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ZAGREB TERMINAL AIRSPACE CAPACITY ANALYSIS

ABSTRACT

The paper deals with the Zagreb Terminal Airspace capacity. The basic scenario has been modelled using the RAMSPlus simulator and capacity has been calculated by using the WMSE method which takes into account the peak-hour workload based on air traffic controllers' tasks. The problem of traffic congestion has been analyzed and several case study scenarios have been simulated. The conducted simulations have demonstrated that in the conditions of increased traffic loads (traffic demand amounting to 6% annually) the working technology and the airspace organization of Zagreb Terminal Airspace will become a restricting factor at peak-hour workloads. The new technologies in Zagreb Terminal Airspace (P-RNAV routes and airspace sectorization) will enable the reduction in air-traffic controller's workload regarding radar vectoring, radio-telephony and coordination tasks. This should increase the airspace capacity and thus enhance the safety and orderly flow of air traffic.

KEY WORDS

terminal airspace, capacity, simulation, workload, task, sectorization

1. INTRODUCTION

Terminal airspace or terminal control area (TMA[1]) is a specific part of the airspace in which aircraft fly in descent during approach for landing, and climb after takeoff, thus changing the flight level, direction and speed, in very short time periods and in a confined airspace, which requires constant surveillance, control and traffic management in order to ensure the stipulated regulations of aircraft separation. The specific characteristic of the terminal airspace is reflected in the fact that it represents a "bridge" between the airport and the enroute airspace (cruising phase of flight), i.e. it "reclines" on the airport airspace, and apart from the functions in approach for landing and procedures following takeoff, it is related also to route flight operations in case when the aircraft fly over crossing the terminal airspace.

Generally speaking, the evolution of aviation all the way to the present days has been characterized by a constant trend of increasing traffic demand which has resulted in aviation development in a series of segments out of which the airspace capacity can be specially emphasized. The existing condition of routes, airways, airspace and applicable technologies at a certain moment of increased traffic demand and peak loads lead to traffic congestion and the possibility of disturbing the stipulated separation standards. The research and selection of adequate solutions should ensure new capacities in all the segments of air traffic system not neglecting the safety factor and the basic tasks of air traffic controllers. The past research of the airspace capacity, including the terminal airspace capacity, went in two directions. In one direction the physical airspace capacity was studied, and in the other the airspace capacity depending on the controller workload. In the former case the maximal number of aircraft is studied, which can be physically within the observed airspace in the defined unit of time, as elaborated by Janić [1] in which the model of the terminal airspace capacity was tested on the example of the Belgrade Airport, obtaining the results that showed that the capacity is a variable value dependent on the distribution and aircraft characteristics per entry points and the number of points. In the latter case, the maximal number of aircraft in the unit of time in certain airspace is studied, and it can be "done" in accordance with the air traffic controller's tasks without disturbing air traffic safety. At its research centre, EUROCONTROL[2] performed a number of studies relating to the controller's workload and the terminal airspace capacity using the RAMSPlus[3] simulation software. The study on the Budapest terminal airspace has come to a conclusion that the capacity can be increased by reducing the separation standards and by designing new approach and departure routes [2]. The Study of Slovenia Airspace was directed to the reduction of aircraft delays in individual sectors [3]. The analytical work, which is based on the performed drills on air traffic control simulators, presented the survey results about the intensity and complexity of controller's tasks and gave a proposal of new instrumental procedures within the Zagreb terminal control area [4].

During 2008 and 2009 the Zagreb terminal control area (Zagreb TMA) or simply Zagreb terminal airspace was studied in a doctoral dissertation entitled "Influence of the Terminal Airspace and Manoeuvring Area on the Flow of Air Traffic" [5]. The main research thesis was to determine the dependence and influence of the manoeuvring area and its characteristics on the terminal airspace capacity, and one of the objectives was to use simulation to calculate the airspace capacity, verify the model and use it in a number of simulations for the analysis of the situations and proposals of possible solutions of the capacity congestion issues. This paper presents the analysis of Zagreb TMA, development of a simulation airspace model using RAMSPlus simulation software (Release 5.32) and provides the proposal of solving the capacity congestion issue.

