Capacity Management based on the Integration of Dynamic Airspace Configuration and Flight Centric ATC solutions using Complexity

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Abstract— **This paper presents a new capacity management concept where Dynamic Airspace Configuration (DAC) and Flight Centric ATC (FCA) are dynamically applied together during the Air Traffic Flow and Capacity Management (ATFCM) pretactical phase. An airspace delineation methodology is also introduced aiming at identifying when and where DAC or FCA can perform better. This methodology entails the establishment of a dynamic vertical boundary that divides the airspace in two different parts where DAC and FCA are deployed. In addition, the geometrical complexity metric has been considered to measure the traffic demand and the sector capacity as an evolution of the current use of entry counts or occupancy counts.**

Three 24 hours scenarios over the Hungarian airspace have been simulated in order to validate the improvements, in terms of capacity and cost-effectiveness, that the dynamic integration of both capacity management solutions may provide in comparison with the two solutions deployed separately. Results shows that when DAC and FCA are dynamically applied, a significant reduction in the number of overloads and underloads detected is achieved, what might lead to a higher capacity since more aircraft can be handled. Furthermore, a reduction in the controlling hours is also registered in this situation, what it is translated into a better cost-effectiveness solution.

I. INTRODUCTION

Air traffic management (ATM) in Europe is facing a sustained growth of demand that forces the ATM system to perform with permanent overloaded sectors and airports. In this situation, Air Traffic Flow and Capacity Management (ATFCM) measures are applied aiming at maintaining the demand below the capacity. As a result, the 9.6% of the flights were delayed by en-route ATFCM regulations in 2018 [1]. Considering the current overloaded situation and the foreseen growth of traffic demand, estimated at 2.0% for the average annual rate between 2019 and 2025 by STATFOR latest forecast [2], the improvement of ATFCM models and solutions has become a big challenge and priority.

Thus, there are two different ways of balancing the demand and the capacity. The first option consists in applying ground delays in order to shift the traffic demand and keep it below the estimated capacity, what is basically the main function of the

Network Manager in Europe. Some research has also been achieved aiming at providing more flexibility to the current methods such as the Enhanced Slot Swapping feature from the User Driven Prioritisation Process (UDPP) [3], [4], or the treatment of the demand and capacity balance problem as an optimisation problem [5], [6], [7], [8], [9].

The second option for balancing the demand and the capacity is the capacity management done by the Air Navigation Service Providers (ANSPs), which is the main focus of this paper, aiming at better using the available ATC resources in order to provide higher rates of traffic throughput. The introduction of new tools for supporting the controller's decision making, as well as new ATC modes of operation can be included in this option. Some research have addressed the improvement of the airspace capacity by introducing new capacity solutions as the Dynamic Airspace Configuration (DAC) and the Flight Centric ATC (FCA).

DAC relies on the dynamic design of the airspace, which intends to provide an accurate adaptation of the capacity to the foreseen demand, thus avoiding the use of pre-defined sectors [10]. Conversely, FCA builds on a sectorless environment where each aircraft entering the FCA area is allocated to an Air Traffic Controller (ATCO) based on a set of FCA operational criteria [11]. Both of these concepts have been also explored in two separate projects in SESAR programme [12] and [13]. It has been shown that DAC solution provides a potential gain in capacity, while FCA solution is more cost-effective in comparison with the conventional ATC mode.

However, DAC and FCA concepts relies on the use of Traffic Monitoring Values (TMVs) such as entry counts and occupancy counts as a proxy to "monitor" and "judge" the controllers workload. TMV's peak and sustained occupancy thresholds are just guidelines for the ATFCM actors to "monitor" the traffic loads but each individual ATFCM actor will apply different logic to each traffic situation being more subjective than objective. This difference in opinion of workload, in addition to the uncertainty of the trajectories, lead to the use of capacity buffer.

In the scope of COTTON project [14], a new capacity management approach is developed, where traffic complexity

assessment is a key enabler to ensure the effectiveness of DAC and FCA, providing a more accurate estimation of capacity and controller workload that goes beyond traffic counts. Furthermore, the project explored the feasibility and potential benefits of a holistic capacity management approach based on the integration of DAC and FCA solutions and the assessment of traffic complexity.

The main objective of this paper is to present the validation of the holistic integration of the enhanced DAC and FCA capacity management solutions proposed in COTTON, to derive potential benefits in terms of capacity and cost-efficiency improvements in comparison with the deployment of only one capacity management solution separately. A novel delineation method for dividing the airspace in DAC and FCA aereas is presented and the current DAC and FCA models are improved with the introduction of the complexity (instead of entry counts or occupancy) as a metric for measuring the demand and the capacity.

