Engineering 7 (2021) 448–451

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Research
Novel Methodologies in Air Transportation—Perspective

SESAR: The Past, Present, and Future of European Air Traffic Management Research

Tatjana Bolić [a,*], Paul Ravenhill [b]

[a] University of Westminster, London NW1 5LS, UK
[b] Think Research Ltd., Poole BH12 1ED, UK

ARTICLE INFO

Article history:
Received 21 April 2020
Revised 12 June 2020
Accepted 4 August 2020
Available online 3 March 2021

Keywords:
SESAR
Air traffic management (ATM)
Single European Sky
ATM research and development
ATM solution
Deployment

ABSTRACT

The Single European Sky Air Traffic management (ATM) Research (SESAR) project is the technological pillar of the European Commission's Single European Sky Initiative to modernize ATM. Here, we describe the process of establishing SESAR and the main parts of the project: the research and development (R&D) part, which is led by the SESAR Joint Undertaking; the deployment part, which is managed by the SESAR Deployment Manager; and the European ATM Master Plan, which collects and lays out both the R&D and deployment needs. The latest European ATM Master Plan was adopted just prior to the current pandemic. The huge loss in air traffic due to the pandemic, and the speed of the recovery of the aviation industry will require reprioritization, but the main elements that have been established—particularly those in support of the environment—remain valid.

1. Introduction

The free movement of people and goods within the internal market is a cornerstone of the European Union (EU)'s society and economy, where mobility ensures the economic, social, and territorial cohesion of member states. Air transport mode mobility is enabled by air traffic management (ATM), which consists of "the aggregation of the airborne and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations" [1]. ATM in Europe is provided by national air navigation service providers (ANSPs) within their national boundaries. At the European level, these national ATM systems are interconnected with EUROCONTROL's Network Manager with the goal of improving traffic flows, enhancing traffic predictability, and increasing network capacity, where the network includes both EU and non-EU countries[†].

To understand the current (and future) ATM research environment in Europe, it is necessary to take a brief look into both the past and the near future. Fig. 1 depicts the evolution of traffic and en-route delay due to the lack of airspace capacity, as well as the key responses to extreme delays in the last three decades. The delay in the late 1980s[‡] [2] (not depicted here) prompted the creation of the Central Flow Management Unit[††] (CFMU) within EUROCONTROL, as well as the successful implementation of reduced vertical separation minima and basic area navigation, which provided significant capacity increases. The delay peak in the late 1990s resulted in the Single European Sky (SES) initiative, with the first legislation package being delivered in 2004. The goal of the SES was to reform the architecture of European ATM, address issues at the European—rather than local—level, and provide a legislative approach to meet future capacity and safety needs. Air traffic and consequent delays continued to increase in the early 2000s, and a delay crisis seemed inevitable in the near future, and policymakers and stakeholders in the field lacked confidence that the technological solutions needed to address the problem existed. This situation prompted the creation of the Single European Sky ATM Research (SESAR) program in 2008. With the adoption of the second package of SES legislation, SESAR was recognized as one of five pillars:

- The first pillar is based on regulating ANSP performance by means of performance monitoring and strengthening the network management function.

* Corresponding author.
E-mail address: t.bolic@westminster.ac.uk (T. Bolić).

[†] EUROCONTROL is an intergovernmental organization with 41 member states and two states with the Comprehensive Agreement.

[‡] In 1988, 20% of traffic, and 25% in 1989 was delayed mainly due to infrastructure con-gestion, see Ref. [2].

[††] Provides Air Traffic Flow Management across Europe and is now a central part of the Network Manager, changing the name to Network Manager Operations Centre.

https://doi.org/10.1016/j.eng.2020.08.023
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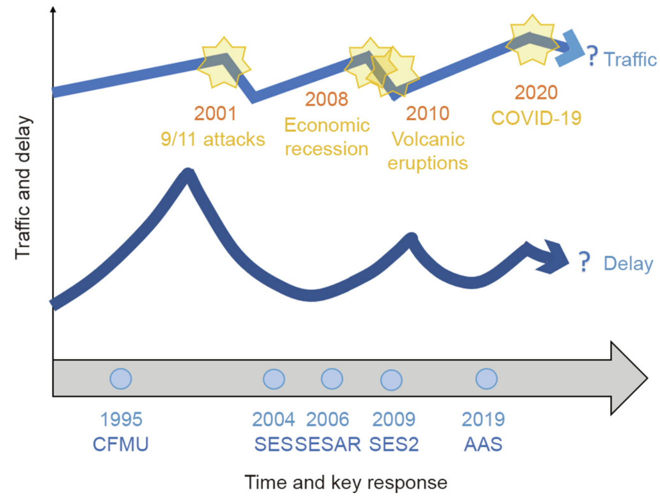

Fig. 1. The evolution of traffic and delay in Europe, along with the key responses to decrease delay. Source: EUROCONTROL traffic and delay statistics.