2. TERMINAL AIRSPACE CHARACTERISTICS

2.1 Terminal Airspace in general

The terminal airspace capacity depends on an entire series of factors, such as: specific characteristic of the position, airspace shape, its connection to other adjacent airspaces and the airspace function itself. Different factors have the highest influence on the airspace capacity, if they are considered in pairs or in a group. If one considers the calculation of the airspace capacity in dependence with the controller's tasks, then the workload factors and the procedures and operative procedures of the air traffic control are the most significant ones for the analysis. Other factors (the number of airports and the configuration and number of runways, the number of overflights, civil and military aviation, geographic position of the airspace, the number of entry/exit points, equipment with radio-navigation instruments, adjacent airspace and environmental protection) affect the position, configuration and load of the traffic flows.

2.2 Characteristics of Zagreb TMA

Zagreb TMA represents a constantly open sector and it is part of the Zagreb area control centre. It covers two control zones of Zagreb and Lučko and the aerodrome traffic zone Varaždin. According to ICAO[4] classification Zagreb TMA has been classified as class C airspace [6].

The unit that performs air traffic control for Zagreb TMA can be radar approach (Zagreb Radar) and non-radar, i.e. procedural approach control (Zagreb Approach). Radar control is performed regularly as long as there are conditions for its operation. In the technology of radar control operation the aircraft are mainly directed on approach and separated by radar vectoring, i.e. usually they do not use standard instrumental arrival procedures. During takeoff, the tower controller gives the aircraft the so-called *dummy* clearance for climbing according to standard instrument departure (SID) procedure and later when the aircraft come under the responsibility of the approach controller they continue further according to the same procedure or get new tactical clearance, depending on the traffic situation.

The actual Zagreb TMA is shown in *Figure 1*; however, the configuration and the characteristics of Zagreb TMA which were used in the simulation are based on the data and charts published in April 2007. There are no major differences between the two charts that would influence the simulation model. This is a complex airspace since, apart from bordering on other sectors and control centres within FIR[5] Zagreb, it borders also on two neighbouring countries thus including their FIRs (FIR Ljubljana and FIR Budapest) and the Mura sector, performing also coordination with their respective controls (area control centres Ljubljana, Budapest and Vienna - ACC[6] Ljubljana, ACC Budapest and ACC Vienna). Within FIR Zagreb aerodrome control towers Zagreb and Lučko are coordinated by the centre providing flight information service (FIC[7] Zagreb) and ACC Zagreb sectors in the lower airspace (Lower North, Lower Adria). Apart from this, Zagreb TMA coordinates also the military ATCC Zagreb sector.

In *Figure 1*, a large number of entry/exit points, dispersedly set in relation to Runway 05 of the Zagreb Airport, and the adjacent sectors (centres) render the

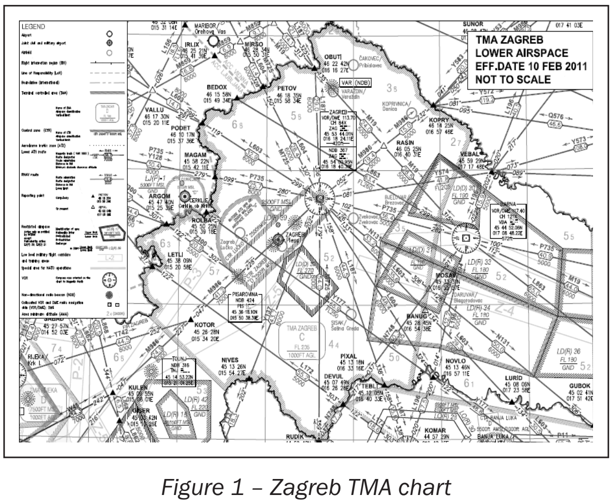

Figure 1 – Zagreb TMA chart

Source: Croatian Air Navigation Services Ltd., Zagreb, 2011 airspace complex for the controller's work. The technology of work, tasks and coordination with adjacent sectors are developed according to the Letters of Agreement (LoA) [7] that the Zagreb approach control unit has signed with the Zagreb area control centre. In developing the Zagreb TMA model it was necessary to analyze and set all the relevant factors that influence the characteristics of Zagreb TMA. The following parameters have been created in the model using RAMSPlus software:

1. operation of radar approach controllers (executive and planning);
2. separation standards – 5NM, 1,000ft;
3. standard instrument departure procedures for Runway 05 of Zagreb Airport;
4. routes that imitate radar vectoring on approach to Runway 05 of the Zagreb Airport;
5. level restrictions at entry/exit points from the terminal airspace (so-called: FLAS[8] levels);
6. minimum radar vectoring altitude (MRVA);
7. traffic input data: IFR – GAT traffic (daily traffic when peak load of 14 operations/h occurred);
8. adjacent centres or sectors;
9. entry/exit points in/out of Zagreb TMA airspace: OBUTI, PETOV, PODET, MAGAM, ARGOM, GORPA, LETLI, KOTOR, NIVES, RUDIK, DEVUL, PIXAL, TEBLI, NOVLO, VBA, VEBAL, KOPRY (some points are not located geographically near or within the Zagreb TMA airspace (GOLUN, GUBOK), but have been established, and they define standard departure or arrival procedures).

In using the data from the chart presented in *Figure 1* the opinion of experts has been taken (air traffic control instructors) who have confirmed that there are no differences in the work of approach controllers at the time of data collection until the end of research so that possible differences on the currently valid Zagreb TMA chart have no major influence on modelling the controllers' tasks which affect the sector capacity.

3. MODEL OF ZAGREB TMA USING RAMSPLUS

In developing the model of terminal airspace, the RAMSPlus simulation software which represents a mathematical simulator for modelling various elements of the air traffic system has been used. Its greatest advantage compared to other simulation softwares is the possibility of simulating the air traffic controller's tasks. It allows *fast-time* simulations that in a relatively short time period simulate and study the problems that would require longer time in actual environment and high financial losses. It allows simulations on macro and micro basis which enables using it for the analysis of large systems or its elements or subsystems.

3.1 ATC tasks in Zagreb TMA

The sector capacity, i.e. capacity of certain airspace is defined as the maximum number of aircraft in controlled airspace or sector in the observed time period with acceptable level of controller's workload [8]. The method of calculating the capacity of a sector or an airspace using RAMSPlus software is based on the controller's workload, i.e. on the assumption that a certain level of controller's workload should not exceed the threshold of high controller's workload (HLT)[9] [9] which is 70% in one hour [10]. This means that the controllers are exposed to heavy load if they do different tasks for 42 minutes within an hour, including cognitive ones. The software allows the calculation of capacities using the weighted mean square error method (WMSE) [10]. The workload represents a set of tasks that the controllers perform within the observed hour and depend on the traffic demand and the configuration and characteristics of the terminal airspace, given procedures and traffic load that is related to airports within the terminal airspace.

Since the objective of the research was the calculation of the airspace capacity, i.e. maximal number of aircraft that can be in the airspace, with acceptable level of the controller's workload, the tasks of the approach controller had to be determined, analyzed and distributed, and statistically processed. It should be noted that the measured values of individual controller's tasks were obtained by measuring the time of performing the tasks of the executive controller within Zagreb TMA on air traffic control simulators within the period of five days (November 2008) for approximately 200 aircraft. It was not possible to carry out measurements at the working position, nor implement the survey method as has been done in the papers [8], [11]. Most of the tasks were statistically processed and normal distribution was assigned, mean values and standard deviation determined. For some tasks it was not possible to measure the statistical data, so that the estimated values provided by expert air traffic controllers from the Croatian Air Navigation Services Ltd. were taken into consideration. Since the total workload of an executive controller is necessary for the very calculation of capacities, for the modelling of the planning controller only the estimated values were taken into consideration. All the controller's tasks can be grouped in five categories (coordination tasks, flight data management tasks, radar tasks which include surveillance and vectoring, routine radio-telephony communication and conflict search). *Table 1* shows the defined tasks per categories and the respective values determined for overflights, arriving and departing aircraft.

