An Innovative Safety-neutral Slot Overloading Technique to Improve Airspace Capacity Utilisation

Innovative enhancements for CASA to optimise the network delay

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***Abstract*—This paper presents a new air traffic flow and capacity management (ATFCM) technique that uses some of the rules and mechanisms that are already existing in the computer-assisted slot allocation (CASA) system, such as slot overloading and compensation of overloaded slots, in a new innovative manner that could potentially allow airspace capacity to be used more effectively, thus reducing the network delay and the impact of ATFCM delays on airspace users (AUs) schedules and costs.**

This new ATFCM technique has been named Resourceful Overloading of Slots (ROS). The early validation of ROS has been achieved through fast-time simulations using the R-NEST tool –an ATFCM simulation developed by the EUROCONTROL Experimental Centre–, and using a realistic scenario of 28 days (i.e. an AIRAC) from Summer 2018 in which more delay was recorded. The preliminary simulation results indicate that the ATFCM delay in that period could have been 23% lower, and the impact of delay 27% lower, compared to the same scenario simulated with the baseline CASA (i.e. default slot sequences calculated by a non-operational CASA module in R-NEST).

The new ROS technique has also been analysed in combination with an existing innovative ATFCM technique, referred to in this paper as the Mitigation of Interacting Regulations (MIR), which was proposed in a recent paper as a means of enhancing CASA. The results of the simulations in which the two techniques were applied jointly are promising: ATFCM delay could be reduced, at least in the simulation setting, by 41% on average and the impact of delay by 55% on average. (Abstract)

Keywords: slot overloading; air traffic flow and capacity management; computer asisted slot allocation; CASA; SESAR

Foreword *– This work has been conducted as a part of the SESAR 2020 Industrial Research project PJ09 "Demand Capacity Balancing". PJ09's main objective is to develop and validate concepts and systems which complement the Network Management Function with network intelligence based on shared situational awareness, a common set of values and rules, and highly interconnected local network management functions.*

I. Introduction

In the European air traffic management (ATM) system the Network Manager (NM) is responsible for air traffic flow and capacity management (ATFCM) functions at network level. Among other tasks, the NM has a responsibility to facilitate the different local demand and capacity balancing (DCB) processes and coordinate all the relevant actors to ensure that air traffic demand never exceeds capacity at any particular sector or airport in the network, while at the same time ensuring maximum operational efficiency and quality of service for airspace users (AUs) [1][2][3].

The application of ATFCM "regulations" by air navigation service providers (ANSPs) and the consequent use of the computer-assisted slot allocation (CASA) system by the NM to calculate departure delays for the regulated flights is a pragmatic DCB solution to resolve network imbalances, which worked efficiently in the past when the ATM system was much less congested than nowadays. However, due to the current traffic levels, many ANSPs have now reached their capacity limits at their controlled sectors and airports. As a result, the DCB processes are becoming more frequent, more difficult to manage, and more costly for airspace users and society [4].

For that reason, there is an urgent need to either increase capacities in the system or reduce latent ones in order to improve the cost-efficiency of current operations and also to guarantee access to the high levels of traffic forecasted for the next decades [7]. In recent years, much research effort has been devoted to making improvements in our understanding and management of the factors and drivers of the ATM system capacity, e.g. new advanced ATM concepts such as traffic complexity, dynamic configuration of sectors, higher levels of automation in some processes, etc. [11].

In this paper we propose a new technique called Resourceful Overloading of Slots (ROS), aimed at utilising the available airspace capacities in a more effective manner, thus reducing the latent capacities in the system. ROS is an innovative and pragmatic new concept because it re-uses some of the rules and mechanisms that already exist in the current CASA system, and proposes certain amendments (i.e. targeted *slot overloads*, as explained later) for some of the slots calculated by CASA, to improve the efficiency of the ATFCM regulations. Early simulation results will be discussed in this paper, showing that the proposed innovative enhancement for CASA could significantly reduce the impact of ATFCM delays on airspace users.

