

# TOWARDS AN OPERATIONAL CONCEPT FOR INTEGRATED ADAPTIVE AND PREDICTIVE ATM

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Hindsight is always 20/20. -  
Billy Wilder

## Abstract

The EUROCONTROL Experimental Centre has developed a new strategy that balances adaptive and predictive elements of Air Traffic Management (ATM). As a next step it would be useful to elaborate a concept of operation, which would integrate the two opposite positions. It is the objective of this position paper to draft a high-level proposal of the operational concept, its vision, goal and scope, and to break it down into conceptual elements. Issues like the context into which the concept is embedded, baseline assumptions of the future ATM system, enablers that are necessary, benefits that can be achieved, as well as transition constraints will also be treated for this new operational concept.

The paper will define the vision of the Operational Concept for Integrated Adaptive-Predictive ATM covering all flight phases including pre-flight, in which a highly predictive, reactive and automated system further complements adaptive ATM. The scope will be set to 2020-2025. It will be important to integrate flow- with separation-, co-operation- and collaboration procedures. Special attention will be given to seamless operations on the boundary between adaptive and predictive concept elements, and the role of the human vis-à-vis automation.

After setting the scene the concept will be outlined in more detail. The paper treats its rationale regarding automation and discusses the reason for improving the predictive side of the system, by pushing predictive automation algorithms and tools into all pre-flight and in-flight phases. The concept will be broken down into its five big concept elements that are:

- Last Minute Central Flow Management
- Automatic Airport Flow

- User-Preferred Flow Synchronisation
- Full-Automatic Traffic Management
- Self-Separation

The discussion is continued on the required enablers of the concept: The predictive chain, automation tools, 4-dimensional navigation, collaborative procedures, improvements of the Central Flow Management Unit and airports, system-wide information management with weather services and datalink, and impact on airspace.

Finally, an initial comparison between this one and related concepts from EUROCONTROL – PHARE and COOPATS, Gate-to-Gate, ICAO, NASA - DAG-TM, RTCA - CD&R and BOEING is started.

## Introduction

The EUROCONTROL Experimental Centre has developed a new strategy that balances adaptive and predictive elements of Air Traffic Management (ATM) [1], facing the challenge of tripling air traffic in the next 20 years under increased constraints from society. The strategy is based on the link of predictive and adaptive parts of the system by a layered planning mechanism [2], that spans from airspace design, flow management, traffic management to separation management. One of the major enablers of the strategy is the collaborative negotiation of contracts between ATM, airline operators, the aircraft and other relevant actors based on 4D trajectories. Based on this, a number of research activities can be considered involving network capacity- and demand management, sector safety and -productivity, airport throughput and society, environment and economics.

At the same time, the two biggest airframe manufacturers started to work on accurate 4D navigation based on 4D trajectories and trajectory negotiation capabilities. The announced 4D functionality will be part of future flight

management systems in the aircraft. That presents a major opportunity for ATM to realistically work on operational concepts that use this capability of the aircraft, which was lacking in the time of the PHARE [3] project.

The proposed operational concept for the integration of adaptive and predictive Air Traffic Management as defined in this document is the next step to complete the strategy of the Experimental Centre. Its objective is to work out the vision as highlighted in the strategy into more details and the convergence of different conceptual ideas into a single holistic, seamless and specific approach. That holistic approach will include the integration of predictive and adaptive elements through automation, collaboration and co-operation.

The expected benefits of the concept are on all dimensions of ATM, i.e. capacity, safety, economics, security, and environment through higher precision, better planning of resources, higher interactivity, higher involvement of stakeholders, higher automation, higher sharing of information, and higher considerations of society needs in the system.

The ideas are shared with experts in the Experimental Centre however, as it will potentially lead to extended research activity, it needs to be justified through an early consolidation of the expected benefits.

The document starts with the definition of the operational concept, its vision, scope, goal, and the outline. It breaks the concept down into five concept elements that are further detailed and justified. After this core part of the document the enablers of the concept are discussed. Further, the potential benefits and transition issues are treated. An analysis of the concept vis-à-vis other related concepts is started. The concept is further put on a realistic baseline of other implemented concepts in the timeframe of 2020, its operational objectives are projected and an early R&D roadmap is designed.

## **Definition of an Operational Concept for Integrated Adaptive-Predictive ATM**

### ***Vision***

The underlying vision can be derived from the EEC strategy, and can be formulated as follows:

Integrated Adaptive-Predictive ATM is an operational concept for all flight phases, in which a highly predictive, reactive and automated system<sup>1</sup> further complements adaptive ATM. It integrates flow with separation and air with ground. It integrates collaborative and co-operative procedures that are highly automated. The boundaries between predictive and adaptive systems are smooth, seamless and clearly defined. The interactions between human and automated operations respect the human, are safe and seamless.

### ***Goal***

The goal of the concept is to increase system performance beyond the year 2020 with regard to a realistic baseline. The objective is to increase all dimensions of ATM performance, i.e. capacity, safety, economics, security, and environment.

### ***Scope***

The Operational Concept for Integrated Adaptive-Predictive ATM is targeted at an implementation in 2020-2025. The concept covers core Europe and remote areas. The concept covers all airspace users (commercial, military, and general). The concept covers all flight phases (pre- and in-flight) and operational domains (gate, surface, terminal airspace, and en-route airspace).

### ***Outline of Concept***

The rationale of the concept is to balance predictive and adaptive parts of ATM (Figure 1). The consequence is that the predictive component performed by the Central Flow Management Unit (CFMU) in today's system is enlarged beyond the CFMU and involves all components in the layered planning mechanism, covering macroscopic flows

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<sup>1</sup> System = humans + procedures + equipment

up to microscopic flows on the per-aircraft level. It introduces additional closed loops between the flight and the planning-, flow- and control tools. It introduces automated procedures where machines can make a better planning than humans and where decisions are simple for machines. It introduces new tools for human interaction with the system for all involved users. It is based on an extended information-sharing and decision-making system, where the accurate 4D trajectory plays an important enabling role.