The table provides the estimated and the measured values of the tasks of the executive and plan-

Table 1–Distribution and duration values of single tasks of air traffic controllers in Zagreb TMA

Flight Data Management Tasks			
Task description	Time of task execution (s)		
	Estimated value		Measured values (Executive controller)
	Planning controller	Executive controller	
Rx departure info from Zagreb TWR	10	10	5
Tx estimate to local airports (Maribor; Lučko)	10	10	--
Assume flight	n/a	2	2
Search and early assume flight	10	10	9
Input CFL and reposition of label	n/a	3	4
SYSCO coordination and data input	n/a	10	10
Manual coordination and data input	15	15	15
Modify FPL (new route)	min 30	min 30	25
Expedite clearance approval procedure (Graz; Maribor)	25	25	11
No FPL procedure	min 40	min 40	45
Conflict Search Tasks			
Task description	Time of task execution (s)		
	Estimated value		Measured values (Executive controller)
	Planning controller	Executive controller	
Conflict search to establish sector exit clearance	3	3	--
Conflict search to establish sector entry clearance	3	3	--
Monitor STCA	2	2	5
Monitor APW	2	2	--
Monitor AHR areas	2	2	--
Application of RBL tool to check possible conflicts	6	6	4
Application of SEP tool to check possible conflicts	6	6	4
Application of prediction vectors to check possible conflicts	4	4	--
Routine Radiotelephony Communication			
Task description	Time of task execution (s)		
	Estimated value		Measured values (Executive controller)
	Planning controller	Executive controller	
First call from an aircraft	n/a	15	13
First call to an aircraft	n/a	15	14
Instruction to avoid (mil. area; bad weather etc.)	n/a	15	--
Tx new clearance (flight level; speed; heading etc.)	n/a	10	11
Tx special information	n/a	15	--
TxandRx last call to aircraft	n/a	15	15
TxILSCLC	n/a	15	13
RxILSEstablished	n/a	5	5

Coordination Tasks			
Task description	Time of task execution (s)		
	Estimated value		Measured values (Executive controller)
	Planning controller	Executive controller	
Inter-centre coordination (revisions; dct route; higher level etc.)	15	15	16
Coordination with neighbour ATC (revisions; dct route; higher level etc.)	15	15	11
Special coordination – military sector	25	25	--
Special coordination – FIC sector (anti hail rocketing; VFR activities etc.)	20	20	--
Verbal coordination – EC and PLC	2	2	2
Rx CLC Request From Local Airport	10	10	8
Radar Tasks			
Task description	Time of task execution (s)		
	Estimated value		Measured values (Executive controller)
	Planning controller	Executive controller	
Radar surveillance of flights	3	3	4
STCA[10] monitoring	10	10	--
Conflict resolution – level change	2	12	12
Conflict resolution – vectoring	5	60	48
Conflict resolution – speed control	4	20	20
Non planned pilot requests	2	12	12
LoA restrictions	2	12	--
Approach heading	4	8	9
Monitoring passing flights	10	20	--
Determine approach sequence	5	5	6
Select flight to vector	5	5	5

Source: Juričić, B. [5]

ning controller. Some tasks are exclusively performed by the executive controller and have therefore not been even mentioned for the planning controller (marked in the Table with N/A[11]). The empty cells indicate that the values could not be measured so that the estimated values were taken.

Before developing the model in RAMSPlus software the following assumptions and starting conditions were taken into consideration [5]:

1. the defined working tasks are tasks that are applied during a flight of an aircraft from the moment of entry to the moment of exit from the observed airspace, in case when Runway 05 of Zagreb Airport is active. The flight of an aircraft and certain tasks are different for an aircraft in approach, departure and overflight;
2. considered were the controller's tasks in normal, usual conditions for IFR/GAT[12] traffic (routine tasks) at peak load, which means that the controller's tasks related to VFR and military flights were not taken into consideration;
3. not considered were the controller's tasks that are not applied on every aircraft and those related to meteorological conditions (*Monitor APW areas, Monitor AHR areas, Instruction to avoid mil. area; bad weather etc., Special coordination – military sector, Transmit special information, Special coordination – FIC sector);*
4. not considered were the emergencies.