Summarising, the contributions of this paper are: 1) a novel delineation method to identify when/where DAC and FCA shall be applied; 2) the introduction of complexity in the DAC and FCA processess; and 3) a validation assessment of the benefits of the integration of DAC/FCA solutions.

II. HOLISTIC INTEGRATION OF DAC AND FCA

The main reason for integrated DAC/FCA is that both DAC and FCA modes of operation deployed separately bring benefits in certain operational environment. Therefore, the ideal way to achieve highest performance and continuous optimal use of the resources (airspace and ATCOs) is to combine, harmonise and eventually fully integrate them.

Initial trigger for this approach is the fact that FCA operations are proven to provide high performance until a certain level of demand complexity in a subject airspace is reached. Beyond this level, FCA mode of operations becomes impracticable. The main reason lies in the way ATC service is provided in FCA (i.e. sectorless controller working positions (CWPs)). When the complexity is high, some situation awareness limitations and a high increment in the number of internal coordination arise, what lead to a potential decrease of safety and an exponential increment of workload.

On top of that, a DAC/FCA integrated environment would require design criteria based on complexity assessment to decide, monitor and refine the airspace boundaries delineating DAC and FCA areas. The design of such boundaries is based on DAC airspace design components, which can be building blocks or shareable blocks. The main difference between them is that a shareable block cannot be operated as an ATC sector by itself and needs to be collapsed with one or more building blocks. Building blocks can also be collapsed in order to create bigger collapsed sectors. As illustrated in Figure 1(a), vertical delineation of DAC and FCA boundaries can be assessed through the analysis of complexity of the 5 vertical layers and then through the complexity assessment of individual building and shareable blocks. The resulting delineation is then illustrated in Figure 1(b).
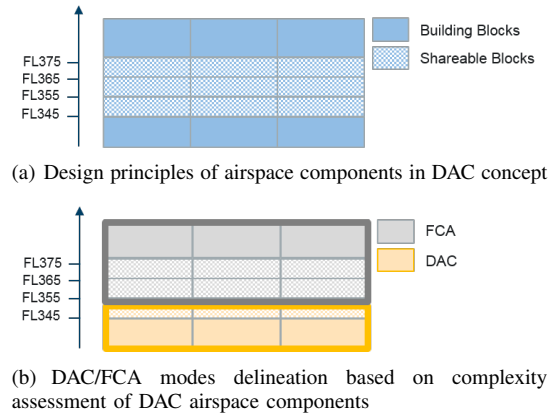

(a) Design principles of airspace components in DAC concept

(b) DAC/FCA modes delineation based on complexity assessment of DAC airspace components

Fig. 1: Delineation process example

Two delineation modes supported by complexity assessment are proposed:

- Static DAC/FCA. It consists in the identification of one single altitude boundary above which FCA can be applied along the day. Static DAC/FCA boundary is identified through the analysis of complexity generated at each vertical layer of the airspace. The highest layer with high complexity level defines the boundary between FCA and DAC.
- Dynamic DAC/FCA. It consists in identifying variable DAC/FCA altitude boundaries per time period depending on the complexity of altitude layers along the day.

Although the presented study in this paper is focused on the pre-tactical phase, the presented methodology is represented in all the ATM layered planning. This methodology is holistic in a sense that each phase is not disconnected from the overall time layered planning.

III. METHODOLOGY

A. Introduction of complexity

As previously introduced, the most of the previous ATFCM models used entry counts or occupancy as metrics for measuring the demand and the capacity. Although entry counts and occupancy have been used as proxy of the ATC workload because of their simplicity, the harmonisation of the traffic or the difficulty required to control a given situation can not be evaluated through these simple metrics. For this reason, a large number of researchers have focused their activities on the development of complexity metrics able to measure more factors representative of the ATC workload. Although SESAR defines complexity as "...measure of the difficulty that a particular traffic situation will present to an air traffic controller..." [15], none of the proposed metrics in the literature has been proven superior to all the others. Authors' intention was not to develop a new complexity metric, but rather use an existing one. Hence, a very extensive study of the existing metrics, their output format, advantages and disadvantages, their classification... was performed in order to select the most adapted one. In [16], an analysis of the main complexity

metrics developed for the application in ATM is provided, together with the identification of the complexity generators that can be key to the definition of complexity in the capacity management. This study was extended in [17] complementing the comparison between different complexity metrics with their suitability with the DAC and FCA concepts. Similar outcomes were also published in [18].

