EFFICIENCY DRIVEN BY JOINT OBJECTIVES: A NEW WAY TO ORGANIZE THE AIR TRAFFIC MANAGEMENT

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Abstract

European experts stress that current Air Traffic Management (ATM) will not be able to cope with the traffic growth planed over the years to come and are advocating for radical changes and new control paradigms. This paper presents operational concepts suggested in the frame of the "Paradigm SHIFT" project aiming at coping with the Air Transportation Demand in a long term vision.

The project Paradigm SHIFT started early 2004 at the EUROCONTROL Experimental Centre (France) is one attempt to response to these challenges. Paradigm SHIFT goal is to investigate a new control paradigm that could cope with future air traffic demand of the horizon 2020 and beyond.

From the different analyses of ATS actors needs, we propose a new way of designing the air navigation system based on the concept of management by joint objectives instead of the management by means currently in use. It defines the foundation of a new ATM system able to cope with traffic growth, while maintaining a very high safety level and supporting a sustainable air transport business development.

We suggest two major concepts as the backbone for the shift of control paradigm from today to the future: "Contract of Objectives" and "Dual Airspace". The first one is turned towards the efficiency and the stability of the system, and the second one towards the capacity. These two main concepts could be independent but could also be combined together because there is no contradiction in their mode of operations.

1. Introduction

Paradigm SHIFT proposes, through an analysis of the aeronautical system and ATM, innovative concepts for responding to safety, capacity and efficiency issues linked to the growth in air traffic in Europe after 2020.

The purposes of this paper are to summarize the analysis of the current European ATM, to better know the main issues to deal with, to focus our attention on key points to base on our research and finally to describe the proposed concepts.

2. Analysis of the current European Air Traffic Management

There is a consensus to declare that the current ATM system will not be able to cope with the traffic growth planed over the years to come ([1][2][3][4]). The initial work achieved in the frame of the Paradigm SHIFT project is to identify the key elements of the ATM which might require major evolutions..

The ATM key-features can be summarized in the following points:

- Air transport is a production system which exists only because it meets cost-benefits criteria. In this context, air navigation is one element in a chain of production which meets financial, safety and efficiency targets. ATM costs refer both to taxes charged on the airlines and passengers, and the consequences of ATM operations like delays.

- The nature of future European air traffic demand is very difficult to assess. Economical, social and geo-political factors can quickly modify the demand and can have great impacts on the air transport system. However, it seems reasonable to work on the following assumptions: there will be a moderate growth of number of flights, route-network will remain complex, the main traffic flows will be north/south and east/west.
- En-route Air traffic is a mix of climbing/descending and cruising aircrafts. Each of these categories has different characteristics in terms of throughput, disruptions, bulk, shape, complexity, and services. The task and responsibility sharing among ATM/ATC actors are based on geographical division of the airspace where all traffic categories are combined. A better consideration of the traffic characteristics in sector design and traffic organization is a fruitful way to have a more efficient task sharing between ATM/ATC actors.
- ATM and ATC are continuously subjected to disruptions and uncertainty management is a key for the future. Disruptions can be classified into different categories: ad hoc events (meteorology, sudden limitations of runway capacity, aircraft failure, etc.), constant imprecision (technologic inaccuracy, noise model), and system-wide problems generated by interfaces between ATM/ATC components (ATFM vs. ATC, and ATC vs. aircraft crew).. The future Air Navigation system should not try to eliminate these uncertainties but rather to live with. The system should not be constrained if this brings no operational benefits, otherwise it will be too rigid and therefore incapable to manage the inherent variability in the air navigation system.
- There is an operational continuity for airlines between ground and air segments. This continuity can be described as the operating cycle of an aircraft. In such a vision, arriving time appears as a key factor for the airlines, and consequently a key challenge for the ATM/ATC to perform. The operating cycle of an aircraft integrates totally the approach developed by CDM-Airports [5] for the ground operation side.
- There are strong relationships between the traffic to manage, the airspace structure and the controller working method. The air navigation system operation modes need to be approached globally. They are the result of a complex compromise between the organization of traffic (flight planning), the airspace structure (routes, navigation points, control units), and lastly, the operational working methods (including the air traffic controllers environment). The strong relationships between the three elements can be described as the "air navigation tripod". The balance between the axes of the tripod is performed to be locally efficient.
- Traffic demand continuously fluctuates. It is now acknowledged that, in order to manage heavy traffic loads, more and more constraints are given to the navigation system. These constraints are appropriate only when traffic load is heavy and becomes counter productive for low traffic density. For this reason, air navigation must be envisaged in the shape of a flexible airspace which has the capacity to adapt itself to meet the demand. Efficiency consists of coping to the traffic demand in the frame of a flexible and optimized ATM/ATC resource management.