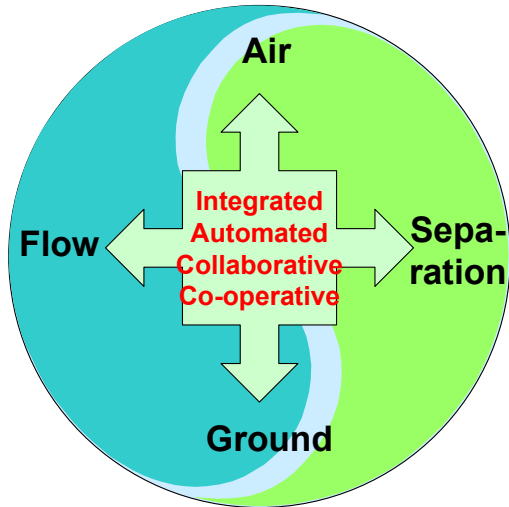


Figure 1. Concept Vision

In addition the concept treats the boundary between adaptive and predictive ATM. It focuses on the safe hand-over between the modes of operation. The gap between the two modes is accomplished with full-automatic traffic management, which acts on a level of strategic control.

The concept is broken down into the following concept elements (Figure 2):

- Last Minute Central Flow Management
- Automatic Airport Flow
- User-Preferred Flow Synchronisation
- Full-Automatic Traffic Management
- Self-Separation

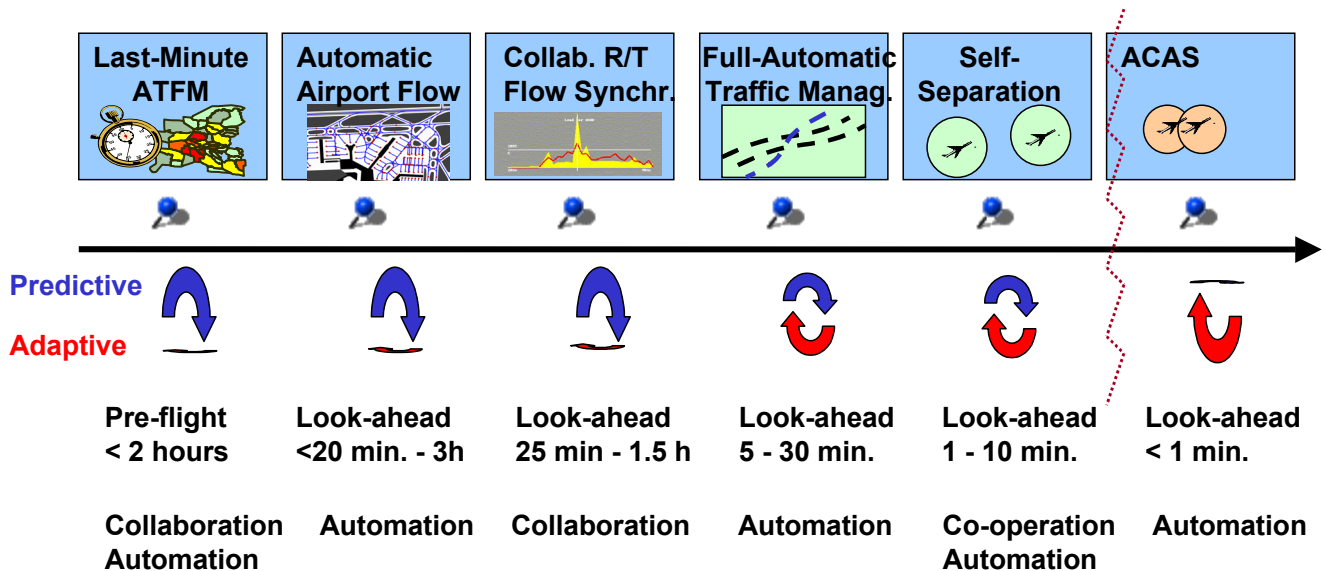


Figure 2. Layered Planning and Traffic Management

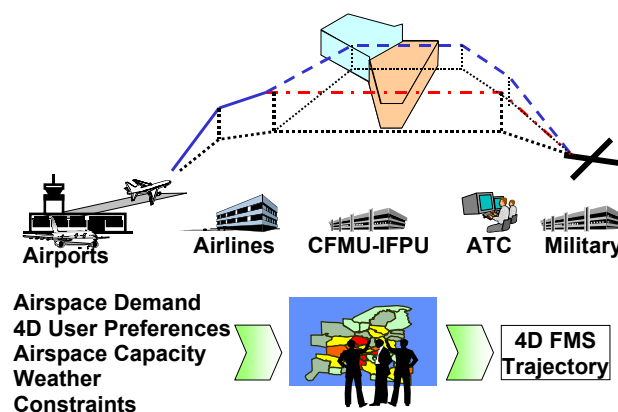
These five concept elements build a single logical and holistic approach to increased prediction of the system. “Last Minute Central Flow Management” and also parts of “Automatic Airport Flow” concern the pre-flight phase, the other treat in-flight phases. As already stated above the boundary between predictive and adaptive system is between the “Full-Automatic Traffic Management” and “Self-Separation” both being adaptive in that they adapt to initially unplanned situations. The first one continues planning and optimising flows, and the latter one uses predictive elements and procedures for separation control. The predictive layered planning spans from look-ahead of 2 hours until 5 minutes. The concept elements have different degrees of automation, collaboration and co-operation. Automation depends on criteria like feasibility, interaction with the legacy human-centred system, performance and cost etc. Collaboration and co-operation are a function of look-ahead time: the longer the look-ahead time, the higher is the degree of collaboration and with this the elaboration of user-preferred solutions. The shorter the look-ahead time, the higher the degree of co-operation up to the complete delegation of responsibility to the pilots. The system is highly dependent on accurate feedback-loops for accurate, consistent, available, interoperable, integrated, secure and safe information-sharing and decision-making procedures at all layers of the planning- and separation processes. This leads to very strong requirements for system-wide information management, including precise 4D trajectory, weather data and datalink.