Considering this previous research, authors propose small adaptation of the existing Geometrical complexity metric. The original Geometrical complexity metric [19], [20] provides 'null' complexity in the traffic situation with diverging and widely distributed aircraft regardless of their number. Based on the expert judgment and simulation tests, in this work it is supposed that in such 'simple' situations ATCO workload won't be null due to the monitoring task, that is a linear function of the number of flights in the controlled area. The formula used to calculate the complexity in a CWP is:

$$C = \sum_{i=1}^{N}(1+\delta)\cdot((1+\lambda)\cdot(\sum_{j|Cv_{ij}}-Cv_{ij}\cdot e^{-\alpha\cdot d_{ij}^2})+m) \quad (1)$$

Where, Cv_{ij} is the pure geometrical complexity that aircraft j produces on aircraft i, which is modulated in order to consider the monitoring complexity through m, the vertical evolution of flights with λ, the proximity with the sector boundary using δ and the aircraft proximity with α.

All modeled parameters are user selected parameters, that are general by definition (i.e. same could be used for other studies, ACC etc.). To find these general values an extensive study is needed, that was beyond the scope of this study. Beside the parameter alpha that is defined in the original Geometrical metrics, in this study other parameters are selected based on the experts judgment and small real-time simulation tests.

B. Complexity threshold identification

Since the complexity metric used in the analysis was a new metric, no threshold had been previously defined. The approach used to find out this threshold was focused in historical regulation analysis, specifically the ones due to ATC capacity. During the AIRAC 1808 there were 48 regulations of this type over the Hungarian airspace, and 34 of them were used in this study. The remaining ones were excluded because they started the day before or ended the day after, or because they were applied in more than one period of time.

The logic behind is that when a regulation is needed, it means a capacity issue (overload) is expected. Hence, it is assumed that any workload metric value is above its threshold, whereas after the regulation is applied, the metric value should be under the threshold.

As assumed, that is what can be observed in Figure 2. Figure 2(a) shows the complexity over the sector before the regulation where some peaks can be seen above the value of 50. After applying the regulation, that is Figure 2(b), the complexity during the regulation period is always below 50. Based on

this assessment on several workable sectors, the threshold was computed and averaged to be 50 for sustained overloads, and 80 for peak overloads.

On the other hand, FCA is not in today's operation, so the same analysis for FCA could not be performed. However, the experience and knowledge obtained in PJ10-01b [13] is applied. Thus, it is assumed that the threshold for FCA will be a little bit lower than for DAC, because of the nature of the concept since the complexity values are aggregated per trajectory and the situation is completely different to that of controlling a sector. In addition, in FCA there is only 1 controller per CWP whereas in DAC there are 2 per CWP. According to these reasons and based on operational expert judgement, the complexity threshold for overloads in FCA has been established at 40, which is 20% less than in DAC.

C. Overload and underload detection process

The overload detection process considers some duration and complexity thresholds, what leads to two different types of overload:

- Sustained overload: the complexity is above the sustained overload threshold during a sustained period of time longer than the sustained duration threshold.
- Peak overload: the complexity is above the peak overload threshold during a short period of time, but longer than the peak duration threshold.

It is important to note that if the demand is above the capacity but during less time than the duration threshold, the overload is not considered. A similar approach is followed for detecting underloads. Nevertheless, only sustained underloads are considered.

The previous detection process is valid for the DAC strategy. For FCA, the process is alike but there is no peak overloads (only sustained overloads and underloads are considered).

D. Airspace delineation process

One of the contributions of this paper is the airspace delineation to identify when and were DAC and FCA may be applied. This subsection is focused on deeply explain how the boundary between the DAC and FCA area can be dynamically assessed.