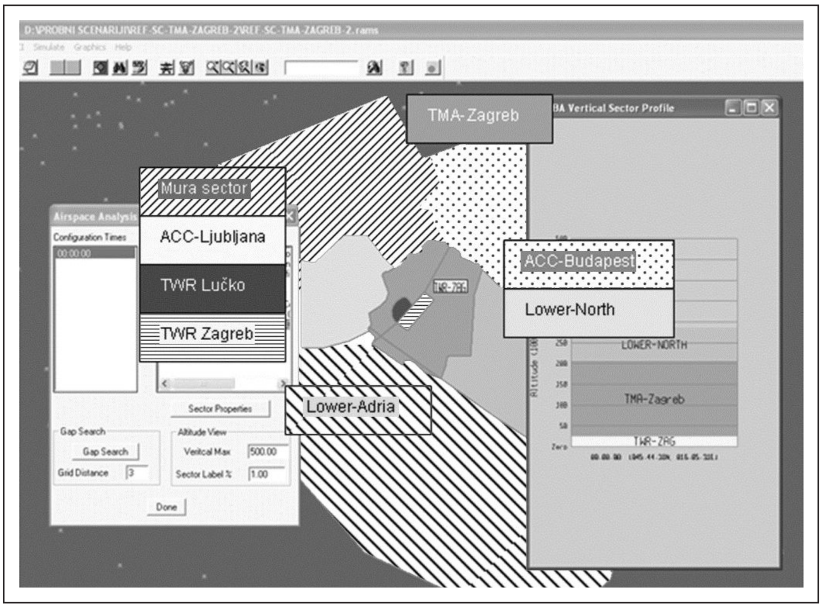

Figure 2 - Created model of Zagreb TMA

Source: Juričić, B. [5]

In RAMSPlus software tasks are triggered by defined triggers under special conditions [9]. Correct defining of the triggers prevents multiple occurrences of single tasks or failure of running certain tasks, preventing thus wrong calculation of capacities.

Figure 2 presents the simulated model of Zagreb TMA.

As can be seen in the Figure, using RAMSPlus software the centres and sectors adjacent to Zagreb TMA were modelled and simulated.

3.2 Calculated capacity of Zagreb TMA

The input data about traffic used in the simulation were obtained from EUROCONTROL's Central Flow Management Unit (CFMU), and they represented the daily traffic with peak load for Zagreb Airport. Using the mentioned method WMSE in RAMSPlus software the value of capacity of 15 operations/h for Zagreb TMA was calculated [5]. The value was verified by comparing it with the declared capacity values that, in the opinion of the air traffic control instructor at Zagreb TMA amount to 12-16 operations/h. Analyzing the result of simulation with expert air traffic controllers, it was concluded that the value of 15 operations/h can be considered an acceptable value since the declared value was obtained by empirical estimate of the controller, and not by analytical methods. It should be emphasized that the obtained value is the airspace capacity when all the tasks are performed only by the executive controller, and the planning controller is not active. If a part of tasks is directed to the planning controller, the capacity value increases to 18 operations/h with peak workload of the executive controller of 55% [5].

4. INCREASED TRAFFIC DEMAND

The analysis of Zagreb TMA congestion was carried out by increasing the traffic sample from the basic scenario. The annual traffic growth rate of 6% (according to the EUROCONTROL forecast for the period from 2008 to 2013) was applied to the basic daily traffic sample and cumulative growth rates of 42 and 49 percent for years 2013 and 2015 respectively were produced [12]. The simulation of increased traffic in Zagreb TMA was performed with the condition that both controllers have been activated and the capacity result of 17 aircraft/h was obtained. The analysis of results shows that the calculated value of capacity was obtained with the data on high workload of the controller (95% per hour) [5]. The obtained result shows that with the annual traffic increase of 6%, by the year 2013, under current conditions and both controllers active, the airspace capacity will be smaller due to greater workload. The values of reduced capacity compared to the traffic growth have been obtained due to the system overload (workload above the possible HLT). Analyzing these data about the capacity, it may be concluded that the current configuration, characteristics and organization of work in Zagreb TMA in the future are going to become the limiting factor in increased traffic demand during peak periods [5].

5. POSSIBLE SOLUTIONS FOR ENHANCING ZAGREB TMA CAPACITY

Possible measures for increasing the Zagreb TMA capacity can go in three directions; as airspace sectorization, change in the design of the airspace and air traffic control operative procedures or combination of these solutions. The selection of adequate solution should follow the carried out cost-benefit analysis which consists of the following phases [5, 13]:

1. airspace modelling,
2. fast-time simulations (FTS) with the aim of narrowing the number of possible solutions to one or two models,
3. real-time simulations (RTS) for the selection, final solution and verification of safety aspect of the solution,
4. implementation of the selected solution.

