OPERATIONAL FEASIBILITY OF TRAFFIC SYNCHRONISATION IN CENTRAL EUROPE - RESULTS

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Abstract

A doubling of traffic is predicted by 2020 by which time the core European Area is expected to be unable to cater the demand. This stipulated an investigation of numerous concepts aimed at improving efficiency and gaining capacity by reducing controller workload. As controllers' productivity is affected by heterogeneous speed on flight levels, some efforts to alleviate the problem have focused on optimising the traffic flow using already known practices.

The hypothesis suggests a shift from current ATM concept, which is non-synchronised, to a synchronised system with constant distance separation between all aircraft evolving in a flow.

The goal of the research is through experimental approach to achieve objective results of traffic synchronisation through flow capacity increase (i) and potential conflict situation decrease (ii) and hence improvements of safety to support the operational feasibility applied in case of Central European Upper Airspace[1].

1 Introduction

Sometimes definitions are not so crystal clear as they should be, and in the case of synchronisation there are few interpretations. Synchronisation in the context of this research means *the tactical establishment and maintenance of a safe flow of traffic with higher throughput.* Synchronisation is a question of better utilization of current route network using present-day practices to achieve throughput benefits while keeping the controllers' workload at least at today's level. A synchronised traffic flow consists of aircraft on certain flight level, using a unified flight speed and thus maintaining constant distance separation. Reorganised traffic on flight levels allows controller to reduce the number of potential conflict in-trail while still maintaining the highest level of safety.

There is a consensus that current ATM system cannot cope with the challenges of future demand (EUROCONTROL OCD 2004 [1], University Concept Team 2003 [2], Gate to Gate project 2004 [3]), and a new paradigm seems to be inevitable. The constant pressure to increase the airspace capacity has stimulated the researches in Europe and US to come with new ideas having in mind the necessity of change in current ATM system.

Several studies and concepts appeared recently in Europe and USA aiming to support the future vision of synchronised ATM system [4] [5] [6] [7]

Numerous organisational changes in the way to handle the air traffic have been proposed – *Dual Airspace* [8], *Multi Sector Planner* [9], *Free Flight* [10], *Free-route* [11] and more recently *Sector-less* [12] or *SuperSector* [13], *Super HighWay* [14], *Tube Concept* [15]. Some other studies on traffic organisation have investigated the potential of flow synchronisation; however they focus mainly on speed control and/or solely on the terminal areas [16] [17].

[1] This work is funded by CEATS Research, Development and Simulation Centre (CRDS), Budapest, Hungary.

All afforecited investigations are based upon the hypotheses that when traffic is synchronised, better efficiency for the overall air traffic management system could be reached thanks to the focus on the management and monitoring of traffic flow instead of individual flights. Since the flights are already organised into the flows in the en-route environment, it directly affects the efficiency and as well improves the throughput of an airport.

Among previous studies, the FAM project at Eurocontrol Experimental Centre has explicitly considered the same assumption [18]. However, none of the above investigations have seriously considered *controllers' acceptability*, and in particular for the task of monitoring aircraft's speed adjustment and assigning flight level to achieve synchronised flows.

The work presented in this paper is framed within a PhD research that investigates the operational feasibility of traffic synchronisation applied in a case of Central European Upper Airspace.

The research and the paper focus on answering the question *"how to arrange the traffic in the most efficient fashion?"* in order to increase the airspace efficiency in terms of airspace throughput while avoiding critical situations. The aim is to demonstrate a simple model and rule-base algorithm to analyse the efficiency (airspace throughput) of synchronising independent flows of traffic in the en-route environment. The next section will briefly describe the model and rule-based algorithm and will emphasize the need for quantitative parameters to evaluate the benefits of synchronisation. The third section will present first results of fast-time simulation and the paper will end with conclusions and future zooming.