The process for delineating the airspace presented in this paper is based on a complexity assessment following a top-down approach from the highest level point of view showing the total complexity of the ACC compared to occupancy to the elementary sector level to show which portions of the airspace and time periods are more critical. The aim is to foster a global understanding of the complexity metric, assess how it resembles and/or differs from occupancy, identify what regions of the airspace contribute more to the complexity and what times of the day are more critical. The methodology of such delineation process can be summarised in steps:

- Step 1: assessment of instantaneous complexity at ACC level. It allows to identify the preliminary time periods when the workload will be higher. In addition, the comparison of the complexity values with occupancy

(a) Complexity before the regulation
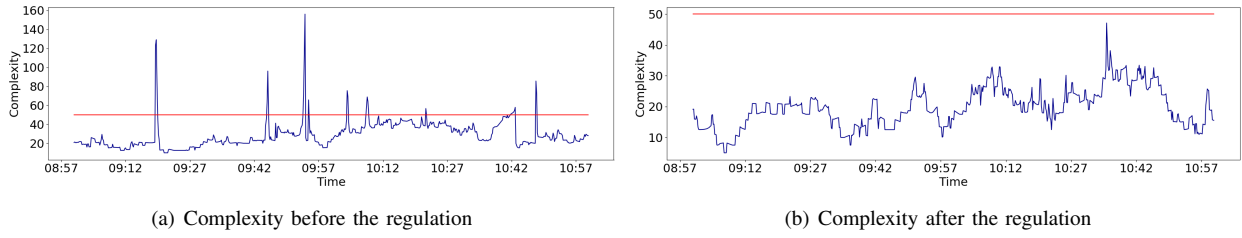

(b) Complexity after the regulation

Fig. 2: Empirical assessment to identify complexity threshold for sustained overload, example for LHCCENH

allows to identify if the workload is generated due to the high number of flights or due to the geometric issues consequence of the traffic flows.

- Step 2: assessment of aggregated complexity per vertical layer. The airspace can be divided vertically in different layers in order to identify vertical portions of airspace where the complexity is higher. The comparison between entry counts and complexity is always recommended since it provides added information about the major source of complexity.
- Step 3: assessment of instantaneous complexity per vertical layer. This step allows to identify the temporal evolution of the complexity per vertical layer and offers a better view to define a dynamic boundary between the DAC and FCA areas.
- Step 4: assessment of instantaneous complexity at elementary sector. The study of the complexity at a lower level allows to refine the outputs of previous steps and clearly identify the portions of airspace where the complexity is high.

Following this top-down approach together with the support of expert judgement allows to identify when and where DAC and FCA can be deployed respectively.

E. Dynamic Airspace Configuration algorithm

The sector configuration optimisation algorithm aims at balancing demand and capacity dynamically inside the DAC area and it is based on the Improved Configuration Optimizer (ICO) developed and refined by the EUROCONTROL Experimental Centre [21]. It internally runs a branch and bound algorithm aiming at finding the best sector opening scheme that satisfies the following multiobjetive criteria:

1) Minimises the overloads and underloads.
2) Minimises the number of controllers.
3) Maximises the overload and underload balance between sectors.
4) Minimises the number of sector changes.

This algorithm evaluates the demand and the capacity using the complexity metric introduced in Section III-A, while the overload and underload detection is done using the approach explained in Section III-C. The optimisation process is also dependant on the following set up parameters: 1) minimum opening duration of a configuration; 2) minimum opening duration of a sector; 3) maximum difference in number of sectors between consecutive configurations; and 4) minimum opening duration of a dynamic airspace configuration.

This last point requires an extended explanation in order to clarify the concept of dynamic airspace configuration. There may be some configurations where the only difference among them is where the shareable blocks are located. In this situation, a change of configuration is less intrusive for the controllers and more flexibility can be given to the optimisation process.

F. Flight Centric ATC algorithm

In order to determine the number of CWPs required for the FCA area in medium-term planning, the FCA algorithm allocates trajectories entering the FCA area to the CWPs with the support of the complexity metric presented in Section III-A. First, complexity is assessed for each trajectory crossing the FCA airspace. Complexity at CWP level is computed by the sum of the complexity that the controller already has when the flight enters the FCA area plus what this particular flight would add to it. Then, based on this complexity assessment principle, the algorithm allocates the trajectories to the controllers so that complexity is evenly distributed among the CWPs along the day of operations.

Thus, although the flight allocation algorithm can not be described as an optimisation algorithm, it aims at providing a solution that tries to:

- Minimise the overloads and underloads.
- Minimise the number of CWPs.
- Balance the workload of the CWPs.

In addition, in order to mimic the current stat-of-the-art status of the FCA solution, no reallocation process between CWPs is considered. It means that once a trajectory is allocated, it will be controlled by the same CWP during all the time. In addition, when a CWP is identified to be closed (because of low traffic demand), it remains open until all flights controlled have left the FCA area.

