Identifying Airspace Capacity Factors in the Air Traffic Management System

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ABSTRACT
Accurate airspace capacity estimation relies on the correct identification of the factors that affect it. Given the current and envisaged developments of the Air Traffic Management system e.g. Single European Sky, which includes an Air Traffic Control automation plan, it is necessary to assess how the appropriate capacity factors will impact these initiatives. This paper introduces the background for this research and outlines the development of a holistic taxonomy of airspace capacity factors for the Air Traffic Management System based on United Kingdom’s airspace sector overload reports, on literature review and on interviews with subject matter experts (SMEs). The paper also highlights the methods by which airspace capacity can be estimated to account for a future automated ATM environment, which in turn depend on a correct factors identification.

Keywords
Capacity, Air Traffic Control, Capacity Factors, Sector Overload

INTRODUCTION
Air travel in Europe has increased rapidly in its recent history, except for the periods around 2001 and 2009 due to the events of 11 September 2001 and the economic crisis respectively. The long-term predictions until 2030 foresee a 2.8% annual growth compared to 2008, in the most likely scenario. With this prediction, the number of flights in European airspace would rise up to 16.9 IFR flights in 2030, 1.8 times more than in 2009 [1].

To cope with the increasing traffic demand in Europe, and at the same time achieve higher environmental, safety and cost-effectiveness targets, the European Commission launched the Single European Sky (SES) programme for Europe Air Traffic Management (ATM) modernisation [2] in 1999.

Under the umbrella of the SES through its implementation program Single European Sky ATM Research (SESAR), started in 2006 by the European Commission and EUROCONTROL, Europe is moving towards a new concept of operations that will theoretically release significant benefits [3]. In terms of capacity, the implementation of the SESAR concept of operations is expected to accommodate a 73% rise in demand between 2020 and 2005, while a three-fold increase of capacity is expected in the long term. In order to achieve this capacity increase, SESAR has established several lines of change that will gradually transform the ATM system and should result in changes to the main drivers of capacity.

Given these shift, capacity estimation, which is fundamental to support any capacity increase [4, 5], promises to be a major challenge for the future.

This document will outline initial research towards accurate and reliable airspace capacity estimating by developing, as a first step, a taxonomy of capacity drivers for use in the future SESAR scenarios.

SECTOR CAPACITY ESTIMATION FOR THE FUTURE AIR TRAFFIC MANAGEMENT SYSTEM – STATE OF THE ART
A review on the current methods employed to assess capacity reveals three main methodologies [6]: Real Time Simulations (RTS) or Human-In-The-Loop (HITL) simulations, fast time techniques comprised of Fast Time Simulations (FTS) and analytical modelling and judgmental or subjective methods. FTS and RTS methods are recognized as part of the MAEVA capacity estimation methodology [7], which is a validation framework focused on the introduction of new ATM components. It begins with an analytical method followed by FTS and RTS and finally conducts operational trials before the start of operations, as shown in Figure 1. However more methods are discussed here as they are considered to have a great potential in the capacity estimations of the future ATM systems.
Workload – Fast Time Simulation Methods

These methods [8-11] use the basic principles of current estimations adapted to account for the new concepts. This adaption is based on a new model of the air traffic controller (ATCo) with new tasks and new times.

The fast time techniques are usually comprised of a traffic generator and an ATCo workload calculator [10, 12]. This means that the main assumption is that capacity is directly linked to ATCo workload. Other variants within this group make use of different factors as drivers of capacity, such as weather [13], although these are just a minority.

These methods have the potential of accurately capturing short-term implementations, in which insignificant functional variations are held in the system. Their main assumption is that controller workload remains the main capacity bottleneck of the system. This workload is fundamentally computed using task-time methods [14] or human cognition models [15]. However, in highly automated environments, where cognitive tasks assume a more important role than physical tasks, or in new operational scenarios such as airborne separation, where the ATCo role would entirely be changed, the way of modelling workload has to be thoroughly discussed.