- The second pillar establishes a single safety framework through the European Aviation Safety Agency (EASA).
- The third pillar provides new ATM technologies through the SESAR project by *defining*, *developing*, and *deploying* technologies and procedures needed to increase ATM performance.
- The fourth pillar addresses the management of airport capacity to keep it aligned with air transport capacity.
- The fifth pillar addresses the human dimension by ensuring that the changes are acceptable to operational staff.

The SES and its five pillars created an environment enabling research, development, and deployment to proceed as rapidly as possible in the fragmented European setting. Nevertheless, significant delays returned in 2018. The Airspace Architecture Study (AAS) [3] identified potential solutions based on the SESAR Joint Undertaking (JU) research results and delineated the mode of their implementation in order to address this latest capacity–demand imbalance, thereby paving the way for a new paradigm and research direction.

Whilst these actions were a response to major delays, actual transformations in the ATM have been limited due to regular reduction in air traffic as a result of economic and natural disasters. As shown in Fig. 2 [4], the latest disaster—and the one with the heaviest impact on air traffic in Europe thus far—is the coronavirus disease 2019 (COVID-19) pandemic.

Traffic growth without the same growth in air traffic capacity creates delays, which in turn spur certain responses. External—usually unforeseen—events decrease traffic and consequently reduce delays, often resulting in a reshuffling of the priorities of the previously established response.

The events and responses depicted in Figs. 1 and 2 are the backdrop against which to introduce and analyze our main topic: the SESAR project and its results, implementations, and future directions.

2. SESAR

As a response to growing air traffic delay and to the need for new ATM solutions[†], and following the successful completion of the SESAR definition phase (explained below), the SESAR project was established by European Council Regulation No. 219/2007 [5]. The important ambition of this regulation was "to integrate and coordinate research and development activities which were previously undertaken in a dispersed and uncoordinated manner" in the EU, and to avoid duplication of research and development (R&D) activities.

Thus, while significant ATM R&D was being undertaken in Europe at both the European and national levels, there was no common plan on how to further develop (i.e., from lower to higher technology readiness levels) and eventually implement promising research results. Furthermore, it was even less clear how to favor solutions aimed at improving overall network performance as opposed to varying local improvements. In a sense, the dispersed ATM research effort was creating a competing, instead of common, view of the future European ATM.

Thus, with the goal of coordinating all European ATM research toward a common goal, the regulation [5] described three phases of the SESAR project, each led by a different entity:

- The *definition phase* was performed by the SESAR Consortium (2005–2008)[‡], with the goal of delivering a European ATM Master Plan (MP) by 2008. The purpose of this MP was to define a research, development, and deployment plan for ATM solutions in Europe, with the goal of achieving SES performance objectives.
- The *development phase* involves the development and validation of the needed ATM solutions, and is managed by the SESAR JU, a public–private partnership established by this regulation. This phase was originally intended to run from 2008 to 2013.
- In the *deployment phase*, the validated ATM solutions are to be produced and implemented on a large scale; this phase was planned to take place from 2014 to 2020.

The definition phase ended with the delivery of the first MP [6], which took into account previous ATM research. For example, the SESAR operational concept and performance framework were adapted from the EPISODE 3 project [7]; the EMMA projects [8,9] offered the first advanced surface movement guidance and control system (A-SMGCS) solutions; the foundation for the SESAR remote tower solutions came from the ART project [10]; and the SWIM-SUIT project [11] came up with the precursors of the current system wide information management (SWIM) solutions.

The Council of the European Union endorsed the MP in 2009 [12], thereby expressing the support of the EU member states for this direction in ATM research. The MP was transferred to the SESAR JU to serve as a plan for R&D activities, and the SESAR JU was given the responsibility of updating the MP with the new developments, research priorities, and deployment road map, consulting all stakeholders (i.e., ANSPs, airlines, airports, military, etc.) in the process.

The R&D (and deployment plan), as laid out in the SESAR JU founding regulation, ended up being too optimistic; by 2013, the year of the planned closure of the development phase, only a part of the solutions described in the MP had been validated and was ready for transfer to the development phase. Furthermore, the economic downturn of 2008 and the volcanic eruptions that occurred in 2010 (Fig. 1) had an important impact on R&D priorities. In 2014, the SESAR JU was extended [13] until 2024.

