Capacity Sharing within Virtual Centre

How much delay can be reduced?

Natália Solčianska, Andrea Gasparin,
Lorenzo Castelli
Dipartimento di Ingegneria e Architettura
Università degli Studi di Trieste
Trieste, Italy

Tatjana Bolić
School of Architecture and Cities
University of Westminster
London, United Kingdom

***Abstract*—Airspace Architecture Study proposed the future Single European Airspace System, based on modern technologies that could divide the air traffic service provision from local infrastructure for data provision, enabling the decoupling of geographical location from the service provision. This decoupling would enable virtualisation where service providers could use data from the common data services, opening doors to different organisation of air traffic service provision, namely more advanced capacity sharing. Virtualisation concept is still under development and several recent studies evaluated some aspects of virtualisation in ATM, but did not yet address in detail the impacts of different Virtual Centre implementation scenarios. In this paper, we propose a linear optimisation model to evaluate the impact of virtualisation and capacity sharing in terms of delay reduction. We show that taking into account the current airspace design and air traffic management resources, even the air navigation service providers that accumulate the highest capacity-caused delays could decrease those in the range of 25-50% up to about 80% through internal collaboration. Furthermore, the decrease of over 50% of the total capacity-caused delays could be obtained if FABEC[1] were to form a Virtual Centre, and the decrease of about 90% of the total European delay if the Single European Sky (SES) area would form a Virtual Centre. The analysed capacity sharing collaborations indicate the possibility of significant delay reductions, but would not be sufficient, on their own, to eliminate capacity-caused issues in Europe.**

***Keywords*—Airspace Architecture, Airspace modernisation, Virtualisation, Virtual Centre, Capacity-demand balancing.**

I. INTRODUCTION

The air traffic control (ATC) has traditionally been set up to deliver the air navigation services within the airspace of a state, thus establishing national air navigation service providers (ANSPs). The airspace of each state can be covered by one or more flight information regions (FIRs), where the en-route air traffic is controlled by an area control centre (ACC). The airspace under ACC control is further divided into sectors (elementary sectors) and sector groups. Air traffic controllers (ATCOs) are usually trained and certified for a limited number of sectors within an ACC. The European airspace network suffers from ANS provision fragmentation, as each state is responsible for its own airspace, and many states imply as many ANSPs (some of them large, other small). The fragmentation has been identified as an important factor limiting the performance of European ATM system, in particular in the areas of capacity and cost-efficiency [1]. Fragmentation does not inevitably reduce capacity, but it increases the cost of providing and augmenting capacities. The Single European Sky (SES) initiative and SESAR, its technological pillar, have delivered several improvements in technical and procedural interoperability, and harmonisation but have not yet overcome fragmentation to allow seamless cross-border operations.

The Airspace Architecture Study (AAS) [2] proposes the future Single European Airspace System (SEAS), based on modern technologies that could split the air traffic service provision from local infrastructure for data provision, enabling the decoupling of service provision from geographical location.This decoupling would enable virtualisation where service providers could use data from the common data services, opening doors to different organisation of air traffic service provision. Thus, virtualisation can be defined as a form of digitalisation that enables and encourages collaboration in the provision of air traffic services [3]. In this paper we define such cooperation between ANSPs and/or ACCs as “Virtual Centre” which allows capacity sharing between participating ANSPs/ACCs, and can differ in size (number of actors) and consequently in geographical coverage.

Of course, before a decision on (virtual) collaboration is made, it would be useful to understand the magnitude of the possible benefits, for example in terms of air traffic flow management (ATFM) delay reduction. An assessment of possible benefits for such a new concept would inevitably require a fair number of assumptions. In this work we propose a model for such an assessment, taking as a starting point current ATC resources[2]. To be specific, the contribution of this paper is a mathematical model designed to assess delay reduction that could be achieved by different Virtual Centre set-ups (i.e. scenarios), with the current resources, over a chosen period of time.

Section II presents the review of related literature and a brief introduction of the Virtual Centre concept as used in the paper and the capacity sharing notion. The formulation of the linear optimisation is described in Section III, and the results

---

[1] Functional Airspace Block Europe Central.

[2] Current airspace design, sectorisations and air traffic controllers.

11th SESAR Innovation Days

are presented and discussed in Section IV. The conclusion and the way forward can be found in Section V.

