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Enhancing Cost-Efficiency and Reducing Capacity Shortages: Strategic Planning and Dynamic Shift Management

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Abstract—**This paper analyses the relationship between capacity and cost-efficiency at an en-route Air Traffic Control Centre level. It develops a set of cost-efficiency metrics to describe the centre planning process, and compares these results to cost-efficiency values. In order to understand the effect of the new tools and procedures implemented at the centre on its cost-efficiency, statistical analysis of the operational data before and after implementation is undertaken. The results show that the introduction of a dynamic shift management enabled by staff planning automation tools, along with a flexible roster and an appropriate planning process can simultaneously enhance capacity and cost-efficiency. These improvements are mapped to the SESAR Operational Improvements, to assess the feasibility of the programme to achieve its capacity and cost-efficiency improvement targets. A set of recommendations is developed.**

Keywords- cost-efficiency; en-route capacity; strategic planning; overstaffing; SESAR; Maastricht Upper Area Control Centre

I. Introduction

Currently in Europe the capacity of an en-route Air Traffic Control (ATC) centre is defined as its ability to control traffic, according to predefined separation standards and given delay values [1]. This capacity is influenced by several factors of which air traffic controller (ATCO) workload is the most significant [2].

The cost-efficiency of an ATC centre is also important. This is understood to be the quality of delivering air traffic services by making optimal use of the available resources. This relationship is expressed as the ratio between traffic and cost of resources in [1].

The planning processes are the most significant drivers of an ATC centre's cost-efficiency. The processes determine staffing (the main resource of a centre) and airspace sector opening sequences. The consequences of overestimation in the planning process can be a low cost-efficiency performance whilst underestimation may lead to shortage of capacity.

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In Europe, air traffic growth has flattened in recent years, with the current number of aircraft movements similar to 2007 [3]. With forecasts envisaging virtually no traffic increase [4], and the impacts of the economic crisis continuing, cost-efficiency is becoming increasingly central in current operations.

In order to assess how well en-route ATC centres can perform in terms of cost-efficiency, and how this in turn affects ATC centre capacity, this paper analyses the performance and its drivers, of one of the major centres in Europe in terms of capacity and cost-efficiency [5]: Maastricht Upper Area Control (MUAC) Centre. An analysis of the relative capacity cost/efficiency performance is carried out based on the introduction of new technologies and procedures at this centre.

II. Background

Traditionally, research has focused on analysing capacity and cost-efficiency separately.

Maximum capacity values have typically been estimated based on: the geometrical characteristics of the airspace and traffic [6], ATCO workload models [7], or weather scenarios [8]. The results of these studies, calibrated specifically for the different en-route centres, have been used to determine the so-called "declared capacities". These are used by the Air Traffic Flow & Capacity Management (ATFCM) function to protect the airspace from overloads, by applying re-routings, level cappings and regulations to the flights [9].

Cost-efficiency has been of less interest in the academic research community, and has traditionally been assessed at the industry level. For instance, [10] calculates a set of performance indicators for the different centres across Europe, enabling the cross-comparison of indivdual performances.

Recently a new concept called Total Economic Value (TEV) has been developed, which attempts to address the interdependencies between performance areas by introducing the concept of financial equivalence for each Key Performance

Area (KPA), including capacity and cost-efficiency [11]. At a more local level a framework has been developed in [12] to simultaneously estimate the capacity-efficiency-safety trade-off.

The approach taken in this paper is aligned with the TEV idea of understanding KPAs as trade-offs, with focus on cost-efficiency and capacity.

III. The Importance of Strategic Planning in ATC: The Capacity/Efficiency Trade-Off

Currently the human, principally the ATCO, is central to the ATC activity. Whilst it can be anticipated that new roles will emerge to ease the ATCO job and make it more efficient, this human-central role will be maintained under the current ATM modernisation initiatives [13].

The current operations in Europan ATC centres attempt to optimize their ATCO workforce to provide minimal disruption in services, with minimum resources, while ensuring the required level of safety. Thus the objective is to provide exactly the capacity needed to meet the demand, thereby being both efficient and expeditious. This requires that the staffing is planned carefully and accurately since any shortage may result in delays.

In an en-route ATC centre, delays are typically the result of weather events, capacity, special events, ATC disruptions and staffing insufficiency [3]. This paper focuses on staffing. Staffing-related delay is caused by an insufficient number of ATCOs in the operations room. In 2011 such delays accounted for 25.3 % of the total en-route delay in Europe [3]. Equally important, but usually overlooked, is the cost-efficiency of the staffing issue: overstaffing (of ATCOs).

Whilst having an insufficient number of ATCOs results in a capacity shortage, overstaffing results in cost-inefficiency. Therefore, appropriate management of the capacity/cost-efficiency trade-off is crucial in order to fulfil the centre's operational needs.