IV. RESULTS

A. Exercise description

Aiming at validating that the holistic integration of DAC and FCA performs better than the application of both concepts separately, a case study of 24 hours of traffic over the Hungarian airspace (LHCCCTA) is proposed because it is representative of any airspace with high complexity values. The day of the study is the 29th of July of 2018 and the traffic

TABLE I: Parameters for the DAC and FCA optimisation strategies

DAC mode	
Minimum opening duration of a configuration	30 minutes
Minimum opening duration of sectors	30 minutes
Limit steps of the number of sectors when there is a configuration change	2 sectors
Minimum duration for dynamic airspace configuration	15 minutes
FCA mode	
Minimum opening duration of a CWP	30 minutes
Flight reallocation between openened CWPs	NO

TABLE II: Parameters for overloads and underloads

Variable	DAC mode	FCA mode
Complexity sustained overload threshold	50	40
Complexity sustained overload duration	7 minutes	4 minutes
Complexity peak overload threshold	80	N/A
Complexity peak overload duration	3 minutes	N/A
Complexity underload threshold	15	15
Minimum complexity underload duration	7 minutes	4 minutes

sample obtained from the DDR2 database contains 3,046 flights crossing the considered ACC. Both DAC and FCA algorithms are simulated using the the R-NEST suite [22] from EUROCONTROL. This validation exercise was done in the scope of the COTTON project and more detailed information can be found in [23].

The DAC process basically consists in an optimisation process in order to get the best sector opening scheme given a great number of configurations. Such optimisation process requires to be calibrated fixing some operating values agreed and validated together with EUROCONTROL and Hungaro-control experts. In this sense, the minimum operating duration of a configuration is limited to 30 minutes. However, a minor duration of 15 minutes is allowed when the change from one configuration to the next one is affecting only to the shareable blocks. In other words, the exchange of shareable blocks between different building blocks is allowed every 15 minutes. In addition, another limitation related with consecutive configurations is the difference in the number of sectors. In this paper, this values is fixed to 2 sectors, what avoids big configuration changes ensuring the traffic situation awareness and safety from the controller point of view. On the other hand, the minimum operating duration of a sector is limited to 30 minutes.

Regarding the FCA algorithm, it also requires some operational constraints. Since the are no configurations neither sectors in FCA, the minimum operating duration is applied directly to the CWPs, limited to 30 minutes. All these constraints for the DAC and FCA algorithms are summarised in Table I.

Focusing on the complexity, the equation 1 has been particularised using the following parameters:

- Monitoring complexity is m = 0.5
- $\lambda = 0.25$ for climb and $\lambda = 0.15$ for descent
- $\gamma = 0.3$ at the border (distance = 0 NM) linearly decreasing to 0 at the distance = 10 NM
- $\alpha = 1.7$

Both DAC and FCA algorithms also requires the definition of the overload and underload thresholds. These values are summarised in Table II.

Three scenarios are defined:

- Scenario 1: full DAC. All the Hungarian airspace is operated under DAC ATC rules.

- Scenario 2: FCA/DAC static. The Hungarian airspace is statically divided in one part operated with DAC rules and another under the FCA paradigm. This scenario is designated as "static" because the boundary between the DAC and FCA airspace does not change during the day. This is equivalent to consider that FCA is deployed alone since it is impossible to use FCA in the full airspace.
- Scenario 3: FCA/DAC dynamic. The boundary between the DAC and FCA areas is dynamically adapted accordingly with the characteristics of the traffic demand.

It must be noted that the definition of the DAC/FAC boundaries in scenarios 2 and 3 is result of the delineation process introduced in section III-D. Next section is devoted to deeply explain this process for the day of simulation.

B. Delineation of DAC and FCA areas

The delineation process for identifying when and where DAC and FCA can be applied is one of the most contributions of this paper and it is introduced in section III-D divided in several steps. The particularisation of these steps for this case study is:

- Step 1: assessment of instantaneous daily complexity at ACC level. In this case the ACC is the Hungarian airspace denoted by LHCCCTA and the instantaneous complexity registered along the day can be showed in Figure 3(a). One can identify periods with low complexity at the beginning and at the end of the day, as well as high complexity values in the middle of the day. It is also possible to compare the complexity values obtained with the occupancy showed in Figure 3(b). The instantaneous complexity follows a similar envelope to the occupancy because the monitoring complexity has a big contribution. However, there are some mismatches in some moments reflecting that the geometry of the traffic demand is so complex in some situations, what may create high workload periods to the controllers
- Step 2: assessment of aggregated complexity per vertical layer. From Figure 4(a) it can be observed that [FL365 to FL375], [FL345 to FL355] and [FL305 to FL345] are the ones handling the biggest complexity contributions, with nearly 20% of the total each. This is logical for FL305 to FL345, since there is more evolving flights that climb or descend to their corresponding En-Route flight levels because they are in a transition zone between the Lower Airspace and the Upper (see Figure 4(b)). However, it stands out that FL365 to FL375 is so complex, when most of the traffic is En-Route and flights are in cruise. It