II. BACKGROUND

AAS defines a new airspace architecture where air traffic provision is no longer tightly coupled with data provision (and physical "sensing" layer), opening doors to new ways of air traffic service provision [2]. Further, it provides an assessment of benefits of dynamic capacity management underpinned by virtualisation, estimating that the network will be able to accommodate more than 15 million of flights with a delay of less than or at most of 0.5 minutes per flight, under the assumptions of increased sector throughput (as a consequence of future improvements) and establishment of separate *air traffic data providers*. The transition towards this vision requires operational, technological, organisational and regulatory changes to the current airspace architecture, as highlighted by the Transition Plan [4]. Main short-term recommendations regarding the operational and technical measures to deliver the SEAS are listed, namely airspace re-configuration, implementation of cross-border free route and air-ground and ground-ground connectivity, and acceleration of market uptake of the next generation SESAR technologies and services. The legal, economic, and regulatory aspects to deliver SEAS, and to establish common ATM data service providers and capacity-on-demand, are presented in the study funded by European Commission [5]. The study proposes and evaluates implementation scenarios and service delivery models for ATM data service providers (ADSPs), as a key enabler for capacity sharing. As a further step, the RoMiAD project analyses the potential economic benefits of virtualisation, by assessing the market size of the three layers envisioned in AAS (air traffic service provision, ATM data provision and physical "sensing" layer) [3]. Potential (maximum) costs savings are identified per layer, and the further analysis looks at the high-level collaboration scenarios and their high-level assessment. One of directions of future research indicates the need to incorporate the information of the actual sector usage, which would make a more detailed analysis possible, and this is the direction applied in this work.

In SESAR, a Virtual Centre refers to the "decoupling air traffic management (ATM) data services, such as flight data, radar, and weather information, from the physical controller working position (CWP)" [6]. In this paper we define Virtual Centre as a collaboration among a group of ACCs, enabled by virtualisation, in provision of location-independent ATC services. Participating ACCs are not required to physically consolidate their facilities, but full technical and operational interoperability is required, supported by airspace management agreements between the parties. We assume that Virtual Centres would make use of ATM data services from a dedicated common data provider/s (unlike today) and share fully standardised methods of operation, data information, technology, and procedures to operate seamlessly. The collaboration is foreseen in such a way that sectors which are usually under the responsibility of one ACC (ACC-A) can be temporary assigned to another ACC (ACC-B) based on the operational needs, regardless of physical location. RoMiAD [3] defines capacity sharing as the ability of an ACC to operate sectors normally allocated to another ACC and describes alternatives on how and under which conditions the capacities could be shared. Delegation of airspace already exists in Europe, Maastricht upper Area Control Center (MUAC) being the most notable example, by being the first. Note that it look about 20 years from the initial idea of setting up the international facility to the creation of MUAC as such [7].

One of the main benefits of virtualisation would be capacity-demand balancing. The CADENZA (Advanced Capacity and Demand Management for European Network) [8] project, developing further the approach introduced in the COCTA project [9], aims at designing and validating a Trajectory Broker concept with different options for advanced capacity-demand balancing at the network level. The main difference with the current system is the reinforced role of the network manager, who acts as a Trajectory Broker between airspace users and capacity providers to match air traffic demand and capacity on the network, pre-tactically. Our work is geared towards initial assessment of potential benefits of virtual collaboration, without taking into account the exact way of working. To that end we present an optimisation model, which is detailed in the following section.

III. MODEL DESCRIPTION

The linear programming model is introduced and described in this section. The model aims at the assessment of possible delay reductions, and can be applied on various Virtual Centre scenarios. We first introduce a few definitions:

- Sector saturation - utilisation of a given sector expressed as the ratio of hourly entry counts[3] over its declared capacity, multiplied by 100.
- ACC Capacity - for the purposes of the model, we define ACC capacity as a capacity of ACC in terms of the number of sectors it can control at the given time. An ACC-A can share its capacity by "opening a sector" in the airspace and on behalf of ACC-B lacking the ATC resources. To share capacity, the ACC-A opening sector in the airspace and on behalf of ACC-B must have sufficient ATC resources at its location and the ACC-A cannot have all its sectors open.
- Sector capacity - is expressed as number of allowed aircraft entries per hour.
- Average ACC sector capacity - average ACC sector capacity, calculated for each ACC taking into account its sector capacities over the period under analysis.

In the following, the assumptions under which the model operates are listed, followed by the mathematical formulation of the model.

---

[3] In Europe, the sector capacity is often expressed as the number of entry counts within a time period.

A. Assumptions

The goal of our work is to assess possible impacts of virtulisation on delay reduction, using current ATC resources as input. However, the virtualisation implies that ATCOs are validated on a range of sectors across the airspace to be controlled, or that they have sector-independent license, as foreseen by AAS and very different from the current situation. Furthermore, we do not take into account the traffic complexity and the physics of exact geographical location. In other words, we asses the macro, not micro aspects of virtualisation. The assumptions needed for appropriate model formulation are listed next.

Assumption 1: An ACC is considered to have capacity issues when it generates air traffic flow management (ATFM) regulation[4] delay, under ATC Capacity (ATC-C) and/or ATC Staffing (ATC-S) reason. ATC-S occurs when unplanned staffing shortages reduce expected sector capacity, while ATC-C measures are imposed when demand exceeds or traffic complexity reduces declared or expected sector capacity.

Assumption 2: ACC capacity can be shared in the notion of number of sectors. Staff located at ACC-A open a sector in the airspace of ACC-B when the required operational resources are lacking at the ACC-B usually responsible for them.