The following paragraphs discuss the concept elements in more detail.

### ***Last Minute Central Flow Management***

Last Minute Central Flow Management treats the pre-departure flight phase and conceives an integrated and collaborative flow management system with closed loops between the CFMU as its central node, Airline Operations (AO), the aircraft, the airport and downstream sectors control. It is based on the 4D trajectory of the aircraft, which is matter of negotiation between the involved parties up to the last minute before off-block time. Its objective is to improve the flow accuracy and herewith increase the planning of flow, with the

effect to smoothen traffic, and hence increase sector capacity to its advertised limits (Figure 3).



**Figure 3. Real-Time Collaboration Process**

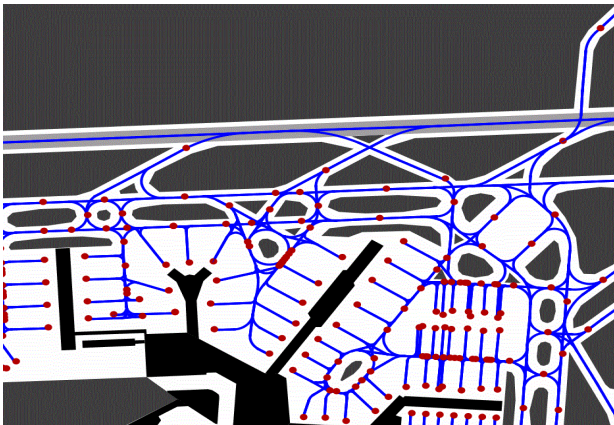
Refined Flow Management [4] and Real-Time Traffic Synchronisation [5, 6] treat the subject but none in an integrated way: The Refined Flow Management focuses on pre-departure trajectory exchanges between CFMU and AO, and frequent updates of a 4D trajectory once in flight, in a highly interactive way. The concept of Real-Time Traffic Synchronisation has elements that target at the improvement of the CFMU concerning real-time behaviour when capacity bottlenecks can be foreseen. Its main objective is the traffic smoothing, by using typical or improved flow-type measures.

These above concepts, which are perfectly complementary, will be compiled into a single concept element. An event that deviates from the planned traffic or demand prediction is at the origin of the process, e.g. the aircraft is delayed at the airport, adverse weather, the advertised sector capacity does not match the predicted traffic forecast etc. That launches an iterative, dynamic and collaborative decision-making process between all involved parties: CFMU, ATSPs, airports, AO, and military control. The result will be that a flow regulation measure is taken, or the trajectories of involved aircraft modified. The state of the system is updated, and the measures are implemented.

### ***Automatic Airport Flow***

Automatic Airport Flow (Figure 4) combines further developments of A-SMGCS with automatic aircraft routing and advanced flow tools for Collaborative Decision-Making (CDM). Capacity

of the airports will be increased through enhancements of throughput by an integrated chain of arrival, surface, gate and parking, and departure management [7]. Accurate knowledge of the aircraft state and its prediction will enable higher accuracy for planning activities and feed back to the CFMU and other predictive tools. Prediction of aircraft movements on the surface will lead to higher safety during surface movement; automation of routing for taxiing aircraft will increase economy of the aircraft and the airport, and may optimise aircraft operations for environmental constraints.

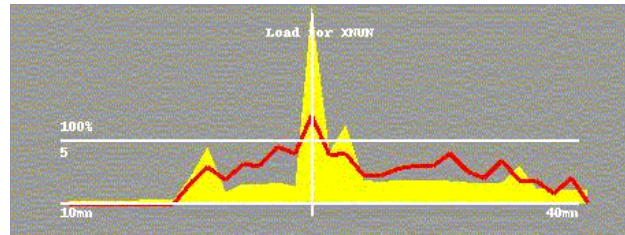


**Figure 4. Automatic Airport Flow**

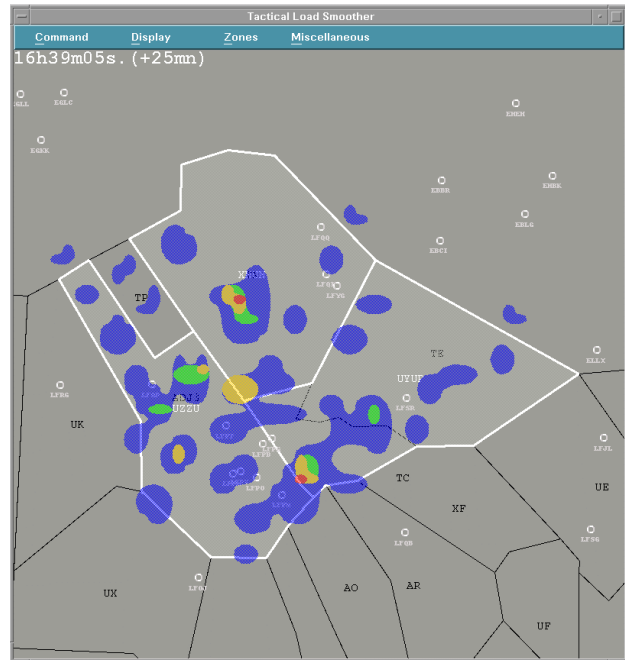
The flow at the airport is a very important but also complex problem, because disturbed by many factors that are often of non-technical nature. The improvement of the convergence between calculated take-off time (CTOT) and actual take-off time (ATD [Actual Time of Departure]) is central to the problem, because it is the most critical parameter in the accuracy of the pre-flight planning process. Therefore processes and tools are needed to increase the predictability of both estimated off-block and departure times. The first is a function of many parameters of airport land and air side, e.g. [8] landing time, aircraft in block, disembarkment terminated, ground handling completed, boarding started, aircraft ready for push-back etc. The latter is a matter of accuracy and predictability of taxiing, which is also a function of air and land side, because the airport might use the taxi phase as a buffer to optimise gate and parking management that may be influenced by land side operations.