Workload – Real Time Simulation Methods

In these methods [16-19] specific tools and concepts are modelled and tested with humans in the loop.

These methods have the potential to accurately model the evaluated concept, ensuring higher fidelity levels than a FTS in the system modelling. Even though [20] reviews different human performance metrics to be measured from these simulations, most of them are focused on workload. Different studies use different techniques to measure the workload metric which can be included in one of the following groups: performance-based, subjective and physiological/biochemical [21].

The main drawback of these methods stands in their reduced flexibility to capture different concepts and in their high associated costs along with time consuming issues. In addition, an important weakness of this methodology identified in [19] concerns the outputs of the simulation and their validity. In particular, the subjective assessments of controllers or pilots suffer from the fact that they have not received appropriate training for the concept, and the values obtained, e.g. workload ratings, can be flawed.

Judgmental or Subjective Methods

Judgmental estimation methods [22-24] are based on subjective ratings of SMEs, who have an overall idea of the system performance and base their judgments on their knowledge about the system [22].

This method is extremely flexible and quick, although when lacking an appropriate framework and methodology can produced biased outputs. A main concern within it is associated with the validation issues.

EUROCONTROL CARE-INTEGRA

There is another estimation methodology with a different approach from the others: the EUROCONTROL CARE-INTEGRA.

The EUROCONTROL CARE-INTEGRA method [25] stands out for its innovative approach to the problem. It is based on the modelling of a concept named Information Processing Load (IPL). This novel concept models the ATM system as a combination of several agents that process information depending on the events occurring. Each agent has a threshold value for IPL, beyond which the agent becomes overloaded.

The IPL overload threshold is easy to determine for machine-agents, but needs SMEs judgment for human-agents. When an agent of the system becomes overloaded, the capacity of the system is reached.

This technique is unique for its ability to determine the bottleneck of the system, instead of modelling the system based on the assumption that the bottleneck is known, as with the other methods.

CAPACITY FACTORS

Even though airspace capacity estimations tend to consider only the relevant factors of the ATM operation e.g. traffic complexity factors based on controller workload [26], additional factors play a role in the operation of the ATM system. These additional factors cannot be ignored within a framework which is looking beyond the current operational concept, as they may become crucial with future operational concepts.

With the introduction of automation as proposed by SESAR, along with new operations and procedures, some of the ATM factors may become more important, the relation between them might change, and new factors might arise. This reorganisation of the ATM capacity factors must be captured by the modelling techniques introduced in the section before, in order to continue producing reliable estimations.

Therefore, within the research here introduced, it was considered crucial to develop a holistic capacity factors list, able to be used both in the current and the long-term ATM system, which guide the modelling needs for the airspace capacity estimations.
In order to develop this holistic capacity factors list, the methodology followed included a literature review on current ATM operational concept, future ATM operational concept [27], human factors in ATC [28, 29] and interviews to subject matter experts and visits to ATC centres.

This initial draft was further complemented by the analysis of sector overload reports, which provide a better understanding of the ATM operations when capacity is reached inside an ATC room.

**Analysis of Sector Overload Reports**

The analysis of operational data provides a better understanding of the interrelations between the agents of the ATM system and the factors that constrain its performance. Such operational data can be obtained from the United Kingdom’s Civil Aviation Authority (CAA) Sector Overload Reports.

These reports, integrated into the United Kingdom’s Civil Aviation Authority Mandatory Occurrence (MOR) Reporting scheme [30], are filled by ATCos in specific circumstances according to CAA regulation. Overload reports in essence record situations when controllers feel their workload is too great for the safe operation of aircraft under their control.

Analysis of sector overload reports confirms the likely change of the capacity drivers due to the introduction of automation. Comparison of overload reports between 2001 and 2010, with various automation tools introduced between these years, shows that the factors reported as a source of overload have changed.

In the example given in Figure 2, the primary factors have changed between 2001 and 2010, with incorrect traffic predictions became less significant in 2010 (fewer times reported), when traffic positioning has become the primary factor.