demonstrates why in the Hungarian Airspace these flight levels are crucial and deserves special attention in terms of ATC. As a result of this assessment, the study considers that FL375 is a good flight level to divide airspace in static DAC/FCA. FCA will handle 9%+14% = 23% of the total complexity which is already a fair amount and DAC takes airspace below FL375 which accounts for 77% of the total complexity, as it is more adequate to this kind of traffic, with more complex trajectories, flight level changes, etc.

- Step 3: assessment of instantaneous complexity per vertical layer. Figure 5 shows how the vertical layers are contributing in terms of complexity during the day. The dark blue strip corresponding to Flight Levels FL365 to FL375 has a big contribution, also containing the most of the peaks, as also seen in Figure 4(a). The valuable information to derive from this graph are the allocation periods for DAC or FCA areas in the integrated and dynamic DAC/FCA concept. Operational experts from EUROCONTROL and Hungarian Airspace (Hungaro-Control) were asked to provide guidance for the delineation resulting in the following delineation according to complexity increments/decrements and peaks:

  - From 0:00h to 3.00h: Only FCA in the airspace, since complexity is low (lower than 40 which is the complexity threshold for FCA).
  - At 3.00h: following the first peak greater than 40 and 50 which are the complexity thresholds for FCA and DAC respectively, open DAC from FL095 to FL305.
  - At 5.00h: There is a peak above 100 and in general complexity is growing, so to extend DAC to FL345.
  - At 8.00h: there are peaks of 200-250 in order of magnitude, and complexity brought by FL365 and FL375 is already important, so DAC is extended to FL375. There is a complexity drop between 12.00h and 14.00h, but it is decided to maintain the airspace allocation because later the traffic is again intense until 16.00h.
  - At 16.00h: After 16.00h the average complexity is dropping, although at 19.00h there is a great peak, so DAC is lowered to FL345.
  - At 19.00h: After the peak at 19.00h, complexity is always below 200 and thus, DAC is lowered to FL305.
  - At 23.00h: Complexity will decrease to 50 and below until midnight, so again full FCA is applied.

- Step 4: assessment of instantaneous complexity at elementary sector. Complementing the high-level assessment, the in-depth analysis of data at elementary sector level was performed, for the 15 original elementary sectors of the original LHCCCTA airspace, confirming the decisions taken in the previous step. For example, Figure 6 shows the instantaneous complexity of the elementary sector LHCCWESTH (FL365 to FL385).

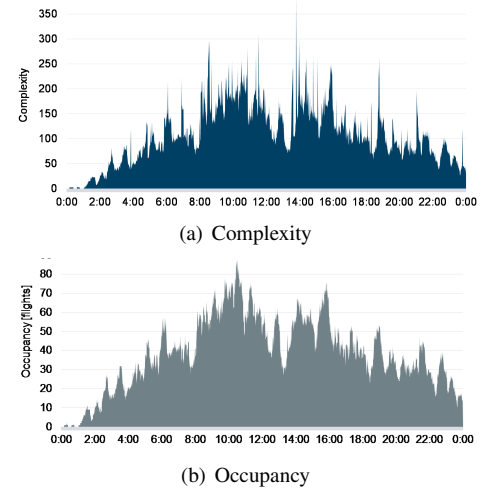The resulting application of this delineation process leads

(a) Complexity

(b) Occupancy

Fig. 3: Demand of the ACC LHCCCTA

(a) Complexity
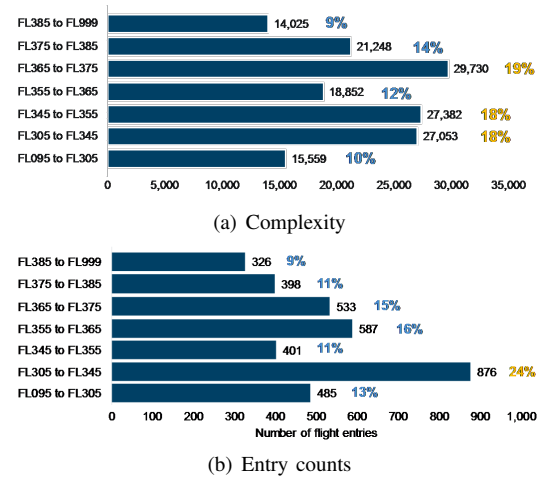

(b) Entry counts

Fig. 4: Demand per vertical layers

to the scenario definition presented in Figure 7.