### **User-Preferred Flow Synchronisation**

User-Preferred Flow Synchronisation has the objective to optimise and increase the ratio between traffic and advertised sector capacity, by applying flow- and capacity management (F&CM) when aircraft are airborne. Its tools are mainly traffic load smoothing, through different macroscopic flow measures that are applied on the traffic and the airspace (Figure 5, Figure 6). It is in general an in-flight concept, but has effect on the pre-departure flight phase. It has a look-ahead from 25 minutes up to 1.5 hours.



**Figure 5. Traffic Load Smoother [10, 11], Sector-Load Indicator**



**Figure 6. Traffic Load Smoother [10, 11], 2D Complexity-Map**



Multi-Sector Planner (MSP) [9] and Real-Time Traffic Synchronisation [5] treat the same subject each one from a different viewpoint<sup>2</sup>: separation control or flow control. The MSP uses Tactical Load Smoothing, whereas Real-Time Traffic Synchronisation uses Tactical Load Smoothing and incorporates a collaborative process between partners that are usually involved in flow procedures, including the flow managers in ATSPs. Here, both concepts will be integrated into this concept element<sup>3</sup>. Both concepts include functions for traffic monitoring, and MSP bases this on complexity. However, both concepts still lack clarity concerning details on traffic flow measures, what they precisely are, and when they apply.

All real-time flow measures are negotiated within a dynamic and collaborative decision-making process. It involves all stakeholders, i.e. flow managers at the ATSPs, CFMU, AOs, Military etc. The synchronisation with AO, where the flow measures might have impact on the airline schedules, is very important and included in the process.

It should be understood that probably all flow measures that come from this concept element change the foreseen trajectory of aircraft, sometimes significantly, and may therefore lead to slippage from the flight plan, and especially from the actual time of arrival. That means that: 1. A good balance has to be found between this concept element and the “Full-Automatic Traffic Management”, which a priori does not have this drawback. 2. A closed loop back to the CFMU is mandatory for the accurate flight planning and prediction of traffic that is still on the ground.

### ***Full-Automatic Traffic Management***

Full-Automatic Traffic Management is the shift in paradigm from human-centred automation in ATC towards full-automation. It achieves this function with the organisation of air traffic on the

strategic level, with a look-ahead of typically 15 minutes +/- 10. It scopes all in-flight phases.

Full-Automatic Traffic Management is an evolution of conflict resolution tools based on medium-term-conflict towards traffic management, together with a higher integration with the different departure-, arrival-, en-route managers for the interested look-ahead time. This shift from conflict-towards traffic-management results in traffic organisations that potentially pack aircraft until the theoretical limits of airspace with respect to applicable separation minima.

Full-Automatic Traffic Management requires the augmentation of the conflict-detection and -resolution functions. It uses predicted traffic density and complexity<sup>4</sup> as a trigger for traffic organisation, in addition to medium-term conflict. In high-density traffic, it is most probable that more than two aircraft are implicated in a complexity hotspot, and that more than two aircraft must be managed to organise and optimise the traffic. The traffic organisation algorithm is based on traffic pattern recognition to analyse and categorise the situation when such a high traffic density is detected. That results in the categorisation of the hotspots into predefined hotspot-patterns e.g. for merging, overtaking, crossing etc. The traffic can be organised once the situation is analysed and categorised. The algorithm applies a number of microscopic flow advisories (FA) and distributes them to or amongst the involved targets. Flow Advisories are flow-optimal, taking into account a high number of constraints: airspace restriction for structured airspace including economical constraints, pilot preferences, flight types etc. The sum of those FAs that are needed to resolve a hotspot is called a Micro-Flow Pattern (MFP), and the involved aircraft are said to be in a micro-flow pattern.

### ***Definition***

A Micro-Flow Pattern (MFP) is a control measure that is applied on one or more aircraft and that organises, de-conflicts, simplifies, and optimises the flow of each individual aircraft in high density or conflict areas, recognising sets of

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<sup>2</sup> Yet there is a major difference that Multi-Sector Planning is larger in scope and has also shorter look-ahead times up to 15 minutes, which is similar to our concept element *Full-Automatic Traffic Management*.

<sup>3</sup> ..., which should not be complicated given the fact that they overlap!

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<sup>4</sup> Complexity for machines.

repetitive traffic patterns for repetitive situations, and applying sets of microscopic flow advisories on the traffic patterns.

The algorithm co-ordinates the implementation of the flow advisories and monitors them. The distribution of the flow advisories is simple in the case of 4D guidance and uses the distribution of 4D trajectories. Its implementation requires a high level of co-ordination between the involved aircraft and the central intelligence of the MFP (that might be allocated to aircraft if this has some kind of benefit). Also aircraft need to co-ordinate amongst another, and the advisories must be co-ordinated with possibly several actors on the ground, especially in transition scenarios.

Full-Automatic Traffic Management requires performing enablers:

- The conflict detection, prevention and resolution algorithm described above,
- High performance air-to-air and air-to-ground datalink, with the capability to share decisions and information,
- Precision-4D capability in the aircraft with reliable trajectory negotiation.

