmental conditions is collected. The environmental data is provided to the Tactical Flow Management System together with Flight Plan data from the Flight Plan Processing System, the Route Catalogue, the daily plan from the Pre-tactical Flow Management System, and ATC updated. The Tactical Flow Management System will produce slots and reroutes, and a network situation overview. The slots and reroutes are provided to the aircraft operators. The network situation overview is provided to the aircraft operators, and ANSPs.

2.5 Optimization methods used with C-ATFM

To solve the generic Air Traffic Flow Management problem mathematically a number of sub-problems have been defined over the years. Odoni was the first to conceptualize the ATFM problem in general [Odoni 1987]. Thereafter Richetta and Odoni addressed the more specific Single Airport Ground Holding problem (SAGHP) and the Multi Airport Ground Holding problem (MAGHP) [Richetta 1993]. The ground holding problem makes decision on release times of traffic into the network. The multi airport problem is an extension of the single airport problem that also takes the network delay propagation into account. The more general Air Traffic Flow Management Problem (TFMP) does not only determine release times, but also optimal speed adjustments for airborne traffic flows in capacity restricted airspace (The TFMP is a special case of the job-shop scheduling problem). The TFMP problem can be extended to take re-routing into account. This Air Traffic Flow Management Rerouting problem (TFMRP) is especially interesting for usage with drastic fluctuations in the available capacity.

The models show a number of variations. The simplest is the deterministic static case. This can be extended with added complexity by taking account for stochastic capacity levels and the dynamically updating of the solution. Richetta and Odoni addressed the dynamic and stochastic case of the SAGHP in 1994 [Richetta 1994]. Vranas extended this with the dynamic version of the MAGHP [Vranas 1994] and Terrab developed a stochastic version of the MAGHP [Terrab 1993].

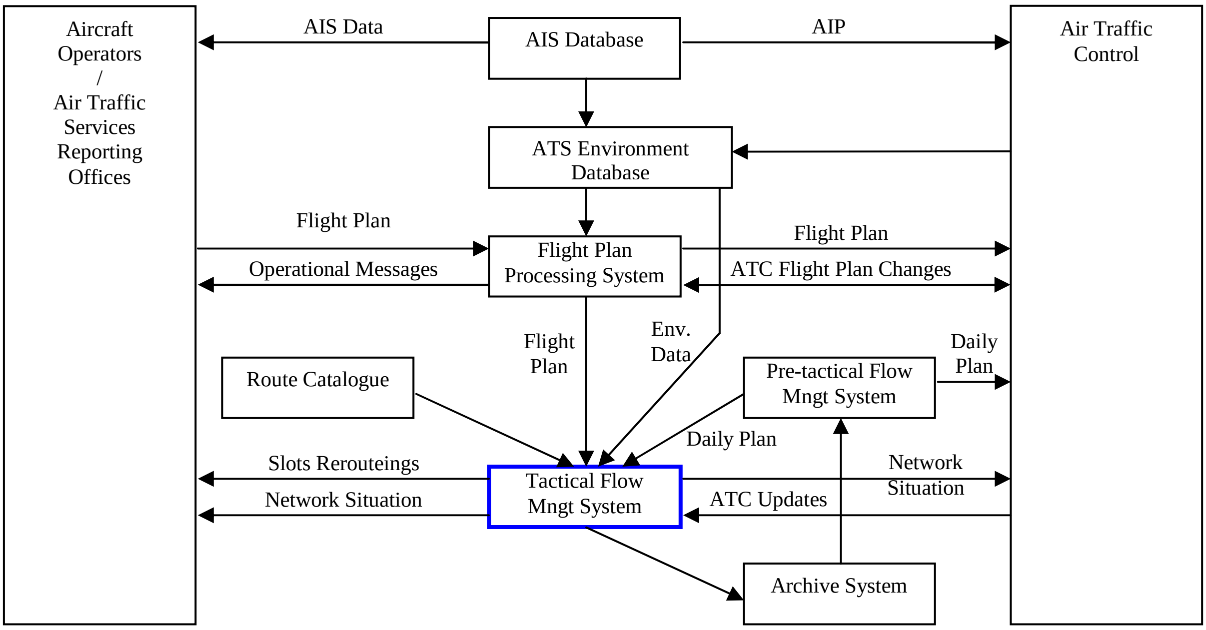


Figure 2 ATFM Systems Overview [Source: CFMU Handbook].

The MAGHP can be extended to take constraints regarding hub connectivity into account. This allows a flight to arrive at an airport and continue after a certain turnaround time as a different flight. The GHP (Ground Holding Problem) can also optimize for minimizing the "spread" of arrival banks into hub airports [Bertsimas 1998].

2.6 Conclusions regarding Centralized ATFM in respect to FMSSA

For the Centralized ATFM it is a considerable problem to keep traffic levels below the actual capacity levels in sectors and at airports without resorting to conservative estimations. This is the result of the fact that capacity estimations by ANSPs, slot compliance by airlines, and flight plans are all uncertain or biased. This results in the need for a conservative approach in centralized Air Traffic Flow Management to be certain to keep traffic within acceptable levels.

In self-separation airspace there is no ANSP responsible for giving capacity estimations and limits. So FMSSA has to determine the restrictions on traffic flow based on a set of rules for self-separation airspace. These rules will be based on physical and agreed boundaries of the self-separation airspace, special weather conditions, the navigational performances, and the traffic characteristics resulting in the conservative approach.

The reallocation of traffic to lower throughput to match capacity levels, or to reduce complexity issues, results in the allocation of delays to flights. This is mostly done on a FCFS bases to be equitable. This will not necessarily result in the most efficient solution. Furthermore, this can be unfair to some types of flights, like short-hauls.
The reallocation of traffic must have clear rules, which are defined beforehand, which are viewed as being equitable over the long run, and can be implemented in a distributed manor, and which results in efficient solutions.

3 ATM problem addressed by ATFM

In [SESAR D1] the current situation with the ATM system has been identified. It is clear that airspace users feel the constraints in the current ATM system and resultingly can not deliver the services to their customers they would like to. The barriers in the system need to be broken down. The issues constraining the airspace users identified within SESAR that addresses or can be addressed with flow management have been summarised in this section.

3.1 Issues identified within SESAR regarding C-ATFM

The current Air Traffic Flow Management (ATFM) process provides for balancing demand and capacity in the traffic system. The SESAR problem identification document [SESAR D1] has identified a number of issues resulting from operating the current ATFM system in Europe. First of all, ATFM in Europe does not address fully the ATM problems for what it was designed for. Secondly, the system has some undesirable side effects and shortcomings.

The en-route ATFM delay costs of around 1.3 minutes of flight delay on average are around €1 Bn. The delays indicate that their is a lack of capacity in large parts of European airspace. Providing ATM, including the ATFM services, results in high charges on route network utilization. These charges are considerable higher than in the USA (United States of America). The level of predictability of flight times, of availability of capacities, and of demand for capacities, results in a conservative approach to the handling of traffic flow ensuring the limitation of the workload of controllers.

Air Traffic Flow Management tries to balance demand and capacity in the traffic system. This has as side effect that restrictions are imposed on flights, like ground delays, airborne holding, route restrictions, level restrictions, speed restrictions, metering restrictions, and separation restrictions. Although this is unavoidable for ATFM, the actual frequency and severity of the restrictions is larger than is strictly necessary. Furthermore, the restrictions are not always assigned in an equitable manner as a result of practicalities. Although the first-come-first-served principle is used to be able to have some form of equitable assignment of flow restrictions, this results in deviations from airport schedules and does not comply with user preferences.

The current ATFM system lacks the availability of accurate and timely data on sector capacities, and traffic forecasts. Airline operators frequently provide ATFM with inconsistent flight plans, and unrealistic time estimates. Furthermore, the respect for flow and capacity measures is such that major percentages of flights depart outside their ATFM slot.

Weather forecasts have considerable influence on regulations although the accuracy of the forecasts would prompt a more probabilistic approach to changing meteorological conditions. Without this excessive regulations are used in practice to be on the safe side.

3.2 Issues identified with C-ATFM in the USA

The C-ATFM (Centralized Air Traffic Flow Management) in the US is aimed at allocating the various resources in the ATM system to maintain an efficient traffic flow consistent with safety targets. To address the ATFM problem a number of ATFM measures have been developed, which can be used depending on the circumstances:

- Ground Delay Programs (GDP)
  - Flights bound for congested airports are delayed prior to departure. It is assumed that delaying traffic at the airport is safer than delaying flights en route and also saves fuel [Vossen 2006].
- Airspace Flow Program (AFP)
  - Flights going through constrained enroute airspace will be issued an expected departure clearance time to meter the demand through a constrained area [FAA Order JO7210.690].
- Playbook reroutes
  - A collection of severe weather avoidance routes that have been preplanned and coordinated with ATC centres [Schwartz 2006].
- Ground Stops (GS)
  - Flights meeting specific criteria may not depart. GS are normally based on flying distance [Schwartz 2006].
- Coded Departure Reroutes (CDR)
  - Alternate routes to avoid airspace blocked by severe weather [Prete 2007].
- Miles-in-Trail restrictions (MIT)
  - The number of miles required between successive aircraft using a specific part of airspace or airport [Schwartz 2006]. This is an effective, but inefficient measure.
- Diversions
  - Deviation from the original flight plan to the alternate airport to reduce demand to a constrained airport.

The GDP, AFP and playbook reroutes can be used as strategic ATFM actions beyond 2 hours in the future and the GS, CDR, MIT, and diversions can be used as tactical actions within 2 hours [Pepper 2003].

The Ground Delay Programs are believed to be not effective tools for managing large-scale en-route weather events. GDP is mainly effective for airport weather issues. The Airspace Flow Program is more effective for the large-scale en-route weather events.

Decision making regarding flow measures experience issues as a result of high uncertainties. Traffic forecasts do not account for weather uncertainties, departure times are uncertain, and airlines react to (expected) flow measures by rescheduling and cancelling flights. Airlines even do this when they are not fully aware of traffic conditions and the status of flow measures. The interaction between various measures is hard to predict; especially when information is not shared. This makes trajectory prediction for flow management purposes hard to realize [Sridhar 2008].

The flow measures are also not regarded to being fair. For instance long haul flights are exempted from delays when local flights are subject to ground delays.

3.3 Performance objectives for FMSSA

Within SESAR a number of Key Performance Areas (KPA) have been defined, which are closely related to the generic set of KPA used by ICAO (International Civil Aviation Organization). The performance areas from SESAR are grouped into three different perspectives [SESAR D2]:

- Societal Outcome (Safety, Security, Environmental Sustainability)
- Operational Performance (Cost Effectiveness, Capacity, Efficiency, Flexibility, Predictability)
- Performance Enablers (Access, Equity, Participation, Interoperability)

Not all of the KPAs identified within SESAR are relevant to the full extent in respect to ATFM. So below the most relevant performance areas are described in more detail with a focus on the flow management related aspects.

3.3.1 Societal Outcome

Safety

Safety is related to the risk, the prevention, and the mitigation of air traffic accidents. The overall objective is to improve safety levels such that ATM related incidents do not increase in number with increasing traffic numbers.

Within the A^3 concept (Autonomous Aircraft Advanced) it has been defined that the airspace users are responsible for separation. Constraints are only imposed for projected congestion, excessive complexity, security, safety or environmental reasons. ATFM can operate by enforcing these constraints, including the safety related constraints.

ATFM should only impose constraints when there is a necessity. ATFM acts when the traffic complexity or density is expected to become a safety issue in a delimited area of the self-separation airspace.

Security

Security is about addressing “the risk, prevention, the occurrence and mitigation of unlawful interference with flight operations of civil aircraft and other critical performance aspects of the ATM system”. Although this subject needs to be addressed in the concept for traffic flow management it is not taken into consideration in the concept design in this report. There is a requirement to address this performance area at a later stage in the concept development.

Environmental sustainability

ATM has a limited influence on the impact of aviation on the environment. Still ATM has an important role in finding ways to reduce adverse environmental impacts. Allowing flights to operate with limited constraints imposed by ATFM and with good knowledge on the weather conditions can close the gap between the optimal flight trajectory and the actual flight trajectory. This will minimise gaseous emissions of flights.

Allowing flights to aim for their individually best trajectory will not guarantee a global minimum in respect to emissions. ATFM can give this global perspective. Though, in practice it is hard to realize a global optimum due to two major reasons. First of all, global optimization gives a need for a considerable amount of relevant data from the airspace users. Secondly, the generic flow management problem is a mathematically hard problem to solve.

3.3.2 Operational performance

Cost Effectiveness

Cost Effectiveness is the gate-to-gate costs of ATM in relationship to the volume of traffic that is managed. The costs of ATM should be acceptable to the airspace users. This includes the en-route costs for providing the flow management services. The costs of providing and having these services should be considerable lower than the monetary value of the performance improvements that flow management provides to the airspace users.

The cost of ATFM are not only those costs that are charged for the ATFM service to the airspace users, but also the costs of providing the necessary information to ATFM by the airspace users, the costs for installing the systems on the airspace user side to allow interaction by the airspace users with ATFM systems, and the costs as a result of complying to flow restrictions. Additional costs of ATFM are the investment costs for developing, and obtaining the ATFM functionality, including new ATFM functionality for an A^3 based ATM system.

For a correct performance evaluation also the cost of not providing ATFM should be considered. This will have effect on the performance of short and medium term operations in the A^3 environment.

<u>Capacity</u>
The ATFM system should be able to allocate airspace capacity to meet the demand at the times when and where it is needed. Capacity is related to the throughput of traffic per unit of time, for the applicable safety level.

Airspace capacity in Self-Separation Airspace needs to be determined using objective rules without the need for human interaction. The rules for determining capacity of airspace will need to be based on recommendations regarding the acceptable levels of A^3 traffic. These rules could be dependent on traffic density, airspace structure, airspace boundary constraints, weather aspects, and traffic complexity.

For the purpose of the ATFM concept it is therefore assumed that the capacity of airspace will be given, as it is not yet known where the limits are for safe traffic and complexity levels in A^3 airspace.

<u>Efficiency</u>
Efficiency indicates the difference in arrival time and/or fuel usage between the business optimal trajectory and the actually flown trajectory. Any interactions with other traffic can introduce the need to deviate from the optimal trajectory resulting in changes in the timing and fuel usage.

ATFM can reduce the efficiency effects on fuel usage and arrival time increases as a result of traffic interactions. ATFM can reduce the need for medium and short term traffic interactions by introducing strategic long term modifications to the traffic. ATFM needs to balance the reduction in short and medium term interactions with the increase in long term modifications in such a way that the expected fuel losses and arrival time increases are at a minimum.

<u>Flexibility</u>
Flexibility is defined as the ability of the ATM system to respond to “sudden” changes in demand and capacity. These changes are reflected through simple and full updates of the Reference Business Trajectories (RBT), including withdrawals of flights. The ATM system should be able to handle also non-scheduled flights which operate more on a demand basis.

To have flexibility for flights to change trajectory ATFM should first of all minimize the need for constraints in the en-route airspace, and secondly keep options for flights open to change their current RBTs [Idris 2008].

Predictability

Predictability is the ability to control the variability of the deviation between the actual flown 4D trajectories of aircraft in relationship to the RBT.

Predictability is relevant when forecasting traffic demand. The quality of current traffic forecasts is such that large safety margins are used to take into account the upward uncertainties in the demand levels. Weather is an important factor in creating these uncertainties in the availability of airspace capacity. Predictability is sensative to the prediction time [iFly D3.2i]. Furtheraway in time the predictability decreases.

Trajectory management can provide an increase in predictability when airspace users provide their RBTs. The airspace users try to comply with these RBTs. This means that there is an active feedback loop trying to reduce any deviations between the actual flown trajectory and the RBT. For flow management therefore the RBTs are important data to forecast demand levels with [iFly D3.2i].

The RBTs should indicate expected uncertainties to the trajectory as this can be used as input for the flow management process to balance capacity and demand given the uncertainties.

3.3.3 Performance enablers

Access

Not all classes of airspace can be used by all types of airspace users. Segregation in the access to airspace should be possible according to the access rules that apply. ATFM should comply with these access rules and for instance not assign capacity to non-appropriately equipped aircraft that want to operate in airspace areas with specific reduced weather conditions.

It is the responsibility of the airspace user to comply with these access rules.

Equity

Equity implies an equal handling of all airspace users, which have access to a specific airspace area. With equity it is possible to achieve an acceptable solution to conflicting interests of airspace users [Poza 2009]. Prioritization rules can give the airspace users a sense of equitable treatment.

Within ATFM the assignment of capacity to specific flights should be fair. First of all, prioritization (sub-) classes (emergency, non-normal, and normal) should be wherever possible complied with when assigning capacity to flights. Secondly, within a specific prioritization class the assignment of capacity to flights will be based on a first-come-first-served basis and will allow exchange of assigned capacity between flights through collaboration. Thirdly, when capacity has to be reduced it is possible that some flights will have to return their assigned capacity or will have to adjust the limits for their assigned capacity. A fair method for addressing this will be needed in the ATFM concept.

Interoperability
ATFM should be interoperable with global standards for flow management, should apply global and uniform principles. Intercontinental flights should be handled no different than intra-European flights.

3.4 Conclusions regarding ATM problems to be addressed within FMSSA
Based on the ATM problems identified regarding C-ATFM the following conclusions can be made, and used as input for a FMSSA concept.

The basis of C-ATFM is to keep throughput levels within the capacity limits. This is first of all due to safety as the workload of a controller would become unacceptable above certain throughput levels. In self-separation airspace the controller workload is not an issue anymore. Still safety can be a concern resulting in throughput or complexity limitations.

In order to be on the safe side of acceptable throughput levels currently C-ATFM assigns restrictions too frequent and too severe. In FMSSA the restrictions should only be applied when it is really necessary.

Forecasting capacity and traffic levels in controlled airspace is dependent on the availability of accurate and timely data from the stakeholders. In self-separation airspace the capacity is only related to the environmental conditions. So given the environmental conditions the self-separation capacity can be predicted. The traffic levels in self-separation airspace can be forecasted based on the RBTs.

Using C-ATFM in practice the compliance to flow management measures is limited. This reduces the effectivity of flow measures. In self-separation airspace the compliance to flow measures can only be ensured through compliance to RBTs.

Although C-ATFM takes a deterministic approach, the problem it tries to address is quite stochastic. FMSSA should take a more probabilistic approach when assigning capacity to flights. FMSSA should allow for some level of inaccuracy.

Within C-ATFM various methods for flow management have been identified, including ground holding, miles-in-trail, and rerouting measures. These measures affect different types of flights on different time frames. For FMSSA the choice regarding the flow measure applicable to a specific flight should be more a choice of the airline. As long as the throughput levels in complex or high density airspaces are within acceptable limits. Furthermore, FMSSA should allow to be effective both in the strategic time frame (before takeoff) and in the tactical time frame (after takeoff). The number of flow measure types should also be minimal to reduce complexity of FMSSA, and as such the cost of operation.

Trajectory prediction for C-ATFM has a high uncertainty. This is mainly due to uncertainties in respect to the takeoff time. The provision of RBTs by the pilot in FMSSA allows for an increased certainty in respect to the predicted trajectory.