C. Capacity analysis

In this paper, the total overload and underload sums are used as capacity performance indicators (PIs). On one hand, overloads can be understood as periods where the capacity could not be increased, but on the contrary could even be reduced, while underloads represent periods where more aircraft could be handled, so that the capacity could be increased. The translation of one to the other one cannot be easily defined, since it depends on the complexity increase of adding new aircraft (and the complexity depends on many parameters), but at least conclusions can be extracted on whether the scenarios are worse or better at managing capacity.

Overload sum observed in Figure 8(a) shows that DAC/FCA both static and dynamic processes outperform DAC alone, reducing the overloads significantly, 33% and 47% respectively. These reductions are significant and demonstrate that capacity planning can be optimised with the use of integrated DAC/FCA mode. A possible explanation for this to happen
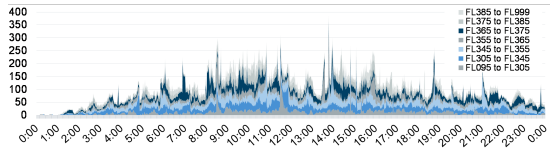
Fig. 5: Instantaneous complexity per flight level division
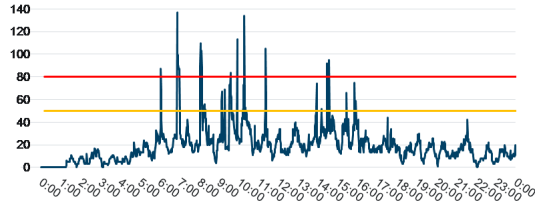

Fig. 6: Example of instantaneous complexity in LHCCWESTH

is that since FCA does not make use of the trajectory reallocation, it opens a new position when foresees an increased complexity period (and new trajectories are arriving). This reasoning is also consistent with the fact that there is a big number of underloads (see Figure 8(b)) for FCA in Scenario 2 DAC/FCA static, since it takes some time to close the active CWPs that were decided to be closed but still have few aircraft and, thus, are really underloaded. In other words, instead of reallocating those few flights to the new CWPs that will open and quickly close the other ones, there is a lapse of time where too many CWPs are opened and many underloads are accounted.

In the case of integrated and dynamic DAC/FCA, results are even better in terms of overloads (there are less overall although more in FCA region, obviously because it is taking more airspace along the day) and underloads (there are less overall) meaning that the capacity is more balanced.

D. Cost-effectiveness analysis

The cost-effectiveness indicators compared are Control Working Position Hours, as a measure of what are the resources needed to handle the demand with the particular airspace configuration. If more CWPs hours are needed, this implies the ANSP would need more Air Traffic Controllers (ATCOs) on duty, thus increasing costs associated to ATCO salaries. A reduction of CWPs would mean that scenario is more efficiently prepared and ANSP can control the same flight hours (which account for their revenues) with less cost. So that their margin for this activity increases.

Figure 8(c) depicts the comparison of the results obtained during the simulation of the three scenarios. Results show an increment of controlling hours when the static DAC/FCA is applied. It can be explained due to the static FL of the DAC/FCA boundary. If complexity is concentrated in the FCA area, additional controllers would be needed to manage the complexity which may have been better dealt with in a DAC scenario whereby 2 controllers could have opened a sector to manage this complex area which would be more efficient than FCA. In addition, because of the FCA trajectory allocation algorithm does not include a reallocation mechanism

of trajectories, some CWPs may be very underloaded during some periods of the day. Looking at the dynamic DAC/FCA scenario a considerable reduction of the controlling hours is obtained, even with lack of reallocation in the FCA algorithm which confirms that the use of DAC mode in some complex areas/periods would be more efficient than FCA mode.

These results shows that the dynamic DAC/FCA scenario is very promising from the cost-effectiveness point of view. However, to achieve the potential benefit especially in longer term, it is very important to introduce more sophisticated Human Resource Planning tools (adapted to this new concept) in order translate the reduction in controlling hours in economic savings.