3. Key elements retained

Behind this analysis of the current ATM system, one can discern three keys elements on which should be build the future ATM concept:

- System efficiency;
- Responsibility;
- Local autonomy.

3.1. Efficiency

Air transportation system is composed of various actors (i.e. Airports, Airlines, ANSP, ATFM….) which all have their own needs, interest and constraints. For example, airport take-off and landing capacities constitute genuine bottlenecks, making it impossible to respond to an increase in air traffic. The largest airports are already operating at maximum capacity and only increased optimization of the take-off and landing sequences will make it possible to cope with traffic growth.

But all these various actors are linked together through the same "object", the flight which should be considered as the corner stone of the Air Transport system. So a new way for enhancing the system efficiency is to improve functional and operational continuity in aircraft management, both on the ground and in the air, keeping safety and productivity as main objectives.

On the other hand, European airspace is partitioned into different Aeronautical Navigation Service Providers (ANSP). Each one has its own route network and working methods constraining traffic capacity and flow, especially at their interfaces with others ANSP. An integrated and global approach of traffic management at European level appears to be the only possible mean to get substantial gain in terms of traffic efficiency. Functional and operational continuity between ANSPs is vital to take in account the entire operating cycle of an aircraft, thereby achieving a better understanding of air traffic as a whole. However, beside the need of global operational continuity and efficiency, different local mode of operation could prevail in different part of the European Airspace [6]. A new ATM system shall be flexible and adaptive enabling optimum use of resources, therefore it should not put constraints when and where it is not required, this will not be cost effective.

To this end, it is proposed to bring together all air navigation components in a system-wide collaborative decision making and negotiation process.

3.2. Responsibility

Currently, the mission of air navigation is to safely organize and monitor the air traffic. But air transport is a production system which exists only because it meets cost-benefits criteria. In this context, air navigation is a link in a chain of production which meets financial, safety and efficiency targets. Consequently, air navigation cannot shelter from the financial rules of air transport behind the safety argument alone. Being effective, as is currently the case in terms of safety, is not sufficient with regard to air transport operations. Better results in terms of cost-efficiency must be achieved. These objectives will become all the more pressing as responses are sought to the growth trend in air traffic. The performance criteria for the navigation system should be, as proposed by ACARE [6], cost-efficiency and time-efficiency. In others words, ANSPs should be competitive and better manage their own resources in order to meet users' needs with punctuality as new prime objective in combination with safety. It's a new responsibility for ANSPs.

Also, whatever the hypotheses envisaged for traffic management in future, it is clear that consideration must be given to a redistribution of tasks between the aircraft and the ground; and to more automation which poses the other problem of sharing responsibilities between the human being and the machine.

. This will have a great impact on responsibility and these questions must be considered from now on.

3.3. Autonomy

European airspace and traffic demand are by nature inhomogeneous in terms of traffic characteristics and also in terms of distribution over time. As stated previously, beside the need of global operational continuity and efficiency, different local mode of operation could prevail in different part of the European Airspace. Modes will correspond to different qualities of service in relation with this traffic heterogeneity. In order to be flexible and adaptive, the services may vary over the time also.

This would result in a European ATM system where the provision of air navigation services would be based on different operational modes. This local tactical adaptation would be more consistent and advantageous overall than the aircraft-by-aircraft adaptation which is sometimes mentioned. We can imagine a system where traffic is globally coordinated at a strategic level by a pan European body grouping the set of districts which are managed at a tactical level by independent local bodies. We assume that local actors have the best view of how to optimize their organization In this system, the tactical districts are involved when strategy is decided (schedule preparation), and involved through the local managers for the strategy's implementation.

The resource management of ATC in relation with the traffic demands requires the district-based airspace to be adaptive. In this case, it is responsibility of the local ANSP in charge of the district to determine the best balance between its local resources, the traffic characteristics, and the chosen airspace solutions (airways, flight levels or waypoints). Therefore, the global ATM organization is decentralized meaning that each ANSP has the authority and the responsibility of their local choices for a greater efficiency.

This can be seen as the counterpart of the notion of responsibility (§3.2). Each ANSP would be responsible, so accountable for respecting the punctuality. So, the system gives to the ATCo the means to locally assume this new responsibility.