2 Modelling

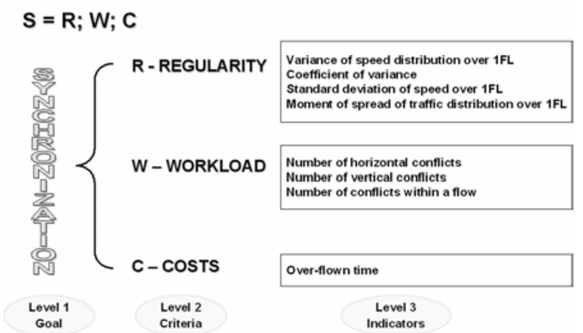
According to the comparison of US and European en-route environment the controllers' productivity in these two continents is unlike. An essential difference is in techniques used to organise the traffic leading to US controllers' ability to handle more traffic (flight-hours for each hour on duty) when working at their maximum throughput [19]. In US, En-route Miles-In-Trail Spacing (MIT) is the most common Air Traffic Flow Management (ATFM) measure defined by the distance between two consecutive aircraft on a given flow. They are used to distribute arrival delays upstream of destination airports and to mitigate local areas of en-route space congestion. They have a significant operational advantage; when flights are formed into in-trail streams, *controllers are able to visualise and control spacing at the sector without automatic assistance*. Nothing comparable to MIT restrictions is applied in European en-route environment, the aircraft start to be organised once they reach the Terminal Area (TMA).

In conclusion, the ATFM system in US tends to work towards better utilization of airspace capacity. This in turn has an impact on controllers' workload. Because peak-time flows are more predictable in the short term, and more regular, controllers in the US are able to handle a larger number of flights simultaneously, contributing to a greater productive efficiency [20].

MIT measures are taken as an example of traffic flow and safety enhancement. Improvement of safety in European environment through removing potential conflict situations and increasing the airspace throughput as a result of traffic synchronisation is not only desired but needed.

2.1 Simplified synchronisation model

To discover the benefits of synchronisation in an en-route environment, a model considering different ATM system actors (airlines, providers, efficiency of airspace use itself) is required beginning with better utilization of existing route network with respect to all above mentioned actors of the ATM system. The simple form consists of three levels: the top is the goal of the research, the second level is represented by the criteria by which the indicators are evaluated, and the third level consists of the measurable indicators themselves 'Fig. 1'.



'Fig. 1. Synchronisation model'

At present, the traffic is distributed on the flight levels mainly with respect to airliners preferences (fuel consumption, optimum speed). This tends to increase controllers' workload, because one flight level accommodates aircraft with heterogeneous speeds and each of these flights requires inevitable communication between pilot and controller; manoeuvres to be done.

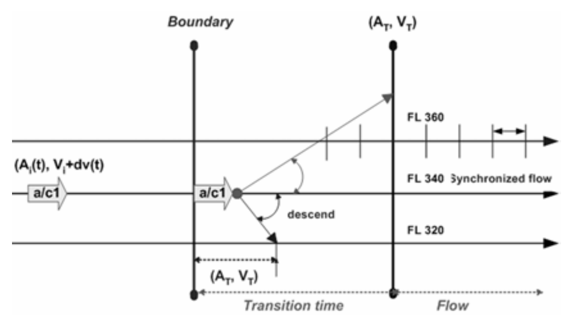
With traffic synchronisation the irregularity of speed distribution on target flight level is removed with direct impact on speed diversity on neighbouring flight levels (as described later in the paper). The traffic on the target flight level is released from the aircraft not following the same target speed. This leads to more balanced traffic between flight levels, since the aircraft change the flight level from more occupied to those less occupied.

Measurable indicators characterising the traffic distribution after synchronisation process are defined with respect to the limiting factors: aircraft performance envelope, number of conflict situations, controller's workload and costs of the over-flown time.

Four values are used for regularity assessment [21]: *variance of speed distribution over 1FL*, *standard deviation of speed over 1FL* (in this case it is used as an indicator how balanced the traffic load is, *coefficient of variance* (with this parameter the consequences of synchronisation on the surrounded traffic are examined) and *bunching index* used as a factor describing the grade of regularity in time on FL. A bunching index of 0 would describe an absolute regular flow. It is calculated by the sum of the square differences of the actual, to the theoretical capacity (of one aircraft) in each interval.