A. Operations of an ATC Centre

Theoretically, the aim of an ATC centre is to optimise the profit, which may be approximated as follows:

$$\text{Profit} = f(\, \text{ATCO}_{\text{Cost}}, \text{Delay}_{\text{Cost}}, \text{Traffic}\,) \tag{1}$$

With European regulations determining the delay target that must be met [11], in reality, centres need to optimise the ATCO staffing levels for the given delay target, expressed mathematically as the minimisation of the ATCO time under the prescribed delay target:

$$\min(\text{ATCO}_{\text{time}} \,|_{\text{Delay Target}}) \tag{2}$$

$\text{ATCO}_{\text{time}}$ is a complex function of working conditions (contractual agreement and legal limitations), roster design, shift constraints and planning capabilities amongst others.

B. The Capacity/Cost-efficiency Trade-off

Due to the objective of an ATC centre, there is a direct relationship between the cost of an ATCO minute and the cost of a capacity shortage.

Since the optimisation of the process involves the management of ATCOs, which is a complex function of several factors, the process of optimising the efficiency of an ATC centre, is undertaken by an iterative planning process that occurs close to the execution period.

The following section, explains how the performance of this process can be measured.

IV. Methodology

Fig. 1 depicts the methodology developed in this paper. The following sub-sections show the fundamental characteristics of each step.

A. MUAC Historical Analysis

The objective of this phase is to understand the evolution of the MUAC in the field of the study. In order to achieve this, a review of internal MUAC documentation was carried out. This was complemented by interviews with Subject Matter Experts (SMEs), including engineers and ATCOs. The interviews involved 15 people including engineers, operational support staff and ATCOs. These interviews were conducted face to face in a semi-structured manner and were focused on extracting the most important achievements of the centre in terms of capacity and cost-efficiency.

The historical analysis conducted referred to the period from the opening of the centre (1972) to date. However, due to data availability limitations (discussed in Section VII), the analysis presented in this paper relates to the period from January 2009 to September 2012.

The historical analysis can be summarised as follows:

1) *MUAC Improvements:* the major improvements implemented during the period; and

2) *Transition Period:* the specific period of time during which a significant change in the centre's operations occurs. The analysis can therefore, be divided into a *pre-* and *post-implementation periods*.

B. Metrics Selection

In order to mathematically characterise the effect of the improvements on the MUAC's planning performance, it is necessary to develop a set of metrics that represent the main elements of the planning process in its different phases, as explained in Section V.

C. Scenario Selection

MUAC is organised in three civil sector groups: Hannover, DECO and Brussels. Each of these groups is further subdivided into several sectors.

The sector group studied was that with the least variation of sector procedures and operations throughout the time period in order to ensure consistency in the results.

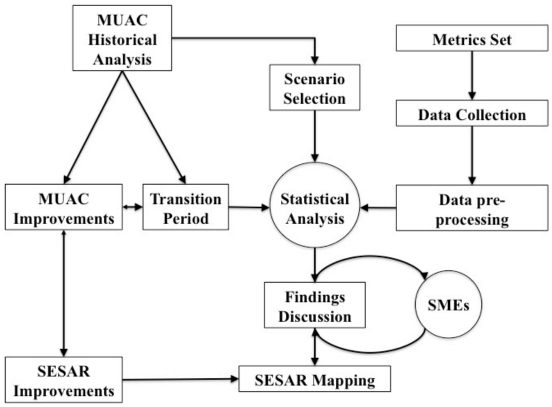

Figure 1. Research methodology diagram

D. Data Analysis

Given the operational nature of the data being studied, it is necessary to make a specific task for data pre-processing in which data outliers were excluded. Data outliers correspond to days when the operations were strongly affected by abnormal situations, as these do not represent the nominal behavior of the ATC operations (see Table I). A statistical analysis is then carried out to compare the pre- and post-implementation scenarios.

The results of the statistical analysis were verified through an iterative refinement process including engineers, Executive Operations Support (EOS) staff and ATCOs from MUAC.

E. Mapping to the SESAR Programme: Extrapolations

The final objective is to extrapolate future ATC system performance based on both the current findings and the anticipated SESAR system evolution (extracted from its Master Plan [14]).

V. MUAC Planning Process

The MUAC planning process belongs to the strategic planning group as opposed to the rigid master planning group [15]. The strategic planning process approach makes use of a layered refinement process able to account for high uncertainty levels of the traffic scenario (traffic occupancy, military activity or weather amongst others) when the time horizon to execution day is large (typically bigger than one day). This layered planning approach, as opposed to the rigid master approach, enables the progressive refinement of the process as more information becomes available.

A. Sector Opening Times

In the en-route ATC centre, ATCOs work in pairs: the “executive” or “radar” controller and the “planner”. The former communicates with the pilots and the latter facilitates the radar controller task, by assuming mainly the coordination role between sectors and strategic de-confliction (the detailed tasks and responsibilities for each role vary among centres) [16]. Each ATCO pair is responsible for a unique volume of airspace, known as a sector.