4. Paradigm SHIFT proposed concepts

Based on the here above key features, two majors concepts have been raised and define our approach of the ATM of the future, the **Contract of Objectives** and the **Dual Airspace**. Those concepts can be investigated independently and can lead to various sub-concepts.

4.1. Description of Contract of Objectives Concept

The Contract of Objectives defines objectives applicable to a flight and links actors together through agreed interfaces. The respect of the Contract of Objectives, negotiate between the appropriate actors, is a way of managing organized traffic and conform the operations to planning. This Contract of Objectives is drafted during a negotiation phase involving all actors (i.e. airlines, airports, ANSPs, military units, etc.) whereas individual objectives are assigned through the breakdown structure of the responsibilities locally at the level of the control center. The objective assignment and negotiation can be performed as a collaborative decision-making process called the "**Operational Plan**".

This global organization is driven by agreed objectives. This objectives assignment is based upon a breakdown of responsibilities in the ANS: the decentralized ATM organization appears as a new concept to increase ATM efficiency. Only local actors have the best view to optimize their organization

"Constraints must be as light as possible". Disruptions are part of the ATM system. Putting constraints to insure safety and fluidity is necessary to manage the traffic. But over constraining close the door to the resilience face to uncertainty and is not cost-transparent. The concept of **Target Windows** defines 4D windows as intermediate objectives for a flight, linking actors together and taking into account constraints and system capability to insure negotiations to reach global objectives.

4.1.1 The Contract of Objectives

Air navigation service efficiency requires better functional and operational continuity between the various actors, whether they are air traffic actors or those playing a role in the more global air transport system (airlines and airports). There must be an operational link between all these actors identifying the role and the resulting redistribution of tasks and responsibilities for each actor, in relation to a clear, well-defined objective that is accepted by all concerned. This objective is general, of course, and will be different for each actor in accordance with the actor's specific characteristics and workload. The challenge is to define a common operational minimum among the actors which is sufficient to strike the right balance between productivity and safety. For this reason, it is helpful to propose a global contract for the "air" segment of the aircraft's operating cycle. Firstly, this would facilitate functional and operational continuity within the ground segment, since it is compatible with the objectives of airports. Secondly, it would play a role in integrating the flight segment into the rest of the system, by creating bonds of reciprocal responsibility between the airlines, the aircrews and air traffic actors. The Contract of Objectives is associated with one flight. It is intended first of all as a guarantee of results offered to all the actors by the air traffic system on the basis of known constraints at the time when the contract is drawn up. Consequently, it is the ATC responsibility to fulfill the contract once all actors accepted this one. For controllers, the incorporation of the Contract of Objectives into their activities brings an additional task. It is clear that respecting the Contract of Objectives becomes a key issue in their activities, safety remaining the controller's top priority. If the Contract of Objectives cannot carry out during the flight, it is renegotiated at strategic level in the operational plan process. The "Contract of Objectives" is not a rigid framework within which aircraft have to operate. It contains built-in margins for flexibility and adjustment in order to manage disruptive factors. These margins are compatible with all the other components of the aeronautical system. The Contract of Objectives is therefore a flight envelope defined on the basis of:

- The aircraft's room-for-maneuver ("commercial" flight envelope).
- The predictions relating to en-route control constraints.
- The final objective to be attained (i.e. destination punctuality). The closer one comes to the final objective, the smaller the room for maneuver becomes.

Like for the controllers, the "Contract of Objectives" significantly modifies the role of aircrew in the conduct of the flight. They are no longer the only persons responsible for adhering to the arrival time at the destination. They cannot, of course, re-discuss the "contract of objective" once it has been accepted by all the partners. As long as the flight takes place within the envelope defined in the contract, it falls to the controller to give orders to aircrews regarding safety and navigation. It goes without saying that under no circumstances can controllers pilot the aircraft. All orders from controllers are submitted for approval to and executed by the aircrew. This means that the aircrew has at its disposal on board the aircraft information telling it the "adherence" of the aircraft in the Contract of Objectives.