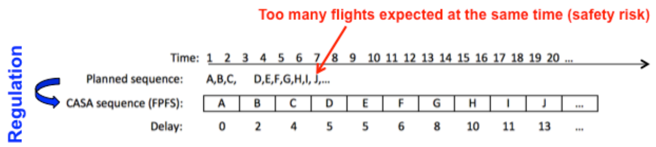

Figure 1: Schema of a CASA sequence during a regulation period

The rest of the paper is organised as follows: section II describes the state of the art and develops the fundamental notion of airspace capacity, which is key to understanding this research. Section III explains the new technique proposed to enhance CASA. Section IV discusses the simulation results. Section V presents the conclusions and future work foreseen.

II. State of the Art

The following subsections deal with: a) the most important factors affecting airspace capacity; b) the ATCFM techniques used today to protect airspace capacities; c) the shortcomings and limitations of such methods; d) the recent CASA developments to overcome some of the current system limitations; and e) the contributions and relevance of this research paper to the state of the art.

A. Airspace capacity

Airspace capacity is a term used to indicate the maximum number of flights that the Air Traffic Management (ATM) system can safely and efficiently control over a period of time [1][3]. Many different factors can potentially limit airspace capacity (e.g. weather, separation standards, CNS infrastructure, etc.), but it is widely accepted that the major bottleneck today at airspace sectors (especially at en-route sectors) is the ability of the air traffic control officers (ATCOs) to safely handle the traffic at each air traffic control (ATC) sector [12]. In other words, airspace capacity is nowadays constrained by the maximum number of flights that the ATCOs can manage safely with an *acceptable/sustainable level of workload*.

The NM and the ANSPs need to accurately assess and protect airspace capacities across the network, thus proper objective metrics and tools are needed. Nevertheless, a standard method to quantify and estimate actual sector capacities (i.e. the *ATCOs' cognitive workload*) has still not been developed, in part because it is not easy to objectivise and quantify the cognitive processes of the ATCOs. Airspace capacity depends on a mix of objective and subjective factors, such as traffic complexity, ATCO skills and experience, their cognitive and physical conditions at the time of operations, and the decision support tools available, among other factors [15][14][12][13].

B. Current ATFCM operations to protect ATC capacities

In today's operations, when a potential demand-capacity imbalance is foreseen a few hours in advance with a certain level of confidence, the NM starts a DCB process to ensure that the demands and capacities in the network are well balanced at all times in order to minimise the impact on airspace users. In the event of an imbalance, the first NM measure, working closely with the ANSPs, is to adapt/increase capacities in the congested sectors. If it is not possible to allocate more capacity to a particular congested airspace region, then the NM starts addressing traffic demand. In order to minimise costs for AUs and the impact on subsequent ATM operations, the DCB solutions that address demand involve re-planning operations in close cooperation with airspace users. However, finding alternate flight plans that can resolve the DCB problems is often not possible due to network congestion. When this happens, the Network Manager can activate, on request by the local ANPSs, a process to regulate the sector (or airport) of interest. As soon as the sector is regulated, the CASA system issues 'ATFCM slots', which are new calculated departure slots for the traffic demand that is expected to enter the sector during the period of imbalance. This ATFCM process is aimed at applying a tactical time-based separation between flights until demand matches capacity, as declared by the ANSPs.

Figure 1 illustrates a high-level model of a CASA sequence of slots, showing how the delay is generated for flights by the regulation. In the example a certain number of flights (identified in the figure with letters, A,B,C...), were scheduled to enter a certain sector. The local flow management position (FMP) of that sector assessed the foreseen traffic situation in the sector, and decided to trigger a regulation to protect the ATCOs from receiving too many flights simultaneously. The NM, attending to the FMP request, triggered CASA to smooth the traffic and balance the situation. The flights were therefore sequenced in first-plan first-served order (FPFS) and their delay calculated with respect to the time in which these flights were originally scheduled. The resulting calculated delay was applied to the departure time of the affected flights (NB airborne and other excluded flights are exempted from this process).

The ATFCM slots are issued to smooth the rate of flights that will enter or arrive at a sector or airport during the execution phase, thus reducing the density and complexity of the traffic, protecting ATCOs from an excessive workload. Due to the high levels of congestion that exist today in the European ATM system, thousands of ATFM slots are calculated and allocated to flights each day, thus generating high levels of delay and extra costs for airspace users (around 30% of the flights operated daily in Europe were regulated in Summer 2018) [5] [6].