2.1.1 Transition time

To achieve synchronised traffic flow, a given traffic shall be transformed from a non-synchronised state to an ordered traffic. In this design, the flow isolates a part of the traffic on target flight level selected according to predefined rules. The aircraft falling into the target speed range is instructed to keep or adjust its speed to join the synchronised flow; otherwise it has to be instructed to change the flight level. In reality the flight level change is dependent on many factors as controller's workload and slot availability on neighbouring flight level or aircraft performance limitations. 'Figure 2[2]' provides an example of an aircraft flight level change and an image of transition phase.



'Fig. 2. Transition time'

The main goal is not only to increase the route throughput without closer look on the time needed to re-organise the inbound traffic. But the impact of the route length to ensure that synchronisation is beneficial should be considered as well. The transition time (T_t) differs for each flight and depends on traffic density and the availability of the slot on target flight level. The question is:

'How much time is needed to transform non-synchronised traffic into a synchronised one? Does the transit phase encompass one or more sectors?'

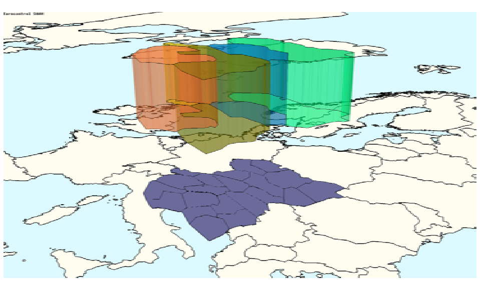
The synchronisation process starts once the aircraft crosses the border of the airspace block. If this is not feasible within the boundaries of

[2] $V_i(t)$ [NM/h] – actual speed, V_T [NM/h] – target speed, $A_i(t)$ [-] – actual FL, A_T [-] – target FL

the first sector, the second sector follows the same procedures to achieve flow-wide improvement and so forth. The coordination and traffic organisation to achieve synchronised flow is the task of the controllers.
In order to simplify the investigation, other issues such as non-nominal weather conditions or military traffic are initially disregarded.

2.2.2 Airspace

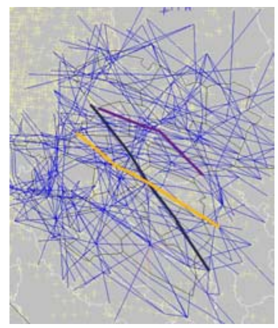
If en-route ATM is required to deliver traffic for the airports in a particular sequence at specific times, then it must have the ability to speed up or slow down aircraft. This will influence aircraft operating levels and, in consequence, flight efficiency. Conversely, organising and sequencing of traffic by speed and flight levels raise questions as to the optimum level of integration which is feasible and the most beneficial.
The Central European Upper Airspace[3] 'Fig. 3' is chosen for this research because of the characteristics of its traffic: high growth and high percentage of over-flown traffic.
The chosen airspace offers high potential for performance improvement with synchronised ATM concept.



'Fig. 3. CEATS Functional Airspace Block'

2.2.3 Selecting route segments

Flow consists of aircraft with a common part of the flight path or part of it spreading on more than one flight level. Adjusting the flow of traffic into given airspace, along a given route or bound for a given aerodrome, so as to ensure the most effective utilization of the airspace is very complex. To simplify this complexity an assumption is made where *each synchronised flow has its own speed & flight level; the flow speed fixes the speed of the flight.*
The discovery of 'interesting flows' depends on both daily traffic distribution and frequency of the aircraft arrivals to CEATS Airspace Block. The investigations show 3 main flows. These three flows carry the heaviest amount of traffic between Western and Eastern Europe; therefore they are selected for further investigation 'Fig. 4'.



'Fig. 4. Selected segments'

Aircraft performance envelopes play a major role in the ability of the aircraft to reach target flight level assigned to the aircraft regarding the speed it flies.