Some flow measures from C-ATFM are not fair for some types of flights. For instance, long haul flights have an advantage in comparison to short haul flights. Often short haul flights are given a ground delay where the long haul is untouched. Within FMSSA the operations should allow also short haul flights to have a reasonable opportunity to get capacity assigned in restricted airspace in comparison to long haul flights.

4 Underlying principles for Flow Management in Self-Separation Airspace

Before a description of the Flow Management concept for Self-Separation Airspace is given in section 5, first a number of novel underlying principles for the FMSSA concept are developed in this section. In sub-section 4.1 an introduction to three main building blocks for FMSSA are given. Then in the following three sub-sections the main building blocks are described in more detail. These are identifying capacity of airspace areas in sub-section 4.2, identifying demand in sub-section 4.3, and limiting demand in sub-section 4.4.

4.1 The main building blocks for FMSSA

Air Traffic Flow Management is by definition [ref. ICAO ECCAIRS 4.2.6 Data Definition Standard] managing flow in an efficient way to or through areas where demand is exceeding the available capacity. This definition contains three main elements: (1) available capacity, (2) demand to or through areas, and (3) managing flow. Any ATFM concept, including an ATFM concept for self-separation airspace, addresses in principle these three elements.

To be able to provide flow management in self-separation airspace therefore these three main building blocks need to be reflected (see Figure 3). First of all, the airspace areas need to be known for which flow restrictions are applicable. The admissible density or complexity for the airspace areas has to be known. Secondly, the demand for the airspace areas has to be known. And thirdly, when applicable the flights through the airspace areas need to be constrained to be able to keep demand and capacity in balance.

In the following three sub-sections these three building blocks are addressed sequentially. In sub-section 4.2 a method is developed for identifying those airspace areas that are prone to density or complexity issues. In sub-section 4.3 the demand for these airspace areas is identified, and in sub-section 4.4 a method for limiting demand for airspace areas is developed.

4.2 Flexible airspace cells with flow restrictions

In managed airspace there is a need for sectorisation to demarcate the boundaries of the responsibility of a controller. In self-separation airspace there is no need for sectorisation to demarcate the controller responsibilities. Though, for ATFM there is a need to limit the demand to specific airspace regions when the density or complexity of that region is expected to become problematic. So without an imposed sectorisation in self-separation airspace there needs to be a method to identify potential problematic regions for ATFM purposes.

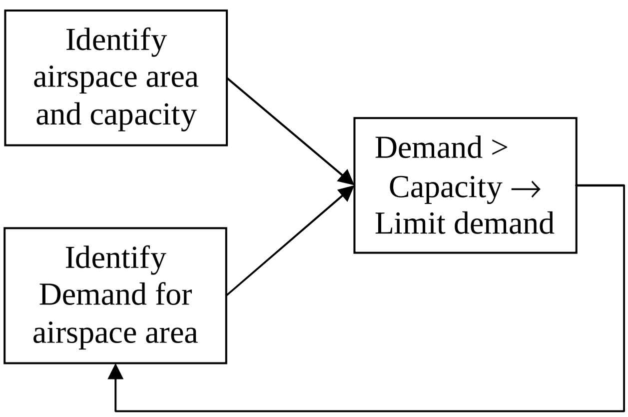


Figure 3 Simplified concept for Air Traffic Flow Management.

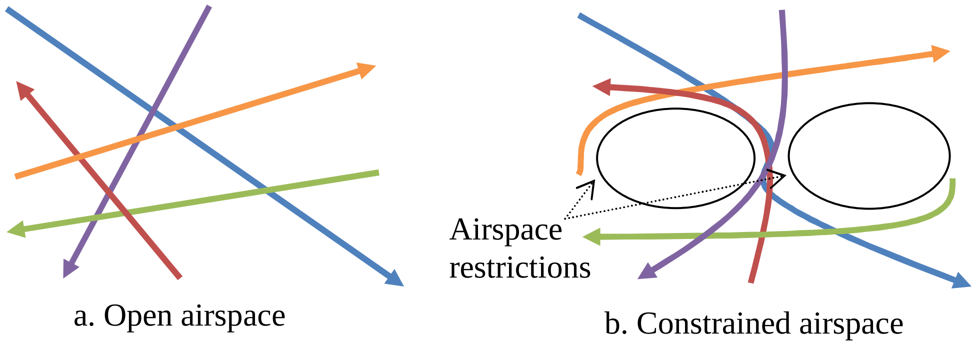


Figure 4 Adding airspace restrictions to an open airspace introduces traffic focal points.

In this sub-section a method is described for identifying these potential problematic regions in self-separation airspace. Furthermore, a strategic flow measure for these problematic regions is identified to limit complexity in these regions.

In sub-section 4.2.1 three types of airspace cells with potential density or complexity issues are introduced. Sub-section 4.2.2 gives a definition of the capacity of an airspace cell with density or complexity issues. Then in sub-section 4.2.3 the first type of airspace cells in between restricted areas is developed, and described in more detail. Sub-section 4.2.4 develops internal flow measures for this first type of airspace cell with density or complexity issues. Finally in sub-section 4.2.5 and 4.2.6 interacting airspace cells with density or complexity issues are developed.

4.2.1 Regions with potential density or complexity issues

Flexibility is defined as the extend to which a trajectory can be modified without causing a conflict with neighboring aircraft or entering a restricted airspace area [iFly D3.2i]. When operating closer to neighboring aircraft or restricted airspace areas the flexibility of trajectories reduces.

An open airspace is defined as an airspace without external and internal constrains (see Figure 4a). Traffic can use the whole airspace without any restrictions. In an open airspace the traffic is distributed more or less random.

With traffic being distributed more or less random the regions with complexity or density issues also arise more or less random. Traffic located in or near regions with these random complexity or density issues can manoeuvre out of these regions without being constrained by airspace restrictions. Aircraft have a considerable flexibility.

In an airspace where airspace restrictions exist the traffic can not use the whole airspace (see Figure 4b). Although traffic may origin from and destine for random locations, the traffic will tend to show concentrations around the airspace restrictions. The concentrations will intensify in between airspace restrictions.

Traffic located near airspace restrictions can encounter complexity or density issues. This traffic can manoeuvre out of these problematic regions, but the airspace restrictions may limit the manoeuvring options. The concentration of traffic and the nearby airspace restrictions reduce the flexibility of the aircraft.

Three types of airspace regions can be identified with potential density or complexity issues. These are (1) random regions in open airspace, (2) regions near airspace restrictions, and (3) regions between airspace restrictions. These three types of regions are described more in detail in the following three sub-sections with a fourth sub-section with concluding remarks.

<u>Random regions with density or complexity issues in open airspace</u>
Traffic operating in an open airspace behaves mostly independent from other traffic. Only when conflict situations are identified traffic will initiate manoeuvres to remove the conflict. Due to the fact that the traffic in an open airspace is operating mostly independent the regions with density or complexity issues arise more or less randomly.

With the RBTs of the flights known it is possible to make a prediction of the future locations of these random regions with density or complexity issues. In theory this prediction can be made a considerable time before the actual event. The predictive value of RBTs reduces further away in time. Similarly, the prediction of regions with density or complexity issues becomes less accurate further away in time.

Anticipating on an uncertain future may be an inefficient strategy. It could result in unnecessary adjustments to RBTs based on expectations which not materialise. An alternative strategy is to wait until the uncertainties reduce, and the predictive value of RBTs increases. Close to the actual time the short and medium term conflict resolution mechanisms start to act.

It is assumed that ATFM is not applied in open airspace with random regions having density or complexity issues. It is assumed that short and medium term conflict resolution mechanisms are effective strategies for resolving the traffic situation in an open airspace.

<u>Regions with density or complexity issues near airspace restrictions</u>
A flight operating through an airspace with airspace restrictions is influenced considerable by the airspace restriction. The trajectory passed the airspace restriction is quite stable near the airspace restriction (see Figure 5). Even with a considerable inaccuracy in the RBT of a flight it is reasonable certain that the trajectory will go along the contours of the airspace restriction. Only the moment of arrival at the edge of the airspace restriction varies considerable with the inaccuracies in the RBT.

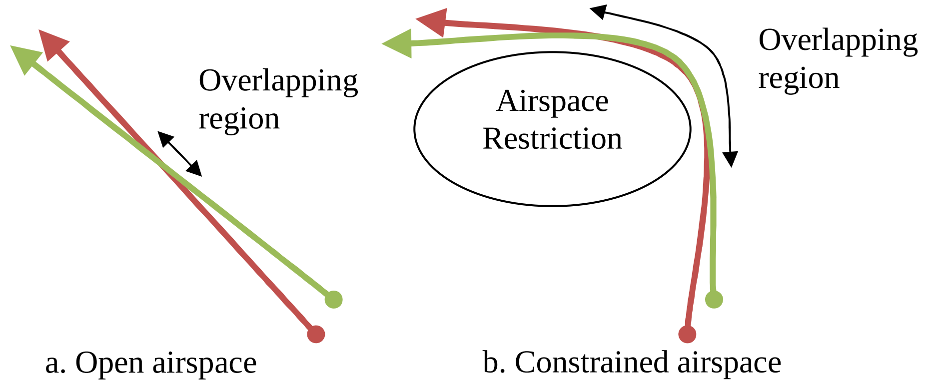


Figure 5 Two possible futures (red and green) of a flight are given. Near an airspace restrictions the certainty in respect to the future location of an aircraft is increased considerable in comparison to operation in an open airspace.

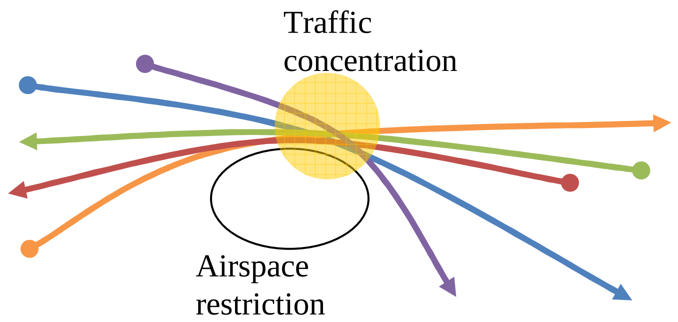


Figure 6 Several flights can be influenced by the presence of an airspace restriction. This results in traffic concentrations on the edge of the airspace restriction.

The contour of the airspace restriction will have concentrations of traffic (see Figure 6). This is the result of flights being pushed away from their optimal flight trajectory by the airspace restriction. The new optimal flight trajectory given the airspace restriction will likely go along part of the contour of the airspace restriction. If this is true of several flights traffic concentrations can be expected at the contours of airspace restrictions.

It is assumed that ATFM near an airspace restriction may be applied when density or complexity issues are expected. It is furthermore assumed that ATFM near an airspace restriction can handle time uncertainties.

Regions with density or complexity issues in between airspace restrictions

A flight operating through an airspace with several airspace restrictions is influenced considerable by the airspace restrictions (see Figure 7). Similarly as with the operation near a single airspace restriction the trajectory is quite stable near the airspace restrictions. The stability is in general increased in comparison to the single airspace restriction.

Even with a considerable inaccuracy in the RBT of a flight it is reasonable certain that the trajectory will go along and in between the contours of the airspace restrictions. Only the moment of arrival at the edges of the airspace restrictions varies considerable with the inaccuracies in the RBT.

Furthermore, the room to manoeuvre in between the airspace restrictions is quite limited. Conflict resolution manoeuvres to the left or right can be restricted or even unavailable. The need for short and medium term conflict resolution manoeuvres in between airspace restrictions should therefore be minimised.

It is assumed that ATFM in between closely spaced airspace restrictions will be applied. It is furthermore assumed that ATFM near an airspace restriction can handle time uncertainties.

Also it is assumed that in between closely spaced airspace restrictions additional strategic flow measures will be applied to limit the need for short and medium term conflict resolution manoeuvres.

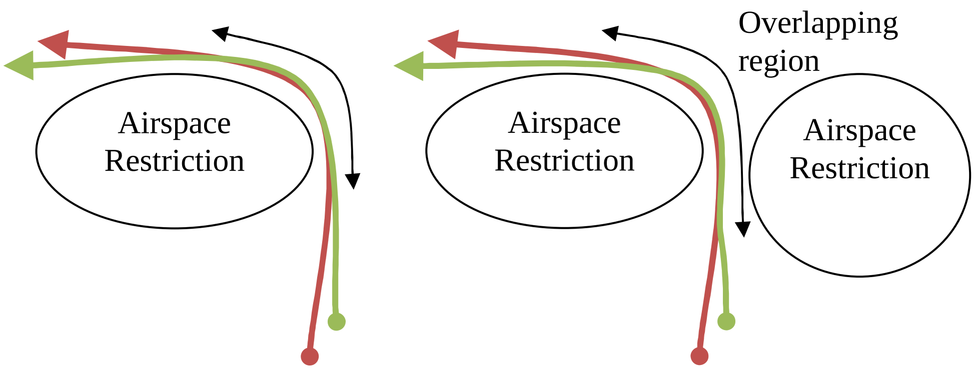


Figure 7 Two possible futures (red and green) of a flight are given. In between airspace restrictions the certainty in respect to the future location of an aircraft is increased in comparison to operation near a single airspace restriction.

<u>Conclusions regarding regions with potential density or complexity issues</u>
Based on the description in the previous three sub-sections on regions with potential density or complexity issues the following can be concluded:

- ATFM is not applied in open airspace with random regions having density or complexity issues. Short and medium term conflict resolution mechanisms are assumed to be effective strategies for resolving the traffic situation in an open airspace.
- ATFM near an airspace restriction may be applied when density or complexity issues are expected.
- ATFM in between closely spaced airspace restrictions will be applied.
- In between closely spaced airspace restrictions additional strategic flow measures will be applied to limit the need for short and medium term conflict resolution manoeuvres.
- ATFM near an airspace restriction can handle time uncertainties.

4.2.2 Capacity of an airspace cell with potential density or complexity issues

The capacity of an airspace cell is defined as the number of flights that can pass through an airspace cell over a given time period.

Once a region with a potential density or complexity issue has been identified the acceptable capacity or complexity for that region needs to be identified. The acceptable capacity or complexity depends on the acceptable traffic limits based on short and medium term conflict resolution, the airspace restrictions, and the applied additional strategic flow measures.

The acceptable capacity or complexity limits of an airspace cell are not yet known. Other research within the iFly project still has to identify these limits. It is therefore assumed that the rules to determine acceptable capacity limits are given for usage within FMSSA.

4.2.3 ATFM in between closely spaced airspace restrictions

In the sub-section above it was concluded that ATFM measures are necessary in between closely spaced airspace restrictions. In this sub-section a method is developed for defining a flow restricted region in between closely spaced airspace restrictions.

Self-separation airspace can contain and be adjacent to various airspace restrictions and hazardous airspace areas. As was identified in the above sub-section, the region between the airspace restrictions has potential to attract traffic flows to a confined airspace.

Before we continue, we will define the term “airspace cell” as an airspace region to which flow restrictions maybe applied. An “airspace cell” is a sub-area of a self-separation airspace.

So the question is how to define topologically an airspace cell to which potentially flow measures will be applied?

Below we will develop a topology for a novel airspace cell design. Furthermore, strategic flow measures for our airspace cell design will be developed.

Triangular airspace cells in between closely spaced airspace restrictions

We define a triangular airspace cell in between the centres of three closely spaced restricted areas (see Figure 8). Flow restrictions can be applied to the triangular airspace cell. This includes the novel scheduling method, which will be introduced in sub-section 4.4.

We assume that the three closely spaced restricted areas will be convex. (In this way the centre of the restricted area is always within the boundaries of the restricted area.) The triangular airspace cell will always cover a section of the trajectory of flights passing in between the three closely spaced restricted areas. This means that flow restrictions for the triangular airspace cell will be applicable to all flights passing in between the three closely spaced restricted areas.

In the next sub-section we will introduce a novel strategic flow measure that can be applied to the triangular airspace cell. After that, we will show that the triangular airspace cell can be used also in areas with more then three restricted areas.

Strategic flow measures for triangular airspace cells

The triangular airspace cell has a property which allows it to pass traffic through the triangular airspace cell without the need for crossing traffic flows inside the airspace cell itself. By geometrically ordering traffic patterns the complexity within the triangular airspace cell can be reduced [iFly D3.2i]. The crossing of traffic flows can and should be done outside the airspace cell where is sufficient open airspace to manoeuvre and resolve conflicts in the short and medium term. It is assumed that in the open airspace short and medium term conflict resolution methods are adequate. Within the airspace cell traffic flows can be separated strategically (see Figure 9).

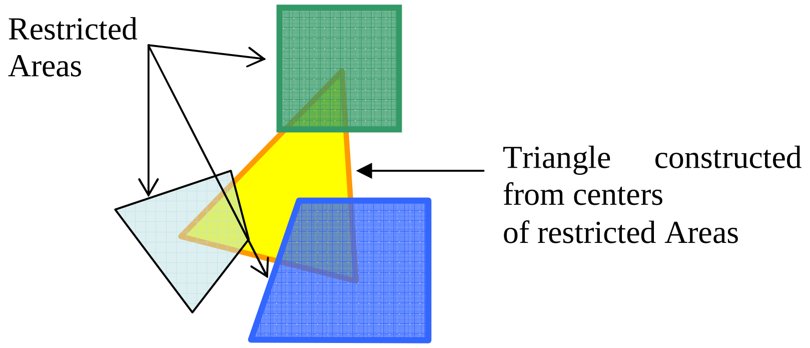


Figure 8 Triangular airspace cell in between centres of restricted areas.

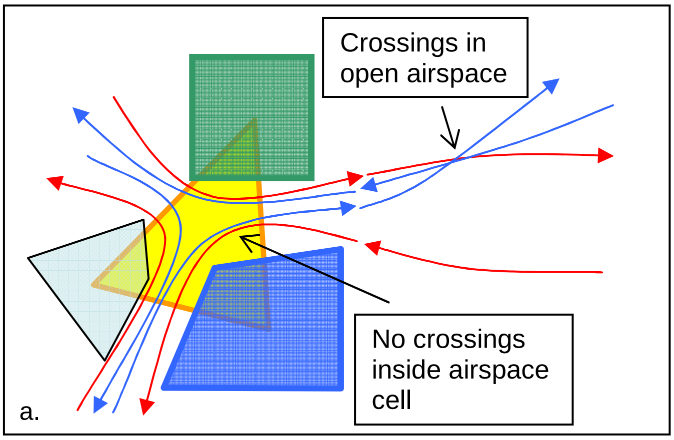


Figure 9 Triangular airspace cells can handle traffic from all directions without the need for crossings within the triangular airspace cell. Crossings can be accommodated in the open airspace.

