14th Air Transport Research Society Conference
Porto, Portugal, July 6-9, 2010.

CONFLICT RISK ASSESSMENT MODEL FOR AIRSPACE STRATEGIC PLANNING

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ABSTRACT - This paper presents a conflict risk assessment model developed for the purposes of airspace strategic planning. The model is intended for comparison and sensitivity analysis of different airspace design and organization scenarios under different traffic flow levels. Risk is assessed using two variables: probability of conflict occurrences and number of conflicts in the observed airspace under given circumstances. The model is based on the concept of critical sections which are traversed by the aircraft during level flight or climb or descent through them. Critical time values estimated by the critical section length as well as total duration of flight through the given airspace are used to define the probability of conflict. The number of conflicts is defined as the product of conflict probability and estimated traffic flows for the given airways. Final values for conflict numbers are determined taking into account all available flight levels and airway combinations in the given airspace. The developed model enables analysis of separation reduction influence on conflict risk and could be used in both en-route and terminal manoeuvring airspace.

KEYWORDS - Risk Assessment, Aviation Safety, Air Traffic Control, Air Traffic Management.

This research has been conducted with support from the project No. 15023 commissioned by the Ministry of Science and Technological Development of Republic of Serbia.

I. INTRODUCTION

The air transport system is recognized as one of the fastest growing areas within the transport sector as well as in overall regional and world economies. Physically and operationally, the air transport system is a rather complex system with the main components - airlines, airports and air traffic control services - interacting with each other on different hierarchical levels, constituting a very complicated, highly distributed network of human operators, procedures and technical/technological systems. In particular, risk of accidents and related safety in such a complex system is crucially influenced by interactions between the various components and elements (Netjasov, Janic, 2008a, 2008b). This implies that providing a satisfactory level of safety (i.e., low risk of accident) is more than assuring that each of the components and elements functions safely (Blom et al, 1998). Due to such inherent complexity and severe consequences of accidents, risk and safety have always been considered as issues of the greatest importance for the contemporary air transport system (Janic, 2000). Consequently, they have been a matter of continuous research from different aspects and perspectives ranging from the purely technical/technological to the strictly institutional. In general, the former have dealt with design of safe aircraft and other system facilities and equipment. The later have implied setting up adequate regulations for system design and operations (Netjasov, Janic, 2008a, 2008b).

The system infrastructure – airports and Air Traffic Control/Management (ATC/ATM) system, although in many cases acting as temporal “bottlenecks”, are expected to be able to support such growth safely, efficiently and effectively. This research is concentrated on ATC/ATM system, i.e. on airspace planning. Ultimate, i.e. unconstrained airspace capacity, given as number of flights per hour, depends on traffic flows on certain or all airways, as well as the applied aircraft separation minima. One of the possibilities to increase airspace capacity is to reduce separation minima. This possibility is driven by the fact that suitable communication, navigation and surveillance (COM/NAV/SUR) technology already exist (Blom et al, 1998). Separation minima reductions will, on one side increase the traffic throughput, but on the other side will affect the safety of the aircraft operations, probably decreasing it. This is why it is necessary to develop a model that will help assess safety of such a change and make a certain balance between the increase of capacity and the unwanted decrease of safety.

The aim of the research described in this paper is to develop a risk assessment model for airspace planning purposes, considering airspace design and organization at the strategic planning level, i.e. airspace sectorization and route network development. Data about forecasted or estimated traffic flows is used on the strategic level as the traffic demand indicator. From the supply side, data about airspace and corresponding network of airways is used. Flight exposure to conflict situations, which are represented by the average number of potential conflict situations and probability of conflict occurrence, serves as a risk and safety indicator on this planning level. The presented model is inspired by the work of Siddiqee (1973, 1974) and Schmidt (1977).

This paper is organized as follows. Section II describes the review of collision risk modelling approaches. Section III provides a modelling framework. Next, Section IV explains the development of a conflict risk assessment model for airspace strategic planning. Section V illustrates the application of developed model in case of a hypothetic and real en-route example. Section VI draws conclusions and presents further research directions.

II. RISK MODELLING APPROACHES

One of the principal matters of concern in the daily operation of civil aviation is preventing conflicts between aircraft either while airborne or on the ground, which might escalate to collision. Although aircraft collisions have actually been very rare, events contributing to a very small proportion of the total fatalities, they have always caused relatively strong impact mainly due to relatively large number of fatalities per single event and complete destruction of the aircraft involved (Netjasov, Janic, 2008a, 2008b).