Assumption 3: An ACC-A can open an additional sector at ACC-B when it does not generate ATC-C and/or ATC-S delay and the number of currently open sectors is lower than number of sectors available in the planned Opening Schemes (pOS) declared in network operations plan (NOP) [10]. In addition to this straightforward definition, we include in the analysis open sectors with a saturation lower than or equal to a threshold s_{th} as a possibly available capacity. We add these underutilised sectors to the analysis, as a proxy of what could be achieved in the future if the staff planning and re-planning could be supported by technology solutions (for example, multi-sector planner).

- Thus, the following thresholds s_{th} are considered:
    - s_{th} = 0%: only the difference between currently available (declared in pOS) sectors and currently open sectors are taken into consideration as underutilised ATC resources.
    - $s_{th} \leq 20\%$: sectors which are open at the given time and have utilisation lower or equal than 20% are considered as underutilised ATC resources.
    - $s_{th} \leq 40\%$: sectors which are open at the given time and have utilisation lower or equal than 40% are considered as underutilised ATC resources.

  Note that in practice, there might be a mismatch between planned and actually delivered OS. At this stage of work for a simplicity, we consider planned OS in NOP as those that could have been actually delivered.

Assumption 4: An additional sector(s) at ACC-A can be controlled by ACC-B only if the number of currently open sectors at ACC-A does not equal the maximum number of sectors designed in its airspace. If all the sectors of an airspace (ACC-A) are already open, the additional ATCOs (from ACC-B) would not be able to open additional sectors in ACC-A.

Assumption 5: Sector capacity as number of maximum aircraft entries per hour (the time period can also vary depending on the monitoring period) varies between various sectors and in time. This capacity depends on the sector size and shape, expected traffic flows, seasonal variation, experience of ATCO etc. For the purposes of this study we calculate average sector capacity per ACC to be used in the model.

The model requires to partition the entire period of interest into smaller time intervals in order to determine for each time interval which ACCs have capacity issues, and which ACCs are able to provide the service (having underutilised capacity). As the structure of the majority of the data sets used is hourly based, the length of the time interval chosen is one hour. The model takes as input the list of ACCs forming the Virtual Centre and according to the aforementioned assumptions identifies the optimal one to one ACCs collaboration configuration that maximises the total delay reduction. *Total delay* refers to the sum of the delay reduction of all the ACCs within the input list.

B. Model formulation

Model formulation requires the introduction of the following notation:

- $\mathcal{A}$ the set of ACCs of interest.
- T the set of all time intervals within the period of interest. The time interval is set to one hour.
- D_{it} the delay of ACC i at interval t.
- $\mathcal{D}_{jt}(i)$ ACC i's total delay that ACC j can absorb[5] at interval t if collaborating with ACC i.

As long as we are trying to reduce the delay of ACCs with capacity issues, the quantity D_{it} is considered greater then zero only if ACC i at time t respects the conditions described in assumptions 1 and 4.

The quantity $\mathcal{D}_{jt}(i)$ is considered greater then zero only if ACC i at time t respects the conditions described in assumption 3. In this case, the value of $\mathcal{D}_{jt}(i)$ is estimated in the following manner:

- first, we compute the number of flights nf_{jt} that ACC j can control at time t by multiplying the number of available sectors of j at time t with the average ACC sector capacity. Then,
    - if nf_{jt} is greater than the number of delayed flights of ACC i at time t, $\mathcal{D}_{jt}(i)$ is set equal to the sum of the delay of all flights as they can all be accommodated by ACC j
    - otherwise, $\mathcal{D}_{jt}(i)$ is set equal to the sum of the delay of the first nf_{jt} delayed flights of ACC i sorted by delay in descending order (Figure 1). This procedure allows to estimate the remaining delay of ACC i at time t in those cases in which ACC j has not enough capacity

---

[4] One of the ATFM measures for capacity demand management at tactical level.

[5] Absorb by controlling the identified flights.

to cover the ACC i demand, under the assumption that ACC j, in order to optimise the delay reduction, would try to accommodate the most penalised flights.

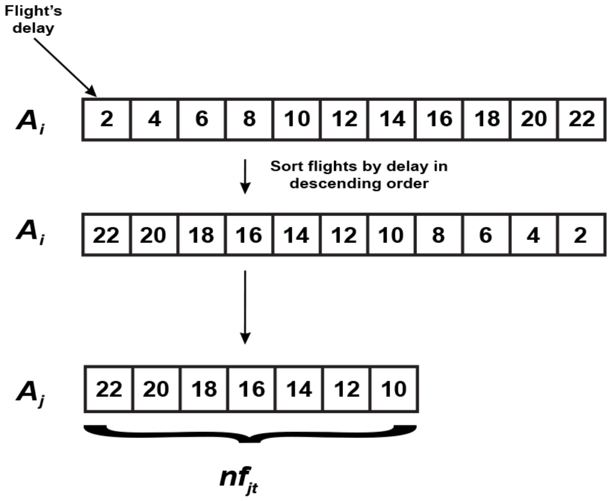

Figure 1. Example of the $\mathcal{D}_{jt}(i)$ computing procedure

The variables used by the model are:

- $x_{ijt} \in \{0,1\}$, the decision variable which is equal to one if ACC i is collaborating with ACC j at time t, meaning that ACC j is absorbing some of the delay of ACC i ,
- $d_{ijt} \in \mathbb{N}$, the minutes of delay of ACC i absorbed by ACC j at time t.

