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PRINCIPLES OF IMPROVEMENT OF AIR TRAFFIC FLOW AND CAPACITY MANAGEMENT IN TERMINAL CONTROL AREAS UNDER UNCERTAINTY CONDITIONS

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Abstract. *The article deals with the analysis of the researches conducted in the field of the air traffic flow and capacity management in terminal control areas under uncertainty conditions. Traffic flows indicators, uncertainty factors and air traffic flow management in terminal control areas have been reviewed. Principles of improvement of air traffic flow and capacity management in terminal control areas have been analysed and conclusions regarding Ukrainian aeronautical system have been proposed.*

Keywords: air traffic flow and capacity management; air traffic management and aeronautical system; safety of flights; terminal control area; traffic flows statistics; uncertainty conditions.

1. Introduction

The most pressing problem facing European Air Traffic Management (ATM) in the past decade has been to provide sufficient capacity to meet air traffic demand, while improving safety and containing costs. Capacity provision in Europe lagged behind demand, leading to flights delays. This accentuated the need to improve capacity planning at European ATM network level. One of the important aspects is to improve capacity management in terminal control areas under uncertainty conditions.

The European ATM Network continues to face capacity challenges as traffic demand is expected to increase strongly in the medium term [Chynchenko 2010; Chynchenko 2011; Kharchenko, Chynchenko 2012; Kharchenko, Chynchenko 2013; Kharchenko et al. 2009]. The EUROCONTROL has initiated further actions to enhance the planning of European ATM capacity through the Dynamic Management of European Airspace Network Framework Programme (DMEAN).

The DMEAN Framework Programme is coordinating and progressively introducing a number of operational enhancements to the European ATM structures and processes in the areas of [Capacity… 2007]:

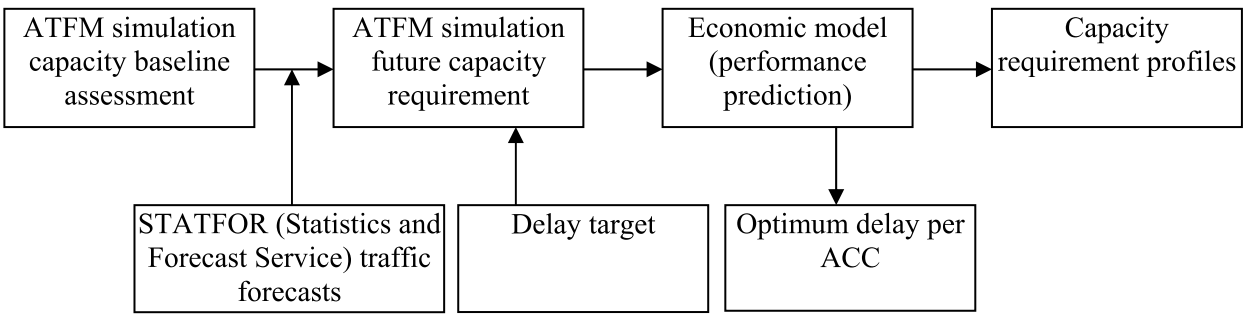
– improved planning and demand/capacity balancing;

– flow and capacity management at network, regional and local levels.

2. Future ATM Profile by Eurocontrol

Future ATM Profile (FAP) is a set of modelling and analysis tools comprising ATFM (Air traffic flow management) simulation facilities as well as spreadsheet and macro-based analysis and reporting tools, that assesses and quantifies how much capacity is delivered by specific airspace volumes within the current ATM system, and evaluates the current and future capacity requirements, at Area Control Centre (ACC) and sector group level (see Figure).

Step 1: In order to provide an accurate prediction of the capacity requirements of the European ATM system, it is necessary to know the current capacity offered. FAP establishes a capacity baseline for each ACC and defined sector group.



Future ATM Profile processes

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Step 2: The next task is to provide a prediction of the future demand on each ACC (and defined sector group) over the next 5 years, according to the expected traffic growth and distribution over the future route network.

Step 3: FAP carries out an economic analysis, balancing the cost of capacity provision and the cost of delay, on the assumption that each ACC is operating at or close to its economical optimum, and that the target level of delay has been achieved.

Step 4: FAP produces, for each ACC and defined sector group, a 5 year capacity requirement profile. Percentage increases with respect to the measured capacity baseline are provided.

Same approach may be applied to estimate current/required capacity, future demand and other traffic parameters in definite terminal control areas under uncertainty conditions.

3. Assessment of current capacity under uncertainty conditions

There are several methods to evaluate current ACC and sector group capacity, known as the capacity baseline. These have been developed and improved over a number of years and the suitability and effectiveness of each depends on whether or not the ACC being measured generates a significant amount of ATFM delay.