V. CONCLUSIONS

This paper aims at validating that the integration of the enhanced DAC and FCA management solutions based on complexity performs better in terms of capacity and cost-effectiveness in comparison with the deployment of only one capacity solution separately.

In order to support this integrated capacity management solution, a delineation process for dividing dynamically the airspace in DAC and FCA areas is introduced and applied to define three scenarios: one where only DAC is deployed; another scenario where the boundary between DAC and FCA is statically located at FL375; and a last scenario where the DAC/FCA boundary is dynamically adapted to the traffic demand measured using complexity.

The simulations considered 24h of traffic crossing the Hungarian airspace and results show that integrated DAC/FCA (dynamic solution) is the most benefitting case because:

a) has the lowest overloads of the 3 scenarios, which is clearly an improvement in the capacity of the airspace; b) has less underloads than the static DAC/FCA scenario meaning that ATC opening scheme probably is more optimised in terms of exploitation of ATC resources, but has more underloads than with only DAC, meaning capacity might be increased and more aircraft can be handled with this ATC mode in comparison with DAC alone; and c) has less controlling hours what entails it is the best profitable solution from the cost-effectiveness point of view.

Although the obtained results are promising, the lack of reallocation mechanism in the FCA algorithm leads to waste ATC resources resulting in big underloads. Thus, this open point is identified as future work to be done. Furthermore, more research is also needed in order to include the uncertainty in this study.

ACKNOWLEDGMENT

(a) Scenario 1: DAC   (b) Scenario 2: static DAC/FCA   (c) Scenario 3: dynamic DAC/FCA
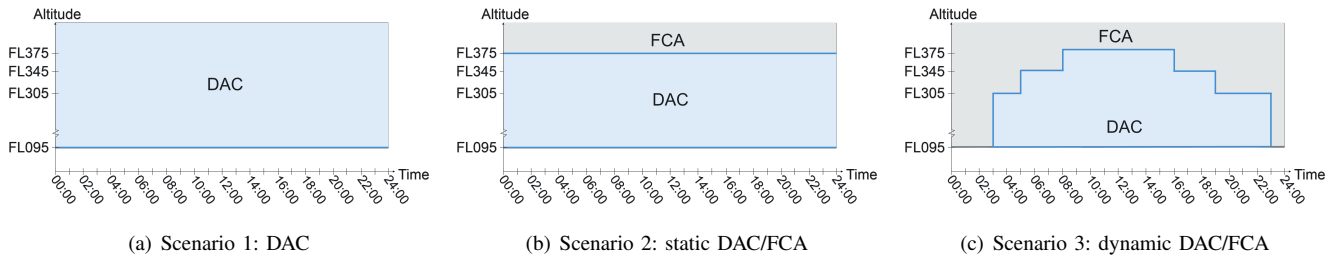
Fig. 7: Airspace delineation for all the scenarios

(a) Overloads   (b) Underloads   (c) Controlling hours
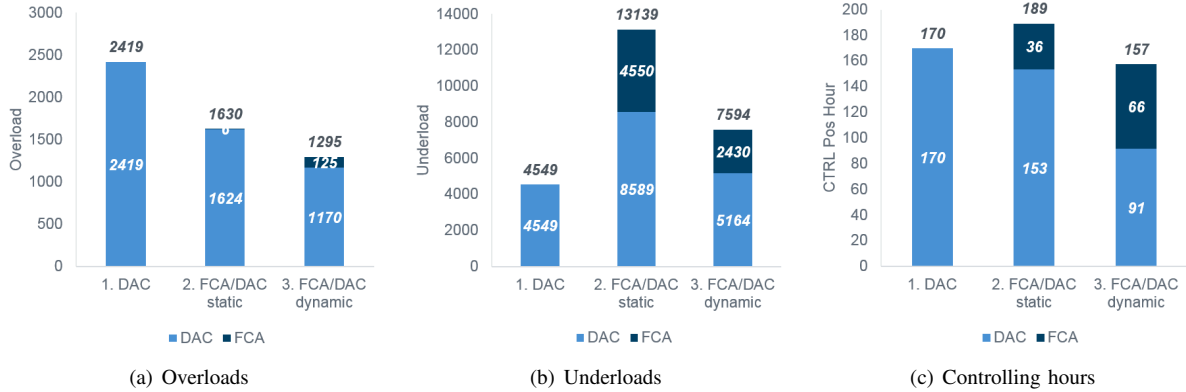
Fig. 8: Capacity and cost-effectiveness indicators for all the scenarios

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