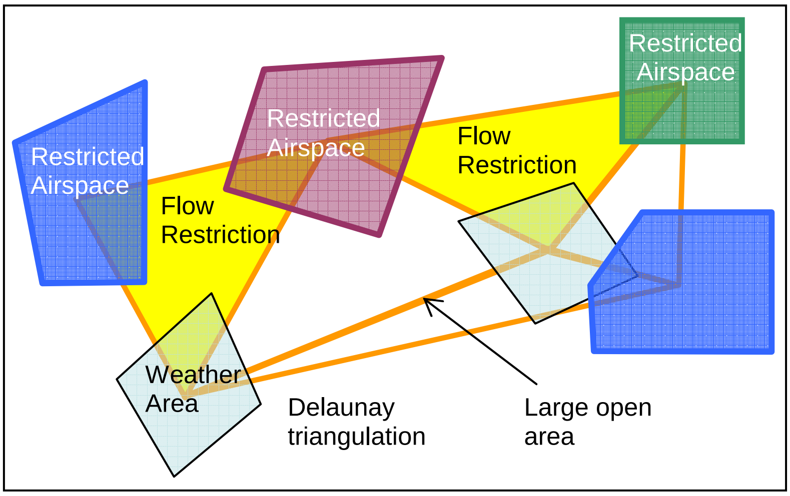


Figure 10 Using Delaunay triangulation the airspace between restricted airspaces can be covered with triangular airspace cells. Large open areas will not be taken into consideration for flow restrictions.

<u>Airspace areas with multiple restricted airspaces</u>

The triangular airspace cell defined above can also be applied to airspace areas with multiple restricted airspaces. Using a Delaunay triangulation [Lee 1980] between the centres of the restricted airspaces the airspace area can be covered with non-overlapping triangular airspace cells between the closely spaced restricted areas (see Figure 10).

The triangulation will result in a set of triangular airspace cells. Not all triangular airspace cells will need flow management restrictions. Triangular airspace cells which cover large open areas will not be taken into consideration for flow restrictions.

The Delaunay triangulation maximizes the minimum angle of all the angles of the triangulation. This will avoid skinny triangles. Furthermore, the Delaunay triangulation ensures that there will be no other centres of restricted airspaces within the circumcircle of any triangle of the Delaunay triangulation.

4.3 Identifying demand for airspace

Once the capacity of the airspace has been identified, the demand for the airspace has to be determined. To be able to determine the demand for airspace it is necessary to know what the expected flight paths of all flights within the self-separation airspace are. Within SESAR the SBT and RBT have been defined. The SBT and RBT are a representation of the expected flight path in route, altitude and time through the self-separation airspace.

With the use of the complete set of SBTs and/or RBTs it is possible to estimate the location of flights over time. The demand for local airspace can be estimated in this way.

There are drawbacks of this method for determining the demand for local airspace. First of all, all SBTs and/or RBTs have to be known. Flights without a SBT and/or RBT are not taken into account for the demand estimation. This results in an underestimation of the demand. Secondly, SBTs and RBTs have a certain level of uncertainty. Due to this the determined demand for local airspace has also a level of uncertainty. This level of uncertainty increases with time.

For the purpose of the scheduling technique that will be presented in the next sub-section it will be required to not only let flights provide there SBT and RBT, but also let flights indicate their expected uncertainty in respect to the SBT and RBT. This should be in regarding route, altitude and time. The level of uncertainty can vary with time. So further away in time the uncertainty can increase. Furthermore, the flights should also indicate their level of flexibility in respect to the time along the route. The level of flexibility can vary with time.

4.4 Flexible schedules for flow restrictions

In this sub-section a novel method for the flexible scheduling of flights through flow restrictions is developed. The method allows balancing the demand with the available capacity for an airspace cell. Before the method is explained in more detail (see sub-section 4.4.2) the problems with two current methods, Flow Control and Arrival Management, are explained in sub-section 4.4.1.

4.4.1 Current Flow Control and Arrival Management

Flow Control

Flow Control allows balancing capacity and demand by setting limits to the number of flights within a bounded airspace for a defined period of time. For instance, 4 aircraft are allowed in a bounded airspace over a period of 12 minutes. Any aircraft beyond the 4 aircraft has to be delayed to enter the airspace in the next period of 12 minutes. In Figure 11 an example is shown for twelve flights being assigned each to one of three time blocks.

Time →

KLM123	AF432	LH945	*Slot cap.*
AF456	KLM532	BA998	
BA789	LH434	AF934	
LH101	BA455	KLM934	
12 min	12 min	12 min	

Figure 11 Flow Control assigns a fixed number of flights in a fixed time period to a bounded airspace. In this example 12 flights are assigned each to one of three time blocks of 12 minutes.

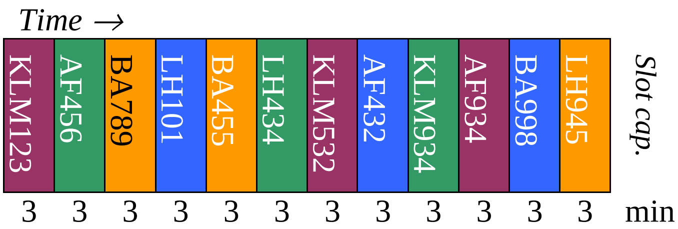


Figure 12 Arrival Management sequences and schedules flights. In this example 12 flights are sequenced with time intervals of 3 minutes.

<u>Arrival Management</u>

Arrival Management sequences and schedules flights to balance demand and capacity. The above example for Flow Control is replicated here for Arrival Management. It is assumed that an interval of three minutes is used for each flight. In Figure 12 an example is shown of twelve flights being sequenced with an interval of three minutes.

<u>Issues with Flow Control and Arrival Management</u>

Flow Control works in the time frame of several hours. Arrival Management works in the time frame of around 20 minutes. Flow Control allows for a considerable level of uncertainty. Arrival Management works best if the level of uncertainty is limited. Flow Control gives flights some degree of flexibility. Arrival Management introduces some hard constraints to flight trajectories. It would be desirable to have a method which has the advantages from Flow Control and Arrival Management and has less of the disadvantages from both methods.

4.4.2 A hybrid method of Flow Control and Arrival Management

In this sub-section we will develop a novel scheduling method that is a hybrid between flow control and arrival management. The method works in the time frame from tens of minutes to several hours till the time frame before departure. It allows for a varying level of uncertainty and flexibility over time.

<u>Capacity is defined as resource per time period</u>

To understand the hybrid method we will first introduce a fundamental property of capacity through an example.

Consider an airspace cell with a capacity of four aircraft per twelve minutes. One could assign four aircraft in each block of twelve minutes. But it is also possible to assign two aircraft in a block of six minutes, or one aircraft in a block of three minutes. Effectively the same capacity is assigned to a flight using a flexible slot that can vary in block size. This example is visualised in a schedule in the following Figure 13. In this schedule the same capacity, or flexible slot, is assigned to four aircraft in three different ways where the block size is varied.

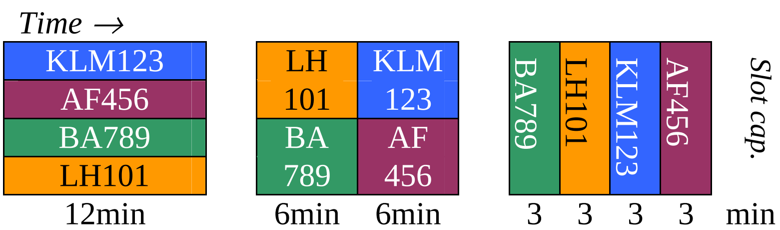


Figure 13 Assignment of flexible slots to a number of flights with varying block sizes (3, 6, and 12 minutes).

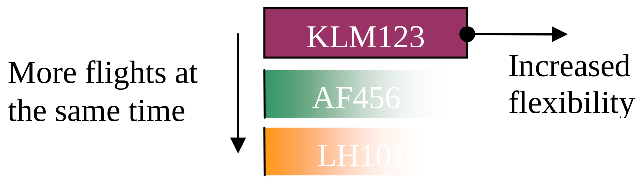


Figure 14 When more flights can be accommodated at the same time also the flexibility is increased, and vice versa less flights at the same time results in less flexibility.

From the example it is clear that having varying block sizes also varies the flexibility given to a flight (see Figure 14). So a large block size represents a large flexibility. An aircraft is allowed to arrive early in the block, but also late in the block. Furthermore, there where it is only possible to accommodate a limited number of aircraft at the same time the block size can be limited. So if only two aircraft can be accommodated at the same time the block size is limited in the example to 6 minutes, and if only one aircraft can be accommodated at the same time the block size is limited in the example to 3 minutes. This simultaneously limits the flexibility given to the flight in the schedule.

Having flexibility in assigning flexible slots to flights opens up a number of opportunities. First of all, regarding the flexibility towards operating RBTs. Secondly, the flexibility in assigning flexible slots depending on the time of arrival to the specific airspace. Thirdly, it is possible to mix various levels of time intervals in the same schedule. This is explained in the following two sub-sections.

a. Flexibility depending on time till actual arrival

Being able to assign slots to flights in a flexible way allows taking aspects of uncertainty and flexibility in to account when aiming for a certain time of arrival into account [iFly ConOps D1.3]. First of all, the uncertainty that a flight will arrive to a specific part of airspace at a certain time will increase with time to arrival to the airspace. Wind, weather, and interaction with other traffic will increase uncertainty over time. Assigning the slots to a specific flight with more flexibility in time can reflect this uncertainty. Secondly, the range of arrival times that an aircraft can aim for, increases with the time period until arrival. Close to the actual arrival it is not possible anymore to move a lot within the arrival time, but a few hours before the actual arrival an aircraft can easily move a few minutes with the arrival time by changing a cruise speed a little. So also here it is possible to assign flexible slots to a specific flight over a larger time interval reflecting the flexibility in being able to reach both the earliest, and also the latest times of the interval. This flexibility regarding time of arrival is reflected in the schedule in Figure 15.

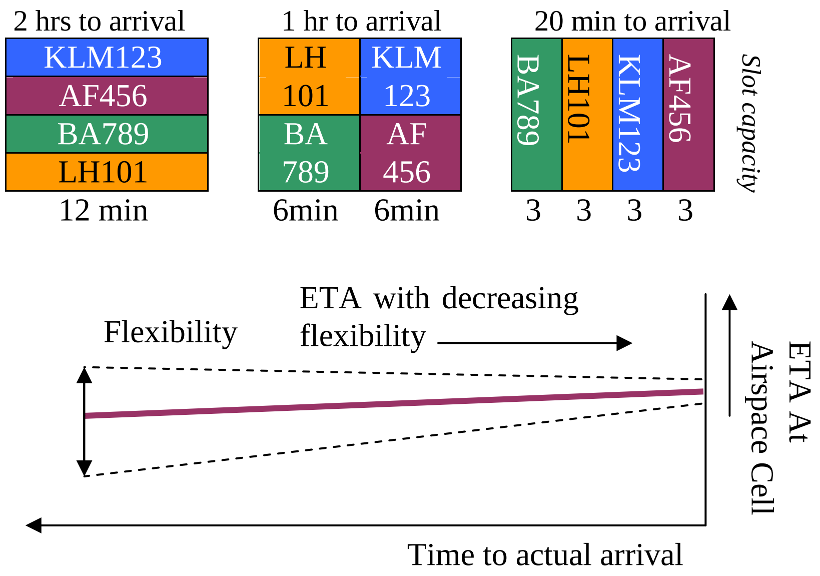


Figure 15 Assignment slots flexible over time. A few hours prior to arrival a flight can still vary with its arrival time. When the time until arrival decreases the level of flexibility regarding the arrival time decreases.

b. Flexibility in having different time intervals for different flights

Due to flexibility in assigning slots to specific flights, and at the same time being able in assigning a specific time interval to a specific flight it is possible to mix various levels of time intervals in the same schedule [Figure 16]. In the example BA455 has a flexibility of 12 minutes, but the LH434 has only a flexibility of 6 minutes.

Dynamic scheduling of the hybrid schedule

Once it is clear that it is possible to populate a hybrid schedule with individual flights having individual levels of flexibility there is a need to have a scheduling technique that handle this scheduling problem. Such a scheduling technique must find a feasible schedule. The schedule has to comply with the slot capacity constraints (for instance it is only allowed to have two aircraft in each six minutes block at the time of arrival). Furthermore, the flexibility a flight has varies in time. With progressing time the flexibility available to a flight decreases. So the schedule has to be adjusted dynamically to reflect the progression in time and the reduction in flexibility.

The hybrid schedule not only has to be feasible, but also optimal. The objective for the schedule is to minimise fuel penalties as a result of restrictions imposed by ATFM. Therefore, the schedule is assumed to be optimal when the largest possible flexibility is given to the flights in the schedule.

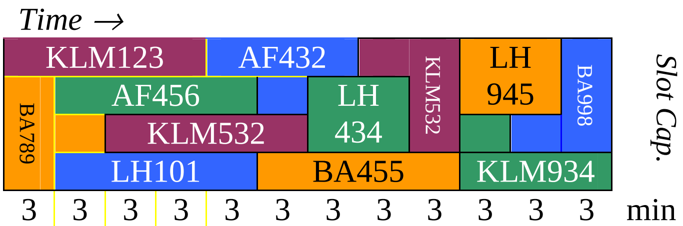


Figure 16 Each flight can be assigned an individual level of flexibility in the schedule for the specific airspace cell.

5 Concept for Flow Management in Self-Separation Airspace

The aim of the following Concept of Operations is to develop a novel Air Traffic Flow Management concept applicable to Self-Separation Airspace (FMSSA). The flights ensure their own separation from other aircraft and conflict elements. Flights also provide their Shared and Reference Business Trajectory to FMSSA.

The time frame for FMSSA is varying from several hours before departure until tens of minutes prior to an aircraft reaching a specific location. The large time frame makes it impractical to perform actual conflict resolution this far in the future. Therefore, the objective of the FMSSA concept is to address the issue of resolving congestion [iFly D5.1] without addressing long term conflict resolution.

The FMSSA concept does not try to provide a full ATFM concept applicable to all aspects that ATFM encompasses inside and outside self-separation airspace. The emphasis of this FMSSA concept aimes on those aspects that basically differ between self-separation operations and operations in managed airspace.

First of all a short overview is given of the FMSSA concept in sub-section 5.1. Secondly, the airspace definition for the FMSSA concept is given in sub-section 5.2. Then the assumptions in sub-sections 5.3 are discussed. In sub-section 5.4 a basic operational description is given followed by an operations description in sub-section 5.5. Sub-section 5.6 and 5.7 describe in more detail the flexible airspace cell and flexible schedules for FMSSA operations.

5.1 Overview of FMSSA

As was defined in sub-section 4.1 Air Traffic Flow Management is managing flow in an efficient way to or through areas where demand is exceeding the available flexible slot capacity. To be able to provide FMSSA service for self-separation airspace we identify four main functions:

1. Identify airspace areas (defined as airspace cells) in self-separation airspace that has the potential for density or complexity issues.
2. Determine the allowed traffic density or complexity for the airspace cells.
3. Identify the demand for the airspace cells.
4. Limit the demand to the airspace cells when the allowed traffic density or complexity is exceeded.

The four main functions of the FMSSA concept are described in more detail within the sub-sections below. The two novel methods, flexible airspace cells and flexible schedules, identified in section 4 will be incorporated within the FMSSA concept. It will be shown that the two novel methods can be generically applied to handle various types of flow management issues.

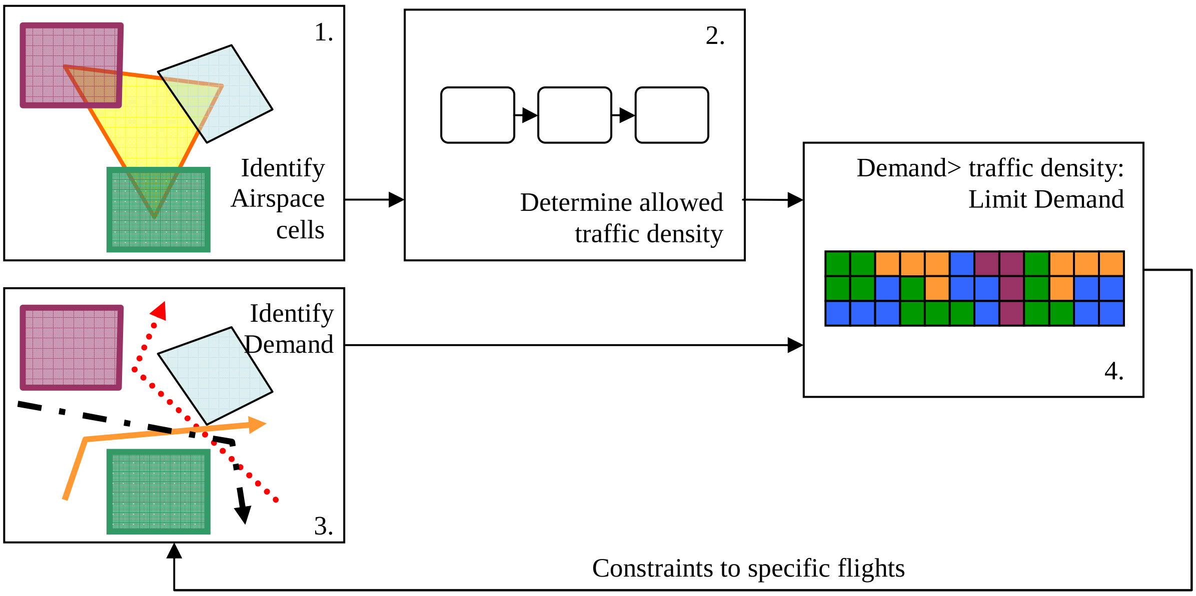


Figure 17 Four main functions for Air Traffic Flow Management in Self-Separation Airspace.

5.2 Self-Separation Airspace with Flow Managed Airspace Cells

The FMSSA concept is applicable to Self-Separation Airspace (SSA) where flights are responsible for their own separation from other aircraft and other conflict elements [iFly ConOps D1.3].

The iFly A^3 ConOps does not cover the airspace around airports. Hence it is assumed that the terminal airspaces are still managed by Air Traffic Control and are not relying on self-separation operations. The ATFM concept described in this section does therefore not take account of terminal airspaces and airport operations although the operations around airports are of utmost importance for an overall ATFM operation.

In Self Separation Airspace the airspace users are the separators. The airspace has no binding flight level structure. Within the airspace aircraft can use their user-preferred routing as long as they separate themselves from the other traffic, and they comply with constraints applied by flow management on their RBTs.

Some airspace areas will be considered to be conflict environments [Figure 18] from which self-separation flights should in general keep away from. Those are:

- Restricted airspace areas (RAA), which are non-moving conflict zones. In some cases only specific flights or priority classes are allowed into the restricted areas.
- Weather hazard areas (WHA), are dynamic conflict zones. Weather areas can be accessible to some certified aircraft.
- Protected airspace zones (PAZ) belong to other aircraft, which are not equipped properly for operating in the SSA.
- Terrain and other obstacles.

For flow management purposes the following airspace area is identified:

- High density areas (airspace cells, AC) provide a considerable reduced flexibility to flights such that self separation gets to the limits of what is considered to be safe for separating traffic from each other.

The airspace information is distributed by different entities through SWIM (System Wide Information Management) to the airspace users. FMSSA can also access the airspace information. FMSSA is the responsible source for the high density area information.