Figure 7 gives a scenario for Micro-Flow Patterns.

- The two aircraft on the bottom left are already in a pattern, which is “relative offset” or “cluster flight”. MFP will work extensively with offset to pack aircraft into airspace when under constraints, i.e. when traffic has to follow a route structure. The offset pattern may have different forms depending on the flights, e.g. the aircraft fly on virtual parallel routes relative to one another like in the figure, or virtual parallel routes relative to the airspace route structure, or the pattern uses temporal offset for overtaking manoeuvres etc.
- The next illustrated pattern is the offset-traffic-merging of the aircraft coming from the bottom, and the three aircraft fly in relative offset into the same direction.
- Then a complex pattern takes place that could be called “left-shift-carry-over” with several Flow Advisories, and where the two aircraft in the middle and the left are shifted by one place to the right, and the aircraft on the right is “carried-over“ to the left, by changing flight level.

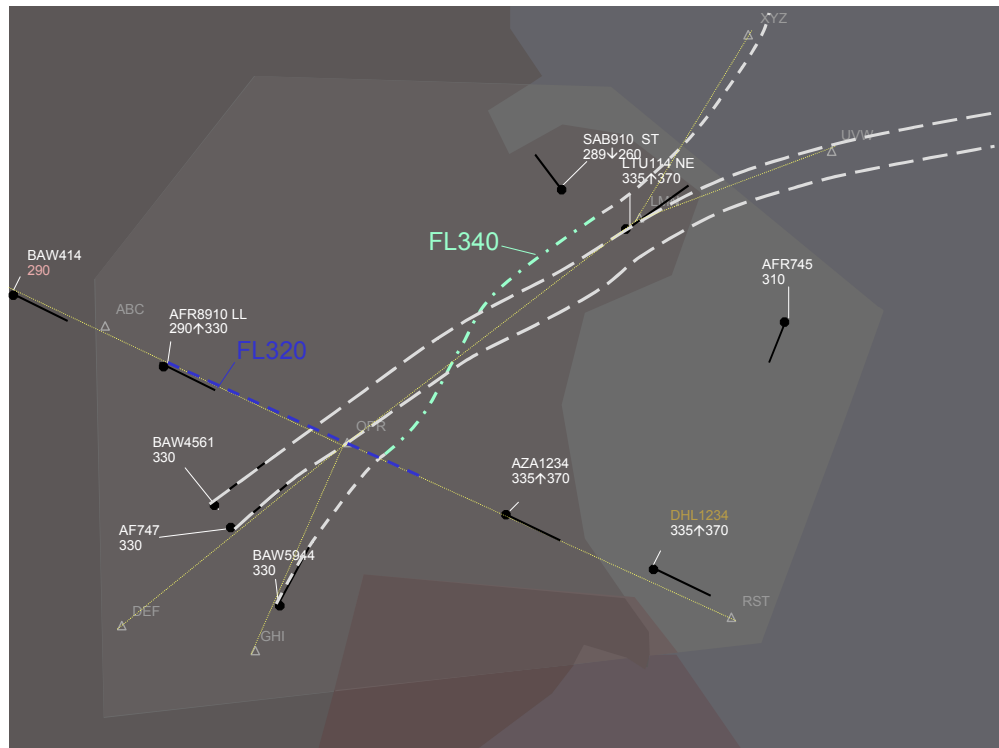


Figure 7. Scenario

Full-Automatic Traffic Management acts on a level of strategic control and can therefore be considered as being adaptive to a specific situation that was not planned initially. However, the tools that are used are of predictive nature, with a reduced look-ahead time set to the strategic control time horizon. These tools are an integral part of the predictive chain.

Transition is of uttermost importance for this concept element. Full-automated Traffic Management integrates well with current concepts of conflict resolution. The gap between the current concepts, which only show advisories to the controllers and full-automation can be filled, e.g. with the use of CPDLC-motors. The smooth transition path will enable engineers to work out the performance of algorithms and other enablers, and controllers to get trust in the system.

The benefit of this concept element is that an airspace volume will be packed with traffic up to highest limits. The traffic will continue to flow, the predictive chain will not be interrupted, and the trajectory of the aircraft will remain smooth and not disturbed by conflict-resolution manoeuvres that deviate it from its destination. Another advantage is that it prevents from conflicts through a finer granularity in flow management, and generates less work for the next concept element: Self-Separation based on CD&R.

### ***Self-Separation***

Self-Separation [12] is a concept element that is on the adaptive side of the concept, because it treats conflict and conflict resolution through separation done by the flight deck and flow is not important. It is an in-flight concept that operates approximately 1 to 10 minutes ahead, typically 5 minutes. The concept element that is developed here pushes predictive components and correlates very strongly with Conflict Detection, Prevention and Resolution (CD&R) based on intent [13]. The concept element needs strong support from tools and procedures.

The concept element is regarded as being the first kind of a safety net when Full-Automatic Traffic Management fail<sup>5</sup>, even though with the

look-ahead time that is under considerations, we are not in collision avoidance yet. The next safety net is ACAS, which will not be discussed because it is in daily operation.

This concept element only adds little to the self-separation concept as it is elaborated at the moment. The modifications come mainly from the fact that self-separation in this overall concept will be handed over from the MFP, and not from a human controller. Therefore non-nominal procedures are very important in that concept element, and differ from the usual error handling in co-operative self-separation. If a traffic management pattern fails to dissolve a conflict, or if it “explodes” by any kind of unpredicted error, then the situation is taken in the hands of the flight deck. Studies [13] confirm that the flight deck is the better choice for such a hand-over, because the workload of the pilot will allow working out the situation. A controller on the ground should at least monitor the situation, as suggested in the self-separation concept. However, one might speak of traffic loads in these situations that cannot be handled anymore by controllers, especially if the controller only has a few minutes to resolve the situation.