TABLE I. MUAC Major Events since 2009

MUAC Events		
Event Name	***Event Type***	***Date***
HACO Resectorisation	Airspace Design	January 2010
Ash Cloud	Weather	April 2010
Ash Cloud	Weather	May 2011
Olympics	Sport	July-August 2012
Holstein Sector Split	Airspace Design	July 2012

Given this relationship between the ATCO pair (operational position) and the airspace volumes, the planning of ATCO minutes should be made in accordance with the prediction of the sector configuration timeline. This sector configuration timeline can be more easily managed in terms of the Sector Opening Time (SOT). For instance, if the plan is to open only one sector in a given day, there are *1 sector x 1440 mins/day =1440 SOT minutes* which corresponds to 1440 minutes of an ATCO pair (2880 single ATCO minutes).

B. Phases of the Planning Process

The planning process at MUAC can be described as a series of stages each of which is focused on delivering a certain milestone as shown in Fig. 2.

1) *Master:* takes place from the beginning of the planning process, approximately six months to three months prior to execution day. An analysis based on economic conditions, available staffing and future traffic is carried out to produce the SOT_{Master} and the roster pre-publication.

In the roster pre-publication, the Operational Roster Time (ORT) can be seen. The ORT minutes are the maximum amount of time that all ATCOs can work on a day, i.e. the sum of the lengths of the assigned shifts. If there was sickness, training or office duties, these are not included in the ORT values.

2) *Planning:* from the end of the Master phase until two weeks prior to execution, the Master plan is monitored to ensure that no major SOT/staff discrepancies exist, and the roster is published.

3) *Pre-Tactical:* during the Pre-Tactical phase Planning, the Master plan goes through a periodic update making use of $SOT_{Executed}$ of the corresponding day of the week e.g. Tuesday, one week and two weeks before. The Pre-Tactical phase is crucial in optimising the use of the flexible shifts according to the variations in pre-tactical demand up to the day before operations.

4) *Tactical:* The Pre-Tactical SOT is refined into the $SOT_{Tactical}$ on the day before execution based on short term information. This is the final plan presented to the operations room as the Day Operations Plan (DOA).

5) *Execution:* Finally the $SOT_{Executed}$ is based on dynamic information, such as occupancy and weather predictions, and on the use that EOS make of that information, depending on the operational needs and factors.

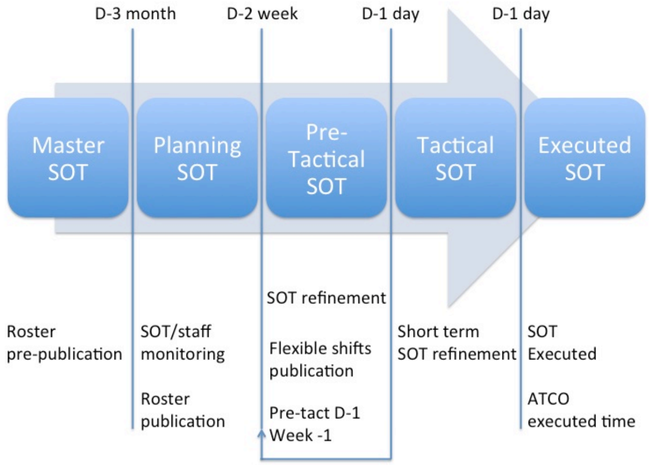

Figure 2. Planning process timeline and major milestones

C. *Planning Buffers*

Buffers need to be introduced to ensure robustness and flexibility in the operations to maintain capacity performance standards in unforeseen scenarios, such as bad weather, military activity, and ATCOs shortages (sickness, delays or no-shows).

These buffers, although providing more robustness to the ATC system in terms of its ability to accommodate unforeseen events, introduce at the same time inefficiencies. This paper makes the assumption that the closer the execution day, the smaller the buffer. This is because increasingly accurate information is available. Three buffers are expected with this rationale:

1. A long-term roster staffing buffer
2. A long-term SOT buffer
3. A pre-tactical SOT buffer.

Furthermore, it is expected that these buffers increase the more distant the planning phase is to the execution day.

Fig. 3 shows the different time values for each day at the different planning phases, together with what appears to be varying buffers.

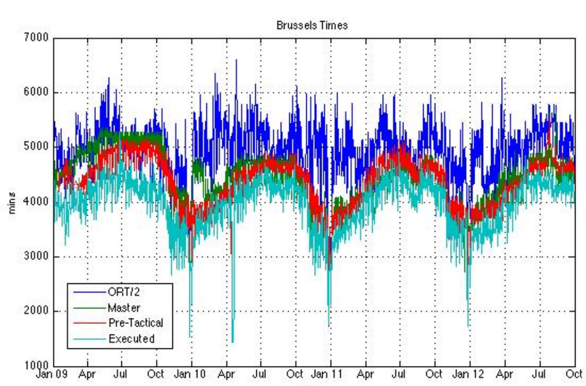

Figure 3. ORT SOT, Master SOT, Pre-Tactical SOT and Executed SOT

The statistical analysis in Section VIII, determines the actual buffers.

VI. MUAC Historical Analysis

This section gives an overview of the most important improvements implemented in MUAC for the January 2009 to September 2012 period. Each of these is discussed in turn below.

1) New Roster:

The new roster introduced 24 different shifts (compared to the 5 shifts of the old roster). Specially novel is the so-called "*Flex-duty*". This shift type enables the assignment of the exact shift period, on the evening before the day of execution. This provides greater flexibility in matching the workforce to the demand at very short time-scales. The "stand-by" duties are back-up shifts created for ATCO replacement in case of ATCO sickness leading to shortages in high demand scenarios.