5.3 Assumptions FMSSA is based on

The design of this concept of operations for FMSSA within Self-Separation Airspace for self separating traffic is based on a number of assumptions. The assumptions are divided into three categories (1) airspace cell related, (2) demand related, and (3) related to flow constraining flights:

Airspace cell related assumptions

- Under specific circumstances, like bad weather areas, it is possible that certain parts of airspace have actual restrictions on the number aircraft that can be handled per unit of time. Although in principle the airspace users are responsible for self separation and therefore must be able to handle these kinds of situations on their own it is assumed that it is more efficient to apply in these restrictive areas flow management.
- Flow management for Self-Separation Airspace does not have to take account for capacity restrictions due to workload limitations in managed airspaces. The only restrictions that apply are those identified as limits for self-separation operations under specific circumstances (e.g. weather cells / airspace boundaries / entry and exit conditions / traffic focal areas).
- Aircraft operating in SSA use self-separation. This means that any flow measure must not restrict self-separating aircraft in their freedom to manoeuvre and make altitude changes to resolve conflicts in the medium and short term [iFly ConOps D1.3]. Strategically deconflicted routes can be used for the trajectory planning through flow restricted airspace.
- The flights are responsible themselves to handle specific weather conditions. The crowding of traffic in certain areas due to interaction with weather systems can result in capacity issues. These issues need to be addressed by ATFM.

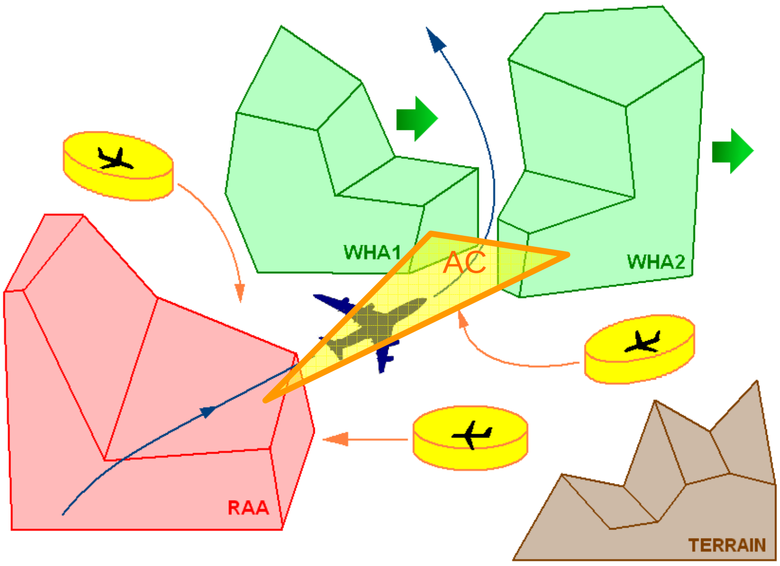


Figure 18 Self-separation airspace [Source iFly ConOps D1.3] including airspace cells (AC) to which flow restrictions can be applied.

- Airspaces with constraints can result in traffic being re-routed around restricted airspaces [Van Balen 2008]. Flow measures can result in the creation of airspaces that have restrictions. It is assumed that the A^3 self-separation concept can handle the specific type of conflicts resulting from re-routes around restricted airspaces (including airspaces with flow measures). As this is outside the airspace cells with flow management restrictions it is outside the scope of the flow management concept. It should be addressed within the more general A^3 ConOps.

Demand related assumptions

- The use of trajectory based operations (TBO) for deconflicting traffic tactically within the time frame of FMSSA will not be practical as the uncertainties grow in time and circumstances easily change over time. Agreeing upon a time range instead upon a specific moment is far easier to comply to for an aircraft FMS (Flight Management System) and it gives more flexibility to fly an optimal regime.
- Predicting demand in specific parts of airspace is subject to a considerable uncertainty due to various influences on the actual ground speed, departure delays, feed forward effects, and specific airline policies [Masalonis 2004]. The RBT provided from the aircraft or airline will give in principle a better estimate of the trajectories than ATFM can provide itself by prediction. So these RBTs will be the bases for the flow management demand estimations.

Assumptions related to flow constraining flights

- When traffic density in a bounded part of airspace is below a certain limit it is assumed that short and medium term conflict resolution can handle traffic efficiently without inflicting significant delays on traffic [iFly D3.2i].
- For having a good demand estimation based on RBTs it is of importance that the aircraft and airlines provide realistic trajectories which are not biased by gaming motives [Hoffman 2003]. The approach is therefore that aircraft may not pass through flow restricted airspace that has not been allocated to the airspace user. This gives aircraft users the motive to provide realistic trajectories otherwise they will not be able to pass through flow restricted airspaces.
- Aircraft that fail to consume their assigned flexible slot to a specific airspace cell will have to find new flexible slot capacity. This can happen due to various reasons like higher priority flights requesting a flexible slot, or deteriorating weather conditions reducing capacity. The reason to do this is to keep schedules for airspace cell capacity robust without resulting in the trickling down of schedule changes to other airspace cells.

5.4 Basic FMSSA Operations

The basic operations of flow management for self-separation airspace are explained in this sub-section. The strategic flow management process has a number of phases it goes through (see Figure 19). It starts long before the actual departure to adjust the airspace organisation to the expected demand. In the hours before the actual departure the demand is adjusted for those airspace areas where density or complexity issues are expected. Once in flight the flow management process continues as the availability of airspace cells and trajectories still can change during flight.

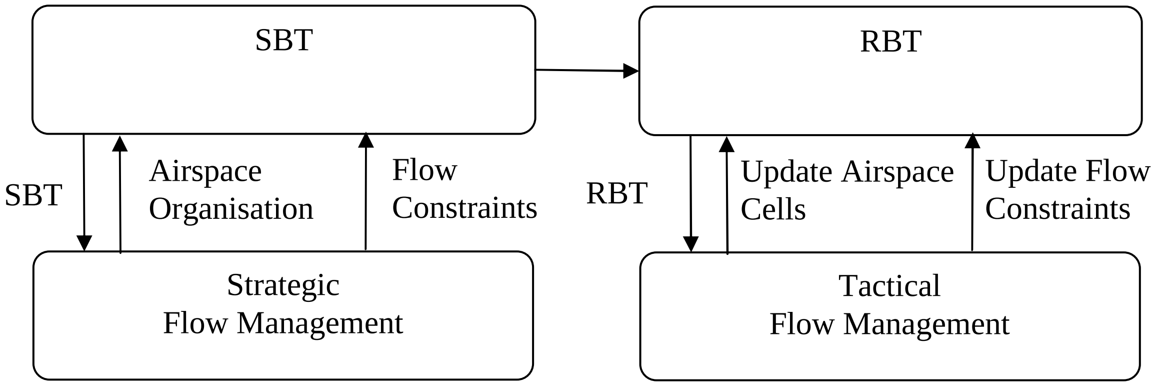


Figure 19 Overview of the Flow Management process. The strategic flow management phase is before departure, and the tactical flow management phase is beyond departure.

<u>Strategic Flow Management Phase</u>

In the weeks and days before the actual departure the Shared Business Trajectories (SBT) are collected. The Network Operations Plan (NOP) is updated and the demand for airspace can be identified. The airspace organisation (e.g. managed airspace, restricted airspace, and self-separation airspace) can be adjusted accordingly to match the expected traffic flows. Regarding the self-separation airspace the Network Manager will identify any parts in the airspace for which density or complexity issues can be expected given the set of SBTs (see Figure 20). For the volumes with density or complexity issues triangular airspace cells are defined and the flexible slot capacity for the airspace cells is determined (see Figure 21).

For the airspace cells the available flexible slots are assigned to flights according to the priority and taking account of the time boundaries indicated by the airspace users. Any trajectories that will not fit into flow schedules for airspace cells may be adjusted by the airspace users.

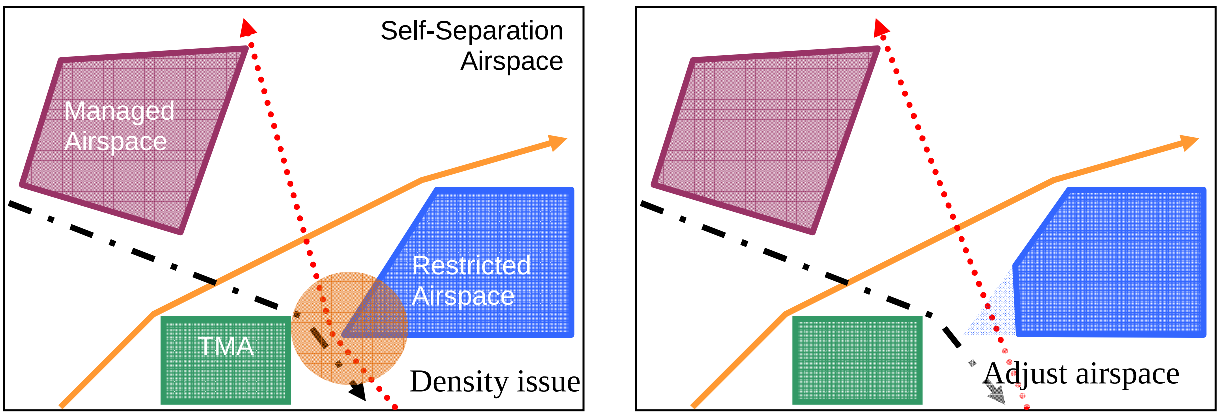


Figure 20 Airspace organisation is adjusted based on demand reflected by SBTs.

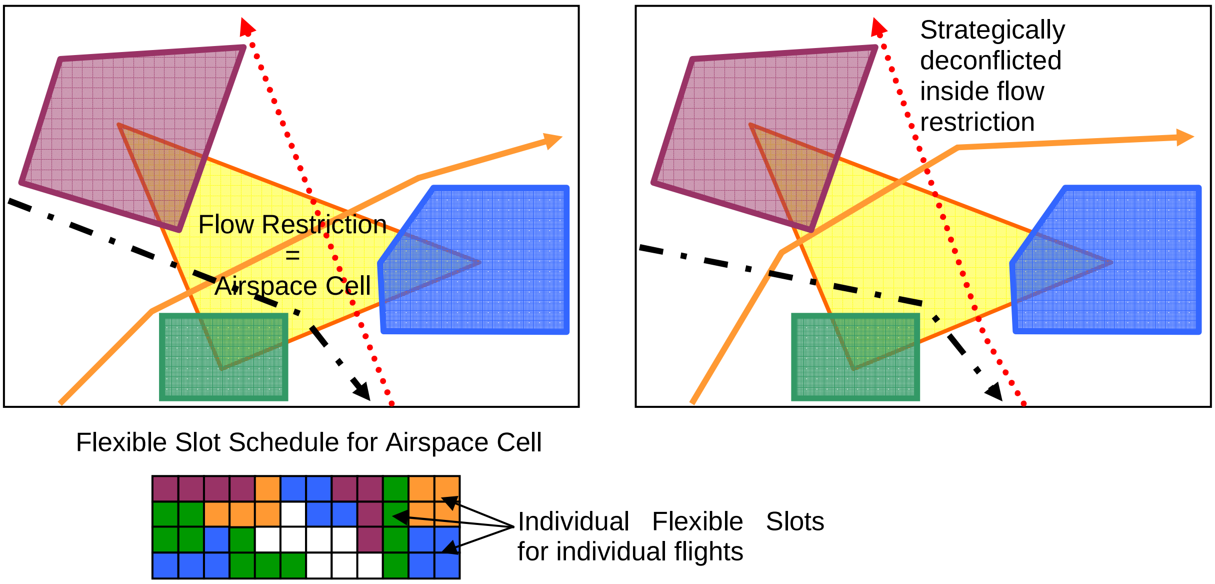


Figure 21 Bounded airspace with a high demand or complexity will be subject to flow restrictions (airspace cells). To each airspace cell a flexible slot schedule will be assigned.

In the hours before the actual departure the SBTs are updated to reflect new scheduling information and the availability of weather forecasts. The NOP will show the updated SBTs. Based on the weather forecasts additional airspace cells will be created. For the new airspace cells the flexible slot capacity is determined. The available flexible slot capacity is assigned to flights according to the priority and taking account of the time boundaries indicated by the airspace users. Any trajectories that will not fit into the schedules for the airspace cells must be adjusted by the airspace users [Figure 22].

<u>Tactical Flow Management Phase</u>
Upon execution of the flight the aircraft will push back, taxi, and take off. Once the take off time is known the RBT is generated based on the SBT. The time boundaries of the RBT are updated regularly to reflect the updated information on the current position, but also indicating the room to manoeuvre by slowing down or speeding up along the nominal trajectory. The flow schedules for the constrained airspace cells are updated accordingly.

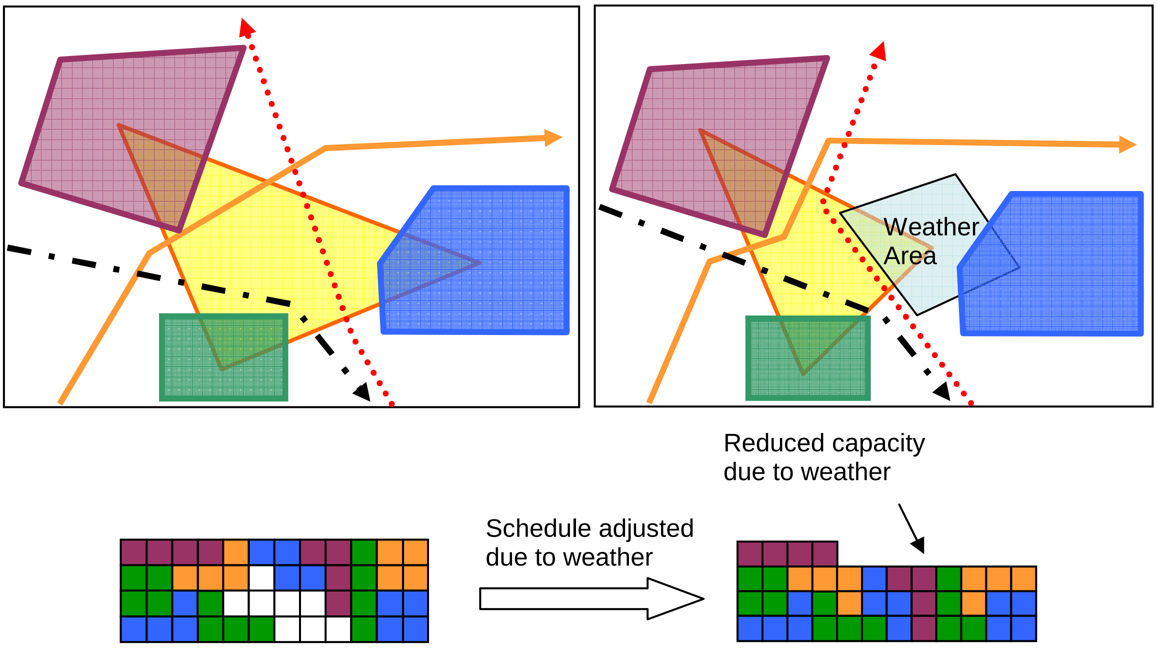


Figure 22 In the hours before the actual arrival to an enroute position new flow restrictions can be created as a result of forecasted weather areas. This can have effect on the available capacity for the flexible slot schedule.

Once in flight the timing information regarding the room to manoeuvre for the RBT is updated regularly. The schedules for the constrained airspace cells are updated accordingly [Figure 23]. The flexibility given to flights is reduced when time passes. The updated constraints from the schedules are distributed to the airspace users to take into account into the flight management systems.

In the following sub-section FMSSA operations are described in more detail.

5.5 Detailed FMSSA operations

The previous sub-section gave a general overview of the FMSSA operations. This sub-section describes the FMSSA operations in more detail. Starting in sub-section 5.5.1 on the roles and responsibilities of relevant stakeholders in respect to FMSSA. Sub-section 5.5.2 describes the flight rules that are applicable for flow management. Sub-section 5.5.3 gives an overview of the priority rules which need to be applied by FMSSA. Finally, sub-section 5.5.4 shows the link between military operations and FMSSA.

5.5.1 Roles, and responsibilities

In respect to FMSSA there are four main stakeholders having a role in the flow management process. The four stakeholders are the network manager, the ANSPs, the flight operations centre, and the flight crew. Their roles and responsibilities are described below:

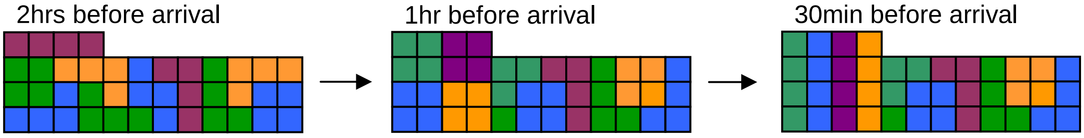


Figure 23 The flexible slot schedule for a specific airspace cell is updated regularly reflecting new information on the time flexibility of the flights.

Network Manager for Self-Separation Airspace

The role of Network Manager in respect to self-separation airspace is

- To place constraints on the flight plans of aircraft operating in self-separation airspace to ensure that the medium and short term conflict resolution systems will not be faced with a situation that they can not handle efficiently [iFly D5.3].
- To place constraints on traffic going from self-separation airspace towards managed airspace entry points. In this way the flight will enter the managed airspace complying with the entry conditions given by the ANSP of the managed airspace.
- To maximise overall performance of global operations in self-separation airspace taking into account the uncertainties of traffic.

The Network Manager for self-separation airspace cannot enforce any route compliance, but only the timing restrictions for a certain area or exit point.

It is the responsibility of the Network Manager for self-separation airspace:

- To be aware of high complexity or high density areas in self-separation airspace.
- To determine an applicable flow management restriction area for regulating high complexity or high density areas.
- To be able to limit traffic to the high complexity or high density area to acceptable levels by applying fair restriction rules.
- To schedule traffic to the flow management restriction area in such a way that it complies with priority rules. The only conflicts known in FMSSA are scheduling conflicts.
- To identify the need for having strategic deconflicted routes in the flow management restriction area.
- To identify the applicable strategic deconflicted routes through the flow management restriction area, and provide the route information through SWIM to the applicable flights.

ANSP’s influencing self-separation airspace

The role of ANSP’s in respect to flow management in self-separation airspace is the following:

- ANSP’s have no direct role in respect to self-separation airspace.
- ANSP’s provide the entry conditions for traffic entering managed airspace from self-separation airspace.
- ANSP’s provide relevant airspace organisational information influencing the self-separation airspace.

Flight Operations Centres operating in self-separation airspace

The role of FOCs operating in self-separation airspace in respect to flow management is:

- Providing and updating SBTs for the Network Manager
- Providing and updating data in respect to the flexibility of the time along the SBT.
- Adapting the SBTs to comply with the flow constraints provided in the NOP.

Flight Crew operating in self-separation airspace

The role of the flight crew operating in self-separation airspace in respect to flow management is:

- Providing and updating RBTs for the Network Manager.
- Providing and updating data in respect to the flexibility of the time along the RBT.

- Adapting the RBT time flexibility to comply with the flexible slot constraints to specific airspace cells.