### ***Entry and Exit between Predictive and Adaptive ATM***

It will be important for the predictive part of the system to be able to treat situations where controllers and pilots take over control and interrupt the predictive chain. That will be necessary for error cases like explained above, but also in situations where the human is still the principle operator, e.g. areas that are not equipped during transition periods. In these situations the interrupt of the predictive chain shall always be accompanied with data about exit and entry conditions, like the state of the aircraft and the time of change. This information is similar to usual update information e.g. trajectory updates when an aircraft deviates from its trajectory. The exit of the predictive chain is counterproductive when it happens early in a flight, because downstream prediction will be imprecise. That will lead to small perturbation of the concept elements that have a long look-ahead time, yet they will continue to be operational because of their relative low requirement for very

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<sup>5</sup> ..., which shall happen!, ...



precise data. Those others that have a short look-ahead time will recover after some minutes in predictive operations. One should avoid having one ATSU equipped, an adjacent one not equipped, the next one equipped and so forth. Implementation is therefore required starting from a central point, which would favour complete centralisation of the entire predictive chain.

### ***Role of the Human***

The role of the human will continue to be important, even if the system starts to shift from the human-centred to an automation paradigm. It should be noted that transition constraints will lead to incremental implementations of the concept elements and their sub-functions, and therefore a healthy co-existence of the two must be assured. Nevertheless one of the objectives of the concept is to increase system efficiency through automation, which will in the scope of 2020 probably mean 'not to increase the numbers of controllers'. With that regard, the concept is not different to all other concepts that aim to improve system performance.

### **Enablers**

A new concept comes with a high number of enablers.

- The predictive chain is essential for the concept. Predictive tools must have correct information and hence need updated information that is looped back to the system at all levels of the layered planning process and from all involved stakeholders. In addition the interference of the prediction tools must be minimised through their interconnection and cross-correlation. I.e. the prediction algorithms of tools for all concept elements will depend on the data they generate and will iterate each time events occur in the chain, and interference must be avoided to produce clear and unique results for all parts in the chain. E.g. User-Preferred Flow Synchronisation can provoke recursions through Last-Minute Central Flow Management and Automatic Airport Flow; or Full-Automatic Traffic Management generates recursions to the previous tools in the chain. In addition Full-
- Automatic Traffic Management may cause constraints for adaptive tools in Self-Separation.
- Automation tools play an important role for Automatic Airport Flow and Full-Automatic Traffic Management. The first needs routing algorithms, the latter pattern recognition, automated solution finding, automated data transactions and more. All are subject to research.
  - Precision 4D (P-4D) navigation capability and trajectory negotiation are important for those concept elements that need high fidelity and navigation precision, and that are those with a small look-ahead, especially Full-Automatic Traffic Management, Self-Separation and Automatic Airport Flow. The P-4D is feasible, however it has high impact on the airborne equipment and the datalink capability, and herewith on the cost of the concept and its transition period.
  - Collaborative procedures and their support tools are central to all concept elements in and around the pre-flight phase, as well as those with medium look-ahead like Collaborative Real Time Central Flow Management. They give strong requirements for SWIM, as explained below.
  - The CFMU needs major enhancements for Collaborative Real Time Central Flow Management with a much higher degree of interaction and responsiveness. The CFMU is the best location for serving Last Minute Central Flow Management and Full-Automatic Traffic Management!, which both have no requirement for distributed computation but instead for high data consistency also between ANSPs.
  - Airports need modification for higher interactivity in the collaborative processes for all concept elements, and especially for the Automatic Airport Flow.
  - System-Wide Information Management (SWIM) with Meteo play a central enabler role. The system will be built upon feedback-loops for accurate, consistent, available, interoperable, integrated, secure and safe information-sharing and decision-making procedures at all layers of the planning- and separation processes. All data

about all aircraft including 4D trajectory, but also their contextual and state data must be managed and accessible to all involved parties. Also, relevant data of involved parties must be shared in the same way. Special attention must be given to higher bandwidth mobile networks to integrate the aircraft, and the need for TIS-C [14] to exchange all kind of data between the air and the ground.

- Airspace structure will be decreasingly important and even counter-productive with increased use of the predictive mechanisms based on P-4D, because it will hinder from flying user-preferred, flow-optimal and citizen-friendly. Instead, a very flexible airspace structure, which may still have constrained volumes, will serve much better all interests, and will be technically feasible with this concept. The concept will have maximal benefits in a free and user-preferred P-4D airspace, where aircraft fly in bubbles along trajectories that form sort of tubes as already elaborated in the PHARE project. Where the airspace is still structured, it might be useful to be optimised to enable more effective flow measures like needed in User-Preferred Flow Synchronisation and Full-Automatic Traffic Management. This new airspace structure is not necessary for the concept, but the concept will give its entire benefits if the airspace is adapted to it. That airspace can be called: User-Preferred Airspace.

## 2020 Baseline

It is important to fix a baseline of concepts that are in operation at the target entry point of this concept, to understand the challenges, overlaps, commonality, complementation, available technology, and added value. The baseline could be (to name some examples):

- Controller-Pilot Datalink Communications (CPDLC),
- Automatic Dependent Surveillance (ADS) and Airborne Separation Assurance System (ASAS),
- Advanced Surface Movement Guidance and Control System (A-SMGCS),
- Collaborative Decision Making (CDM),

- Arrival and Departure Managers (AMAN, DMAN),
- Medium Term Conflict Detection (MTCD) with basic automatic resolution advisories,
- Precision Area Navigation (P-RNAV) for departures, en-route and approaches,
- Free-Route Airspace,
- Gate- Departure- (En-route)- Arrival Managers,
- CFMU enhancements like Enhanced Tactical Flow Management System (ETFMS),
- Wake Vortex,
- Time based separation,
- Speed control,
- Flight Data Management and Interoperability,
- Global Navigation Satellite Systems (GNSS), Ground-Based Augmentation System (GBAS), Satellite-Based Augmentation System (SBAS),
- etc.