2) Statistical Prediction Tool (SPT): the SPT is a tool that generates traffic predictions based on the statistical analysis of past traffic. This tool enables the staff involved in the planning process to calculate the most probable scenario based on historical data. However, this tool has never been fully deployed totally as it has lacked the trust of the EOS.

3) Refinement of the Planning Process: the Pre-Tactical plan is generated on the basis of past planning information, after-analysis of execution data for days one week and two weeks prior, and fine tuned by the characteristics of the execution day.

4) TimeZone: TimeZone is an automation tool that enables the optimised use of staff based on a dynamic shift management that responds to the latest traffic predictions.

It relocates staff within shifts, by changing the time of the breaks as well as the start and end shift time. This therefore contributes to avoiding the underuse of staff early in the shifts, which can later in the day result in capacity shortages.

5) Central Supervisory Section (CSS): The introduction of the CSS involves a change in the roles of the operations room personnel, in particular of the EOS. Old sector group supervisors are removed and the structure is divided into two tactical and capacity room supervisors. This is together with the old tactical capacity manager and Flow Manager Position (FMP), whose role is to maximise efficiency whilst protecting sectors. The room is managed by the Executive Duty Supervisor.

TABLE II. MUAC Major Improvements since 2009

MUAC Improvements		
Improvement Name	***Improvement Type***	***Date***
New Roster (Flex-shift)	Gradual	2008-2009
SPT	Step change	January 2010
Refinement of planning process	Gradual	1st quarter 2010
TimeZone	Step change	March 2010
CSS	Gradual	March 2012

A. Transition Period

The transition date is extracted from the analysis of the improvement dates. After listing all the improvements, a questionnaire survey was carried out with 15 MUAC SMEs to rank the relative importance of the improvements, in terms of their impact on the planning process performance. The output of this survey distinguished between the low impact factors (SPT and CSS) and the high impact factors (new roster, planning process refinement and TimeZone). Based on the importance of each improvement and its implementation timeline, March 2010 was identified as the key milestone between the pre- and post-implementation periods.

It has to be noted that the transition period is just a reference period and not a singular date after which operations experience a step change. In fact, changes in a safety related system such as ATC suffer from large procedural inertia in terms of gaining acceptance, trust or motivation and training or adaptation. Therefore, ATC improvements tend to be gradual.

VII. Metrics for an ATC Efficiency Analysis

The metrics used for the research needed to represent the evolution of the planning process in comparison to the actual operation execution in order to identify buffers and overall performance.

A. Data Availability

In MUAC, since the implementation of the New Flight Data Processing System (N-FDPS) system in December 2008, the data warehousing capabilities have increased significantly. Automatically triggered data recordings eased the post-operation analysis process and increased the amount of data processed.

Even though the analysis initially aimed to accomplish a before-after statistical data analysis with a larger data sample for the before- system, the data scope had to be narrowed to January 2009 onwards, due to the date of the introduction of the N-FDPS.

B. Metrics Set

As stated in Section V, the analysis of the planning process can be simplified to the analysis of a single metric, the SOT. Since the aim of the cost-efficiency analysis is to find out the accuracy and buffers of the prediction process towards the execution time, the SOT values in the different phases of the planning process are compared to the SOT values in later phases. This enables to appreciate the amount of inefficiency introduced during the different planning steps.

Given this approach, the metrics used are:

1) Pre-Tactical Planning Efficiency (PPE): expression of the efficiency of the pre-tactical phase compared to the execution as seen in (3):

$$PPE=SOT_{Executed}/SOT_{Pre\text{-}Tactical} \tag{3}$$

2) Planning Refinement Ratio (PRR): indication of the amount of refinement and changes accomplished during the intermmediate phases of the planning process, from the master to the pre-tactical stage

$$PRR=SOT_{Pre\text{-}Tactical}/SOT_{Master} \tag{4}$$

It is a measure of the evolution of the planning process between the two stages.

3) Shift Planning Efficiency (SPE): efficiency of the planning process from Master to Execution:

$$SPE=SOT_{Executed}/SOT_{Master}=PPE \ x \ PRR \tag{5}$$

Since the Master stage is the one used in the development of the roster architecture, and the Execution represents the actual operational needs, this metric is a good estimator of the efficiency of shift planning, hence its name. However, it is seen in later sections that the SOT_{Master} estimation hardly corresponds to the Operations Roster Time (ORT) values, due to the overstaffing and workforce management problem. This means that even with an accurate SOT_{Master} estimation, the ORT planned is highly inaccurate, because ATCOs have to be rostered to work their minimum hours.

This inefficiency is captured in the next metric.