2.2.4 Rule-based algorithm

To perform the synchronisation a rule-based algorithm with four steps was developed according to which aircraft are organised into synchronised flows. The algorithm implements spatial satisfaction by organising the traffic on flight levels depending on preferred flight speed. First, all aircraft on particular route involved in synchronisation process are organised on speed levels (each flight level has its own speed; flow fixes the speed of the flight). It this particular case two flight levels are selected to be synchronised depending on the aircraft preferences (see later in the paper). Second step is to select speed range also based on current aircraft preferences on selected flight levels. Next step is to experiment whether the cruising speed of the aircraft can be adjusted. With respect to the result, either the aircraft has to adjust the speed or it has to change the FL.

[3] The activities of CEATS are centred towards improving the operation in this area, where Air Traffic Services are currently provided by different Area Control Centres in Vienna, Budapest, Bratislava, Ljubljana, Zagreb and Padua, and to be replaced by a unique common control centre in Vienna, called CEATS Upper Area Control Centre (CUAC), planned to start its operation in 2012.

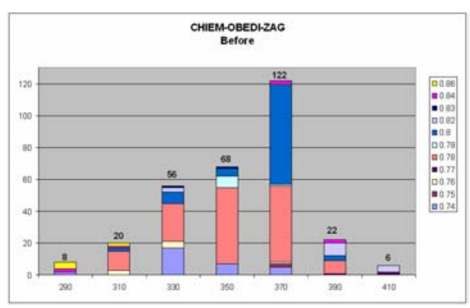
This happens under the consideration of the aircraft performance limitations.
Three scenarios of rule-based algorithm are considered:
Speed adjustment on FL of +/-0.02M;
Speed adjustment on FL of +/-0.01M;
Speed adjustment on FL of +/-0.02M, change FL of aircraft falling into target speed range in neighbouring FL into target FL selected for synchronisation.
The limitations are set to minus two flight levels to descent and plus one FL for climbing.

3 Results

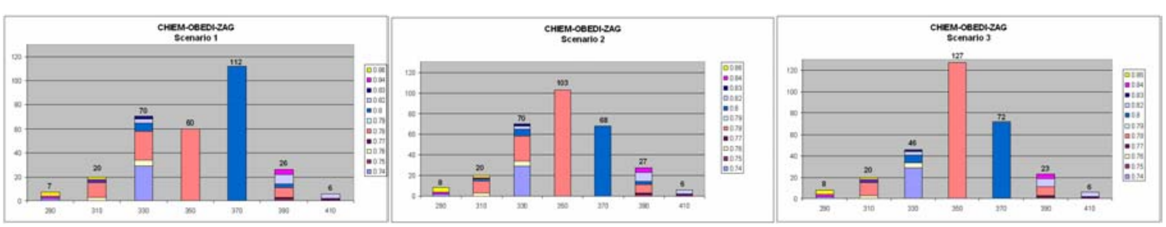
Due to the fact that CEATS is not under the operation yet the modelling approach uses the data obtained with the two last model based simulations (FTS4, FTS6) as baselines for comparative study [22]. Two 24-hours traffic samples (June 28, 2002; September 10, 2004) are used during the course of this study increased of 36% (as estimated for the start of CUAC's initial operations in FTS4) and for year 2015 (FTS6). These simulations were performed with the Reorganized ATC Mathematical Simulator (RAMS Plus™) - a fast-time simulation tool commonly used at CEATS Research, Development and Simulation Centre (CRDS).
In first sample more than 7 000 flights are considered of which 5241 are in upper airspace (above FL285) in second sample more than 10 000 flights are considered. To make a comparison, adequate aircraft performance data are necessary, especially true air speed during the cruising phase of flight. In reality, there is a great disparity of aircraft performances, so to simplify it those data were obtained from the aircraft performance summary tables for the Base of Aircraft Data (BADA 3.6) document [23]. For each aircraft type, the performance table specify the true air speed, rate of climb/descent and fuel consumption for each phase of flight. In the course of the study the cruising, plus cruising and descending aircraft are examined. Moreover those aircraft which have only a small offset of their entry or exit flight level to the cruising flight level were also added to the traffic sample[4]. This is done under the assumption that in this case still most of the cruising phase of flight is performed within the CEATS boundaries. To understand the traffic behaviour some additional measurements have been made including: over-flown time (mean value per sector); average speed versus % of traffic; aircraft types versus speed; speed versus FL.