The most accurate for delay producing ACCs is Reverse CASA, with NEVAC (The Network Estimation & Visualisation of ACC Capacity tool) being the preferred option for non-delay-producing ACCs until ACCESS was developed in 2004. The ACCESS methodology was developed to enable the baseline of all ACCs to be assessed using one methodology, and to ensure a continuity for ACCs that move from one category into the others.

In order to provide efficient air traffic flow and capacity management in terminal control areas under uncertainty conditions:

– Visualise TMAs related data (demand, sector capacities, configurations, delay, routes etc.);

– Optimise configuration opening schemes;

– Calculate future traffic samples;

– Measure protection and penalisation network interactions;

– Create virtual TMAs and evaluate airspace reorganisation options between adjacent TMAs;

– Calculate TMAs baseline capacities for a given period;

– Perform detailed analysis of demand structure, network interactions, configuration suitability, saturation and ATFM delay all of which affect TMAs capacity;

– Analyse TMAs demand in terms of its structure, load distribution and constituent flows.

A comparison of the different methodologies of assessment of current capacity is given in the Table 1 [Capacity… 2007].

4. How to increase TMA capacity

An increase in TMA capacity can be achieved (en-route) by 3 initiatives [Capacity… 2007]:

The 1st task. Optimise network utilisation. Optimisation of available capacity through management of traffic flows, to better fit the sectorisation to the traffic flow at any moment in time, so that the capacity is available where and when it is needed.

Table 1. The current capacity assessment

Method	Advantages	Disadvantages
Reverse CASA (Computer Assisted Slot Allocation)	Extremely accurate measurement of ATM capacity offered during the measured period. Takes network effect into account. No input from ANSPs (Air Navigation Service Provider)	Useful only for delay-producing ACCs. Iterative simulation takes time
NEVAC (The Network Estimation & Visualisation of ACC Capacity tool)	Can be used for all ACCs. Measures the potential capacity that could be offered during the period. Quick and easy	Does not take the network effect into account. Results depend on the accuracy of CFMU (Central Flow Management Unit) data. Cannot measure offered capacity, only potential
ACCESS methodology	One method for all ACCs. Continuity for ACCs that change categories. Measures capacity offered during the period. Takes network effect into account	Requires proactive input from ANSPs to ensure accurate data. Iterative simulation

Traffic flows can be changed very quickly, so a flexible, dynamic system and a proactive flow manager are essential:

– improved traffic predictability;
– system support for dynamic sectorisation;
– flexible configuration management;
– improved FUA (flexible use of airspace);
– controller multi-sector validation;
– controller support and co-operation.

The 2nd task. Increase sector throughput. Increase sector productivity of congested sectors, by increasing the monitoring value without additional changes, i.e. to allow more aircraft per hour into the same airspace volume before application of ATFM regulation:

– improved civil military coordination and full implementation of FUA;

– improved controller confidence in ATFM (through increased reliability), allowing removal or reduction of declared sector capacity 'buffer';

– reduction in controller workload through reduced complexity through airspace structure development (dualisation of routes, move of conflict points, more balanced workload), implementation of the best practice procedures (reduced coordination, increased efficiency) and enhanced system support (vector prediction, air/ground data link, ground based safety nets);

– application of a structured contingency plan and controller training programme (to allow increased sector throughput during contingency situations).

To restructure congested sectors allowing higher sector throughput, by reorganising an existing group of sectors to optimise the airspace structure; thus retaining the same overall number of sectors, but with generally higher declared sector capacities:

– airspace structure development (planning, design, computer modelling, fast and/or real time simulation);

– dedicated operational planning staff;

– release of active controllers to participate in simulations.

The 3rd task. Increase number of sectors open. Extend sector opening times (when delays occur outside peak period) by means of controllers.

Create additional sectors (when delays occur during the peak period). When delays occur during maximum configuration because existing sectors or sector groups become congested, the creation of additional sectors should be considered:

– operational planning staff;

– airspace structure development (computer modelling, simulation);

– controllers;

– infrastructure (sector suites, system hardware);

– system capability and support (software);

– available frequency with required coverage and protection.

5. Tools for TMA capacity/workload analysis

EUROCONTROL uses special software in conjunction with specialised pre- and post-processors to analyse airspace and airfield systems. With special software generated the aircraft flight, both in the air and on the ground, gathering statistics for each aircraft. These statistics are processed to return aircraft travel and delay times, estimates of sector workload indices, and a graphical animation of the simulation.