5.5.2 Autonomous Flight Rules for Flow Management Restrictions

Autonomous aircraft that operate in self-separation airspace have to comply with the following rules:

- Autonomous aircraft are responsible for maintaining separation with all other aircraft. ATFM has no role in tactically separating traffic.
- Autonomous aircraft are required to comply with time constraints from ATFM. In case it is not possible for the flight crew to comply with the applicable flow constraint the flight crew will have to request an altered flow management time restriction.
- Autonomous aircraft that are not given access to the flow restricted area should not enter the flow restricted area and should maintain a minimum separation from the flow restricted area.
- Trajectory Management can use the strategic deconflicted routes provided by ATFM for planning trajectories through flow restricted areas. The flight crew is not required to use the strategic deconflicted routes through the flow restricted areas. The flight crew can expect considerable levels of conflicting traffic when operating outside the strategic deconflicted routes.
- Aircraft operating in the self-separation airspace shall not enter Managed Airspace through the dedicated exit points without approval of the responsible ANSP on the Managed Airspace.
- Aircraft with a raised priority should, whenever this is operational feasible, not try to enforce a passage through the flow restricted area outside the strategic deconflicted routes in the flow restricted area.
- In case there is no flexible slot capacity in a flow restricted area and an aircraft with a raised priority wants to pass through the flow restricted area it is allowed to the ATFM to withdraw the assigned flexible slot from a lower priority flight through the flow restricted area. This flexible slot will then be assigned to the raised priority flight.

5.5.3 Priority rules for FMSSA

When flights are assigned flexible slots in airspace cells with flow restrictions a number of priorities have to be taken into account. First of all there is a distinction between the following classes: normal, non-normal and emergency. Secondly, within a class there are different categories.

Aircraft higher in class and category have priority above aircraft lower in class and category when being assigned flexible slots in airspace cells. When flexible slot capacity is not available in the airspace cell then one or more aircraft with assigned flexible slots and a lower priority and/or category will have to return their reserved flexible slots. The higher priority aircraft will be assigned this flexible slot. The aircraft that have to return their flexible slot to FMSSA will have to find capacity at another time interval or will have to find an alternative route around the restricted airspace cell. This will prevent the propagation of scheduling adjustments through the network.

<u>Normal operations</u>

Under normal conditions the flight crew is able to perform all self-separation operations and comply with the restrictions applicable to airspace they are operating in. Aircraft operating with a normal priority level can be divided into a number of categories: ambulance flight, military aircraft in a national defence mission, military ordnance transport, special transport, scene of search, priority VIP aircraft (Very Important Person), and normal aircraft.

Non-normal operations

There are two non-normal categories. These are non-own surveillance capable and non-self separation capable. The predictability of these non-normal flights is highest when the number of trajectory changes is minimised. This is also necessary due to the reduced update rate on data available through SWIM on the non-normal operating aircraft. Therefore giving these flights priority when assigning flexible slot capacity in airspace cells will reduce the need for trajectory changes due to the unavailability of flexible slot capacity. The flexible slots reserved for the non-normal categories will probable be larger than is necessary for aircraft in the normal category.

The need for assigning flexible slots to aircraft in the non-normal categories will be low as these aircraft are required to leave self-separation airspace as soon as possible. The timeframe for flow management restrictions will be probable be beyond the time needed to exit to managed airspace.

Emergency operations

An aircraft in an emergency condition has a degradation of equipment, crew, or aircraft performance in such a way that the aircraft can not continue to operate under the assumption that it can maintain its own separation from other traffic [iFly ConOps D1.3]. A degradation of the SWIM network performance can result in an emergency condition for several aircraft at the same time.

In case of an emergency condition the aircraft is leading in determining the need for trajectory changes. The unpredictability of the trajectory under such circumstances beyond the medium time frame makes it that flow management can not really contribute to the situation. It therefore has no real advantage to put any flow restrictions on the other aircraft to increase the room to manoeuvre for the aircraft in the emergency condition. The aircraft in an emergency condition will try to leave self-separation airspace as soon as possible towards to land at a suitable airport. We therefore assume that the situation will be handled using the available medium and short term procedures for handling aircraft with a higher priority and dynamic restricted areas.

In case there is a degradation of the SWIM network performance it can affect several aircraft. This means that it is possible that those aircraft have no up-to-date information regarding airspace cells with a reduced capacity. Any updates regarding schedules for specific restrictions should take into account that the affected aircraft can not be rescheduled.

5.5.4 Military operations

Military aircraft which are properly equipped for self separation operations in SSA will also have to comply with the flow management measures. The priorities of military aircraft are taken into account in the flow management schedules applicable to flow restricted airspace cells.

When operating an interception mission through flow restricted airspace without requesting a flexible slot in the flow restricted airspace schedule the interception mission should try to use the strategically deconflicted routes through the flow restricted area as much as possible.

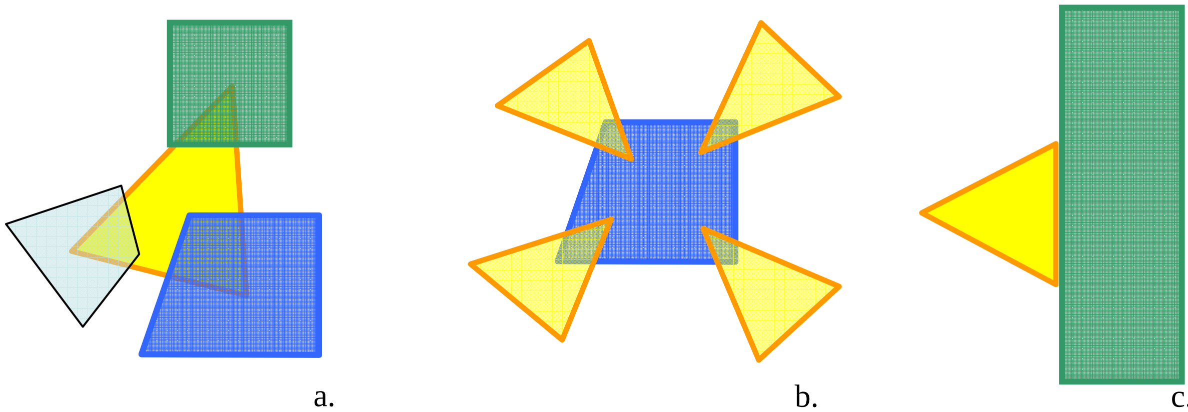


Figure 24 Triangular airspace cells used a.) in between closely spaced airspace restrictions in between centres of restricted areas, b) near single airspace restrictions, and c) for transition areas from self-separation airspace to managed airspace.

Head-of-state aircraft can request a larger share in the available flexible slot capacity in a flow restricted airspace if this necessary to be able to accommodate the larger than normal separation distance within the flow restricted airspace.

5.6 Identifying Airspace Cells

In sub-section 4.2.3 the concept of triangular airspace cells was developed. This concept is applied in three different ways in the FMSSA concept: a) between closely spaced airspace restrictions, b) for flow management near airspace restrictions, and c) for transition areas from self-separation airspace to managed airspace (see Figure 24).

In the following sub-sections the three different ways that the triangular airspace cells are applied are explained in more detail.

5.6.1 Triangular airspace cells in between closely spaced airspace restrictions

The triangular airspace cell can be applied in between closely spaced airspace restrictions. Flow restrictions can be applied to the triangular airspace cell. As vertices of the triangular airspace cell the centres of a set of three closely spaced airspace restrictions will be used. In this way the triangular flow restriction will be applicable to all flights passing in between the three closely spaced restricted areas.

As was explained in sub-section 4.2.3 crossing traffic can be handled outside the flow restriction in the open airspace. Inside the triangular airspace traffic from all directions can be strategically deconflicted (see Figure 25a).

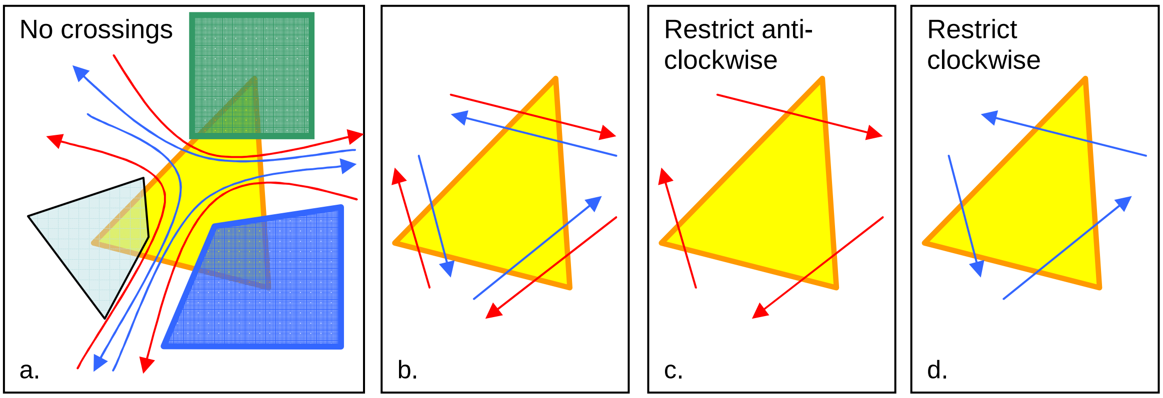


Figure 25 Triangular flow restrictions can in principle handle traffic from all directions without the need for crossings within the triangular airspace cell (a. and b.). When the entrances to the triangular airspace cells get to narrow it is possible to restrict traffic which is in the anti-clockwise (c.) or clockwise direction (d.).

<u>Limited lateral space for strategically deconflicted routes</u>

When the lateral space available for the strategically deconflicted routes through the airspace cell becomes too narrow the number of routes through the airspace cell has to be reduced. To always have an exit through the airspace cell it is best to restrict the strategically deconflicted routes only in the clockwise or anti-clockwise direction. This is illustrated in Figure 25c and d. Traffic going in the opposite direction can still pass the restriction by choosing a new route going in the opposite direction (see Figure 26).

<u>Two closely spaced airspace restrictions</u>

In the special case that there are only two closely spaced airspace restrictions it is not possible to create flow restriction triangles between the available airspaces. In this case it is possible to choose for a single line restriction instead of a flow restricted airspace in the shape of a triangle. The line restriction is enough to restrict traffic in between the two adjacent restricted airspaces without unnecessarily restricting traffic in the larger area around the two airspaces [Figure 27].

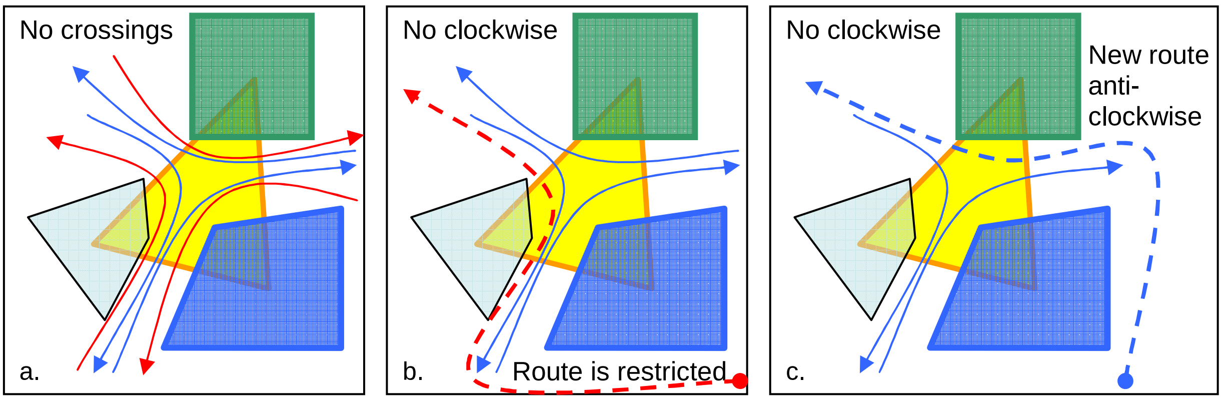


Figure 26 When the entrances to the triangular airspace cells get to be narrow it is possible to restrict traffic to for instance the anti-clockwise direction. It is still possible for traffic to pass the restriction by flying a different route and entering the restriction from another side.

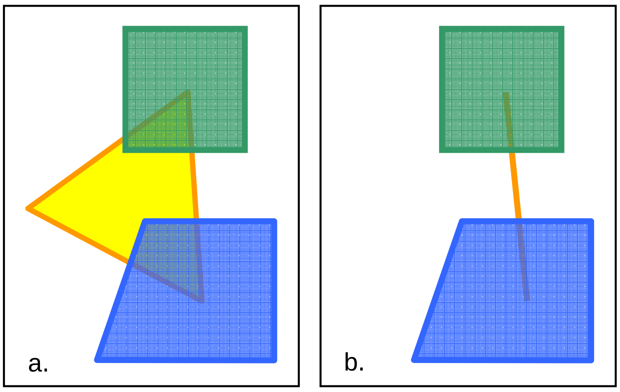


Figure 27 Flow restrictions between two closely spaced airspace restrictions can be handled by a line restriction (b.). The line is one of the sides of a triangle (a.).

Dynamic airspace cells

The use of triangulation, as explained in sub-section 4.2.3, has an additional advantageous. In case of dynamic airspace cells like hazardous weather areas the triangular flow restricted airspace cell can adjust dynamically to the new configuration without the need to create new and eliminate old flow restrictions all the time. The accompanying schedules to the flow restricted airspace cells can stay relatively intact in this way. This reduces the need for an increasing number of schedules due to dynamic situations (see Figure 28). Flights have to adjust their routes though to reflect the new situation.

Interaction with adjacent airspace cells

Adjacent triangular airspace cells with flow restrictions can not guarantee to be strategically deconflicted. A minimum set of strategic conflicts are left over. As Figure 29 shows the strategic conflicts consist of two types: merging conflicts and crossing conflicts. Both can be dependent.

The strategic conflicts should not be a problem for the self-separation concept. This should be validated though.

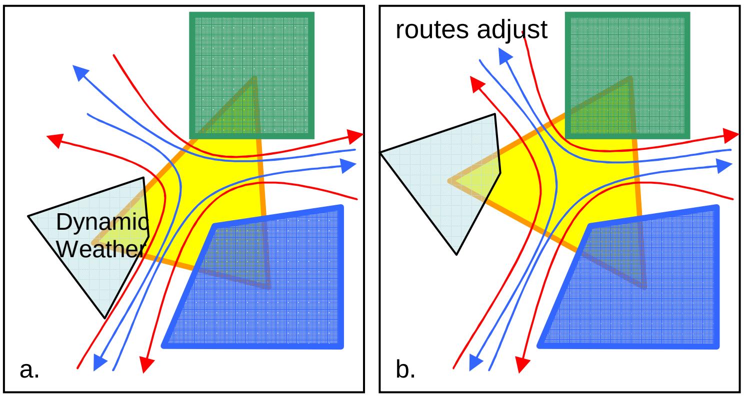


Figure 28 The dynamic nature of hazardous weather areas results in dynamic adjustments (from situation a. to b.) to the triangular flow restriction area.

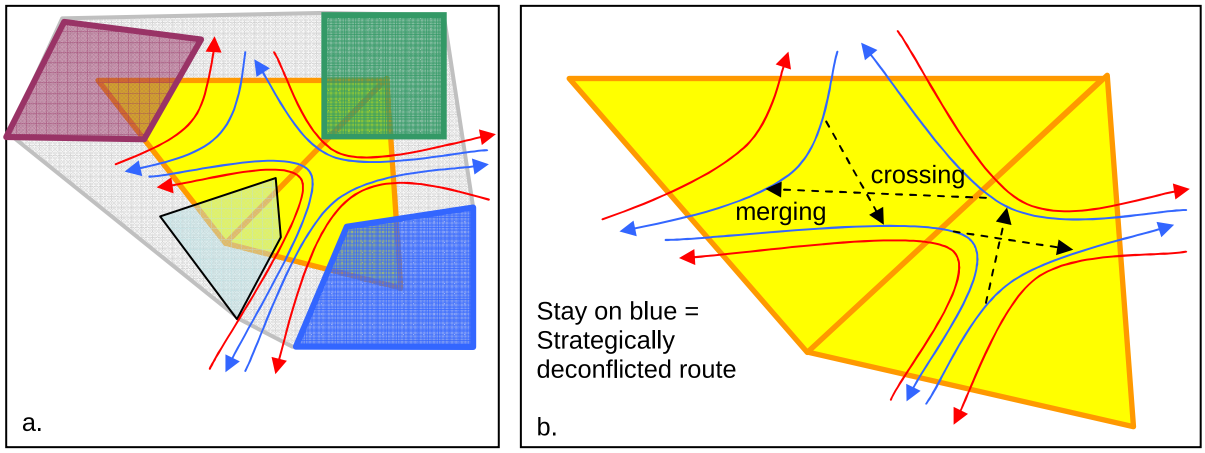


Figure 29 With adjacent triangular airspace cells with flow restrictions it is not possible to get a completely strategically deconflicted airspace. A minimum set of strategic conflicts is left over.

The strategic setup of the adjacent triangular airspace cells has the advantageous that in case the self-separation algorithm can not find a satisfactory solution without creating additional conflicts there is always a strategically deconflicted route out of the flow restricted area. This strategically deconflicted route is to not cross over to another route. This can be seen in Figure 29.

Adding additional flow restriction triangles to a set of two adjacent flow restriction areas will not change the situation. The same types of strategic conflicts will remain. So this means that additional flow restriction triangles can be added without actually adding complexity to the situation.

The number of possible routes through two adjacent triangular airspaces is 12 (see Figure 29.b). Of these possible routes 4 are only through a single airspace cell and 8 are through two adjacent airspace cells. This means roughly that two thirds of the routes through two adjacent airspace cells have dependent schedules. Adding more adjacent airspaces with flow restrictions will increase the dependency rate even further. This suggests that it is probable best to have a single schedule for a set of adjacent airspace cells with flow restrictions. This eliminates the need to synchronize dependent schedules of adjacent airspace cells, which would add unwanted complexity.

5.6.2 Airspace cells near single airspace restrictions

As was identified in sub-section 4.2.1 traffic concentrations are to be expected near airspace restrictions. It is possible to use the airspace cells defined for closely spaced airspace restrictions also as flow restrictions near single airspace restrictions. This includes the usage of strategically deconflicted routes through the airspace cells.

In this sub-section we will explain how the airspace cells will be used near single airspace restrictions. We will show where they are applied around the single airspace restrictions. We furthermore show how the strategically deconflicted routes are defined through the airspace cells.