3.1 Traffic analysis

The initial investigation exposed that 54% of the traffic uses the speed 0.8M (503knots); flight level FL370 is highly preferred by 18% of the overall traffic. As this analysis shows only the traffic distribution on the level basis, another step is to look deeper and perform an analysis with the same approach on selected three main route segments.



'Fig. 6. Traffic distribution on CHIEM-ZAG segment before synchronisation'



'Fig. 7. Scenario 1-2-3: Traffic distribution on CHIEM-ZAG segment after synchronisation'

[4] E.g.: Flight DLH2888: Entry = 250, Cruise = 370; Exit = 0

Preliminary results with respect to criteria inter-dependences shows that as the highest priority is to synchronise the inbound traffic with the lowest number of aircraft shifts it is suggested to apply scenario 1 in all three route segments. Through adjusting over the well acceptable speed range of +/- 0.02M (+/-12knots) only a few aircraft are rerouted to another flight level. Until now the estimation is made on independent segments hence the next step is to experiment the synchronisation on the network basis to confirm the hypothesis.

3.2 Experimentation

Experimentation is to set up and empirically validate the hypothesis. Validation method is aimed on: making sure that synchronisation is effective and estimates the potential benefits of the concept. The method used in this research consists in running fast-time simulation, first with reference traffic, and second with a modified traffic scenarios, where flights belonging to the main flows are to be reorganised. The number of detected conflicts allows comparing these traffic situations, considering that flights following same flow have the same speed and should be able to maintain their separation with other along-track traffic. In the reference traffic the flight plans are considered as they are. In the modified traffic, the flights belonging to the target flow follow the same speed. The other flights follow their standard route, as declared in their flight plan.

The objective is to verify through measurements the ability of the en-route airspace (particular routes) ***to accommodate substantial increases in traffic volume through the increase of route throughput (1).*** The second profit of the synchronisation is computed by ***comparing the number of conflicts detected in the reference traffic, to the number of conflicts in the reorganised traffic (2)****, removing the conflicts occurring between flights following the same flow*. This factor directly affects ***controller's productivity (3)*** and is very important for its reduction. Currently in fast-time model simulations the measurement of workload is derived from the mathematical calculation of the total working times recorded for each ATC task category (Flight data management, Co-ordinations, Conflict search, Routine R/T, Radar). This main categorization in CEATS studies and each category consists of ATC task set. These tasks are assigned to defined actors, i.e. planning and/or executive controller. The last measure is the potential impact of synchronisation on ***minimising over-flown time (4)***.

3.2.1 Simulation Scenarios

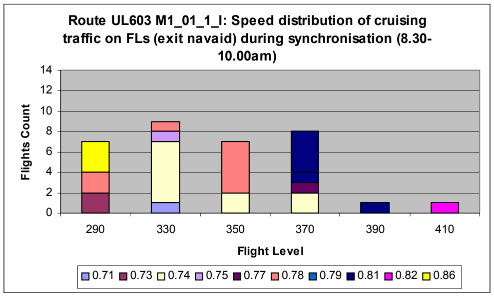
About 50 scenarios were run, each taking between 6 to 12 hours and from which only few are presented here. One scenario covers 1.5 or 2hours traffic during peak morning period when the synchronisation is applied. The traffic baselines are taken from the CEATS fast-time simulation number 4 and 6 as explained in previous section. Traffic on up to three routes is experimented by synchronisation with four changeable variables:

- 1 route, 2 crossing routes and 3 routes are synchronised
- speed adjustment: +/- 6 knots or +/- 12 knots
- intra-sector synchronisation or inter-sector synchronisation
- synchronisation at 1 or 2 flight levels

3.2.2 Simulation results

Due to the fact that the analysis is still ongoing only results of synchronisation on up to two route segments are presented in this paper.