## Benefits

The objective of the concept is to increase all dimensions of ATM performance i.e. capacity, safety, economics, security, and environment in comparison to the baseline as defined in the previous paragraph. Therefore some assumptions of the technical and political context of the concept in that timeframe are made. Also, many of today's challenges will be accomplished by the above stated baseline - still the following objectives relative to the 2020 baseline are assumed:<sup>6</sup>

- Capacity increase of 25% for the following decade;
- Decrease total system operating costs by 25% (not per flight);
- Reduce fatalities caused by ATM by 50%;
- Zero-level tolerance for any kind of abuse by intrusion into the system.
- Reduce any kind of pollution through ATM procedures by 15%;

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<sup>6</sup> The author extrapolated data from the ATM2000+ Strategy [18] towards objectives given in the Strategic Research Agenda [19] and the spirit of the European Transport White Paper [20].

The expected benefit of the concept is to increase system performance beyond the year 2020 with regard to a realistic baseline, at same or improved levels of safety.

At this stage it is cumbersome to give even qualitative benefits, however, one can consider that the concept improves many of the parameters that lead to improvements of sector, airport and network capacity. This can be achieved through higher precision, better planning of resources, higher interactivity, higher involvement of stakeholders, higher automation, higher sharing of information, and higher considerations of society needs in the system. E.g. if the concept is able to prepare the traffic flows so that the probability of conflicts occurrence is reduced to the minimum level and aircraft are organised in a fluid way, then one could think of a more ‘physically’ filled airspace. Hence capacity in airports, TMA and en-route airspace can dramatically be increased. But there are other benefits e.g. more cost-effective and less polluting flights through an increase of user-preferred trajectories and the collaborative planning processes. Also, safety will be increased in free-P-4D airspace even if more aircraft are in the same volume, because the probability of identical trajectories will be reduced. Further, tube-base departures and approaches will support e.g. noise-abatement procedures in a more efficient way etc.

## **Transition of the Concept**

Transition is an important issue for every concept, because together with investment decisions it may stop any effort for evolving the system. Therefore it is necessary to be aware of the difficulties that will be encountered on institutional, operational and technical level.

### ***Institutional***

The issues are manifold and span from changes in airspace, modifications in legal responsibilities like already encountered with ASAS, to in-depth modifications of international procedures. Also the role of the ANSP may be modified.

### ***Operational***

Transition of operational procedures and operation modes may be less dramatic as one could

expect from a concept that places automation as one of its pillars, because the concept is conscious about the need to integrate the traditional ATM system<sup>7</sup> with the new parts of the system. The balance of these two modes is in the centre of the concept. However, operational procedures will have to change, and where automation plays an intensive role like with Automatic Airport Flow and Full-Automatic Traffic Management, it will impact human operation – and lead to difficulties.

### ***Technical***

Transition of the technical system will be accompanied with safety procedures and international standardisation. The information-sharing and decision-making system must be safe, secure, interoperable and robust. It will be an opportunity to review the European technical ATM system, and will most probably give good arguments for further centralisation like already started with the CFMU, when taken from an economical angle.

Transition will have regional differences for different needs. The full concept as explained in this text is suited for the high density and complexity European core area. Remote areas, however, may opt to implement only parts of it depending on their objective for improvement, e.g. only Last-Minute Central Flow and Self-Separation - or only Full-Automatic Traffic Management with feedback to the CFMU when needed. This ability of the concept to be implemented on different levels makes it most cost-efficient.

## **Preliminary Analysis**

This section elaborates a brief analysis of the concept in comparison to existing ones to understand how it can be matched.

At the highest level there are a number of political documents to which this concepts references to:

*ICAO Operational Concept Document (OCD)* [15] treats a much wider scope including all operational and technical improvements until 2025, and this concept overlaps partly with it. The OCD

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<sup>7</sup> ... of the year 2020 ...

treats airspace organisation and management, aerodrome operations, demand and capacity balancing, traffic synchronisation, airspace user operations, conflict management, and ATM service delivery management. Its guiding principles are safety, the human in the loop, technology evolutions, information management, collaborative principles and continuity. This concept is very much inline with those principles, adding specific objectives that can be assumed for the year 2020: still capacity increase at improved safety levels, economics of scale, security, environment and other societal needs for a sustained development. In brief, the Integrated Adaptive-Predictive concept is a full subset of the OCD, and it applies most of the higher level principles and objectives from the OCD. One could consider this concept as a directed extrapolation of the OCD, especially the traffic synchronisation definition in the OCD is a total overlap with the User-Preferred Flow Synchronisation concept element.

*EUROCONTROL Operational Concept Document* [16] states the target concept as “A collaborative and layered planning system, strategically co-ordinated and operating gate-to-gate”. Our operational concept is fully inline, not only with this highest level statement, but with all trends of the OCD:

- Towards integrated flow management;
- Towards adaptive demand and capacity balancing;
- Towards speed and time control techniques;
- Towards high network integration with flow management;
- Towards airborne responsibility;
- Towards a pre-planned time horizon;
- Towards full automated support;
- Towards integrated airport operations;
- Towards system-wide information management.

Nevertheless this operational concept is still a further extrapolation, notably towards fully integrated 4D handling of flows and traffic.