The triangular airspace cells will be applied around an airspace restriction at the vertices at the edge of the airspace restriction. The size of the triangular airspace cell will be such that one

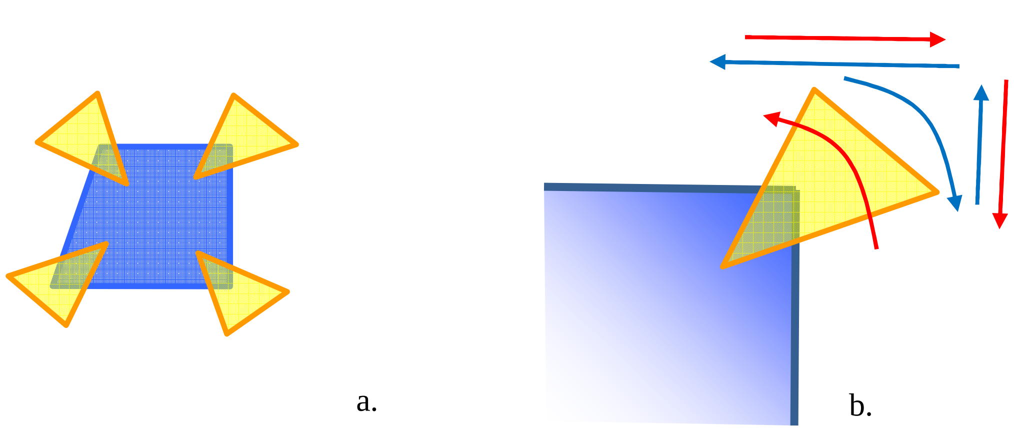


Figure 30 Triangular airspace cells used near single airspace restrictions (a.). One strategically deconflicted route can pass through the airspace cell. Other traffic passes freely outside the airspace cell (b.).

laterally spaced route can pass through the triangular airspace cell (see Figure 24b.). Only this laterally spaced route is put inside the airspace cell. It is assumed that other traffic flows can pass outside the airspace cell unrestricted using only short and medium term conflict resolution methods.

5.6.3 Airspace cells for transitions from self-separation to managed airspace

Transition operations involve the movement of aircraft from one airspace to another airspace. Two specific variants are discussed here. The transition from managed airspace to self-separation airspace and vice versa the transition from self-separation airspace to managed airspace.

In this transition there is both a role for flow management in self-separation airspace and ATC of the managed airspace. The detailed procedures concerning ATC during the transition will not be considered. Only the aspects regarding flow management in self-separation airspace will be described [iFly ConOps D1.3].

In this sub-section it is shown that the triangular airspace cell, which was developed in sub-section 4.3.2., can also be applied to transition operations. For the transitions operations also the strategically deconflicted routes will be applied.

<u>Transition from managed airspace to self-separation airspace</u>

An aircraft exiting managed airspace into self-separation airspace will do this at a specific MA exit point. The ANSP of the managed airspace will be responsible for both separation and flow management for the aircraft inside their MA. It is therefore that the ANSP will issue and update the exiting restrictions in order to maintain safe and efficient operations inside the managed airspace.

The ANSP has to ensure that the business trajectory will be conflict free for a limited time when exiting managed airspace. As the ANSP is not responsible for active separation control in self-separation airspace this means that the ANSP has to ensure the separation in another way.

An option to do this is to define a small airspace cell which is restricted [Beers 2002]. Only the aircraft exiting from the managed airspace are allowed to enter the restricted airspace. Aircraft within self-separation airspace are not allowed to enter the restricted airspace or have to leave the restricted airspace as soon as it has become active. The following Figure 31 illustrates this process. The shape and strategically deconflicted routes within the restricted airspace cell are the same as with a triangular airspace cell for flow restrictions in between restricted airspaces.

This means that the ANSP is activating the restricted airspace at the MA exit point. For aircraft in the self-separation airspace the restricted airspace at the MA exit point can be viewed just as any other restricted airspace with a full restriction to traffic flow from Managed Airspace.

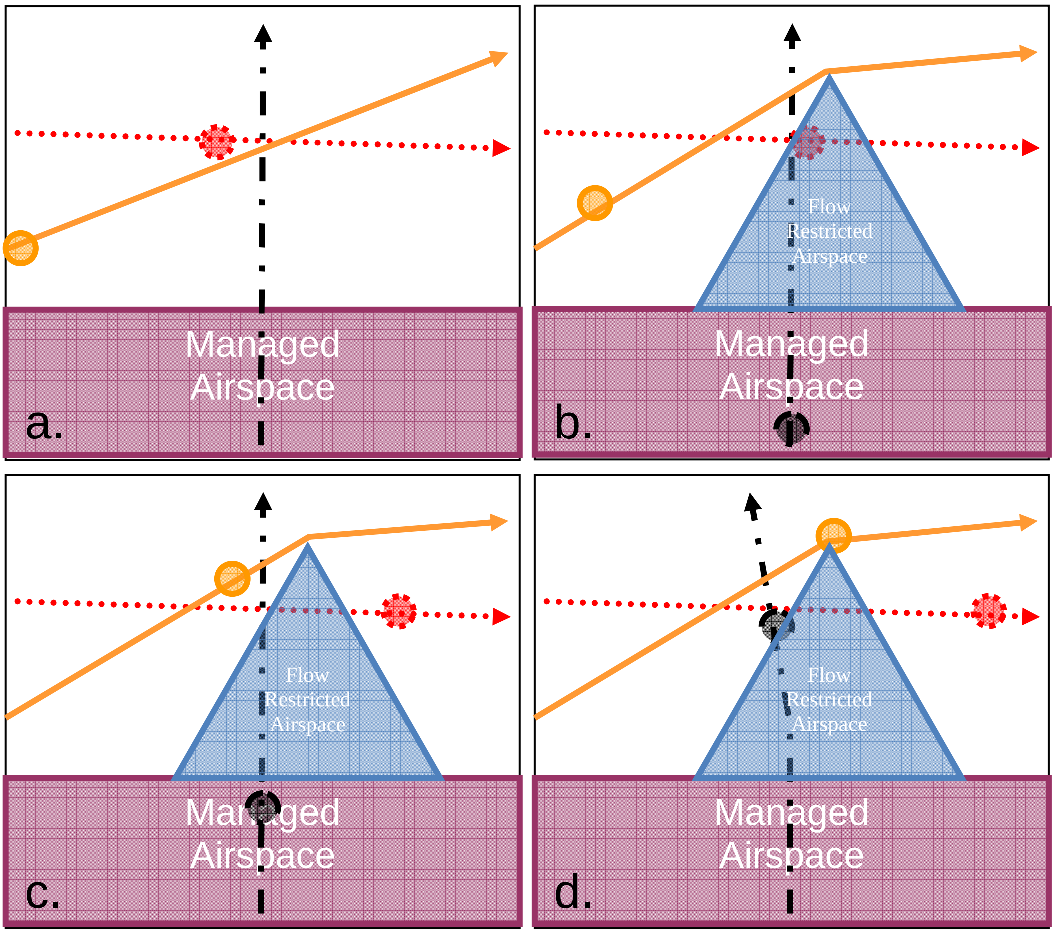


Figure 31 The ANSP creates a restricted airspace outside the MA exit point (b.). The aircraft in managed airspace can now exit to the self-separation airspace being assured of separation from other traffic (c.). Once inside the restricted airspace the aircraft is made responsible for its own separation when exiting the restricted airspace (d.).

<u>Transition from self-separation airspace to managed airspace</u>

An aircraft exiting self-separation airspace into managed airspace will do this at a specific MA entry point. The ANSP of the managed airspace will be responsible for both separation and flow management for the aircraft inside their MA. It is therefore that the ANSP will issue and update the entry restrictions in order to maintain safe and efficient operations inside the managed airspace.

The ANSP must always have the option to not allow traffic into the managed airspace at the last minute due to operational reasons. This means that the transition from self-separation airspace to managed airspace must allow for an abort manoeuvre which can safely be executed. In other words, a strategically deconflicted abort route within the transition region back into the self-separation airspace is needed.

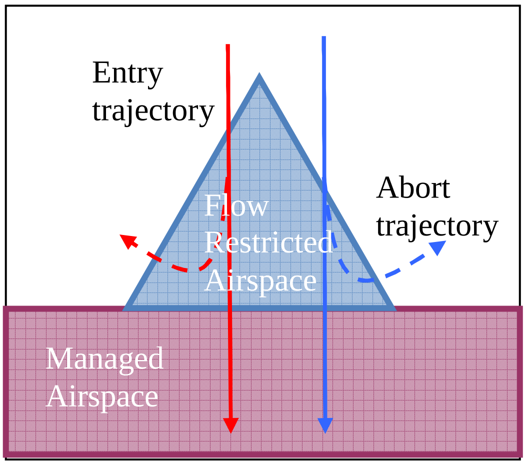


Figure 32 The Managed Airspace entry trajectory includes an abort trajectory.

5.7 Limiting demand within Airspace Cells

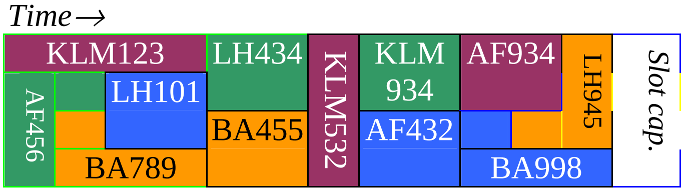
In sub-section 4.4.2 a hybrid method for flow control and arrival management was developed. This hybrid method, called flexible scheduling, will be applied to the FMSSA concept. Each airspace cell within self-separation airspace for which it is expected that there will be density or complexity issues a flexible flow schedule will be created.

It was shown in sub-section 4.4.2 that the flexible schedule can handle flexibility of arrival times to the flow restriction dynamically. Far away in the future a large flexibility is allowed. When getting closer the schedule is dynamically adjusted to reflect the decreased flexibility of flights to move with the time of arrival to the flow restriction.

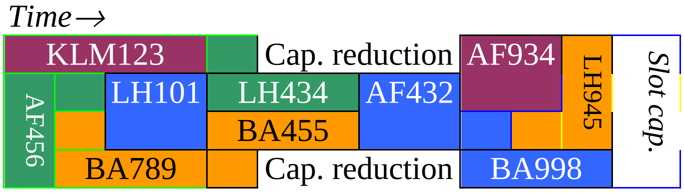
The flexible scheduling also can be applied to situations where flexible slot capacity of an airspace cell is changing dynamically. Furthermore, it is possible to use flexible scheduling in a probabilistic setting where weather can influence the availability of airspace cell capacity stochastically.

<u>Flexibility for dynamic capacity</u>

The flexibility in assigning slots to specific flights allows also to adjust the flow schedule in such a way that it can adjust to dynamically changing capacity [Figure 33b]. In the example the capacity is reduced for a specific time range. The flexible slots assigned to specific flights can be adjusted to cope with the temporary reduction.



a.)



b.)

Figure 33 Flexible slot capacity in the flexible schedule can be adjusted dynamically (a. to b.). When demand is exceeding flexible slot capacity some flights will have to be removed from the schedule.

<u>Assigning traffic to more than one piece of airspace</u>

In the situation that in a certain area unfavourable weather conditions are forecasted there is always an uncertainty regarding the specific location and severity of the predicted weather cells. To approach this uncertainty it is in theory possible to assign parts of flexible slots to a specific flight at a specific time in several airspaces. So when time elapses and the certainty regarding which airspace will be available the permanent trajectory can be chosen with having already part of the flexible slots reserved.

6 Scenarios

FMSSA addresses a number of events that can occur in self-separation airspace and which can be a solved are alleviated through flow management. The main events are identified in the following scenarios:

- No restrictions.
- Airport weather events, which temporarily close the airport for traffic.
- Airport weather events, which reduce the acceptance rate of the airport.
- Temporary airport closures and reduced acceptance rates (expected and unexpected)
- Large-scale en-route weather events.
- Small-scale en-route weather events.
- Demand exceeds the available flexible slot capacity of airspace cells.
- Demand exceeds the indicated flexible slot capacity of the airport.

The scenarios are explained in more detail in the following sub-sections. Only the en-route scenarios are elaborated in further detail.

6.1 No restrictions

In the event the local Self-Separation Airspace has no restrictions due to weather or airspace boundaries no flow management restrictions will be necessary. It is assumed that the room to manoeuvre is enough for self-separation operations to be able to handle safely the traffic load with only medium and short term manoeuvres [Blom 2007].

There is a chance that the use of only medium and short term manoeuvres will result in inefficient solutions to pass a certain part of airspace. The probability of this happing is quite low. In most cases the medium and short term solutions will be very efficient. This means that the expected cost for passing a certain airspace will be low [Barmore 2003].

Enforcing flow management restrictions on aircraft expected to pass through unrestricted airspace will result in a limited cost, with a high probability. It is expected that beyond a certain time to conflict it is more efficient to wait than it is to react early. The uncertainty in the trajectories at that time to conflict is that large that it is more advantageous to wait until the uncertainties have decreased [Figure 34].

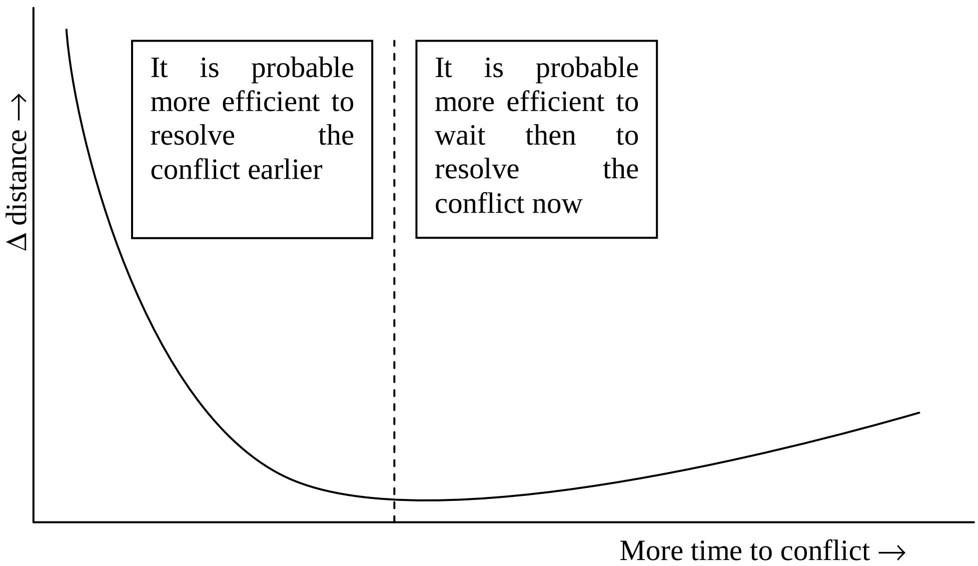


Figure 34 The expected added distance to resolve a conflict depending on the time to conflict.

In case of weather cells or airspaces boundaries, traffic can be bundled at the edges of the boundaries. The probabilities of conflicts in the medium and short term will increase by this bundling. Furthermore, the efficiency of the medium and short term resolutions decrease as there is less room to manoeuvre. In these situations it becomes more efficient to resolve the expected conflicts at a greater time to conflict. So here flow management resolutions can take an important role.

6.2 Airport weather event resulting in temporarily closure

In the event of local weather areas, like thunderstorms, local air traffic control can order to close the movement in and out of the airport temporarily. They do this based on weather forecasts. The actual timing of the closure and opening is done by watching the movement of the local weather area on the weather radar and by visual inspection.

The problem with this scenario is that it is not always clear if a local weather cell will pass over the airport. The movement and timing of a local weather cell has not a high predictability. This means that it is very possible that the airport will not have to be closed temporarily. Furthermore, the start, ending, and period of the closure is not clear, until the last moment.

Although this is a very important scenario regarding Traffic Flow Management it is outside the scope of iFly being aimed at en route operations. Therefore, this scenario is not further elaborated.

6.3 Airport weather event resulting in reduced acceptance rate

In the event of local reduced visibility conditions, like morning fog, local air traffic control can order to reduce the acceptance rate to the airport. They do this based on weather forecasts. The actual timing of the reduction is done by watching the weather station data and by visual inspection.

The problem with this scenario is that it is not always clear if reduced visibility conditions will become real as forecasted. The timing of reduced visibility conditions has not a high predictability. This means that it is very possible that the airport will not have to reduce the acceptance rate temporarily. Furthermore, the start, ending, and period of the reduced acceptance rate is not clear, until the reduced visibility conditions start to build up or reduce.

Although this is a very important scenario regarding Traffic Flow Management it is outside the scope of iFly being aimed at en route operations. Therefore, this scenario is not further elaborated.

6.4 Unexpected temporary airport closure or reduced acceptance rate

Due to other reasons then weather local air traffic control can decide to close or reduce the acceptance rate to the airport. This can be unexpected as a result of some event (e.g. runway closed due to aircraft emergency). The traffic flow within the vicinity of the terminal area has not enough margins to anticipate on the changed circumstances. The traffic will encounter serious delays or will even have to deviate to their alternates.

Although this is an important scenario regarding Traffic Flow Management it is outside the scope of iFly being aimed at en route operations. Therefore, this scenario is not further elaborated.

6.5 Expected temporary airport closure or reduced acceptance rate

Due to other reasons then weather local air traffic control can decide to close or reduce the acceptance rate to the airport. This can be expected as a result of some event (e.g. runway inspection). The information regarding the closure or reduction is available in a timely manor. The actual start time of the closure or reduction can be adjusted to be outside traffic peaks.

Although this is an important scenario regarding Traffic Flow Management it is outside the scope of iFly being aimed at en route operations. Therefore, this scenario is not further elaborated.

6.6 Large-scale en-route weather event

In the event of a large-scale weather system the closure of large volumes of airspaces and/or reduction of acceptance rates of volumes of airspaces will be necessary. This is done based on weather forecasts and nowcasts. The timing is based initially on the forecasts and adjusted according to the nowcasts. The large-scale weather system is that large that routing around the system is for a number of flights not an option.

The problem with this scenario is that it is not always clear if closures/acceptance rate reductions of volumes of airspace will become necessary. Furthermore, it is uncertain if the right volumes of airspaces are selected. The timing of closures and reductions has not a high predictability. Furthermore, the start, ending, and period of the closures and reduced acceptance rates is not clear, until a relative short time before it is actually happening.

So FMSSA will make schedules for airspace cells in the weather area reflecting the expected capacities. With time passing and uncertainties decreasing the expected capacities of the airspace cells are adjusted to the updated information. Flights can change their trajectories accordingly and choose to allocate a flexible slot in the airspace cells with enough flexible slot capacity.

Large-scale en-route weather events will result in three major issues (see Figure 35): (1) some flights are not able to fly around the weather area, (2) many flights will aim for available openings in the weather area, and (3) many flights will fly around the weather area.

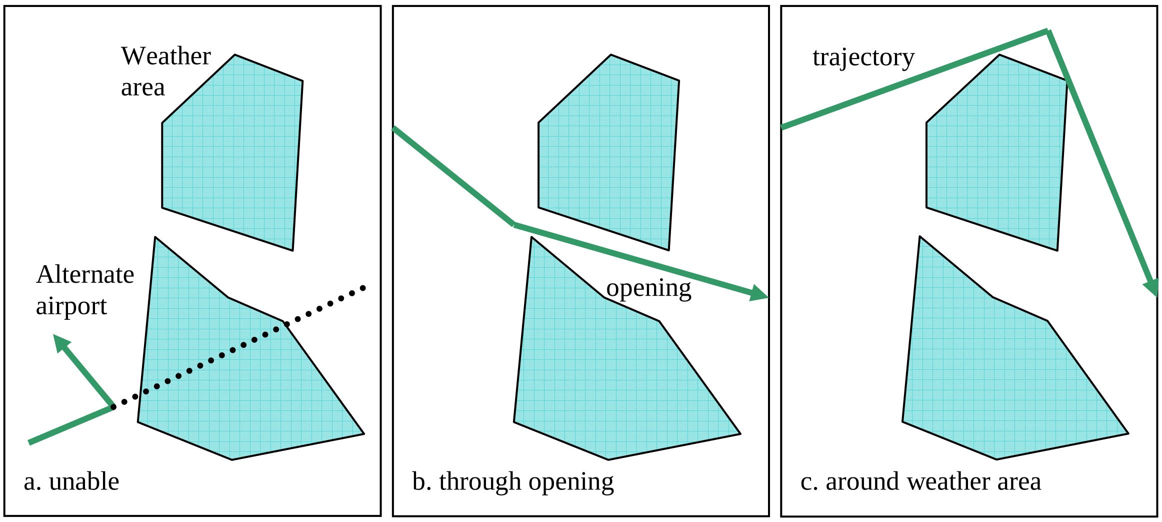


Figure 35 A large-scale en-route weather event can result in flights being unable to go around, and flights going through or around the weather area.