The model is subject to the following constraints:

Constraint 1: At each time t an ACC can collaborate with only one ACC and it cannot collaborate with itself:

$$\sum_{j\in\mathcal{A}} x_{ijt} \leq 1 \quad \forall i \in \mathcal{A}, \forall t \in T \tag{1}$$

$$\sum_{j\in\mathcal{A}} x_{jit} \leq 1 \quad \forall i \in \mathcal{A}, \forall t \in T \tag{2}$$

$$x_{iit} = 0 \quad \forall i \in \mathcal{A}, \forall t \in T \tag{3}$$

Constraint 2: If at time t an ACC is requesting a collaboration with another ACC, it cannot provide within the same time interval any delay transfer to other ACCs:

$$1 - \sum_{j\in\mathcal{A}} x_{ijt} \leq \sum_{j\in\mathcal{A}} x_{jit} \quad \forall i \in \mathcal{A}, \forall t \in T \tag{4}$$

$$1 - \sum_{j\in\mathcal{A}} x_{jit} \leq \sum_{j\in\mathcal{A}} x_{ijt} \quad \forall i \in \mathcal{A}, \forall t \in T \tag{5}$$

Constraint 3: At each time t a delay transfer from one ACC to another occurs only if the two ACCs are collaborating at time t:

$$d_{ijt} \leq x_{ijt} \cdot \mathcal{M} \quad \forall i, j \in \mathbb{A}, \forall t \in T \tag{6}$$

where $\mathcal{M} \gg 0$ is an appropriate dummy constant.

Constraint 4: For each time interval the delay absorbed by one ACC from another is naturally limited by the entire delay of the ACC in need or the delay which the matched ACC is capable to absorb

$$d_{ijt} \leq \min\{D_{it}, \mathcal{D}_{j,t}(i)\} \quad \forall i, j \in \mathcal{A}, \forall t \in T \tag{7}$$

In this case the goal is to find the best collaboration configuration at each time interval t in order to minimise the total delay:

Objective 1:

$$\min \sum_{i,j\in\mathcal{A}, t\in T} d_{ijt} \tag{8}$$

C. Input data

The dataset used for this study was sourced from EUROCONTROL's Demand Data Repository (DDR2), and covers two AIRAC[6] (Aeronautical Information Regulation And Control) cycles - 8 weeks of traffic, network and airspace information from 20^{th} June to 14^{th} August 2019, for the European airspace network. The following data and statistics were extracted from the two AIRAC files:

- *Sectors and their saturations* - lists of open sectors at all one hour intervals, and their saturation values using the entry counts of "actual trajectory" type[7].
- *Delayed flights* - list of all flights exceeding 5 minutes of delay, delay being assigned due to ATC-C and ATC-S regulations for all ACCs.
- *ATFM Regulations* - contains ATFM regulation-specific information such as total delay, delay per regulated flight, regulation reason, duration and capacity, for ATC-S and ATC-C regulation reasons.
- *Configurations* - Configurations for each ACC, listing the sectors that can be open when the configuration is chosen.
- *Opening Schemes* - contains opening and closing times of active configurations in all ACCs.
- *Sector capacity* - defined as the number of hourly entry counts, which are used to calculate the average ACC sector capacity.

Other data sources:

- *Declared pOS for summer 2019* - pOS figures are published in Network Operational Plan (NOP) [10][8].

D. Example

In order to better understand the model's dynamics, before showing the results extended to the whole period, we focus on a single time interval to show the functioning of the model in detail. Each time interval is an independent instance of the problem which can be solved in parallel, as the constraints do not link variables across time intervals. As an example, we present here the optimal collaboration setting for the DSNA case at time interval 17:00-18:00 of the 13th of July 2019 with saturation 40%. The red bars in Figure 2 show the two DSNA's ACCs (LFRR and LFMM) which had capacity issues

---

[6] Defines a series of common dates and an associated standard aeronautical information publication procedure for States [11].