4) Operations Roster Time Buffer (Δ_{ORT}): This metric represents the buffer or inefficiency introduced in terms of extra ATCO minutes compared to the predicted SOT_{Master}

$$\Delta_{ORT}=SOT_{Master}/(ORT/2) \tag{6}$$

This factor is introduced for two reasons:

a) Planning Buffer: if the ATCO minutes plan is too tight, under unforeseen scenarios (e.g. sickness), staff shortages may occur.

b) Overstaffing: when the number of ATCOs for a given time period (typically winter) is high compared to the expected traffic levels, ATCOs are appointed to shifts to ensure either that their minimum license hours or minimum days agreed in their contracts are met. This translates into an inefficiency, not by poor prediction, but by inflexible workforce management.

1) Overall Planning Efficiency (OPE): is a metric of the efficiency of the overall planning process in terms of how many of the rostered ATCO minutes where actually used during the execution.

$$OPE=SOT_{Executed}/(ORT/2) \tag{7}$$

OPE is both a metric of cost-efficiency (OPE<100% means wasting available resources) and capacity (OPE>100% means insufficient ATCOs available, which would theoretically lead to understaffing delays). OPE can take values higher than 100% (this would mean that the actual ATCO minutes worked are higher than the total minutes rostered). This can occur due to one of the following:

- ATCOs working voluntary extra time;

- EOS working as ATCOs;
- Use of ATCOs in stand-by duties which are not taken into account in the ORT time.

Therefore, the OPE is a measure of how much ATCO-capacity there is and how much ATCO-capacity is used. The OPE is a single metric able to capture the trade-off between the capacity and efficiency KPA.

Additionally, the OPE captures the accumulated inefficiencies throughout the planning process. As shown in (8), OPE is a function of the efficiency of the workforce planning (Δ_{ORT}) and efficiency of the SOT prediction (SPE):

$$OPE = \Delta_{ORT}\, x\, SPE = \Delta_{ORT}\, x\, PRR\, x\, PPE \qquad (8)$$

VIII. Statistical Data Analysis

A. Scenario Selection

The Brussels sector group was chosen for the analysis in this paper. The main reason for this in comparison to the other two sector groups is the absence of major airspace re-design during the assessment period.

B. Pre-Tactical Planning Efficiency (PPE)

1) Hypothesis: PPE is always below 100% at a constant value that differs to the 100% by an amount corresponding to the Pre-Tactical buffer.

2) Actual Behavior:

- Hypotheses are confirmed after the transition date (March 2010).

TABLE III. Significant PPE Values

PPE	Statistical Values	
	μ[a]	**σ**[b]
Before	88.8956	6.7355
After	92.1052	6.4688
Buffer After	100-92.1052=7.8948	-

a. Mean (%)

b. Standard Deviation (%)

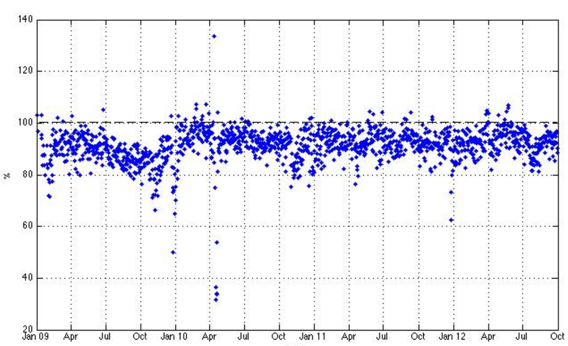

Figure 4. MUAC – Brussels sector group PPE

- Before the transition date, data tends to exhibit a seasonal trend. The reason for this is that before the refinement of the planning process, pre-tactical information was rarely used and an almost constant value was instead applied throughout the year.
- The estimated buffer is close to the actual standard deviation after the transition period. This means that staff in charge of the planning process (fundamentally FMPs) were able to calibrate, on the basis of their experience, their plans in order to create by experience a buffer almost equal to the amount of uncertainty seen during the execution.

C. Planning Refinement Ratio (PRR)

1) Hypotheses:

- PRR is expected to be around 100% with a standard deviation due to the amount of information updates. In other words, if the SOT_{Master} prediction was overestimated at the Pre-Tactical stage, PRR would be below 100% (and vice versa).
- No improvement from Table II was seen by SMEs as having a direct impact on this metric, therefore, no significant changes are expected.

2) Actual Behavior

- Mean PRR value for post-transition equals 100.52, confirming first hypothesis.
- Kolmogorov-Smirnov tests fail to reject the null hypothesis that pre- ($p=0.02$) and post- ($p=0.02$) come from normal distributions at 1% significance level.
- Two samples F-Test (95%) reject the null hypothesis that the samples come from normal distributions with equal variances ($p\approx0$).
- Two sample un-paired t-test assumming unequal variances shows at 5% significance level rejection of the null hypothesis that both samples come from normal distributions with equal means ($p\approx0$). This finding, is opposed to the second hypothesis. The SMEs most probably underestimated the effects that the refinement of the planning process had in the metric.