The analysis of TMAs is performed according to following indices:

– workload indices for the TMA;

– TMA occupancy results (total aircraft flow through the TMA, peak number of aircraft in the TMA and average aircraft travel time in the TMA);

– holdstack results (total number of aircraft held by holdstack and average and maximum time in the holdstacks);

– aircraft travel and delay time results (average air and ground travel time for arrivals, average air and ground travel time for departures, average air and ground delay time for arrivals and average air and ground delay time for departures);

– gate and departure queue occupancy statistics.

In order to check the statements of ATFM users concerning their objectives, specific performance indicators are used to measure the performance of ground regulations regarding [Review…2008]:

– the prevention of hourly over-deliveries;
– the prevention of traffic bunching.

These indicators have been built to measure for each ground regulation, its ability to contain the incoming traffic flow under a given threshold (expressed in proportion to the requested flow rate) during a given period of time (expressed in relation to the regulation period).

In order to determine TMA capacity/workload and traffic flows, the Eulerian model will need to include the effects of air traffic control actions [Menon et al. 2004]. Moreover, the model will be cast in terms of flow rates and the number of aircraft in the control volume.

The control volume is a one-dimensional entity of a specified length, with aircraft entering at its input and leaving at its output. The air traffic control actions modulate the outflow from the control volume by varying the speeds or by stretching the paths of aircraft inside the control volume.

Let p_j be the number of aircraft in the control volume j at the time instant i. Then the change in the number of aircraft in this control volume can be described by the discrete-time difference equation, [Menon et al. 2004]:

$$p_j(i+1) = p_j(i) + \tau_j[q_{j-1}(i) - q_j(i)].$$

The number of aircraft entering the control volume j from the control volume $j-1$ in a unit interval of time is $q_{j-1}(i)$, and the number of aircraft leaving the control volume is $q_j(i)$. The time step τ_j is computed from the average aircraft speed in the control volume v_j and the control volume dimension Ω_j as $\tau_j = \Omega_j/v_j$. Thus, τ_j is the time that an aircraft takes to transit through the control volume.

Under normal conditions, the air traffic flow rate out of the control volume j will be proportional to the spatial density of air traffic and the average traffic speed:

$$q_j = \frac{v_j p_j}{\Omega}.$$

To control flow through a control volume, the air traffic controller may vary the traffic speed or stretch the paths of the aircraft within the control volume.

Because the Eulerian model does not describe the behaviour of individual aircraft, these effects can be lumped together by the introduction of an air traffic control flow rate $q^{\mathrm{ATC}}{}_j$ to modify the flow rate out of the control volume as [Menon et al. 2004]

$$q_j = \frac{v_j p_j}{\Omega} - q_j^{\mathrm{ATC}}.$$

To satisfy the conservation principle, this negative air traffic flow rate at the output can be added in as an additional inflow into the control volume. Physical limitations dictate an air traffic control flow constraint of the form $0 \le \tau_j q^{\mathrm{ATC}}{}_j \le x_j$, that is, the flow out of a control volume in a time step cannot exceed the number of aircraft in the control volume.

With the foregoing discussions, the discrete-time difference equation for the j-th control volume can be obtained as [Menon et al. 2004]

$$p_j(i+1) = \left(1 - \frac{a_j v_j \tau_j}{\Omega_j}\right) p_j(i) + \tau_j q_j^{\mathrm{ATC}}(i) + \tau_j q_{j-1}(i),$$

$$\tau_j = \frac{\Omega_j}{v_j},$$

$$q_j = \frac{v_j p_j}{\Omega} - q_j^{\mathrm{ATC}}.$$

In the cases where the aircraft are slowing down during descent from cruise conditions, or accelerating to cruise conditions during climb, control volume can be set up to define several constant speed segments to approximate the slowing down and speeding up of air traffic.

The Eulerian model may be recast in a more familiar form by definition of the number of aircraft in the control volume p_j as its state variable x_j, the outflow q_j as the control volume output y_j, and the ATC flow $q^{\mathrm{ATC}}{}_j$ as the control variable u_j. The Eulerian model is now in the form of a linear, discrete-time dynamic system of the form [Menon et al. 2004]

$$x_j(i+1) = a_j x_j(i) + \tau_j u_j(i) + \tau_j y_{j-1}(i),$$

$$y_j(i) = b_j x_j(i) - u_j(i).$$

The Eulerian model is now in a form suitable for analysis by the use of well-known techniques in modern control theory.