[7] Actually flown trajectory, or so called m3 DDR2 trajectory

[8] The data kindly provided by EUROCONTROL's Aviation Intelligence & Performance Review Unit

reporting the number of delayed flights and total delay. The green bars show instead the delay which the three ACCs with available capacity (LFBB, LFFF, LFEE) would be able to absorb. The number of available sectors as well as the sector capacity of LFBB, LFFF, and LFEE is fixed as it represents the available resources of the three ACCs during the time interval considered; however, the resulting potential delay reduction for the two ACCs with capacity issues (LFRR and LFMM) is different. This happens because, as explained in III-B, the potential delay reduction of each particular ACC with capacity issues is computed summing the delay of the flights that the matching ACC is able to accommodate, so the same capability in terms of number of flights of an ACC with underutilised capacity might result in a different potential delay reduction for different ACCs in need.

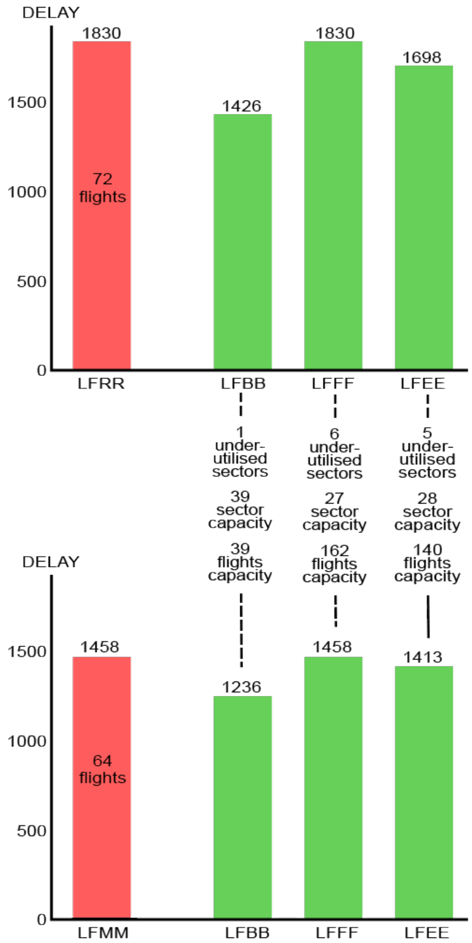

Figure 2. DNSA capacity issues and underutilised capacity during the time interval 17:00-18:00 of the 13th of July 2019 (saturation 40%)

The model is asked to match the two ACCs in need with the ones with underutilised capacity in order to minimise the overall delay. Figure 3 shows case by case the outcome in terms of delay reduction of all the possible combinations. The black rectangle indicates the optimal collaboration set up.

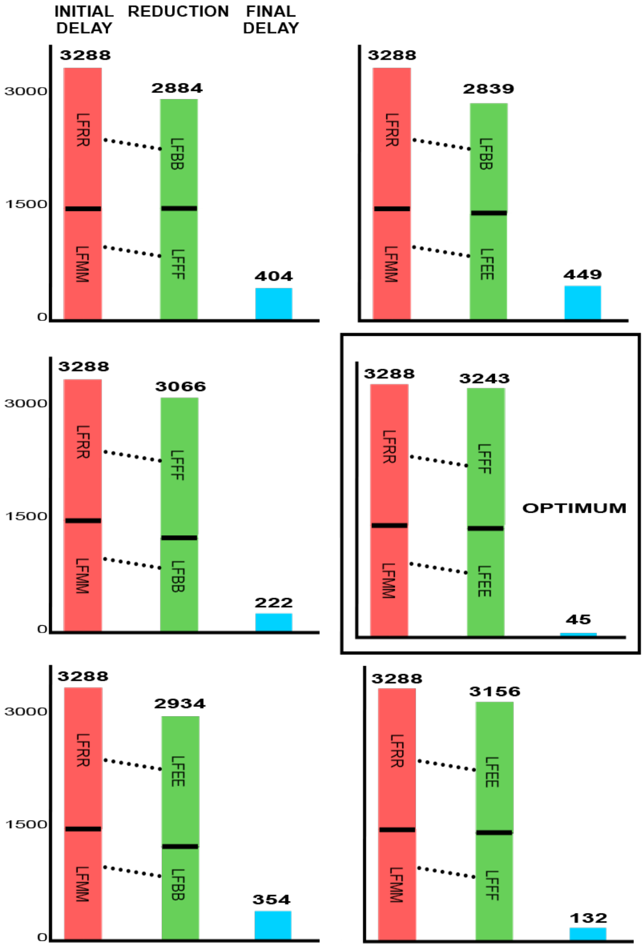

Figure 3. Delay reduction for all possible combinations

Computing the reduction of all combinations represents quite a brute force approach which, especially when several ACCs are considered, might turn out computationally expensive. The linear programming formulation presented in section III-B enables reaching the optimal solution and reducing the computational effort. In addition, this formulation enables easy inclusion of further constraints that might be taken into account in the future developments. For instance, enforcing collaboration of at least two or three hours, restricting the set of possible collaborations for some or all ACCs, or imposing country collaboration constraints.

IV. CASE STUDIES AND RESULTS

We apply the case study approach to test the model and analyse the results. Case studies cover three levels of geographical extension of the Virtual Centre:

- Single ANSP,
- Functional airspace block (FAB),
- Single European Sky (SES) area[9].