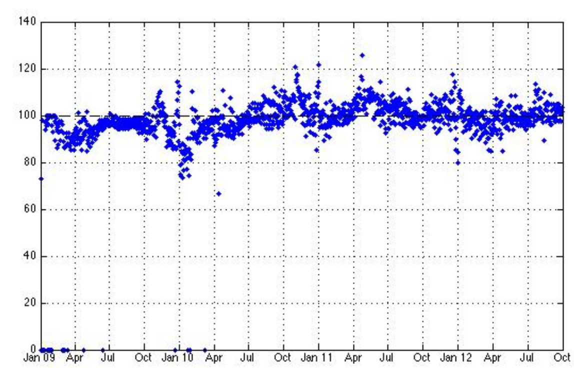

Figure 5. MUAC – Brussels sector group PRR

D. Shift Planning Efficiency (SPE)

1) Hypotheses: SPE is always below 100% at a constant value that differs by the Pre-Tactical buffer, with a STD proportional to the level of uncertainty in the long-term phase.

2) Actual Behavior:

- Data filtered excluding outliers reveal normality at 95% confidence level with a Kolmogorov-Smirnov test for pre- ($p=0.20$) and post- ($p=0.31$) transition.
- F-test for equal variances show no significance ($p=0.19$) at 95% confidence level which enables making the assumption of equal variance between the before and after data sets.
- Therefore, with the equal variances hypothesis an un-paired t-test is made at 95% confidence interval showing statistical significance between the pre- and post-transition data samples for their mean values ($p \approx 0$)
- Hypotheses are mostly confirmed before and after the transition date. However, overshooting points are found. These points correspond to scenarios where the SOT_{Master} was underestimated. If the ATCO time planning is tight i.e. Δ_{ORT} close to 100%, then understaffing delays would occur. It is for these scenarios that the staffing planning buffer acts as a back up.

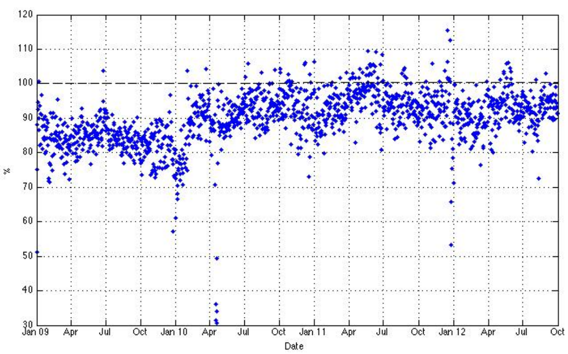

Figure 6. MUAC – Brussels sector group SPE

TABLE IV. SIGNIFICANT SPE VALUES

SPE	Statistical Values	
	μ^a	σ^b
Before	83.6599	5.9431
Before Buffer	100-83.6599=16.3401	-
After	92.5048	7.1285
Buffer After	100-92.5048=7.4952	-

a. Mean (%)

b. Standard Deviation (%)

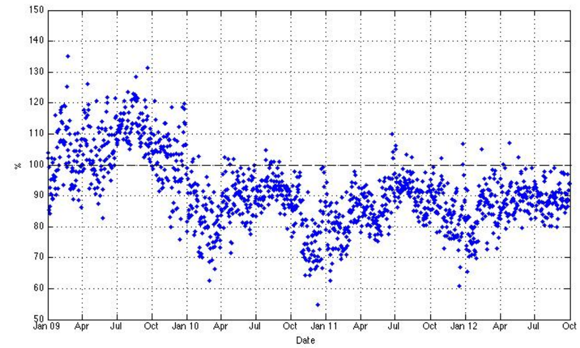

Figure 7. MUAC – Brussels sector group ΔORT

E. Δ_{ORT}

1) Hypothesis: Δ_{ORT} is always under 100% by a value that differs from the 100% by an amount corresponding to the additional planning buffer. No step type variation is expected after the transition period. The main contributors to a Δ_{ORT} change would be a new roster design and a refinement of the planning process. However, these two improvements are gradual, and the Δ_{ORT} change is therefore, expected to be gradual too.

2) Actual Behavior:

- Seasonal variation: overstaffing in winter. The staff design point is for the most critical period of the year, the summer. During summer, traffic rises at the same time as ATCOs are entitled to take summer leave. Since the workforce is designed to provide control services within capacity standards during the most critical period (summer), overstaffing occurs for the rest of the year, which finally leads to significant inefficiencies.
- Values above 100%: these indicate that an insufficient number of ATCOs were rostered for the predicted SOT_{Master}. This can be either because it is known that the SOT_{Master} is largely overestimated and less ORT is planned or because not enough staff is available (which has rarely been the case since the traffic drop in 2009).
- Values under 100%: These represent the planning buffer or the overstaffing inefficiency described in Section VII.B.4). The lower, the value of Δ_{ORT}, the higher the buffer.

Fig. 8 depicts this overstaffing seasonal variation according to the traffic levels. In fact the monthly values for the number of ATCOs per flight movements have significantly increased, as shown in Table V.

F. Overall Planning Efficinecy (OPE)

1) Hypothesis: OPE increases as a result of the enhancement of the planning process and dynamic shift management

2) Actual Behavior: There is no such increase; instead the effect of overstaffing masks any other improvement.

IX. DISCUSSION

This section gathers the main findings from the statistical data analysis.

A. *SPE Buffer Reduction*

The reduction of this buffer, i.e. the gain observed in the metric, can be explained as follows: either the prediction is significantly better or given that the prediction is not sufficiently accurate, the management of the ATCOs is able to dynamically accommodate the demand.