5.1 Sectorization

Airspace sectorization is one of the possible solutions of increasing the Zagreb TMA capacity, and it may be carried out in two ways, as vertical or lateral division of the current airspace. The airspace division would result also in the division of workload, i.e. controller's tasks that are necessary to calculate the capacity using the WMSE method. This paper presents the lateral sectorization of the current airspace into two sections (*Figure 3*) when Runway 05 at Zagreb Airport is active, i.e. the separation of airspace for arriving and departing traffic.

The new sector (called South-TMA-Zagreb) occupies the southern part of the current Zagreb TMA and encompasses the entry points for the western traffic (ARGOM), for approach from the direction (KOTOR, GOLUN), and south-eastern traffic (RUDIK, TEBLI). Vertically, the bottom boundary of the airspace is defined at 1,000ft above the terrain outside the controlled zone and 2,500ft above the terrain at the controlled zone, whereas the upper boundary is at FL[13]125. The condition for this area would be that it was only used for arriving IFR/GAT aircraft that arrive and approach from the entry points at a level of FL125 or lower. The overflights would be performed above FL125, and departing aircraft from Runway 05 before entering the sector should already have reached levels above FL125.

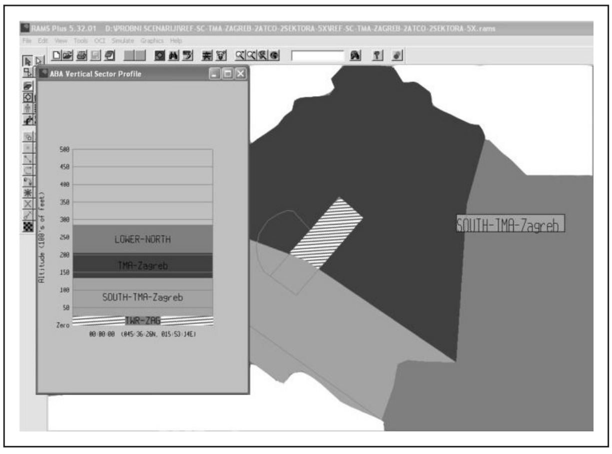

Figure 3 – Proposal for Zagreb TMA sectorization

Source: Juričić, B. [5]

The controller's tasks in the new airspace and in the remaining terminal airspace are adapted to these assumptions. This would significantly reduce the number of controller's tasks since in the new airspace they are limited only to approaching aircraft. The northern part of the current Zagreb TMA and the airspace above South-TMA-Zagreb up to FL205 would form the new Zagreb TMA. The simulation of the new airspace and the tasks using RAMSPlus software yielded the following capacity results: South-TMA-Zagreb 17 operations/h, and Zagreb TMA capacity 23 operations/h [5]. The mentioned solution could be activated when there is need to do that, i.e. during daily peak periods when the traffic demand is such that the controller's workload is around HLT for a longer period of time.

5.2 Introducing P-RNAV[14] in Zagreb TMA

Another possible solution to the problem is the need to change the working technologies of air traffic control, i.e. by redesigning the airspace. This would mean the usage of advanced technical and technological solutions of developing approach or departure procedures based on area navigation using the waypoints whose data are derived from GNSS[15] or DME/DME[16] navigation system. According to ICAO terminology one should distinguish between P-RNAV and Basic RNP1 systems in aircraft on-board system performances. The Basic RNP1 is a P-RNAV system which includes also a part for on-board performance monitoring and alerting if the aircraft deviates significantly from its intended track [14, 15].

The advantages of this system: reduced number of radio-transmissions, higher awareness about the situation for pilots, reduced controller's workload, shortened route length and higher flight accuracy along the desired route, which directly affects the environmental protection, i.e. reduction of noise, possibility of implementing the approaches with continuous descent (CDA[17]), reduction of fuel consumption [16]. The procedures allow the aircraft to fly along the defined routes within accuracy of 1NM which allows the pilots to use the *fly-by* functions for the defined waypoints. *Figure 4* shows one of the possible P-RNAV route configurations for Zagreb TMA in combination with the conventional routes, which would allow in the beginning the so-called *mixed mode* operations, i.e. aircraft flying with P-RNAV and conventional navigation systems.