C. Limitations of the DCB mechanism and research needs

To facilitate the strategic and pre-tactical DCB measures of NM, as well as proper coordination between all the actors during the day of operations, the ANSPs must declare, well in advance, their sector configuration plans and the estimated capacities to the NM. As discussed, a major difficulty of that process is to estimate the actual capacities of the ATCOs on duty at each specific sector. The ANSPs must therefore be conservative when declaring their capacities and some safety buffers are added on top of the capacity estimations, meaning that the capacities declared are lower than actual capacities [12][16][17]. These buffers represent a latent capacity in the

ATM system, which should be minimised to reduce the levels of congestion and the delays in the network.

Increasing the predictability of the traffic monitored by the FMPs could help to reduce the capacity buffers, because the FMPs could make a more accurate and reliable assessment of the congestion levels expected in their sectors, and thus identify any potential demand-capacity imbalance in a more effective way [11][12][17]. One way of achieving this is to improve the metrics and techniques used by the FMPs in order to quantify more accurately how much airspace capacity (i.e. ATCOs' cognitive burden) will actually be used, which will ultimately allow latent ATC capacities to be reduced.

In recent years, some improvements have been made with regards to the metrics and methods the FMPs use to predict imbalances and manage use of capacity. *Entry counts* (EC) is an objective metric traditionally used by the ANPSs to measure the number of flights entering a sector within a certain period (e.g., 1 hour). EC is a relatively simple metric that has worked very well in the DCB context until recent years, when traffic congestion in the system rose sharply. Today, some ANSPs need to complement the EC information with another metric called *occupancy counts* (OC), which takes into consideration the period in which each flight entering a sector will be monitored and controlled by the ATCOs. The OC is a better estimator of ATC workload than the EC. When the OC is monitored, two monitoring thresholds are normally used, i.e. *peak capacity* and *sustainable capacity*. The former expresses the maximum number of flights that an ATCO can manage in a certain short period (peak), while the second expresses the level of traffic that an ATCO can manage under acceptable levels of workload over a prolonged period of time [11]. Therefore, effective monitoring and management of the OCs by the FMPs is key to improving the way they set up their regulation requests (starting time, duration, rates, etc.) so that the ATCOs do not operate below their sustainable workload levels (spare capacity), especially during a regulation period. Other advanced capacity metrics aimed at greater accuracy are currently being researched, such as the metrics of *traffic complexity* [11][14][15].

Some capacity inefficiencies in today's system can be attributed directly to the CASA slot allocation process itself. During regulated periods, the FMPs normally set the allowed entry rate of the regulated traffic to the maximum capacity, and sometimes even to a slightly higher rate. However, the ATCOs in the regulated sector often experience less workload than in the absence of such regulation. In other words, the ATCOs could often deal with more traffic when the traffic is regulated, and thus smoothed (i.e. time-separated) than when the traffic is not regulated. This is due to the (over-)*smoothing effect* of the CASA sequences, which reduces the complexity of the traffic patterns received by the ATCOs and typically brings the occupancy counts below the ideal sustainable levels. This is somewhat paradoxical, because it means that ATCO capacities are often underused during periods of congestion, just when a more efficient use of capacity is desired [16][17]. Furthermore, past studies have demonstrated that some of the slots available during a regulation are unused (i.e. *wasted capacity*), due to diverse reasons that affect the CASA processes, e.g. the lack of demand scheduled at certain sub-periods of a regulation, flights missing their slots, interactions with other regulations, etc. [18]. Therefore, new improvements for CASA need to be developed to minimise such wasted capacities. In this sense, the ROS technique proposed in this paper is aimed at improving the current CASA slot allocation process in order to have better control of the capacities available (with less over-smoothing effect) and potentially to reduce the presence of undesired unused slots ('idle time' for ATC) during periods of regulation.

D. Another recent innovative CASA enhancement: the Mitigation of Interacting Regulations (MIR) mechanism

Another source of inefficiencies in the system comes from a known problem referred to in the literature to as the *interacting regulations problem* [9][10]. When the network is highly congested, the traffic delayed by certain local regulations can often be involuntarily pushed in time to other congested and already-regulated sectors, thus starting a 'resonant domino effect' that can substantially increase the overall levels of congestion and delays in the network. To mitigate the interacting regulations problem and optimise the overall delay in the network, a new concept was recently developed at the EUROCONTROL Experimental Centre (EEC), i.e. the Mitigation of Interacting Regulations (MIR). MIR has been implemented in a prototype called Enhanced CASA (ECASA), and is today under operational validation in the NM [9][10] (NB the term MIR is introduced for the first time in this paper to differentiate between the two different ECASA optimisation mechanisms, i.e. MIR and ROS).