At single ANSP level, DSNA (France) and DFS (Germany) are chosen, as these ANSPs accounted for most of ATFM

---

[9] Austria Belgium, Luxembourg, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom

delay in 2017 [12], 2018 [13] and 2019 [14][10]. At the FAB level, the FABEC[11] is chosen as both France and Germany are its members. For the widest geographical scope, the collaboration at the SES level is assessed.

Figure 4 depicts total en-route capacity-related ATFM delay (ATC-C and ATC-S reasons) accumulated in summer 2019, across the organisations grouped at three chosen levels: 4.3 million minutes of delay in SES area, followed by FABEC (2.18 million minutes), and individual ANSPs (DSNA 1.04 million minutes, and DFS 865 thousand minutes).

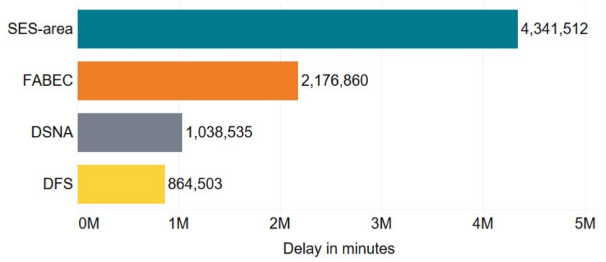

Figure 4. ATC Capacity and ATC Staffing delays per entity, summer 2019

We assess four capacity sharing scenarios, based on the geographical extension of cooperation. Note that in Virtual Centre, the sectors usually under the responsibility of one ACC can be temporarily assigned to another ACC, regardless of their physical location. Thus, the following Virtual Centre scenarios are assessed:

a) Within ANSP,
b) With one of the neighbours,
c) Between FABEC member states,
d) Between all SES member states.

For each capacity sharing scenario assessed and each saturation threshold (as described in Assumption 3), for the time period of two AIRACs (see III-C), we show:

- Initial delay - en-route ATFM delay with ATC-C and ATC-S regulation reasons, per given entity.
- Final delay - the final delay achieved by the given collaboration.

A. DSNA

During the summer of 2019, the DSNA accounted for 22.5% of the total European ATFM delay, of which 16.1% was due to ATC-S and 6.43% due to ATC-C reason. Here we show how much of this delay could have been reduced by the collaboration within an ANSP (capacity sharing scenario a) and capacity sharing with one of the neighbours (scenario b).

Figure 5 shows the potential delay reduction for DSNA internal capacity sharing (five ACCs - Bordeaux, Brest, Marseille, Paris and Reims). A significant difference can be seen between different saturation thresholds. This suggests that within DSNA there are underutilised sectors. Using a Virtual Centre concept, DSNA could plan and reallocate those underutilised capacities efficiently and reduce the delay up to 72%.

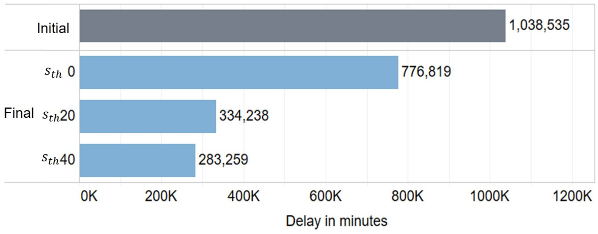

Figure 5. DSNA as a Virtual Centre - initial and final delay

Figure 6 shows the potential delay reduction in a scenario where DSNA and one of their neighbours collaborate. Based on the results, the collaboration with the Italian ENAV would be the most beneficial, reducing delay, between 82-94% depending on the saturation threshold.

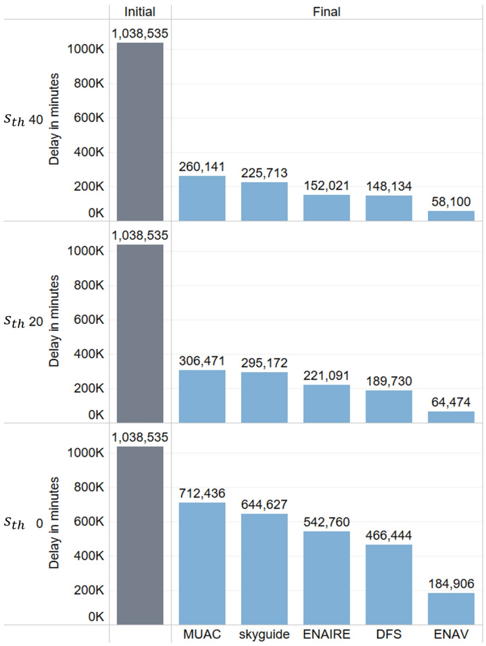

Figure 6. DSNA with neighbours - initial and final delay

B. DFS

German DFS accounted for 18.17% of the total ATFM delay, of which 15.19% due ATC-C, and the remaining 2.92% due to ATC-S reason. Figure 7 shows that DFS could significantly reduce these types of delays through internal virtualisation.