6. Air traffic controller task specification

The Airspace Model analyses the progress of each flight as it transits the simulated area in order to detect the ATC (air traffic control) actions necessary to process the flight. In determining these ATC actions, the model is capable of identifying and recording up to 110 different ATC tasks. These tasks are grouped into five main categories [Airspace… 1997; Kerkira…1997]:

1. Flight Data Management (includes tasks of loading, preparing and discarding flight progress strips, etc., and also includes computer updates).
2. Co-ordinations (records co-ordinations between centres (external) and between sectors of the same centre (internal)).
3. Conflict Search (before issuing clearances, the controller searches his/her data to ensure that the action does not jeopardize separation).
4. Routine radiotelephony (includes first and last calls on frequency, position reports, etc.).
5. Radar Tasks (records tactical conflict resolution by the controller - radar supervision and intervention tasks belong in this group).

A radar supervision task occurs when a radar controller identifies a potential conflict between two aircraft and keeps a close surveillance on both aircraft to determine whether a radar intervention is necessary or not.

Basically, the execution times for radar supervisions have been obtained by estimating the duration of the period of surveillance (expressed as a number of radar display updates or turns of the antenna), and the time devoted by the radar controller to the surveillance of a given conflict situation at each update of the display. The Table 2 shows the execution times for the various radar supervisions that have been used in a number of en route simulations.

Table 2. Execution times for the various radar supervisions

Conflict Type	Duration of Surveillance, s	Number of Display Updates	Execution time, s
1	2	10	20
2	2	12	24
3	2	12	24
4	2	15	30
5	3	12	36
6	4	9	36
7	2	9	18
8	3	9	27
9	4	9	36

For certain types of conflict, it is considered that close surveillance by the radar controller would be required, on average, once every two display updates.

List of radar conflict types identified by the airspace model (Table 2), two aircraft on [Airspace…1997]:

– on the same track, at the same flight level and in cruise;

– the same track, one in cruise and the other in climb or descent;

– the same track, both in climb or descent;

– crossing tracks, at the same flight level and in cruise;

– crossing tracks, one in cruise and the other in climb or descent;

– crossing tracks, both in climb or descent;

– opposite tracks, at the same flight level and in cruise;

– opposite tracks, one in cruise and the other in climb or descent;

– opposite tracks, both in climb or descent.

Each task is allocated to different positions in accordance with the sector manning and distribution of duties specified for each sector. In this way the model is able to calculate not only the actual workload on each working position but also the percentage loading on each position, either over the entire simulation period or over certain peak periods.

When specifying the execution time for a task the following principles are followed:

– the execution time for each task is allocated in seconds;

– the time specified is the average duration of time spent on the tasks by a trained controller, ignoring extreme situations which could favourably or unfavourably affect the execution time;

– the execution time is not intended to represent the actual duration of the task, but the amount of time for which the controller is considered to be totally committed to the task to the exclusion of all other tasks;

– in some cases a task may involve more than one control position and different execution times may be allocated to each position;

– different execution times may be assigned to the same task occurring in different sectors.

7. Conclusions

The activities/programs in following areas should be performed in order to improve Ukrainian airspace TMAs capacity under uncertainty conditions: improved controller confidence in ATFM (enhanced tactical flow management services and implement collaborative flight planning), dynamic sectorisation and flexible configuration management, Improved civil military coordination with full implementation of FUA (extend FUA with dynamic airspace management and implement collaborative civil-military airspace planning at European level), reduction in controller workload (implement arrival management tools, implement automated support for departure management and implement automated support for conflict resolution) and airspace structure development.

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В.П. Харченко[1], Ю.В. Чинченко[2]. Принципи вдосконалення управління потоками повітряного руху та пропускною спроможністю в термінальних диспетчерських районах в умовах невизначеності

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Розглянуто показники потоків повітряного руху, фактори невизначеності та управління потоками повітряного руху в термінальних диспетчерських районах. Запропоновано рекомендації щодо аеронавігаційної системи України.

Ключові слова: аеронавігаційна система; безпека польотів; організація повітряного руху; статистика потоків повітряного руху; термінальний диспетчерський район; умови невизначеності; управління потоками повітряного руху та пропускною спроможністю.

В.П. Харченко[1], Ю.В. Чинченко[2]. Принципы усовершенствования управления потоками воздушного движения и пропускной способностью в терминальных диспетчерских районах в условиях неопределенности

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Рассмотрены показатели потоков воздушного движения, факторы неопределенности и управления потоками воздушного движения в терминальных диспетчерских районах. Предложены рекомендации для аэронавигационной системы Украины.

Ключевые слова: аэронавигационная система; безопасность полетов; организация воздушного движения; статистика потоков воздушного движения; терминальный диспетчерский район; управление потоками воздушного движения и пропускной способностью; условия неопределенности.

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