The SESAR JU combines public funds (i.e., the EU funds and EUROCONTROL in-kind contribution) and private funds for ATM R&D. The European Commission (EC) and EUROCONTROL are the founding members and provide about two thirds of the R&D budget, while the remaining third is covered by the SESAR JU members. The current SESAR JU has 19 members (representing 37 individual companies), as a result of a call for members in 2014. The R&D is financed through restricted and open calls. Restricted

[†] ATM solution represents a change in the way ATM is performed. ATM solutions are new operational concepts, procedures and relevant technologies.

[‡] The Consortium was led by EUROCONTROL and consisted of 30 members and 20 sub-contractors. It was financed by the European Commission and EUROCONTROL.

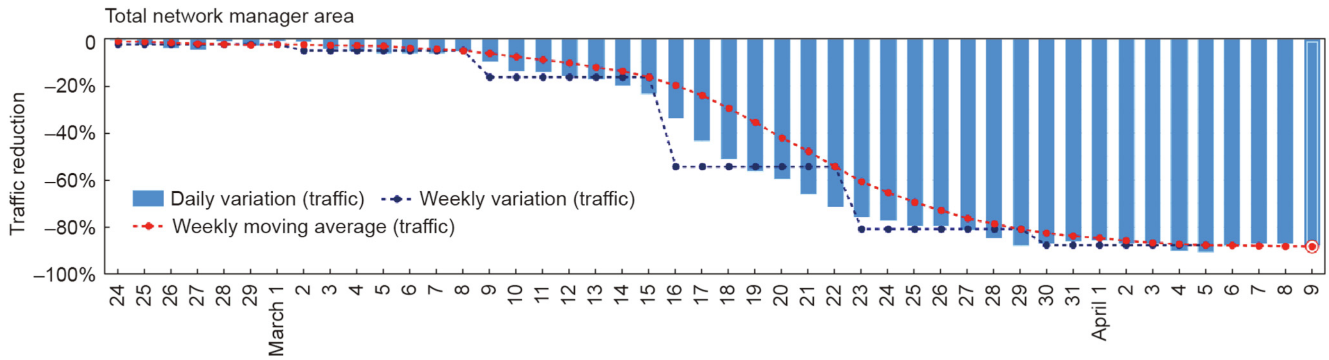

Fig. 2. Daily traffic variation in the European network in 2020.

calls cover maturing and validating ATM solutions, which are dedicated to SESAR JU members. Exploratory, low-maturity research and some very large demonstrations are met through open calls. As the EC contribution comes from Horizon 2020 (H2020) funds, participation is open to all entities eligible for the H2020 research programme, under the H2020 rules (for more details on SESAR JU membership, governance, funding sources, and calls, see Refs. [14,15]).

As some ATM solutions were ready by 2013, and as the fastest path to achieving the ATM modernization and SES performance objectives lies in a timely, coordinated, and synchronized deployment of these solutions, the SESAR Deployment Manager function was instituted in 2013 [16]. In particular, the responsibility of the Deployment Manager is to manage the implementation of Common Projects [17]. The Common Projects comprise mature ATM solutions delivered by SESAR JU that are deemed necessary for the "achievement of the essential operational changes" [17] in the European ATM network, where coordinated and synchronized implementation across the network is required. Deployment is funded through the Connecting Europe Facility, and is aimed at infrastructure investment at the European level.

At its inception, the SESAR project was envisioned to follow a linear path from definition to deployment. It is now evident that ATM modernization requires a continuous life-cycle. The SESAR JU performs R&D activities and updates the MP. These updates are necessary to account for changing external conditions, such as changes in EU policy and economy, or the emergence of new challenges, like drones and the digital transformation of ATM. Every few years, all aviation stakeholders are consulted in order to identify gaps, based on which the research and innovation needs are defined and deployment strategies are adjusted. Based on the MP, the SESAR JU proceeds with research, development, and validation activities, and the SESAR Deployment Manager organizes the implementation of Common Projects (i.e., chosen mature ATM solutions). The latest, fourth edition of the MP [18] takes into account a steady traffic increase forecast, growing environmental concerns, and emerging new air vehicles (i.e., drones and very high altitude vehicles).