In short, the MIR optimisation technique consists in preventing the flights that are delayed by their most penalising regulation (MPR) from entering the beginning of large *tension zones* of other regulations. *Tension zones* are sub-periods within a CASA sequence (thus within a regulation period) where there is actual congestion and thus where the delay is generated (NB within a regulation period there can be sub-periods with no delay because the demand can sometimes be equal to or below capacity, e.g. at positions where empty slots are found, or at the beginning of tension zones). Therefore, to optimise the network delay, the MIR component applies targeted amendments to some identified flights in the default CASA sequences to remove them from the tension zones of other non-MPR regulations crossed by these flights, where they are producing extra unnecessary delay.

Figure 2 shows a realistic typical situation which was often observed in the archived data. In the example, flight F is delayed 5 positions (typically 10 or 15 minutes) by R1, which is its MPR. Note that the ETO of F before it was delayed corresponded to the current position of flight B in regulation R1. Owing to the delay allocated by R1 the flight is forced in R2 to the beginning of the tension zone TZ2b, and it also enters at the beginning of TZ3a, in R3. As a result, each flight placed after F in TZ2b and in TZ3a will be 'pushed' one position, thus increasing the delay of all those flights, typically by around 2 or 3 minutes. Note that tension zones may often include tens or hundreds of flights, thus the total delay could easily increase several hours in total due to the interaction of just one flight.

The proposed MIR optimisation strategy consists in detecting such situations and applying less delay to flight F in R1 (its MPR) to prevent the extra delay in other regulations.

The sequences optimised with the MIR strategy are shown in the bottom part of the figure. In these sequences, flight F has been delayed by R1 three positions instead of five. With this targeted amendment, F no longer enters the tension zone TZ2b in R2, nor does it enter TZ3a in R3. In addition, F is allocated to one of the empty slots available in R2, thus better use of the available capacity (less wasted capacity) has been achieved.

In terms of delay changes, in R1 a few flights (D and E) are slightly more delayed than before applying the optimisation mechanism, but the total delay in R1 would remain the same because F now has less delay (the delay is exchanged between these three flights). In R2 and R3, the delay reductions could be, and often are, quite large, i.e. of the order of hours in each regulation. Therefore, important delay reductions can be achieved if the proposed allocation strategy is applied to the flights that are found multiple times daily in similar situations to flight F, i.e. flights pushed by their MPRs at the beginning of the tension zones of other regulations.

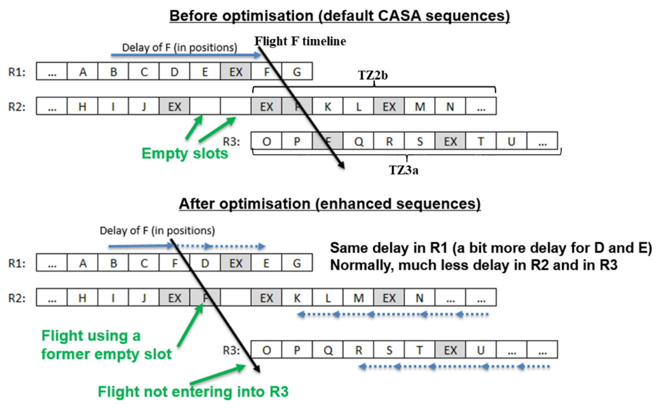

Figure 2: Mitigation of Interacting Regulations (MIR) technique

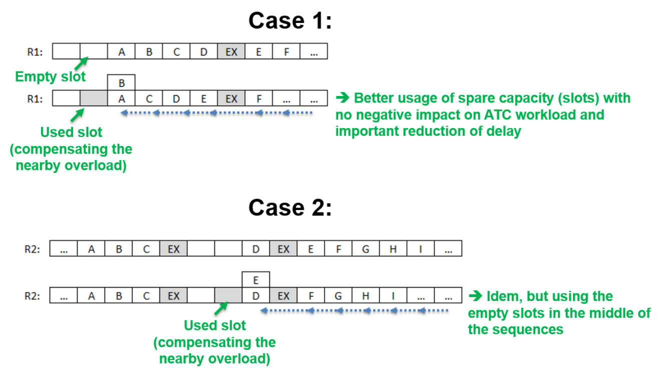

Figure 3: Resourceful Overloading of Slots (ROS) technique

The early simulation results validating the MIR solution confirmed significant potential benefits for the network: around 27% less network delay on average and 42% less impact on AUs.