---

[10] The 2020 performance assessment is not considered as the COVID -19 disruption significantly reduced traffic volumes

[11] Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland, where MUAC controls the upper airspace of Netherlands, Belgium, Luxembourg and a part of western Germany.

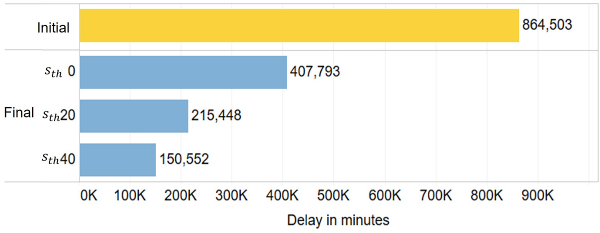

Figure 7. DFS as a Virtual Centre - initial and final delay

Collaboration with skyguide would offer the most benefits at the saturation of 0% (about 62% reduction), and with ANS CR at saturation 40% could reduce the delays about 88% - Figure 8.

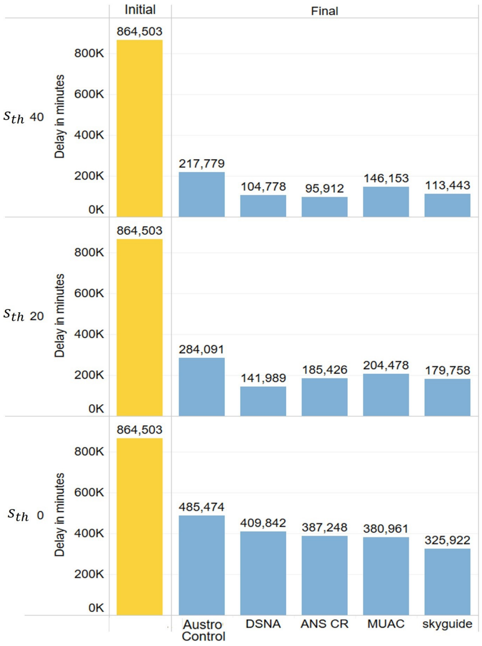

Figure 8. DFS with neighbours - initial and final delay

C. *FABEC as Virtual Centre*

FABEC accounted for more than 2 million minutes of delay due to lack of capacity, which is about 50% of the total capacity issues in Europe. Figure 9 shows the reduction in delay in a scenario where FABEC is operated as a Virtual Centre, where all ACCs operate as a single organisation. The results show that such a collaboration could lead to a delay reduction of up to 87% of the total FABEC delay.

Reduction of delay per participating ANSP is depicted in Figure 10, showing that DSNA and DFS would have the possibility of largest reduction (percentage-wise) of delay.

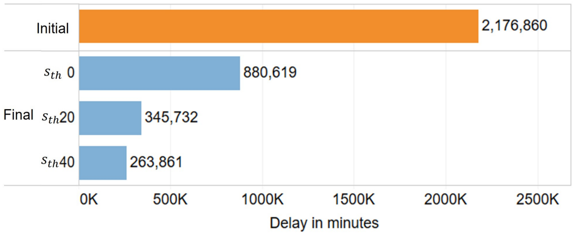

Figure 9. FABEC as a Virtual Centre - initial and final delay

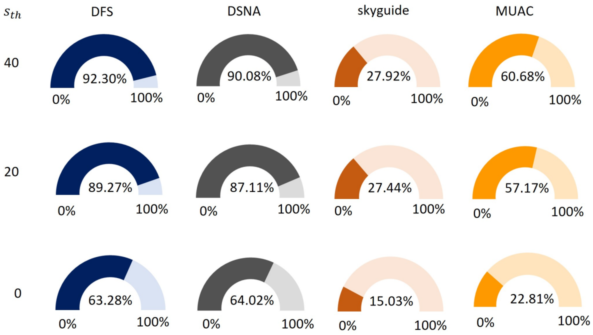

Figure 10. FABEC as a Virtual Centre - delay reduction per ANSP (%)

D. *SES as Virtual Centre*

The scenario where entire SES area is virtualised offers interesting results, depicted in Figure 11. The three chosen saturation levels offer very similar results. The interesting part is that the reduction (of about 90%) would be achieved already at saturation level 0, indicating the existence of a fair amount of available capacity in today's congested network.