To date, the SESAR JU work program has successfully validated 63 ATM solutions [19], with a further 79 solutions in the pipeline for delivery in the next few years. These solutions include maturing key enablers of future concepts such as remote towers, time-based separation, and extended arrival management (AMAN) from the mature solutions; as well as virtual centers, improved aviation meteorology (MET) information, and full SWIM from the solutions in the pipeline. Each solution is supported by business, safety, performance, and human performance cases, as well as by material to support standardization. The SESAR solutions have already been deployed at over 300 locations in Europe, and Common Project implementations are continuing (see Ref. [20] for deployment monitoring). However, there is space for improvement in deployment strategy, as the European Court of Auditors' report [21] states: "We conclude that the EU's regulatory intervention in the form of common projects has added value. However, we also found that EU funding in support of ATM modernisation was largely unnecessary, and that the management of the funding is affected by some shortcomings." The report's findings acknowledge the value of a timely, coordinated, and synchronized deployment of solutions to achieve modernization, but point out that the management of deployment funds needs to be focused on transformational solutions rather than on piecemeal local improvements.

3. The future of European ATM modernization

The three main challenges listed in the latest MP are: first, the mismatch between traffic demand and available ATM capacity; second, the need to address environmental concerns more seriously; and, third, the emergence of new entrants in the airspace. The European ATM infrastructure was on a path to reach the limit of its ability to manage the increasing volume of different types of air traffic. Conventional air traffic has been forecast to increase by 50% in the next 17 years, with a risk of accruing delays 15 times greater than those at present [4].

Such growth prompts environmental and health concerns, as the EU is committed to the European Green Deal [22]. By its nature, ATM has a limited range of actions to reduce aviation emissions: It can contribute to emission reduction by providing sufficient capacity and flexibility to enable aircraft to safely fly environmentally optimized trajectories.

Furthermore, new types of air vehicles—such as very low level drones, military medium-altitude long-endurance unmanned aircraft systems, automated air taxis, super-high altitude (FL600+) operating aircraft, next-generation supersonic aircraft, and electrically propelled aircraft—need to be taken into account and woven into the conventional ATM. These challenges have prompted the creation of "A proposal for the future architecture of the European airspace" [3] (known as AAS). The proposal is based on the SESAR ATM solutions (described in the MP), interwoven with a new ambition that requires transformational technologies and faster deployment of digital enablers in order to support enhanced automation and virtualization.

The future research program will need to aim higher. We need to overcome the problems and inefficiencies caused by bespoke national ATM systems, in favor of new service-oriented ATM architecture. What is the difference between the two? At present, each ANSP owns all the assets needed to provide air navigation services (ANS)—namely, communication and navigation, surveillance, air traffic, and ATM data services—which are tightly integrated within the legacy ATM system. These systems are then connected by a range of bespoke interface standards specific to ATM, resulting in limited interoperability, high maintenance costs, and difficulty in achieving widespread deployment of new systems.

Service-oriented architecture would allow the decoupling of these tightly integrated services into independently operated services, which could then be run from anywhere. Using digital means, it is possible to detach the information service provision from the physical hardware on which it is executed, thereby enabling the virtualization of ATM services. Virtual centers can be flexible concepts. A virtual center can be composed of one or more air traffic service units (current ANSPs) that use ATM data services remotely provided by one or more ATM data service providers. Thus, ANS can be provided over any geographic location, rather than being constrained by state boundaries.

To enable this vision, research must focus on a small number of breakthrough technologies that would enable this virtual infrastructure. Furthermore, significant research into regulatory issues is required, as this concept touches on many regulatory issues, including:

- Allowing member states to employ dynamic change of responsibility for the ANS in their airspace;
- Certification and approval of highly automated systems;
- Changes in controller training and licensing;
- Changes in the economic regulation of the transformed ATM system.

The new architecture is a framework, the achievement of which needs to be highly coordinated and based on commonly agreed-upon service and infrastructure principles. Once established, it will allow different parts of the system to develop at different speeds depending on local needs, whilst maintaining overall coherence at the network level.

At the time of writing, all parts of the ATM value chain worldwide—that is, airlines, airports, ANSPs, and their suppliers—are just starting to slowly exit from the standstill caused by the COVID-19 pandemic. With such a dramatic decrease in traffic (e.g., there was a 90% decrease in the EU on some days in April and May), the urgency of achieving short-term capacity gain may have evaporated. Replanning is necessary. The short-term focus will probably be on managing the reduced traffic as cost-efficiently and sustainably as possible. However, the current situation does not alter the longer term priority for a wide-ranging transformation of ATM to deliver cost-efficient services that support sustainable aviation and new forms of air vehicles using modern technology. If anything, this crisis shows that we need an ATM system that is sustainable, scalable, and resilient, which does call for the envisioned transformation. The MP and the AAS remain the most viable approach in Europe to achieve this objective in a cost-efficient manner.

Compliance with ethics guidelines

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tatjana Bolić is a member of SESAR JU's Scientific Committee and she works on exploratory research projects funded by SESAR JU. Paul Ravenhill occasionally works on research projects funded by SESAR JU.

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