E. Contributions of this paper

This research paper contains two major contributions:

1. A new innovative technique called Resourceful Overloading of Slots (ROS) is proposed to enhance the slot allocation process of CASA by avoiding wasted capacity (empty slots) at regulated sectors, thus making better use of the available ATC capacities (reducing the over-smoothing effect) during periods of congestion.
2. We provide quantitative evidence based on fast-time simulations by way of a preliminary validation of the ROS technique. The results of two ECASA prototype configurations will be discussed, one in which only ROS was activated and assessed during the simulations, and a second one in which both ROS and MIR were activated in combination to optimise the default CASA sequences.

III. An Innovative Slot Allocation Technique to Reduce Network Delay: The ROS Mechanism

To minimise the network delay, a new optimisation mechanism referred to in the paper to as Resourceful Overloading of Slots (ROS) is proposed. One of the main goals of the suggested method is to make it rapidly deployable in the CASA system of the European Network Manager.

In a nutshell, the ROS mechanism takes the default slot sequences calculated by CASA as an input, and identifies opportunities (i.e. empty slots in the sequences that match certain criteria) in which a particular slot could be allocated to two flights instead of one (*slot overloading*); thus increasing the use of capacity at the regulated sector. The major constraint imposed is not to exceed the capacities declared at sectors (i.e. the entry rates accepted).

The concept of slot overloading is not new. In the current CASA system only one flight per slot is allowed in general. However, in certain special circumstances justified by operational reasons, up to two flights can be allocated a single slot, e.g. when two flights are forced by their MPRs in a same slot of a third regulation. When this happens, the slot is said to be *overloaded*. According to current ATFCM practices [1], overloaded slots are accepted, but must be 'compensated' from the point of view of ATCO workload. For that purpose, an empty slot needs to be forced in the sequence in a position as close as possible (i.e. 'nearby') to the overloaded slot. The *compensation slot* (i.e. the forced empty slot) cannot be used by any flight, since it is designed to compensate the extra workload required by the ATCO to control the two flights that were allocated an overloaded slot. This practice is considered to be safety-neutral under normal circumstances, and thus it is well accepted today by ATCOs, FMPs and the NM because: a) during periods of regulation traffic complexity is smoothed by the CASA slots, thus normally requiring significantly less ATC workload; b) the probability of traffic bunching does not change significantly when a slot is overloaded (due to traffic uncertainties); and c) any potential risk of workload increase is considered to be compensated by the introduction of the compensation slot.

The new ROS technique consists in re-using the slot overloading principles and mechanisms discussed above, but inverting the operational logic to use them in favour of reducing latent capacities: if a non-forced empty slot is identified in the sequence, then a nearby non-overloaded slot could be overloaded with an extra flight. The term *nearby* is used here to mean that the overloaded and compensation slots do not necessarily need to be adjacent, but close in time up to a specified threshold, which in our paper was set to 20 minutes.

The integration of the new ROS feature with the default CASA process requires the addition of just two additional steps on top of the normal CASA process executed at each True Revision Process (i.e. every minute):

1. Run CASA as usual ('normal' CASA is the core).
2. Identify empty slots and nearby slots that could be overloaded by close-by flights. Only flights whose MPR is the focus regulation are amendable; the closest of these that is not further from the empty slot than a specified threshold (e.g. 20 min.) will be picked for slot overloading (if there is no flight matching these two conditions, then no slot overloading is produced in this iteration for the particular empty slot identified).
3. Change the position of the selected flight and overload the targeted slot. The targeted slot is normally the earliest possible non-overloaded slot to which the cherry-picked flight can be allocated. Note that the amended flight will release its position and thus the flights placed after will take a better position in the next true revision process (step 1), when the sequence will be compressed, and the delay optimised.