4.1.2 The Operational plan

The process by which the contracts of objectives of all flights (i.e. refined demand) are elaborated is the operational plan. The operational plan mechanism is both a negotiation and refinement process between all actors involved in the air operations (airlines, airports, ATM/ATC providers). "Refining is more efficient then redefining". This granularity-oriented method permits to optimize co-operations and allows agreement to be found in an early state of the process. In this case, refinement appears as implicit agreements because elements are specifying more in detail and not "called in question". This philosophy drives the whole process of the planning phase of the ATM. The process of drafting "contracts of objectives" is at the heart of the air transport system, since this process will define the framework within which flights will be performed and the responsibilities which will be applied to ATC actors. The Contract of Objectives is drafted on the basis of two sets of requirements:

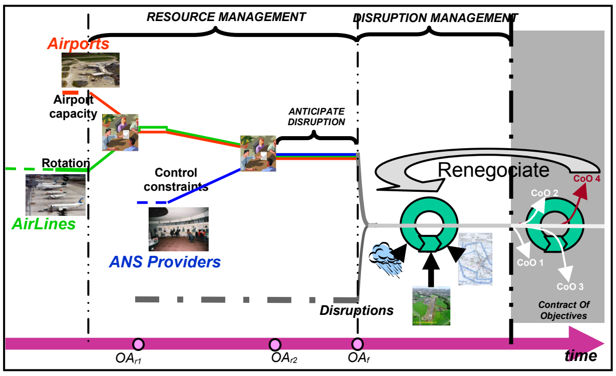
- The individual requirements of the flight in question.
- The general or global requirements of the air transport system and all its partners. The individual requirements are a subset of the general requirements.

The aim of the operational plan is to better manage the scarce resources represented by runway capacities and ATC organization to avoid bottlenecks. To this end, the aims of this approach to the drafting process will be:

- To adjust the resources available to fit demand. This adjustment is a two-way process, i.e. ATC resources are adjusted in accordance with user demands in the full knowledge that the resources are limited and will not be able fully to satisfy demand. This also constitutes an acknowledgement that for certain areas of airspace, it may not be possible to satisfy the whole of the demand. The system will, however, be optimized in order to satisfy demand as far as possible.
- To enhance cooperation between the various actors in air transport in order to share and work on the most precise and up-to-date information.
- To minimize and/or attenuate global problems in order to encourage adjustments and limit the drawbacks.
- To reason at each stage of the drafting process with an appropriate level of granularity that depends on the precise information and the time remaining for the issuing of the final contract.
- To use "real-time" information as soon as it becomes available in order to increase the precision of the planning.

The challenge at the heart of the drafting process is therefore to build a system based on adaptive procedures and the sharing of considerable amounts of information. Operational plan is a three-step process leading to various releases of the global agreement (i.e. operational agreements). It begins far ahead (e.g. six month) before the flights for managing the scarce resources which are the runways capacities in relation with the airline demands. In a second step, Air Navigation Services Providers (ANSPs) are involved for adjusting the first version of the operational agreement to the ATC resources and finding the best solutions in the district airspace. The third step is a refinement and update process for managing the disruptions being able to modify the second version of the operational agreement. Operational plan is a continuous process which leads to the deliverance of contracts of objectives at each flight before its departure from the airport block. The operational plan aims at increasing the decision making process in the elaboration of contracts of objectives by a better transparency and data sharing.

Fig.1. Operational Plan process



4.1.3 Target Windows

At the European level, the size of the airspace and the traffic diversity conduct to share the Air Navigation Services responsibility between different actors. To assume responsibility, there need to have a significant autonomy in term of organization, as presented in the Decentralized ATM organization. To ensure a global coherence between actors concerned by the airside, intermediate objectives have to be negotiated. The Target Windows define milestones marking out traffic progress. These intermediate objectives assigned to air actors have the following functions:

- They constrain traffic progress in term of boundaries. At the strategic level, they permit to define or refine the airspace at the local level according to expected traffic density and ATC capability. These open dynamicity in Airspace domain.
- They create a strong link between the planning phase and ATC operations increasing robustness of the whole system. The nature of the link has to preserve ATC initiative and windows are to be calculated according to the balance between constraints, disruptions and costs. Robustness comes also from the fact that local means are not directly the aim of the negotiation but only objectives on interfaces are discussed.
- The collaborative planning on objectives permits to take into account technical and economical diversity of actors and give guaranties. Target Windows create add-values to technical and economical organizations.

The Target Windows create a common language between all the operators involved, and between the planning and the execution phase. Target Windows are a tool that defines efficiency objectives for the operators, and provide a monitoring tool at tactical and strategic levels, enabling them to deal with disruptions as soon as possible and with a clear view of the situation. They are expressed in terms of 4D intervals of adapted width, rather than precise points or 4D trajectory. Their size and localization reflect constraints faced by downstream components, such as punctuality at destination, runway capacity, or congested en-route area. The room for adaptation left to operations ensures resilience to disruptions. Operational divergence from this planning frame is still possible, and triggers a specific decision process at strategic level called renegotiation.