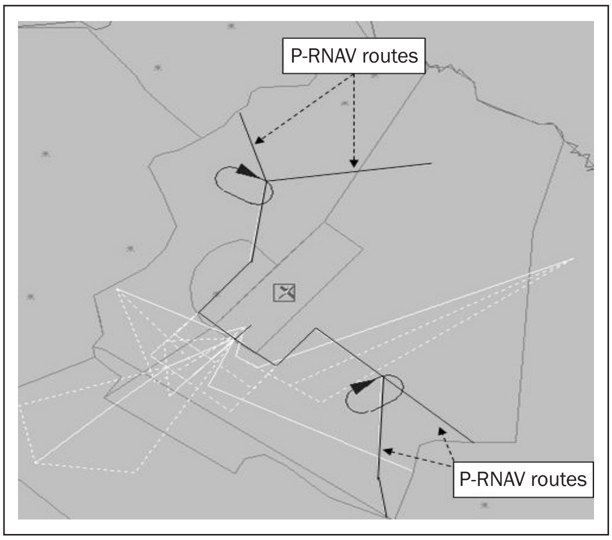

Figure 4 - P-RNAV routes in Zagreb TMA

Source: Juričić, B. [5]

P-RNAV routes introduce four starting traffic flows into one joint sequence after the waypoint WP_IF. The traffic flows are defined by the northern (entry points PETOV and RASIN) and the southern direction (entry points TEBLI and RUDIK). All the points on these directions are the so-called *fly-by* points and allow optimal direction and radius of aircraft turn.

The mentioned P-RNAV routes and new holding areas are implemented into the basic simulation model of Zagreb TMA, whereas all other characteristics of the airspace have remained the same [5]. A significant change occurred in the controller's tasks: aircraft that fly along P-RNAV routes have not been given vectors, but only clearance for ILS approach and landing so that tasks were started only for departing traffic. All this reduced the total workload which increased the capacity value to 22 operations/h (increase of 22% compared to the basic scenario with two controllers) [5].

6. CONCLUSION

This research showed that in the current conditions of air traffic demand, the airspace capacity amounts to 15 operations/h with acceptable level of controller's peak workload. This is the consequence of the complexity of the airspace regarding the large number of adjacent sectors and centres and dispersion of approach routes to Runway 05. The study has shown that under the conditions of continuous increased traffic demand of 6% by the year 2013 increased peak loads may occur, which result in increased total workload above the limit defined as HLT. The execution of the controller's tasks in such conditions becomes complicated and may have direct influence on the safety of air traffic. The current configuration of Zagreb TMA, as a single airspace, is not sustainable in the future with increased traffic demand during peak periods and requires new solutions. This paper proposes two solutions: lateral sectorization and introduction of P-RNAV approach procedures.

These solutions are not the only ones. The sectorization of the Zagreb terminal airspace can be carried out also vertically, and the introduction of P-RNAV procedures may also have a larger number of entry points and possible elimination of radar vectoring for other routes and a possible implementation of Basic RNP-1 system. The possible initial solution of the Zagreb TMA capacity problems need to be further studied by real-time simulations and conditions in order to study the safety condition and develop a safety study before their potential implementation. Similar simulation studies should be performed also for the other direction of Runway 23 at Zagreb Airport.

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SAŽETAK

ANALIZA KAPACITETA U TERMINALNOM ZRAČNOM PROSTORU ZAGREB

Rad se bavi problematikom kapaciteta u terminalnom zračnom prostoru Zagreb. Koristeći simulator RAMSPlus modeliran je osnovni scenarij terminalnog zračnog prostora Zagreb te metodom WMSE izračunat njegov kapacitet na osnovu vršnog radnog opterećenja kontrolora. Analiziran je i problem zagušenja prometa te je izvršena simulacija za nekoliko različitih scenarija. Izvršene simulacije su pokazale da će u uvjetima povećanja prometne potražnje (6% godišnje) tehnologija rada i trenutna organizacija prostora postati ograničavajući čimbenik kapaciteta u uvjetima vršnog radnog opterećenja kontrolora. Nove tehnologije koje su navedene u radu (uvođenje P-RNAV ruta i sektorizacija prostora) omogućit će smanjenje ukupnog radnog opterećenja kontrolora kroz smanjenje radarskog vektoriranja te radnih zadaća radio-telefonske komunikacije i koordinacije. Navedeno bi trebalo povećati kapacitet prostora, a time i sigurnost i redovitost zračnog prometa.