Figure 3 shows two examples of non-forced empty slots that were often observed in many CASA regulation sequences, i.e. at the beginning of the sequences and/or in the middle of the sequences, which often appear even during periods of congestion due to the lack of traffic demand scheduled to such specific slot times. In the first case of the example, flight B is selected to overload the slot allocated to A. In the second case, flight E is the first amendable flight after the empty slot (the adjacent one is an exempted flight), thus it is picked to overload the slot where flight D is also allocated.

The ROS technique has the advantage that the flights selected are allocated to earlier slots that are compatible with their schedules (i.e. not ‘too early’ slots, taking into consideration that flights often have a tolerance of around 5-10 minutes to depart earlier than scheduled), while from the point of view of capacity the solution is equivalent to allocating the previously unused slots to those flights selected. Consequently, less wasted capacity and less delay impact for AUs are expected. From the ATCOs workload perspective, the new ROS slot sequences should be acceptable, since any slot overload generated by the ROS technique could have appeared in the sequence as a result of other operational reasons, or by chance, in today´s system. Thus, provided that the overloaded slots are duly compensated, the ROS sequences can be argued to be safety-neutral with respect to CASA sequences. Equity is also unaffected because the sequences preserve the original FPFS order and no airspace user is unfairly penalised (indeed, all the airspace users should normally benefit from less delay impact).

IV. SIMULATION RESULTS

A. Experimental set-up

The hypothesis of this research is that the ROS mechanism proposed could contribute to reducing the total network delay generated by ATFCM regulations. To verify such a hypothesis, a simulation model has been developed and integrated into R-

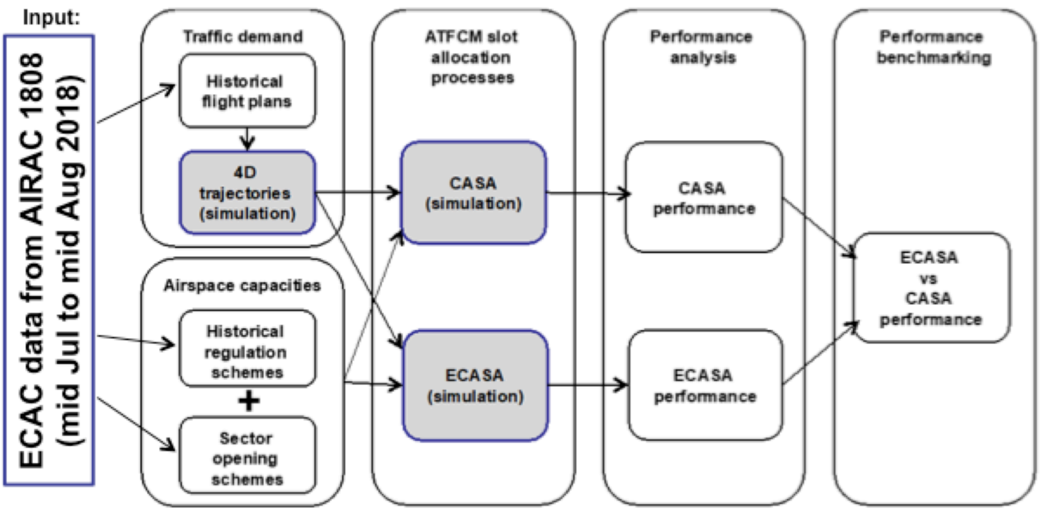

Figure 4 Research methodology with fast-time simulations

NEST, a tool developed at the EEC that incorporates an ATFCM simulation model with a slot allocation process based on the real CASA used in operations [19][20].

Figure 4 illustrates the methodology followed in this research to simulate and benchmark the new ECASA features (i.e. ROS and MIR) against the reference scenario in which only the normal simulated CASA system is active (i.e. not enhanced). The simulation scenarios used correspond to real scenarios from the most congested 28-day period in Summer 2018 (i.e. AIRAC cycle 1808). The flights plans and regulation schemes were extracted from the repository Digital Data Repository (DDR2). The simulation results of ECASA and CASA were benchmarked in terms of network delay and impact on AUs.