A set of semi-structured face-to-face interviews was carried out with capacity managers. These highlighted that the main enabler for the buffer reduction was the introduction of TimeZone along with the flexible roster architecture. The enhancement of the planning process would have had a less important contribution to the actual accuracy of the prediction.

1) *Long-term SPE Gains*

Table IV shows a SPE buffer of 7.5%, which is very close to the actual standard deviation of 7.2%. This result suggests that enhanced SPE would firstly come from a reduced standard deviation (less SPE variability) and finally from a more accurate prediction. An improvement in the average prediction, i.e. the mean SPE, would by itself not lead to any significant improvement because the buffer would need to remain the same due to the inherent variability.

Given these values, the MUAC Brussels sector group may expect a maximum theoretical gain of 7.5% prediction accuracy associated with potential future planning improvements.

The sub-section below assesses the sources of SOT variability, in order to understand the possible means of reducing the SPE standard deviation.

a) *SOT Variability*

In theory it is thought that for a given traffic demand, for instance 2000 flights in a day, the same $SOT_{Executed}$ would always be needed. However, in reality there is no univoque relationship between the number of movements and $SOT_{Executed}$, as seen in Fig. 9 (for instance, 2000 flights have been controlled from 3400 to 4400 $SOT_{Executed}$ minutes).

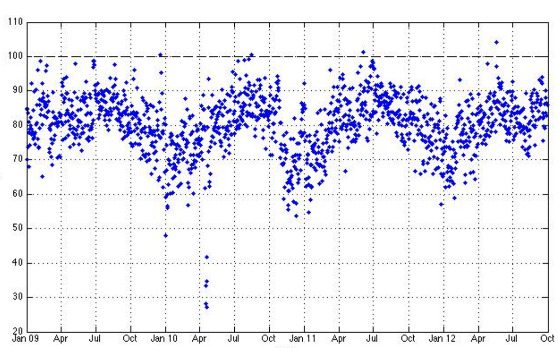

Figure 8. MUAC – Brussels sector group OPE

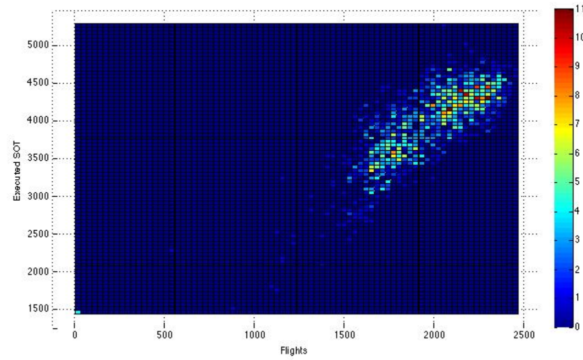

Figure 9. MUAC – Brussels sector group daily Exectuted SOT vs. Traffic (colormap representing the frequency)

There are many drivers other than traffic demand, in the ATC system that affect execution performance. However, most of these drivers are hardly predictable during the planning period, and therefore, rough estimates are made in advance, leading to significant variations on the day of execution.

- Traffic Pattern and Network Effects

The air transport system is variable because of the inherent randomness of the system and its effects on the remainder of the system variables. During planning process, this random activity is not currently modelled. Therefore, different days are typically planned with the same sector configuration schemes despite this variability.

- Unforeseen Scenarios: Weather and other Events

Degraded weather conditions, intensive training activities, system degradation or system maintenance, social unrest or new operations room component implementation transition, are examples of special scenarios which are difficult to predict.

- Military Activity

Military activity is a major factor contributing to the airspace management execution. When Temporary Reserved Areas (TRAs) are activated/de-activated, the flows and restrictions vary. Traditionally the link between military stakeholders and ACC centres has been FAX, telephone. Bookings can be either made with short notice or long in advance. This is in fact the core of the Flexible Use of Airspace (FUA) concept.

- ATCO Workload and Performance

ATCOs have varying levels of performance. A recently licensed ATCO may be able to handle less traffic than an experienced ATCO, therefore different airspace management requirements are needed depending on the individual person manning the position.

- EOS Performance

The decision of opening and closing sectors is made by a duty supervisor who is advised by the rest of the EOS team (FMPs and capacity managers) and the tools supporting them. Because the decision is ultimately made by a human, it is challenging to model or predict the executed configuration.

- Events

In planned events, such as the Olympics, it is difficult to predict the traffic scenarios due to the novelty of the event. Hence, larger buffers may be applied. This is for instance the case in 2012 summer when larger Pre-Tactical buffers were applied to prepare for any abnormal situation.

- SOT sensitivity

Bunched traffic patterns consume more SOT minutes than smooth traffic patterns. Opening sectors in order to meet demand for small periods of times is cost-inefficient. The ideal scenario would be on in which the traffic is spread out throughout the day, operating all the sector configurations at maximum traffic load. However, the traffic patterns change daily due to random network effects.

B. Workforce Issues

As seen in Fig. 8 overstaffing is an issue in the low demand periods of the year i.e. the winter season. In order to improve the OPE metric, a drastical change in the management of workforce during valley periods is required.