![Figure 2 Evolution of capacity factors from sector overload reports](image)

This shift will lead to a necessary adaptation or new development of capacity estimation techniques to be able to account for the new ATM configuration.

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The analysis of these reports has shown that the most common factors reported as sources of overloads can be summarised in the six following groups:

- Information sharing
- Airspace complexity
- Equipment
- Human performance and staffing
- Abnormal or new situations
- Sector protection

Even though it could be though that these factors appear independently, the analysis has shown some patterns regarding the overloading mode. In this regard, sector protection and airspace complexity usually come together as the former leads to the latter, whereas information sharing and human performance and staffing constitute another separate overloading mode. The remainder factors can appear independently although airspace complexity is almost ubiquitous, confirming findings from previous research [28].

In addition, the analysis of the duration of the overloads brings along the issue of which metric should be used for capacity estimation. For the London Area Terminal Control Centre (LATCC), Manchester Area Control Centre (MACC), Scottish Area Control Centre (ScACC) and London Area Control Centre (LACC) the mean and standard deviation values for the overloaded time are (mean, standard deviation):

- LATCC (31.8511, 18.5343)
- MACC (23.9231, 9.639)
- ScACC (51.129, 24.823)
- LACC (31, 17.1167)

As seen from the above values, capacity can be overshoot for periods of time lower than an hour, which in turn, introduces the idea of new capacity metrics (such as occupancy) able to provide more realistic capacity figures which are not captured by current ones (such as traffic load per hour).

**Capacity Factors Taxonomy**

In line with the sector overload capacity factors identification, further research (literature review [15, 28] and interviews with subject matter experts) has led to a holistic taxonomy of capacity factors, depicted in Figure 3. This taxonomy encompasses the following four related groups.

**Spatial-Geometrical Factors**

It embraces both the complexities and characteristics of the traffic pattern and airspace configuration, and the operational space availability. The latter accounts for geometrical capacity limitations which are the limiting factor at airports and Terminal Manoeuvring Areas (TMAs) [31].

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Figure 3 Holistic taxonomy of airspace capacity factors
Controllability
This group is the main focus of current capacity estimation models. However, two sub-groups can be identified: ground controllability and air controllability.

Given for instance the future airborne separation concept, [32] pilot performance will have a central contribution for any capacity enhancement. Even in current operations pilot performance affects directly the work of the ATCo and therefore capacity.

Capacity Resilience
Capacity resilience is the ATM function that protects sectors from overload whilst ensuring that the use of available capacity is maximised.

The capacity resilience function is used in strategic and dynamic time horizons i.e. adapting for long term and short term capacity imbalance notices.

AUTOMATION IMPACT ON THE CAPACITY FACTORS
Automation can be defined as “a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator” [33].

According to this definition and given the SESAR deployment sequence [34], automation may be introduced into the system in one or more of the following categories:

- Conflict detection
- Conflict resolution
- Situational awareness enhancement
- Planning
- Separation provision
- Complexity management
- Communication & information transmission
- Trajectory management support
- Monitoring
- Prediction enhancement

Each of these automation categories has specific features and characteristics that affect ATCo performance in different ways resulting in different capacity factors and therefore different capacity models.

Similar to the work conducted in [35], this research will further investigate the links between the automation categories and the capacity factors. This analysis would serve as an input for the capacity estimation framework, in which the different capacity estimation techniques will be assessed in terms of what factors they modelled, and therefore assessing their ability to model different automated scenarios.

CONCLUSION
The assessment conducted on the methods to assess the impact of automation on capacity, the development of the capacity factors taxonomy and the analysis of the automation categories within SESAR reveal the necessity of developing an integrated framework able to capture the impact of different types of automation in a single framework.

Further stages of the research will assess the impact of the different automation categories on the capacity drivers and on the capacity estimation modelling techniques in order to create the foundations of a framework able to assess the impacts of automation on capacity during the SESAR transition phase.

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