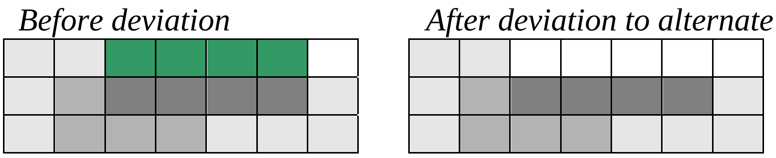


Figure 36 A large-scale en-route weather area result in a flight being unable to go around the area and deviates to the alternate airport. The flow schedule is updated accordingly.

a. Unable to go around weather area
In case an airspace user identifies that the available fuel is not enough to go around a large-scale en-route weather area the airspace user will decide to turn around to the departure airport or go to an alternate airport. Any flexible slots allocated by the airspace user will be freed (see Figure 36 a.).

b. Go through opening in weather area
Some weather areas have openings large enough for flights to pass through (see Figure 36 b). If there is a certain demand for flexible slot capacity in the opening airspace FMSSA will define an airspace cell and accompanying schedule. For the airspace cell the allowable flexible slot capacity limits are defined based on the weather forecasts and probabilities, the airspace size and boundary properties and eventually the expected complexity of traffic. The flights with a trajectory through the airspace cell before the schedule was defined will be put on the schedule according to the available information from their RBTs. Any new flights will need to allocate a flexible slot in the schedule for the airspace cell.

c. Go around the weather area
A large-scale en-route weather area will result in a considerable number of flights going around the weather area (see Figure 36 c.). This is likely to result in a concentration of flights at the edges of the weather area (see Figure 37). If there is a certain demand for flexible slots at the edge of the weather area FMSSA will define one ore more airspace cells and accompanying schedules. For the airspace cell the flexible slot capacity limits are defined based on the weather forecasts and probabilities, the airspace cell size and boundary properties. The flights with a trajectory through the airspace cell before the schedule was defined will be put on the schedule according to the available information from their RBTs. Any new flights will need to allocate flexible slot capacity in the schedule for the airspace cell(s).

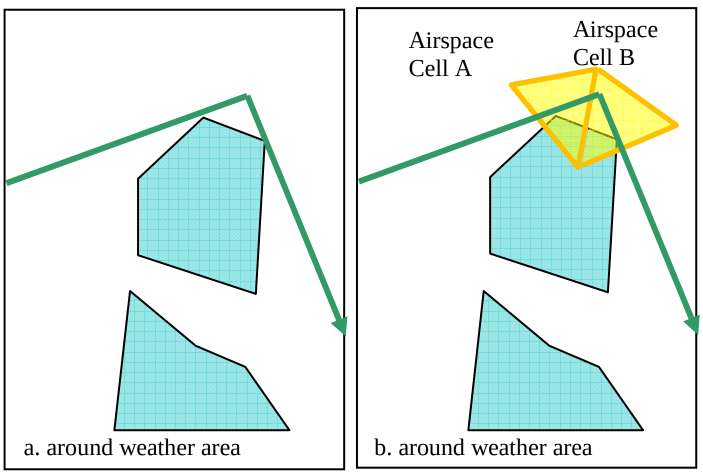


Figure 37 A large-scale en-route weather area focuses trajectories at the edge of the weather area. Airspace cells with flow restriction are added.

6.7 Small-scale en-route weather event

In the event of a small-scale weather system FMSSA can order the closure of an airspace cell and/or reduction of the acceptance rate of an airspace cell. This will be done based on weather forecasts and nowcasts. The timing is based initially on the forecasts and adjusted according to the nowcasts.

The problem with this scenario is that it is not always clear if closure/acceptance rate reduction of an airspace cell will become necessary. The timing of closure/reduction has not a high predictability. Furthermore, the start, ending, and period of the closure/reduction is not clear, until a relative short time before it is actually happening.

So FMSSA will make schedules for airspace cells in the weather area reflecting the expected capacities. With time passing and uncertainties decreasing the expected capacities of the airspace cells are adjusted to the updated information. Flights can change their trajectories accordingly and choose to allocate available flexible slot capacity in the airspace cells with enough capacity.

<u>Example scenario of small-scale en-route weather event</u>

For a large Performance Based Airspace a small-scale en-route weather event is forecasted. The forecasts will consist of a number of probabilistic weather cases [Lindholm 2009]. Based on the cases and the probabilities specific airspace cells can be defined and the applicable flexible slot capacity can be determined.

In Figure 38 the weather forecast provided two probabilistic cases both with a probability of 50%. Part of the weather cell is specified hazardous and part has reduced flexible slot capacity. At the time the forecast is provided it is not clear which of the two cases will develop. So therefore two possible trajectories are determined by the airspace user. A Northern and a Southern trajectory. Both trajectories go through airspace that has a 50% probability of 0 aircraft per time unit and a 50% probability of 4 aircraft per time unit. So ATFM defines two airspaces A and B with both 50%*0 + 50%*4 = 2 aircraft per time unit. The airspace user in the example chooses to split allocation of flexible slot capacity both on the Southern and Northern trajectory [Figure 38]. When time passes by and new forecasts come available the actual development of the weather cells becomes clearer. The airspace user can decide with the improved forecast to decide to go fully for example for the Northern route. The airline user tries to find the needed additional flexible slot capacity in the schedule for Airspace A. ATFM can also decide to update the capacities for Airspace A and B based on the updated forecasts (see Figure 39). Flights going through airspace with a lowered flexible slot capacity can switch to go through a neighbouring airspace with increased capacity [Figure 38].

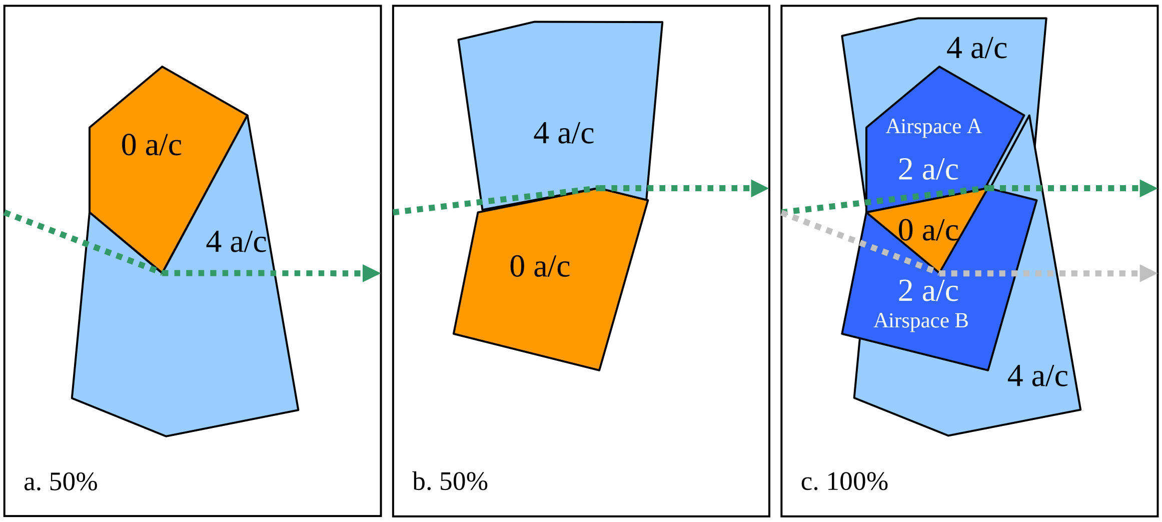


Figure 38 Two probabilistic weather cases (a. & b.) are combined in graph c. The possible trajectories around the weather cells are indicated passing through Airspaces A & B.

<u>Forecasted constraints overestimated or underestimated</u>

Based on a weather forecast the flexible slot capacity in airspace cells is adjusted accordingly. The forecast can be over- or underestimated. This can result in flights not being allowed through some airspace cells or initially being allowed through some airspace cells and later on have to change trajectory to fly around the airspace cell. The forecasted constraints have a certain probability. Once the constraints are confirmed to be (non-)existent the flexible slot capacity can be set to the right level [Lindholm 2009].

When the flexible slot capacity was originally underestimated airspace users can request for the reclaimed flexible slot capacity to optimise their flights. When the flexible slot capacity was originally overestimated some airspace users will have to change their business trajectory on a short notice (see sub-section 5.7).

In the [Wanke 2007] study a technique based on a decision tree was suggested to indicate the best strategy for using probabilistic weather forecasts. The study showed that wait and see strategies are less effective then strategies that suggest earlier action in the presence of weather forecast uncertainty.

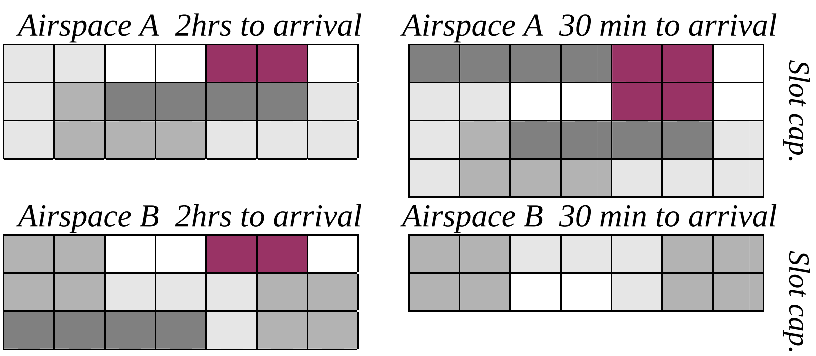


Figure 39 Assignment parts of flexible slots to a flight in two airspaces at the same time until the uncertainty has decreased.

This strategy is also an option for the FMSSA concept. Based on the weather forecast uncertainties the capacities in certain airspace cells can be adjusted accordingly. Airspace users can then independently decide which is the best RBT under the knowledge of weather forecast uncertainties. The best strategy for the airspace user can be developed and improved over time without any need to change the FMSSA concept.

6.8 Demand exceeds the capacity of an airspace cell

In the event the demand for flights through an airspace cell exceeds the flexible slot capacity of an airspace cell FMSSA will not accept these flights from neighbouring airspace or terminal areas. These flights will have to hold at the neighbouring airspace or at the airport until the number of flights in the constraint airspace cell has dropped to acceptable levels. The airspace users will need to allocate flexible slot capacity for themselves that is still available or to find an alternative trajectory around the congested airspace cell. Furthermore, the flexible slot capacity can drop below the demand.

<u>Reallocate flexible slot capacity at a different time</u>
In case at the requested time interval no flexible slot capacity is available it is possible to find the needed flexible slot capacity outside the time interval. This can be at an earlier time, by speeding up, or at a later time by reducing speed.

It is up to the airline user to determine what level of speed change is still acceptable and allows still maintaining the downstream schedule. [Delgado 2009] showed that a speed reduction is possible within limits without increasing fuel flow per distance unit. It can even decrease fuel flow if the speed is reduced to around the speed for maximum range.

<u>Determine an alternate trajectory</u>
In case at the requested time interval no flexible slot capacity is available in the airspace the airspace user can define an alternate trajectory around the restricted airspace cell.

<u>Flexible slot capacity drops below demand</u>
In case the flexible slot capacity in an airspace cell drops due to a certain reason the demand level in the airspace cell can get above the available flexible slot capacity level. At this point it is needed to redistribute the flights in the schedule in such a way that demand and capacity is in balance again.

6.9 Demand exceeds the regular capacity of an airport

In the event the demand for landings/departures at an airport exceeds the regular capacity of an airport air traffic control will not accept additional flights into the terminal area or to leave the gate. These flights will have to hold at one of the holding stacks outside the terminal area or at the airport gate until the demand has dropped to acceptable levels.

The problem with this scenario is that holding traffic in a holding stack is a measure of last resort. Airborne holding is not efficient and should be kept to a minimum.

Although this is an important scenario regarding Traffic Flow Management it is outside the scope of iFly being aimed at en route operations. Therefore, this scenario is not further elaborated.

7 Concluding remarks

This section summarizes the objective of this report, the FMSSA concept developed, and the follow-on work on creating essential techniques for FMSSA in self-separation airspace.

7.1 Objective of this report

The objective of this report is to describe an Air Traffic Flow Management concept which allows for autonomous aircraft operations. The concept is aiming at intruding minimally on the user-preferred routings. Furthermore, it keeps the responsibility for separation assurance with the autonomous aircraft crew. The Air Traffic Flow Management concept only acts upon the traffic when it is likely that this is more efficient then solving the traffic situation using short and medium term solutions.

The Air Traffic Flow Management concept described takes into account the available iFly Autonomous Aircraft Advanced (A^3) ConOps, the view of SESAR and AP23 on flow management, and concepts described in iFly WP5 aimed at long term conflict resolution in self-separation airspace.

7.2 FMSSA concept developed

The FMSSA concept can be seen as a possible conceptual description of a future (2025+) flow management operation in a self-separation environment in the en-route phase of flight.

The FMSSA concept is aimed at working in an environment with user-preferred routing and self-separation operations without tactical ground support. This environment aims at giving the airspace users the greatest possible freedom to choose the best route from a business point-of-view from airport to airport. In principle the self-separation concept with the short and medium term view should be able to handle most traffic situations encountered within the self-separation airspace. In certain areas in the self-separation airspace, like in the transition areas and in confined airspaces, it is foreseen that a need for restricting traffic levels is necessary. This would keep traffic interactions limited to a safe level and would make operations more efficient.

The FMSSA concept only provides restrictions to traffic flows where traffic interactions are predicted to be above a certain level. The sizes of flow restrictions areas are kept to minimum to be just effective enough to capture the congesting traffic flows. Traffic flows close by are not affected by the flow restriction areas. The concept allows for flexibility in the scheduling limits of the business trajectories. In this way ATFM will minimally intrude on the user-preferred operations, and will only do that in the situations where it is preferable from an efficiency point-of-view.

The FMSSA concept only restricts within limits the timing of flights in self-separation airspace. This means that flights are still able to do their own trajectory management and conflict resolution without restricting the current A^3 concept of operations.

The FMSSA concept consists of three main elements. First of all, it tries to detect congestion areas with a high complexity or a high density. Secondly, it will define a flow restriction area, which captures the flows through the congested area. Thirdly, it will limit traffic by establishing a flexible schedule for the flow restricted area.

FMSSA is in principle ground based and uses SWIM to communicate with the flight operations centres, flights, and ANSPs of Managed Airspaces. A major source of information for the FMSSA is the shared and reference business trajectories provided by the flight operations centres and flights.

7.3 Follow-on work

The FMSSA concept described in this report is dependent on three important aspects. First of all, regarding the specific triangular design of the flow restriction areas. Secondly, regarding the flexible scheduling techniques used for the flow restriction areas. And thirdly, regarding the use of strategically deconflicted routes in the flow restriction areas.

The triangular flow restriction areas should be tested for their applicability to restricting traffic in a congested area. Furthermore, it should be tested what the relationship is between the size and design of the triangular flow restriction area and the level of acceptable traffic through the flow restriction area. This should also be performed for adjacent triangular flow restriction areas.

It will be necessary to identify an operational research methodology which can be applied to the flexible scheduling technique as proposed in this document. It is also necessary to test the applicability of the scheduling technique for air traffic management. It is necessary to test if the resulting traffic will be flyable through congested flow restriction areas. Furthermore, it needs to be tested if the predicted flexibility of the scheduling technique is working in practice. Also it needs to be possible to use the scheduling technique in a dynamic fashion when getting closer the actual time of arrival.

It has to be identified what the requirements will be for the strategically deconflicted routes. It also needs to be known if the strategically deconflicted routes are necessary in practice, or that the limiting of traffic density through the scheduling is enough to get safe levels of traffic through the flow restriction areas.

8 Figures

9 Glossary of terms

9.1 Abbreviations

Abbreviation	Description
4D	Four dimensional (position, altitude, and time)
A^3	Autonomous Aircraft Advanced Concept
AFP	Airspace Flow Program
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Services
ANSP	Air Navigation Service Provider
AP23	FAA/Eurocontrol Action Plan 23
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATM	Air Traffic Management
ATS	Air Traffic Services
BDT	Business Development Trajectory
BT	Business Trajectory
C-ATFM	Centralized Air Traffic Flow Management
CDR	Coded Departure Reroute
CFMU	Central Flow Management Unit
CTA	Controlled Time of Arrival
E-OCVM	European Operational Concept Validation Methodology
FAA	Federal Aviation Administration
FCFS	First Come First Served
FMSSA	Flow Management for Self-Separation Airspace
FRA	Flow Restriction Area
FMS	Flight Management System
FOC	Flight Operations Centre
GDP	Ground Delay Program
GHP	Ground Holding Problem
GS	Ground Stop

HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
KPA	Key Performance Area
MA	Managed Airspace
MAGHP	Multi Airport Ground Holding Problem
MIT	Miles-in-Trail
NOP	Network Operations Plan
OCD	Operational Concept Description
PAZ	Protected Airspace Zone
RAA	Restricted Airspace Area
RBT	Reference Business Trajectory
RTA	Reference Time of Arrival
SAGHP	Single Airport Ground Holding Problem
SBT	Shared Business Trajectory
SESAR	Single European Sky ATM Research
SSA	Self-Separation Airspace
SWIM	System Wide Information Management
TFMP	Air Traffic Flow Management Problem
TFMRP	Air Traffic Flow Management Rerouting problem
TMA	Terminal Manoeuvring Area
USA	United States of America
VIP	Very Important Person
WHA	Weather Hazard Area

9.2 Definitions

Term	*Definition*
Airspace Cell	Delimited airspace to which flow restrictions are applied
Flexible Slot	Flexible entry conditions for a flight through an airspace cell
Air Traffic Flow Management	ATFM manages flow in an efficient way to or through areas where demand is exceeding the available capacity

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11 Appendix A: FMSSA System Description

In this appendix the systems necessary for FMSSA are described. First in sub-appendix A.1 the enablers for FMSSA are described. Secondly, in sub-appendix A.2 the communication systems are described. Thirdly, in sub-appendix A.3 the information flows to and from FMSSA are described. Next, sub-appendix A.4 gives an overview of the functional architecture for FMSSA. Furthermore, sub-appendix A.5 shows the relationship with the SESAR ATM system of FMSSA. Finally, sub-appendix A.6 shows the relationship between trajectory management and FMSSA.

A.1 Enablers

The ATFM enablers are those elements that are needed to allow ATFM in SSA airspace to be possible. The ATFM enablers are a subset of the A^3 ConOps enablers [iFly ConOps D1.3].