Even the traffic is increased for future operations; in many cases the 100% synchronisation on target flight levels was not achieved. The aircraft have such a distance from each other, that there is no need for speed adjustment to avoid conflict situation in a flow 'Fig. 8'. This is also a reason why it is not reasonable to synchronise flight levels with low traffic. Following example illustrates such situation. One of selected route segments crossing airspace block is CHIEM-JULIE with two target flight levels: FL370 with 29.17% and FL350 with 19% of total number of flights preferring this route. In this example a distance



'Fig. 8. Scenario 1: speed adjustment of +/-6knots and traffic synchronised on flight levels 370 and 350'

of 7 minutes between two flights with heterogeneous speeds was found. The faster flight with the speed of 510 knots follows the slower flight with the speed of 535 knots (target speed). The second flight exits the CEATS airspace with the distance of 5 minutes to the trailing flight, meaning the flights are not in potential conflict situation and there is no potential need for synchronisation. On flight levels with lower traffic are these distances more significant.

Estimation of potential improvement in all measured parameters can be expressed by ratio N_Δ between particular hourly performance in current situation (N_c) and in synchronised mode (N_s) (Formula 1). This index is calculated only during morning peak daily period with sufficiently high demand when the synchronisation is applied (08h30-10h00 in FTS4 and 09h00-11h00 in FTS6).

$$N_\Delta = \left(100 * \frac{N_C}{N_S}\right) - 100 \quad (\%) \qquad (1)$$

Route throughput is determined by the number of route entries per hour. This parameter is calculated for each route segment separately and compared with current situation. The results point out, that unnecessary aircraft shifts from target flight level to adjacent, (when the traffic is low) [due to performance limitation of the aircraft to adjust the speed to achieve synchronisation] impair both: throughput and degree of synchronisation. The degree of synchronisation (ΔG_s) represents traffic balancing on flight levels and is calculated through variances of speeds on the flight levels. In the case of a complete synchronisation of target speed, the value of the variance for this FL is zero. But adjacent FLs must be considered as well, as they are also effected by synchronisation. During the synchronisation process, flights which can not adjust to the target speed are sent to adjacent FLs. This might increase the number of speeds found in these FLs, thus decreasing their regularity. This is a contrary effect to the absolute regularity created on the target FLs. As the variance has no maximum, no absolute value can be calculated. Thus, changes in the degree of synchronisation of traffic on the routes are used and are expressed as a relative value (ΔG_s). ΔG_s can be calculated with formulas intended for variance analysis [21]. The variance is the root-mean-square deviation. In order to compare the conditions between flight levels, the square deviation of each FL is added up (Formula 2) and then divided by the number of the degrees of freedom (Formula 3) (as the variance of one aircraft on one flight level cannot be calculated, this value is never 0). ΔG_s is calculated as a relation of MQW after synchronisation to the value of MQW before. Comparing two degrees of synchronisation can result also in negative values, in case the situation after synchronising is worse then the current situation.

$$SQW = \sum_{i=1}^{p} \sum_{j=1}^{n} \left(x_{ij} - x_{mi}\right)^2 \qquad (2)^5$$

$$MQW = \frac{SQW}{(n-p)} \qquad (3)^6$$

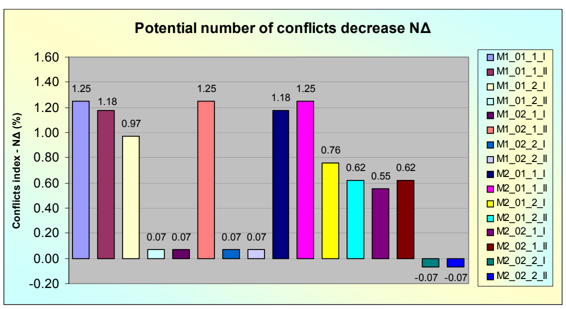
[5] x_{ij} [-] – speed of aircraft j on the FL i; $x_{m,i}$ [-] – average of speeds of the FL i; n [-] – aircraft count on the route; p [-] – number of flight levels of the route