Table V summarises the overstaffing problem in terms of the ratio of ATCOs to traffic volume handled.

C. The Capacity/Cost-efficiency Trade-off

OPE as explained above is a single metric able to represent the relationship between the cost-efficiency of an ATC centre, in terms of its planning process, and the ATCO-capacity performance deliverd, commonly measured as staffing delays.

X. The Role of the SESAR Programme

Section VIII describes the effect of the introduction of the new improvements (introduced in Section VI) on the metrics listed in Section VII. Section IX discussed the main findings from the analysis and the limitations of the current air transport system that prevent an enhanced ATC performance.

Based on these findings, this section assesses the ability of the SESAR programme to yield cost-efficiency gains given its planned Operational Improvements (OIs).

A mapping is made between the OIs of the SESAR Master Plan[14] and the outcomes of the discussion.

A. Mapping of Operational Improvement Steps

Given the outcomes of the previous sections, and based on a review of the SESAR Master Plan [14] the following OIs are found to be directly linked to the research.

1) Flexible Sectorisation Management

This OIs with expected deployment between 2011 and 2016 focus on enhancing the utilisation of resources (ATCOs) through better planning procedures and harmonised operations between centres. Section V shows the solution adopted by MUAC in this respect and Section VIII, the actual performance during the transition phase and the fully-deployed phase.

Expectations for other centres around Europe should be in accoradance to the MUAC experience described in this paper.

2) Interactive Network Capacity Planning and Co-ordinated Network Management Operation Extended until the Day of Operation

As mentioned previously, opening sectors is not efficient under low traffic load. These two OI steps aim to transfer load from saturated regions to those that are below their capacity threshold. The benefit of trading these loads would be to reduce delay and capacity constraints, at the same time as making optimised use of available resources.

3) The Business Trajectory

The business trajectory will evolve from the Business Development Trajectory (BDT), to the Shared Business Trajectory (SBT) and finally to the Reference Business Trajectory before the actual trajectory is executed.

Theoretically, this trajectory updating process introduced will enable increasingly accurate predictions as the time of execution approaches. This is expected to be translated into higher variations in the PRR metric, specially due to the variation on the SBT since its timeframe coincides with the PRR timeframe..

The trajectory updating negotiation process will have to be closely monitored by ATC centres to ensure that the PRR values do not exceed pre-defined boundaries, that may result in capacity shortages and operational inefficiencies.

4) Generic (non-geographical) Controller Validations

SESAR operational improvement SDM-0203 Generic (non-geographical) Controller Validations, may be of help during understaffing scenarios representative of the summer period. In these occassions ATCOs would be able to solve ATCOs shortages. However during the winter period, overstaffing would almost be ubiquituous, hence no improvement due to this validations would be expected.

5) Civil/Military coordination

New tools, within the SESAR concept, such as the Local and Regional ASM Application (LARA) may ease the booking process by means of providing a unique tool for relevant stakeholders. However, this brings along another trade-off: between the flexibility of the airspace use and the predictability, and therefore the cost-efficiency of the operation. The larger the amount of not-planned military activity, the larger the buffers will need to be.

In order to assess the potential effect of military activity on a centre level performance, a statistical comparison between working days and weekdays is made for SPE (OPE may include staffing factors that are not caused by military activity). This analysis shows no variation on the metric between working days and weekdays.

This suggests that the military activity uncertainty is a second order factor (small compared to traffic variability).

What actually happens is that during working days more sectors are opened for the same amount of traffic.

TABLE V. ATCOS PER TRAFFIC VOLUME INCREASES

Overstaffing	*Number of ATCOs / Monthly Traffic (10^{-3})*	
	minimum - Summer	*maximum - Winter*
2008	1.192	1.481
2012	1.382	1.941
Increase	+16%	+31%

In fact if the $SOT_{Executed}$ is normalized by the flights for the day, and the average of this metric is calculated separately for working days (Monday to Friday) and for weekend days (Saturaday and Sunday) the weekend curve is consistently below the working-days curve. This means that during weekends less SOT is used for the same amount of traffic.

$$[(SOT/TFC)|_{working} - (SOT/TFC)|_{weekend}] / (SOT/TFC)|_{weekend} \quad (9)$$

The average of (8) for 195 weeks since January 2009 is 6.5. This is the intrinsic military effect on cost-efficiency.

XI. RESEARCH LIMITATIONS AND FUTURE WORK

This research assumes that the executed SOT equals the optimal SOT, although that is not necessarily true. Future work will incorporate a SOT execution efficiency metric in the cost efficiency analysis to assess the goodness of the executed SOT.

XII. CONCLUSIONS

The paper has developed a set of metrics able to represent the accuracy of an en-route planning process. It has assessed the impact of dynamic shift management and a layered planning process on the centre cost-efficiency. The results suggest that, although the predictability has not significantly improved, the ability of matching demand with the available resources has increased. Finally, it has linked these improvements to those proposed by SESAR, in order to extrapolate the possible effect for the rest of European en-route ATC centres.

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