4.2. Dual Airspace

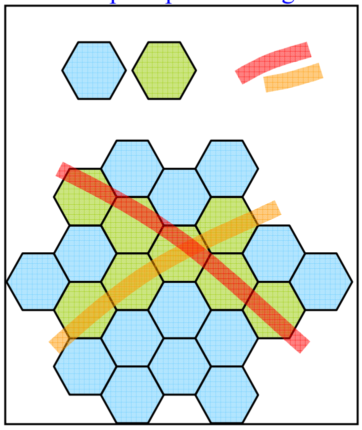
The traffic complexity in the "core area" requires defining a specific mode of operation by separating the various types of flight, (i.e. climbing, descending and cruising), in which the traffic is segregated into flow-based and district-based traffic. The aim here is to propose an original air traffic management system which will enable to cope with the peaks in demand expected in the future. It is reasonable to suppose that the increase in demand will result in an increase in en-route traffic over the core area, which is already congested to the point where it gives rise to numerous regulations. The aim is to relieve pressure on the main traffic axes forming part of the core area's interlinked network by setting a set of highways independent of the current core area network. The highways will span the continent, and they will be reserved for cruising aircraft in level flight. Traffic management on highways will be flow-based, with closure conflicts but no convergence conflicts. In the core area, the theory is that there will be a limited number of highways along the main east-west and north-south axes. Highway intersections generate no routes convergence since they are managed through different level allocations. The highway constitutes a privileged airspace with tremendous potential for innovation. The aircraft using the hiway network, are stable at a given level; they all move in a predictable manner, in the same direction and the same way. An aircraft flight path is then no longer three-dimensional but mono-dimensional. The possible benefits of this situation are threefold and complementary:

- simplified traffic, giving the opportunity to get a larger number of aircraft in this specific airspace area;
- simplified ATC procedures, through the use of a limited system of elementary instructions: change in speed and change of route (digital airspace);
- simplified displays, replacing the map backgrounds with synoptic tables would become possible;

The district-based traffic will be specific to local traffic in order to cope with the local constraints of traffic and airspace. Regional airspace should turn to its advantage the isolation of a significant proportion of cruising traffic:

- direct decrease in the volume of traffic;
- increase in the reliability of predictions on highway;
- functional specialization of the different sub-system;
- increase in airspace availability;

Fig.2. Dual Airspace possible organization



Conclusion

An detailed analysis of the current ATM system gives us a better understanding of the the key elements of the ATM which might require major evolutions enabling us to build a new control paradigm, able to cope with the future challenges of the air transport.

Any viable new ATM system should be resilient to any possible changes in the business models of the each actors involved in the air traffic system and should not be based on safety criteria only. The Contract of Objectives proposed here is a consensual trade-off issued from negotiation between all the actors, so even if the business models change from punctuality issues to, for example, fuel cost leading to short haul flight or new ecological considerations, the proposed new ATM system will remain resilient.

The Paradigm Shift project emphases that coping with the increase in traffic demand should not rely on Air Traffic Controllers only but would need on a total re-organization of the air navigation system as a whole.

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Sandrine Guibert, B.Sc. in Electronics and Information Technology (University of Nice, 1991), Mil. ATC Diploma (France, 1992), graduated in Human Factors (University of Paris V, 2002), had been a Military ATCO before joining EUROCONTROL in 1998, as a simulation analyst (RVSM, Three States, FRAP, Look). She was involved in various projects such as Stress, Implicit, Explorer, SuperSector and she is currently Research Assistant and Deputy of the Paradigm Shift Project at the Innovative Research Area in EUROCONTROL Experimental Centre in Brétigny.

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Didier Dohy, PhD in Physics (University of Paris XIII, 1987) is an ATM architecture & engineering specialist. NeoSYS' R&D managing director, he has been involved in earlier EUROCONTROL Experimental Centre Innovative Research projects such as SuperSector or Paradigm Shift. He has 15 years of experience in ATC center design and engineering as well as data-link software implementation and validation.

Jean-Yves Grau, Doctor of Medicine, was an ergonomist at the French Aerospace Medicine Institute before becoming a consultant in Human Factors in ATM. His research interests include the design of decision supports, human error, flight safety and ergonomic assessment of complex systems. He was also involved in the SuperSector project at the EUROCONTROL Experimental Centre as its experimentation lead.