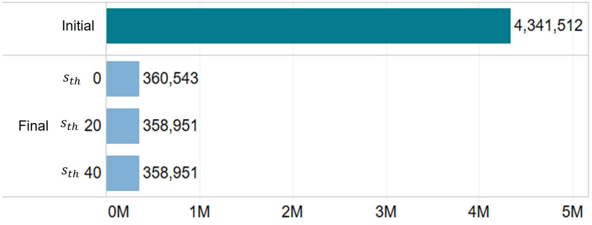

Figure 11. SES-area as a Virtual Centre - initial and final delay

V. CONCLUSION AND WAY FORWARD

The main objective of this study was to evaluate the benefits of virtualisation in terms of delay reduction. Using the proposed linear optimisation model, we conducted a case study in which we investigated different Virtual Centre set-ups. The results show that virtualisation could provide significant reduction in delay, which varies depending on the geographical scope and the ANSPs involved in the Virtual Centre. At saturation level 0, the collaboration in FABEC and SES areas provides rather different results. The FABEC Virtual Centre could reduce about 60% of delays, while the extension to SES could reduce delays by 90%. The FABEC results indicate that the region it covers controls higher amounts of traffic than what appears in other parts of SES. However, even in a scenario where all SES member states form Virtual Centre, and operate as a unique organisation sharing their current ATC resources, the maximum total delay reduction would not exceed 90%. These results suggest that while virtualisation could significantly reduce capacity issues in Europe, it would not be sufficient on its own, to eliminate them completely. Such a reduction with the current airspace design and the current air traffic control capacities indicates that a redesign of the airspace with dynamic capacity sharing, as proposed in AAS, might be necessary to overcome the current capacity-driven issues and, in addition, to be able to accommodate more flights in the future.

One of the limitations of this study is the time frame (8 weeks in summer 2019) to which the model was applied. The results presented here are based on a short-term assessment and therefore might not represent long-term solutions. Next, the data used is a mix of planned and post-operational data as the best available and sufficient for a high-level assessment. The model does not take into account geographical/physical constraints, nor traffic complexity and is therefore providing high level results. This can serve as a first approximation, as virtualisation is likely to entail re-organisation of airspace, higher levels of automation, and change in ATCO training and licensing, just to mention some envisioned and needed changes. Each of these changes is likely to significantly change the way of air traffic control and management at the micro level. This first approximation shows that the current airspace organisation and number of ATCOs available could provide ample capacity to deal with the majority of ATC-C and ATC-S capacity-demand imbalance in the network. As always, the devil is in the detail, as to be able to collaborate in even this simple way, a number of other matters should be resolved. To start with, the ATCO training and licensing should be extended or changed to be sector-independent. Next, solving sovereignty matters of allowing the control of state's airspace be delegated to entities outside of state. From various cross-border cooperations in place today, this issue can obviously be solved. However, if past experience is to be relied on, the extension of geographical coverage is likely to require long times to reach needed agreements between the parties. Taking all the limitations into account, more detailed simulations or model, applied on a number of different scenarios should be used to further our high-level results. Note that we do not mention more radical changes to air traffic control, like flight centred ATC, as those would require completely different set of assumptions, and input data.

Future research should further develop and validate these initial results using entire year-round data-frame to assess whether the Virtual Centres could be beneficial during winter traffic schedules when traffic volumes are lower and planned capacity is adjusted accordingly. In addition, further research should consider the cost of different Virtual Centre set-ups to ensure that the cost of the provided solution does not exceed the cost of the issue.

ACKNOWLEDGMENT

The work presented here is part of a PhD research co-financed by EUROCONTROL under contract No. 18-220569-C1. Opinions expressed in this work reflect the authors' views only. Under no circumstances shall EUROCONTROL be responsible for any use that may be made of the information contained herein. We would like to thank EUROCONTROL for kindly providing the data used in this study.

REFERENCES

[1] Helios Economics and Policy Services. The impact of fragmentation in European ATM/CNS, 2006.

[2] SESAR Joint Undertaking. A proposal for the future architecture of the European airspace, 2019.

[3] Paul Ravenhill, María Isabel Tomás-Rocha, and Alexandra Vasile. Role of Markets in the AAS Deployment (RoMiAD), 2021.

[4] SESAR Joint Undertaking. Future architecture of the European airspace: Transition plan, 2020.

[5] EY – Helios - Integra. Legal, economic, and regulatory aspects of ATM data services provision and capacity on demand as part of the future European air space architecture, 2020.

[6] SESAR Joint Undertaking. Virtual Centres, 2021. URL https://www.sesarju.eu/node/3775. Accessed on 11.10.2021.

[7] EUROCONTROL. About our maastricht upper area control centre. website, 2021. URL https://www.eurocontrol.int/info/about-our-maastricht-upper-area-control-centre.

[8] CADENZA Consortium. Initial TB concept and ADCB options, 2021.

[9] COCTA Consortium. Final Mechanisms, 2017.

[10] EUROCONTROL. European Network Operations Plan 2014-2018/19, 2019.

[11] EUROCONTROL. Aeronautical information regulation and control (AIRAC) dates, 2021. URL https://www.eurocontrol.int/publication/aeronautical-information-regulation-and-control-airac-dates. Accessed on 11.10.2021.

[12] Performance Review Commission. Performance Review Report, 2018.

[13] Performance Review Commission. Performance Review Report, 2019.

[14] Performance Review Commission. Performance Review Report, 2020.