[6] MQW – mean square deviation within FLs (variance); SQW – sum of square deviations on the FLs; n [-] – aircraft count on the route; p [-] – number of flight levels of the route

$$\Delta G_s = \frac{MQW_S}{MQW_o} \qquad (4)$$ [7]

This is the case of route segment UL3 carrying 67 flights resulting in average downgrade of both: degree of synchronisation of -104% and increase of 25seconds crossing time per flight. On the other side all scenarios of route segment UL603 (95 flights) show benefits (average crossing time improves of 1.15%), even though higher benefit can be seen applying intra-sector synchronisation (enhancement of 1.75% = 35sec. per flight), when the flow is build within first sector crossed. In this case, the degree of synchronisation rose of total average 17%.

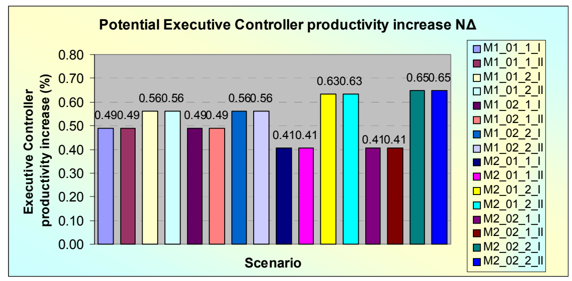
Comparing the **number of conflict situations** detected in the reference traffic, to the number of conflicts in the reorganised traffic results in total average improvement of 0.6% 'Fig. 9'. The



'Fig. 9. Potential number of conflicts improvement'

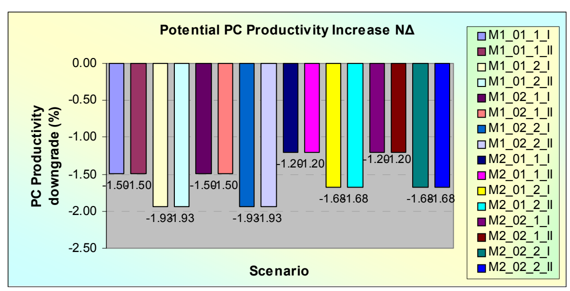
number of conflicts is closely linked with number of vertical movements which improves on CEATS centre basis of 0.2%. Even these numbers are quite low, it must be stressed out, that CEATS airspace consists of approximately 32 sectors and only 6 (when traffic on one route segment is synchronised) or 9 (in case traffic on two route segments is synchronised) are effected. Cutting it down on sector basis, the downgrade is visible in sectors, where the synchronisation is built, resulting in high number of vertical movements and thus increase of conflict situations. The results on effected sector where the synchronisation is maintained is more promising with up to 15% less conflict situations.

Controller's productivity is directly effected by conflicts solving, vertical movements and necessary communication. In all scenarios enhancement of executive controller productivity is noted with total average of 0.5% on CEATS centre basis 'Fig. 10'. In effected



'Fig. 10. Potential executive controller productivity

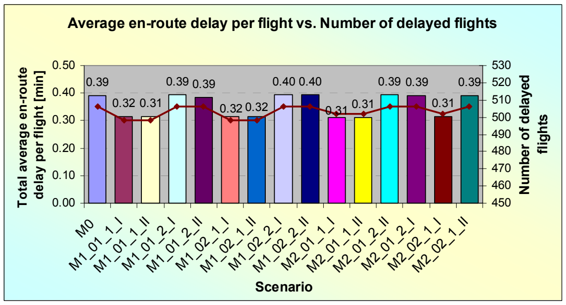
sectors this number is higher. For example in sector D15UH where the synchronisation is maintained the situation gets better in average of 16.7%. On the other side, as expected the productivity of planning controller impairs on centre basis in average of 1.6%. This may be due to the fact, that planning controller is solving the conflicts situation and organising the traffic whilst the executive is responsible for communication with flights 'Fig. 11'.