Two different simulation analyses were performed. In the first one, only the ROS mechanism was activated on ECASA and benchmarked against CASA. In the second one, both ROS and MIR mechanisms were coupled and activated to work jointly in combination. The goal was to check if these two optimisation mechanisms could be complementary and, if so, to quantify how much the combination could reduce the network delay and the impact of delay on AUs with respect to the CASA baseline. To ensure a fair comparison, both the ECASA and the CASA sequences were simulated under the same conditions.

B. *Network delay optimisation potenial*

The average delay per day in the busiest period of summer 2018 was around 200,000 minutes of delay per day, with a minimum of 100,000 and a maximum of 340,000 minutes of delay in a single day. An average of 10 non-requested/unused slots per regulation was found in the simulated scenarios, while the median was 5 (NB the median is possibly more representative to describe such an asymmetric and largely heterogeneous distribution). These figures correspond to the simulation outputs from R-NEST, whose ATFCM delay generated is around 10-15% higher than the actual delay officially reported. This bias is due to certain limitations and simplifications of the current simulation environment (e.g. some operational events were not simulated in our experiments, such as flight cancellations, re-routings, level capping, etc.).

Figure 5 shows the distribution of delay reductions (i.e. optimisation) achieved in the period of analysis with the simulation environment after applying the ECASA mechanisms. According to the figure, the ROS technique achieved a 23.4% average daily reduction in delay compared with the baseline CASA. The MIR mechanism achieved an average reduction of 26.6%. Therefore, both mechanisms could achieve substantial delay reductions of a similar order of magnitude.

The figure also shows the distribution of the delay reductions achieved by the ECASA system when the two mechanisms were activated in combination, i.e. ROS and MIR acting one after the other at each true revision process (NB MIR acted first, and then ROS, because we gave priority to mitigation of the unnecessary delay produced by the interacting regulations problem). The results show that the delay of the AIRAC 1808 could potentially have been 41% lower on average, while on certain days the delay could have been reduced by almost half (47.3%). Note that the major reduction in delay brought by the combination of mechanisms indicates that both mechanisms are quite independent from each other and therefore largely compatible and complementary.

C. *Delay impact optimisation potential*

It is well known that the cost of delay is not linear and that it may impact each flight differently [5][6]. In this paper it is assumed that flights are scheduled with some tolerance to delay, and only the flights with more than 15 minutes of ATFCM delay are considered to be at risk of suffering large operational disruptions and/or cause significant costs for the airspace users that operate them. Thus, flights with 15 minutes of ATFCM delay or less will be considered to be unaffected, at least not significantly affected, by the slot allocation processes.

To assess the potential benefits, in terms of impact of delay, three key performance indicators have been calculated for each simulation: a) the average number of flights delayed each day; b) the average number of flights delayed by 15 minutes or less each day (i.e. flights delayed but not impacted significantly); and c) the average number of flights delayed by more than 15 minutes each day (i.e. flights that could incur significant costs).

Figure 6 shows the assessment in absolute terms and *Figure 7* shows the assessment relative to the simulated CASA results (i.e. the *baseline*). The daily average number of flights delayed by the simulated CASA in the AIRAC 1808 was about 10,600 flights (of an average of 34,600 flights operated each day). Both ROS and MIR techniques reduced the number of flights delayed by the same order, i.e. by approx. 13% (approx. 1,500 fewer flights delayed). However, MIR performed significantly better than ROS in terms of distribution and impact of delay, i.e. the frequency of 'innocuous' delays (15 minutes or less) augmented for MIR by 12% with respect to CASA and ROS, and the number of flights with high risk of impact (i.e. flights with more than 15 minutes of delay) decreased by 42% in the case of MIR and by 27% in the case of ROS, both compared to the CASA baseline.