KLJUČNE RIJEČI

terminalni zračni prostor, kapacitet, simulacija, radno opterećenje, radna zadaća, sektorizacija

REFERENCES

1. TMA - Terminal Airspace (EUROCONTROL) or Terminal Control Area (ICAO)

2. EUROCONTROL - the European Organisation for the Safety of Air Navigation
3. RAMSPlus – Reorganized Air Traffic Control Mathematical Simulator Plus
4. ICAO – International Civil Aviation Organization
5. FIR – Flight Information Region
6. ACC – Area Control Center
7. FIC – Flight Information Center
8. FLAS – Flight Level Allocation Scheme
9. HLT – Heavy Load Threshold
10. STCA – Short-Term Conflict Alert
11. N/A – Not applicable
12. IFR/GAT – Instrument Flight Rules/General Air Traffic
13. FL – Flight Level – level of aircraft when altimeter is set to standard atmospheric pressure
14. P-RNAV – Precision Area Navigation
15. GNSS – Global Navigation Satellite System
16. DME – Distance Measuring Equipment
17. CDA – Continuous Descent Approach

LITERATURE

[1] **Janić, M.**: *Air Transport System Analysis and Modeling - Capacity, Quality of Service and Economics*, Gordon and Breach Science Publishers, Amsterdam, 2000

[2] *Budapest Lower Airspace and TMA MBS Study - CRDS Note* No. 21, EUROCONTROL, CRDS, Budapest, 2007

[3] *Slovenia MBS - CRDS Note* No.24, EUROCONTROL, CRDS, Budapest, 2006

[4] *ZAGREB TMA and TMA/ACC Interface - Real Time Simulation - PMP and Final Report*, Croatian Air Navigation Services ltd., 2007

[5] **Juričić, B.**: *Influence of the Terminal Airspace and the Manoeuvring Area on the Flow of Air Traffic*, doctoral dissertation, Zagreb, 2009

[6] *Air Traffic Services, Annex 11*, ICAO, Montreal, 2001

[7] *Letter of Agreement on Coordination Procedures between Zagreb ACC and Zagreb APP*, interne document, Croatian Air navigation Services Ltd., Zagreb, 2007

[8] **Majumdar, A.**, **Ochieng W.**, **McAuley, G.**, **Lenzi, J.M.**, **Lepadatu, K.**: *The Factors Affecting Airspace Capacity in Europe: A Framework Methodology Based on Cross Sectional Time-Series Analysis Using Simulated Controller Workload Data*, 6th USA/Europe ATM Research and Development Seminar, Baltimore, 2005

[9] *RAMS Plus User Manual*, Release 5.32, ISA Software Ltd., Paris, 2009

[10] *Capacity Analysis Using Model-based Controller Workload Estimation Technique*, EUROCONTROL, Experimental Centre, Paris, 1999

[11] **Čujić, M.**: *Analysis of the Task List Impact upon RAMS Workload Calculations*, International Conference on Research in Air Transportation – ICRAT, Žilina, 2004

[12] **Steiner, S.**, **Mihetec, T.**, **Božičević, A.**: *Prospects of Air Traffic Management in South Eastern Europe*, PROMET – Traffic&Transportation, No. 4, Vol. 22, p. 293-302, Zagreb, 2010

[13] *EUROCONTROL Airspace Planning Manual*, Section 5 - Terminal Airspace Design Guidelines, EUROCONTROL, Bruxelles, 2005

[14] **Rawlings, R.**: *EUROCONTROL Navigation Strategy for ECAC*, EUROCONTROL RNAV Workshop, Luxembourg, 2003

[15] *RNAV Application in Terminal Airspace – an ATC Operational Perspective*, EUROCONTROL, Bruxelles, 1999

[16] **Ullvetter, C.**: *P-RNAV in Sweden*, EUROCONTROL RNAV Workshop, Luxembourg, 2003