'Fig. 11. Potential planning controller productivity increase'

Additional measurement is made for **en-route delay**. 'Fig. 12' shows the numerical overview per flight (Da/c) for each specific scenario. Application of synchronisation results in average of 11% improvement. However, overall performance is very much dependent on the intra-sector or inter-sector synchronisation with difference of 22%. In inter-sector

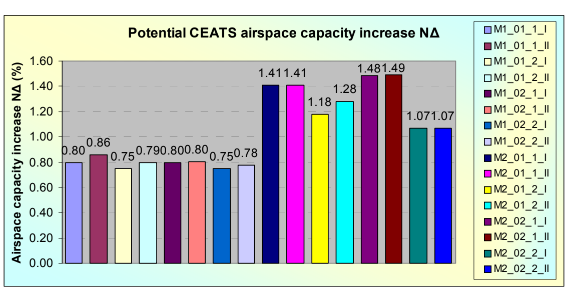
[7] 0 – index for value before synchronization; S – index for value after synchronisation



'Fig. 12. Average en-route delay per flight vs. total number of movements'

synchronisation the en-route delay per flight downgrades. This may be due to fact that controllers have in inter-sector synchronisation more time to build the flow and the maintenance phase covers shorter distance and there is no time to make synchronisation beneficial.

There are many different definitions of airspace capacity. Each kind of definition serves the purpose of the research it is used, and may not be universally suitable. In this thesis is the sector capacity based on definition, that:
'The sector capacity is the maximum number of aircraft that are controlled in a particular ATC sector in a specified period, while still permitting an acceptable level of controller workload.' When a sector has reached its maximum capacity, no further aircraft can enter the sector, and thereat those aircraft have to be delayed or rerouted.
Application of synchronisation confirms the hypothesis – reduction of **airspace capacity**. Following 'Figure 13' depicts the comparison of increase ratio N_Δ between scenarios compared to current situation taken as a basis. It can be observed, that scenario with traffic synchronised



'Fig. 13. Potential capacity increase'

on one route segment performs with average improvement of 0.8% in overall and scenarios with traffic synchronised on two route segments with 1.3% capacity increase. Cutting in down to sector basis in could be seen that the overall performance is very much dependent on the building or maintenance phase of synchronisation. The improvement in sectors with maintained flow is noticeable as for example in sector D15 with 15% sector capacity increase.

4 Conclusions and future work

It is reasonable to suppose that the increase in demand will result in an increase in en-route traffic over the core area, which is already congested to the point where it gives rise to numerous regulations. The aim is to relieve pressure on the main axes forming synchronised flows with flights flying the same speed. This could span the continent and they could be reserved for steady aircraft in level flight.
This paper presents the results of traffic synchronisation on up to two route segments under specific condition. Eight scenarios for each route segment were simulated and analysed in RAMS Plus^{TM} and RAMS Analyser Tool. They prove the potential benefit of synchronisation introduction in all cases. However, the level of improvement depends mainly on inter- or intra-sector synchronisation; there is no significant difference noticed between traffic synchronisation on one or two flight levels. This is due to low traffic level on second target flight level. The potential airspace capacity increase vary between 0.8-1.4% in whole CEATS centre with much higher benefits in effected sectors with 3-15% capacity enhancement.
When taking into account all the parameters the scenarios with intra-sector synchronisation are preferred even the capacity figures are lower than by inter-sector. Due to simulation tool limitations and low traffic level (synchronisation was not 100% achieved) it was not possible to measure time needed to achieve synchronised traffic flow.

Nevertheless, it is too early to state that the more flight levels and traffic on more route segments is synchronised the more capacity is available and controllers are more productive. The analysis is ongoing taking into account situation when traffic on three route segments is synchronised. In addition data for one additional date needs to be analysed, making all together 50 scenarios, where until now only 13 scenarios have been analysed and presented.

Additional measurement will be done considering the needs of airlines, the extra costs they have to pay (e.g. fuel burn) in the synchronisation process. And attention will be paid on the time needed to synchronise.

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