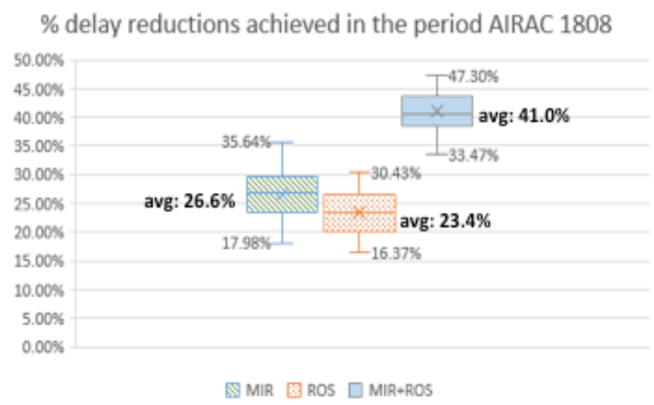

Figure 5: Distributions of network delay reductions achieved

It was also observed that the combination of both mechanisms, MIR+ROS, drastically improved the delay figures. Around 25% fewer flights were delayed (2,600 fewer flights than the CASA baseline), and a reduction of 55% on average was achieved in the number of flights delayed by more than 15 minutes. Nevertheless, it must be highlighted that such hugely positive figures should be viewed with caution at this stage, since they must be validated further before extrapolating the simulation results to the real –much more complex– operational environment.

V. Conclusions and Future Work

This paper has presented a new innovative ATFCM technique that could potentially contribute to significantly improving the performance of the CASA slot allocation process, i.e. the Resourceful Overloading of Slots (ROS) technique. According to the simulation results, the ROS technique could significantly reduce the delay in the network and the impact of delay on the airspace users.

The ROS technique could potentially improve actual use of the available capacity, thus reducing the number of unused ATFCM slots and the over-smoothing effect of the slot allocation process. The ATM cost-efficiency/effectiveness is expected to improve too, as a result of the expected increase in ATCOs productivity (fewer 'idle times' in regulated periods) and the lower delay costs of the ATFCM functions (fewer flights delayed and reduced impact of delay). Equity is maintained since the FFPS order is preserved and no negative impact is generated for any airspace user. The impact of the ROS technique on safety has been discussed and the preliminary conclusion is that the slot sequences amended should in principle remain safety-neutral. In particular, it is not expected that the ROS technique can generate slot sequences that could be unacceptable for ATC. Nonetheless, further validation is required to confirm or dismiss this preliminary conclusion.

The proposed method has been integrated with another recently proposed innovative mechanism for CASA, i.e. the Mitigation of Interacting Regulations (MIR) technique, and major delay reductions have been achieved when both mechanisms were working jointly in combination.

The largely positive results of this research are preliminary and based on simplified fast-time simulation models that are not free of limitations. Therefore, the exact figures from these preliminary results, both absolute and relative, should be treated with caution at this stage.

Next steps of this research will include validation of the new ECASA techniques in the operational NM systems, including shadow-mode simulations and other exercises closer to real operations. The impact on network stability will also be further assessed. The aim is to introduce these innovative techniques in real operations, and thus potentially contribute to improving the performance of the ATM system.

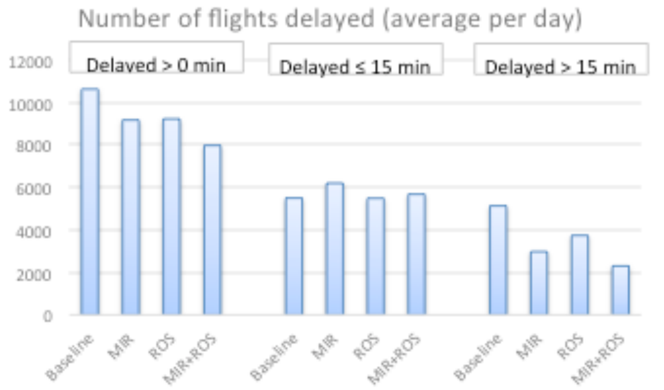

Figure 6: Average number of flights delayed per mechanism

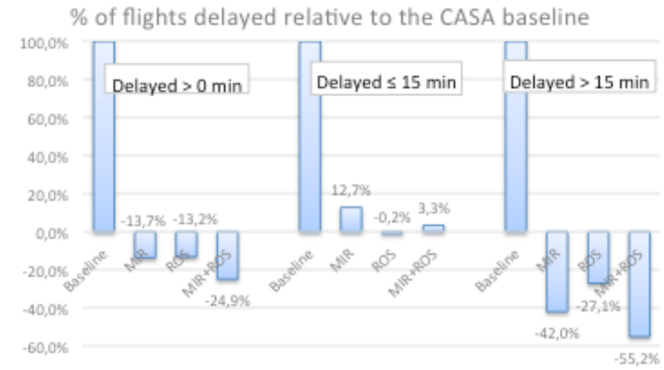

Figure 7: Reduction of delayed flights per mechanism relative to the CASA default sequences

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