- System Wide Information Management System: SWIM.
    - SWIM will provide the airspace users, ATFM, and other relevant stakeholders with the data that is needed for flow management operations. The data is provided in a timely and reliable fashion.
- Air-Ground Data Link Communications
    - SWIM is connected to the aircraft in SSA through an Air-Ground Data Link.
- Ground-Ground Data Link Communications
    - SWIM is connected to ATFM through a Ground-Ground Data Link.
- On-board Decision Support Tools
    - The A^3 airborne decision support tools will aid the flight crew in the decision making process including trajectory management.
    - The trajectory management system can independently determine alternative trajectories to identify the bandwidth of scheduling options (e.g. earliest and latest time of arrival to a specific airspace cell or exit point) and the fuel cost associated. This information can be used in determining scheduling options for ATFM.
    - The trajectory management system can create trajectories that comply with the time restrictions that are applicable to high complexity areas, congested areas, and exit points. If this is not feasible, the system should indicate that it can not comply with the restrictions.
- Air Traffic Flow Management Tools for Self-Separation Airspace
    - The airspace cell identifier will identify airspace cells which have potentially traffic density or complexity issues.
    - The Airspace cell capacity estimator will identify the allowable traffic density or complexity for a given airspace cell.
    - The Demand estimator will estimate the expected airspace demand of flights in the various airspace cells.
    - The flow scheduler will schedule flights to airspace cells taking into account the allowable traffic density.
    - The flow limiter will apply constrains to flights willing to pass through airspace cells based on the flow schedule for the airspace cell.
- Advanced Human Machine Interfaces
    - The Advanced HMI (Human Machine Interface) which is aimed at allowing A^3 operations will also provide the relevant flow management information to the pilots. This includes the constraints on the RBTs based on the flow schedule.

- New Procedures
    - The new procedures and flights rules for A[3] operations will include procedures and rules for ATFM operations.

A.2 Communications with FMSSA

Air traffic flow management will communicate with the flight operations centre and the aircraft through the SWIM network.

The communication will be utilized for:

- Data exchange with SWIM regarding the SBT or RBT
- Data exchange with SWIM regarding the active flow restricted areas, the recommended strategically deconflicted routes in the active flow restricted areas, and the availability of flexible slot capacity in the active flow restricted areas.
- Requests for a flexible slot and the associated time window to FMSSA
- Assignments of flexible slots and the associated time window to the requesting flights or denials of flexible slots.

The information that is communicated is described in the next sub-section on information flows.

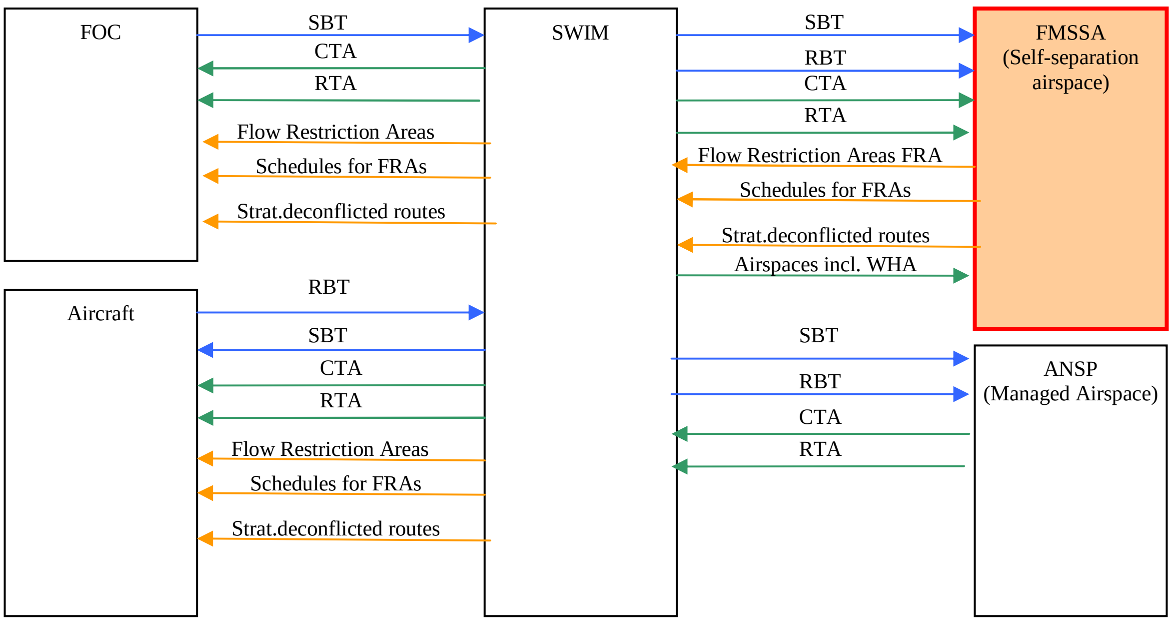

Figure 40 FMSSA is connected through SWIM to the aircraft, flight operations centres, and the ANSPs of the Managed Airspaces.

A.3 Information flows

The FMSSA process is dependent on information from the ANSPs, FOCs (Flight Operations Centre), and aircraft on the SBTs and RBTs through self-separation airspace, the exit conditions, and the existing airspace definition including weather hazard areas (see Figure 40).

The FMSSA process provides information on the flow restricted areas, the accommodating schedules, and the strategically deconflicted routes through the flow restricted areas.

All information to and from FMSSA is passed through SWIM.

A.4 Functional architecture

This sub-section gives an overview of the main functional architecture for FMSSA (see Figure 41). This architecture is only aimed at the creation of airspace cells, and the limiting of demand based on flexible flow schedules. Other FMSSA processes are not described.

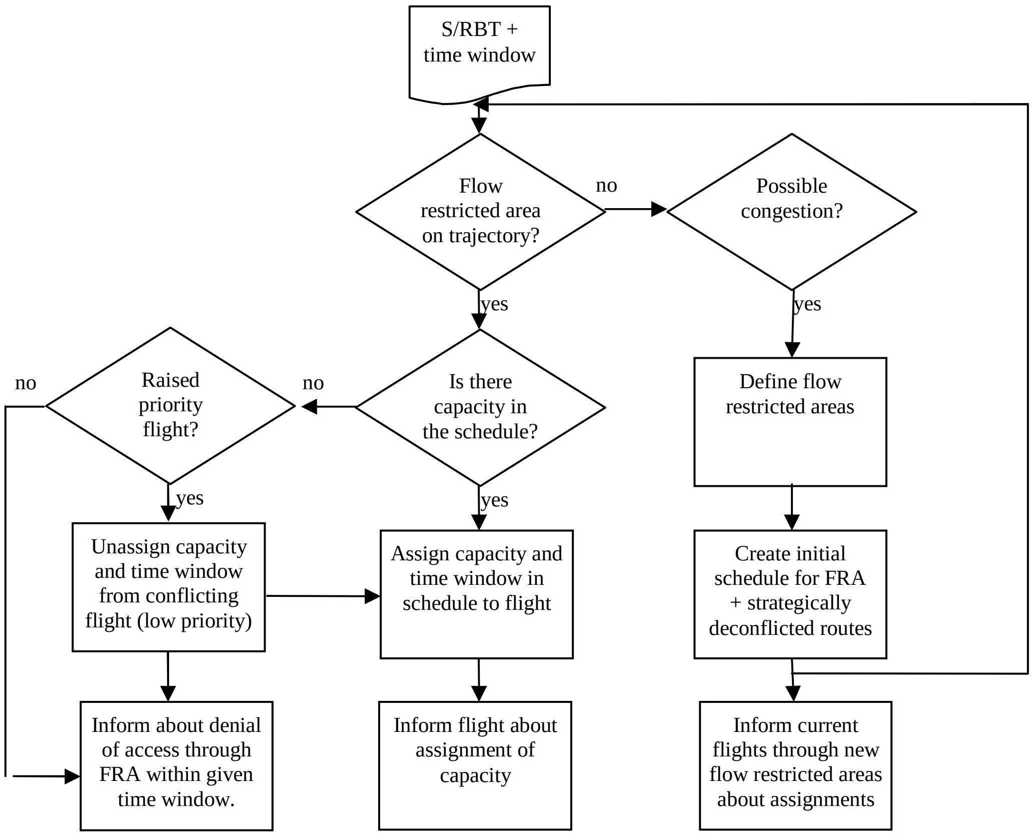

Figure 41 FMSSA process regarding the creation of flow restricted areas, and the assignment or denial of flexible slots to the flow restricted areas.

Identify flow restricted areas on the trajectory

This function will identify based on the given SBT and the associated time window if an aircraft trajectory will pass through a known and active flow restricted area.

Identify possible congestion on the trajectory

If there is no known flow restriction on the trajectory it is possible that the new or updated business trajectory will get traffic density or complexity at some point along the trajectory to a level that it becomes necessary to establish a flow restriction area.

Define flow restricted areas

If a flow restriction area has to be established it needs to be first defined. This means that the flow restriction area needs to be designed based on the location of the identified congestion area and the location of the surrounding restricted airspaces. The flow restriction area should be able to restrict all traffic flows passing through the identified congestion area. For the flow restriction area also the applicable flight levels should be identified.

Create initial schedule for flow restricted areas
For the new flow restriction areas schedules will be created based on the already known traffic (e.g. known SBTs) through the flow restriction areas. The already known traffic will be assigned to the schedules. As there was no congestion predicted until then all known traffic can be assigned to the schedule without any denials.

Define strategically deconflicted routes through flow restricted area
When the flow restriction area has been defined and it is foreseen that the traffic complexity or traffic density is above certain limits it is possible to use strategically deconflicted routes within the flow restricted area. These routes need to be defined.

Inform current flights through new flow restricted areas about assignments
The known flights through the area with the new flow restriction will be informed that they will operate in a flow restricted area. Furthermore, they will be informed about the time window they can operate in. From that point on the known flights will have to comply also with the time window in the flown restricted area.

Find a flexible slot in the schedule of the flow restricted area
In case a flow restricted area has a given schedule it is possible to find if a new or updated business trajectory will be able to find a flexible slot in the schedule. In principle the available flexible slot capacity in the flow restricted area is known through SWIM to the flight operations centre. This allows the flight to directly request a flexible slot of which is known that it is available.

Assign a flexible slot in the schedule of the flow restricted area
When flexible slot capacity is available in the schedule of the flow restricted area this can be assigned to the flight. The assigned flexible slot complies with the indicated time window as much as possible. A larger time window is no option, but a smaller time window is.

Inform flights about assignment of a flexible slot
The decision about the assigned flexible slot in the schedule of the flow restricted area is provided through SWIM to the flight operations centre and to the aircraft. The information includes the applicable flow restriction area, the assigned time window for the flow restricted area, and the suggested strategically deconflicted routes through the flow restricted area. The aircraft can take the information into consideration when determining and updating its business trajectory.

Has the flight a raised priority?
In case there is initially no flexible slot available to a flight in the schedule for the flow restricted area it is possible to check if the flight has a raised priority. This allows the flight to be provided with the flexible slot of an already assigned flight with normal priority.

Unassign a flexible slot from conflicting flight with a lower priority
In case there is no flexible slot available for a flight with a raised priority it is possible to unassign a flexible slot from a conflicting flight (with normal priority) in the schedule. This flexible slot becomes available and can be assigned to the flight with a raised priority. The flight with the unassigned flexible slot has to change its business trajectory and find new capacity to be able to fly through the flow restricted area.

<u>Inform flight about denial of access through flow restricted area.</u>
The flight that is known to be unassigned its flexible slot in the schedule will need to be informed about the denial of access through the flow restricted area within the requested time window. The flight has to provide the ATFM with an updated business trajectory.

A.5 SESAR ATM architecture for network management

The SESAR ATM concept uses trajectory-based operations as its core element (see Figure 42). The trajectory represents the intent of the airspace users in compliance with the ATM and airport constraints. The trajectory is shared through a system wide ATM network. Using a Collaborative Decision Making process the trajectory is agreed upon using an iterative process [SESAR D3].

The Network Manager has as a goal to achieve an agreed and stable balance in demand and capacity.

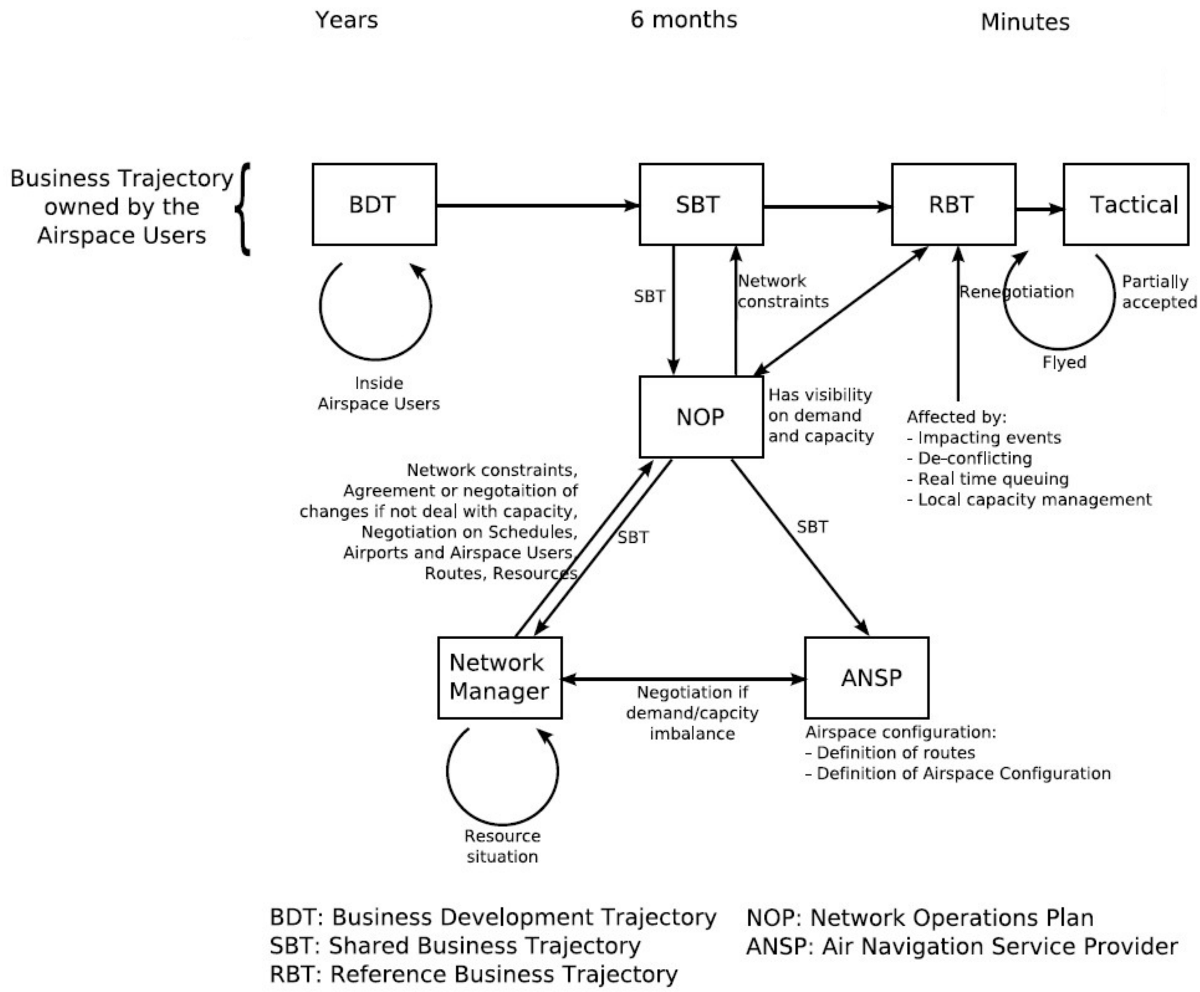

Figure 42 Concept of operations of SESAR [Source: Delgado 2009]

A.6 Trajectory Management and ATFM

The basic architecture for trajectory based operations using self separation in a context of traffic flow management can be based on three components [Prevot 2003]:

1. Using time-based flow management to regulate traffic density.

2. Using trajectory-based operations to create trajectories which comply with traffic management constraints and which indicate the range of options for flow management.
3. Maintain local separation using self separation operations.

In the following diagram (Figure 43) the relationship between the three components is given.

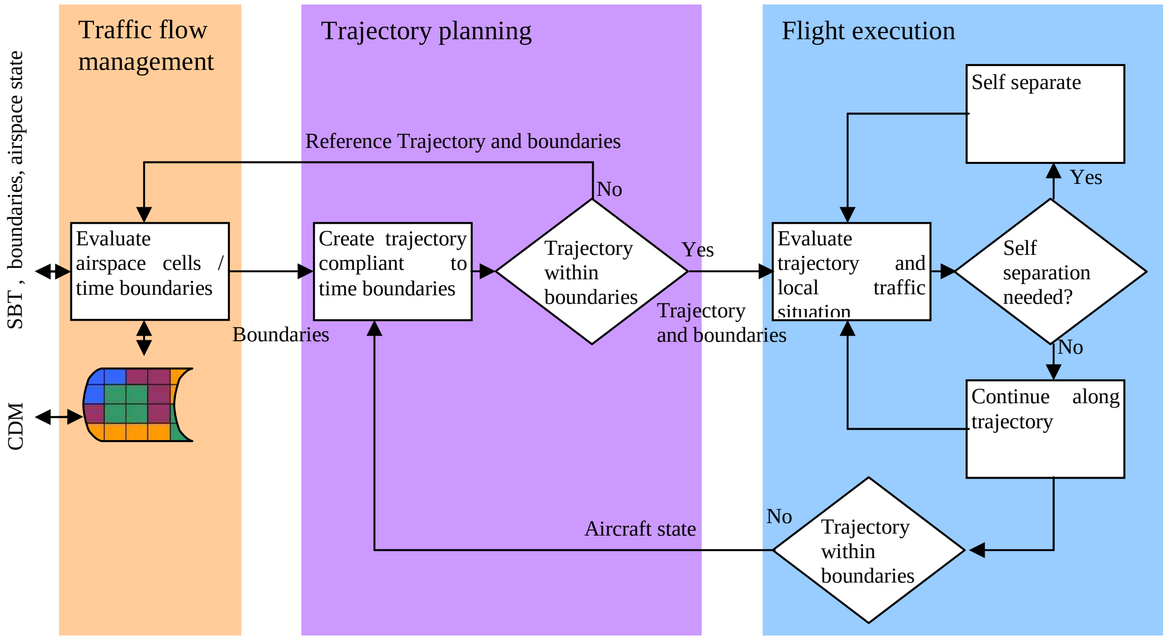

Figure 43 The basic architecture for trajectory based operations using self separation in relation to traffic flow management.

Using the SBT, the RBT, and the accommodating boundaries specified by Airline Operations or by the aircraft trajectory planning a Traffic Flow Management schedule can be created. For this also knowledge on the airspace boundaries, special use airspace, and weather forecasts is necessary. The Traffic Flow Management schedule shows the time boundaries which are applicable for a flight through specific airspace cells subject to flow management measures.