*The EUROCONTROL Strategic Performance Framework (SPF)* [17] and *ATM2000+ Strategy* [18] are not concepts in itself and will not be compared to this one, however, they indicate a strategic process to support the justification, or not,

of concepts and projects. The Strategy ATM2000+ sets its scope to an implementation roadmap that is important for us to define the baseline. Issues beyond plus-fifteen years are not specified in the strategy.

*The European Transport Policy White Paper* [19] gives a high level view on political and herewith societal objectives of all transport modes in Europe, with little precision on ATM (Single Sky, Galileo). However, it presents a major input for objectives for a sustained growth path of the European transport industry.

*The Strategic Research Agenda (SRA)* [20] is at the foundation of the new EEC policy, therefore this concept can be considered as a direct instantiation of it.

There are some concepts that are of importance for the Integrated Predictive-Adaptive ATM, which partly overlap in scope and vision:

*The Programme for Harmonised ATM Research in Europe (PHARE)* [3] is the father of predictive in-flight concepts. It has shown feasibility of 4D navigation, and treated for the first time tactical traffic load smoothing and multi-sector planning. However, its scope was limited to departure, en-route and arrival.

*Gate-to-Gate* [21] is also an approach to develop a layered planning system with the scope from gate to gate. Its timeframe is earlier, starting 2010. Identical is the trend towards higher integration of predictive, adaptive, co-operative and collaborative principles. Differences are its inclusion of strategic and pre-tactical planning including airspace issues. This concept, however, shifts paradigm from human-centred towards automated systems, and uses extensively the P-4D enabler. Gate-to-gate can herewith be considered as a big part of the baseline in this concept.

Distributed Air-Ground Traffic Management (*DAG-TM*) [22] is close to this concept, with approximately similar vision, scope and goals. However, this concept puts less weight on the distribution of tasks, especially when the flight deck is concerned. Instead, the focus is on automation and central flow management. Also, a selection of adaptive and predictive concept elements is made rather than a redundant co-existence; and automatic

airport surface movement, guidance and control is included.

*COOPATS*. The Co-operative ATS Concept [23] is also overlapping with this concept and has commonality in parts of the vision. However, its scope in time is different (beyond 2007) which introduces major differences for assumptions. Its objectives are very much targeted on the co-operation of controllers and pilots, with a strong emphasise on the human. It hardly includes any concept elements of flow-type.

The *Revolutionary Concepts That Enable Air Traffic Growth While Cutting Delays* [24, 25] from the *Boeing* company shares parts of the vision, scope and goal with this concept. An important commonality is the predictive character with the weight put on flow measures, and its influence on airspace design. However, the technology centric view and the from-scratch-space-based-CNS-architecture are not shared with us<sup>8</sup>.

*Airborne Conflict Management (CD&R)* [26] can be considered as one of the key enablers underlying some of the concept elements, especially Self-Separation. The scope of this paper however is much wider and shows that Conflict Management, especially its conflict-prevention part, can be extended to Full-Automatic Traffic Management.

*Super-Sector* [27] is an innovative project in the EEC with the objective to increase capacity by changing controllers' working methods and adapting airspace structure to traffic flows. It partly overlaps with the objectives of this concept, because it introduces flow-related measures in the 10-20 minutes look-ahead time horizon, which are handled by additional controllers. It has the advantage of being low-tech, but needs complete restructuring of airspace and controller practices. However, the scope of this paper is larger, and its approach is different. Some principles of Super-Sector could possibly be used in transition, and its airspace management is complementary to this concept.

*University-Team* [28] report has about the same target timeframe, but is rather orthogonal to the approach presented in this paper. It overlaps in the use of self-separation in remote areas, and a

traffic synchronisation function. It differs in that it foresees airspace structures in tubes to organise dense traffic, with self-organisation inside the tubes.

*The Concept for Next Generation Air Traffic Control System* [29] is closely related to the in-flight automation presented in this paper, but with the difference to treat the safety-net with yet another automation algorithm, whereas a hand-over to the flight deck is suggested here. The self-separation is built on automation and procedures for the safety-net function.

## Conclusion

The present paper is a proposal for a way forward from the EEC strategy towards an operational concept for integrated adaptive and predictive ATM. The scope in time and the expectations for that new concept have been fixed. Then the concept and its five basic concept elements that form a seamless layered planning mechanism have been highlighted. Further, its enablers, the expected benefits and transition issues were discussed. This needed the elaboration of a baseline of operating concepts at the 2020 time horizon. A brief analysis vis-à-vis other concepts was given.

This paper has passed review by experts in the EEC and found resonance to lead to innovative research. Next steps should be to break each concept element further down, and to start qualitative assessments.

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<sup>8</sup> i.e. the author and maybe some others.

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## Acronyms

ACAS	Airborne Collision Avoidance System
ANSP	Air Navigation Service Provider
AO	Airline Operations
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSP	Air Traffic Service Providers
ATSU	Air Traffic Service Unit, sometimes used as synonym for Air Navigation Service Provider (ANSP)
CD&R	Conflict Detection, Prevention and Resolution
CDM	Collaborative Decision Making
CFMU	Central Flow Management Unit
COOPATS	Co-operative ATS

CPDLC	Controller-Pilot Data Link Communications
EEC	EUROCONTROL Experimental Centre
FA	Flow Advisory
F&CM	Flow- and Capacity Management, sometimes also ATFCM
MFP	Micro-Flow Pattern
MSP	Multi-Sector Planner
OCD	Operational Concept Document
P-4D	Precision 4 Dimensional Navigation (also called RNP-RNAV, we would prefer RNP/t and find P-4D more expressive)
P-RNAV	Precision RNAV
RNAV	Area Navigation
RNP	Required Navigation Performance
SMGCS	Surface Movement Guidance and Control System
SWIM	System-Wide Information Management
TIS-C	Traffic Information Service - Contract mode