The main driving force for developing risk methods/models during the 1960's was the need for increasing airspace capacity over Atlantic through decreasing aircraft separation minima. In general, separating aircraft using space and time separation standards (minima) has prevented conflicts and collisions. However, due to reduction of this separation in order to increase airspace capacity and thus cope with growing air transport demand, assessment of the risk of conflicts and collisions under such conditions has been investigated using several important methods/models. The methods/models were expected to show if reduction of separation and spacing between the flight tracks would be sufficiently safe, i.e., determine the appropriate spacing between tracks guaranteeing a given level of safety. Following methods/models were in use (Netjasov, Janic, 2008a, 2008b):

- The Reich-Marks model is developed in early 1960's by Royal Aircraft Establishment, UK (Reich, 1966). It is based on the assumption that there are random deviations of both aircraft positions and speeds from the expected. The model was developed to estimate the collision risk for flights over the North Atlantic and consequently to specify appropriate separation rules for the flight trajectories (Shortle et al, 2004). The model computed the probability of aircraft proximity and the conditional probability of collision given the proximity (Machol 1995; FAA/EUROCONTROL 1998);
- The Machol-Reich model was developed after the ICAO had established the NAT SPG (North Atlantic System Planning Group) in 1966 with the idea of creating the Reich-Marks model as the workable tool as well as increase of airspace capacity. Consequently, the ICAO NAT SPG has adopted the threshold for risk of collision of two aircraft due to the loss of planned separation (Machol 1975, 1995);
- The intersection models belong to the simplest collision risk models. They are based on assumptions that aircraft follow pre-determined crossing trajectories at constant speeds. The probability of a collision at the crossing point is computed using the intensities of traffic flows on each trajectory, aircraft speeds, and the airplane geometry (Siddiqee, 1973; Geisinger, 1985; Barnett, 2000);
- The geometric conflict models are similar to the intersection models. In these models (developed in 1990's) the speed of any two aircraft is constant, but their initial three-dimensional positions are random. The conflict occurs when two aircraft are closer than the prescribed separation rules (Paielli, Erzberger, 1997, 1999; Irvine, 2002);
- Generalized Reich model was developed by removing restrictive assumptions of Reich model based on the fact that Reich model does not adequately cover some real air traffic situations. Such a generalized collision model was developed during 1990's and has been used as part of the TOPAZ (Traffic Optimization and Perturbation AnalyZer) methodology (Blom et al, 1998, 2003; Shortle et al, 2004; Bakker, Blom, 1993; Blom, Bakker, 2002; Bakker et al, 2000).

The collision risk methods/models have gradually been developed from Marks, Reich and Machol to the latest versions used in TOPAZ methodology. The main purpose has always remained to support decision-making processes during system planning and development through evaluation of the risk and safety of proposed changes (either in the existing or new system). Some problems, recommendations and relations of mentioned models with new technology are described in (Netjasov, Janic, 2008a, 2008b).

III. RISK MODELLING FRAMEWORK

Basic idea of the research presented in this paper is that different planning levels in ATC/ATM are requiring different models for risk assessment. A modelling framework containing three planning levels (strategic, tactical and operational) is proposed in this paper. For each of three planning levels necessary inputs are listed and possible types of models are proposed (Table I). In following text, a framework is described separately for each planning level.

TABLE I. INPUTS FOR RISK ASSESSMENT VS. PLANNING LEVELS

Planning level	Inputs	Nature of the Models
Strategic	- fixed airway network; - assumed aircraft fleet; - estimated traffic flows per airway; - average ground speed per traffic flow; - given separation criteria (horizontal and vertical).	Analytical
Tactical	- fixed airway network; - known aircraft fleet; - known temporal and spatial distribution of aircraft on airways; - average ground speed per aircraft type; - given separation criteria (horizontal and vertical); - ground and airborne systems characteristics.	Simulation
Operational	- fixed airway network; - known aircraft fleet; - known temporal and spatial distribution of aircraft on airways; - average ground speed per aircraft type; - given separation criteria (horizontal and vertical); - ground and airborne systems failure rates; - operational procedures followed (ATC vs. pilots); - human factor issues included (situation awareness, workload, fatigue, …).	Simulation (Petri Nets)

A. Risk assessment model for application at strategic planning level

For the purpose of ATC/ATM planning at the strategic level (a year or more in advance), data on forecasted (estimated) traffic flows is used as a traffic demand indicator. On the other hand, the supply side is represented by the airspace geometry (sectors or terminal manoeuvring areas – TMAs) which is characterised by the number and spatial distribution of available airways, as well as available number of flight levels (FL). Airspace capacity is approximated by the traffic flow on some or all airways, which depends on the applied separation rules. The influence of Humans – operators (pilots, air traffic controllers, etc.) is not considered at this level.

On the strategic planning level it is possible to consider the total risk of conflict situations or risk of collision in a given airspace. A model can be used for comparison of alternative airspace design scenarios (e.g. sectorization), as well as for comparison of alternative airway networks from a risk and safety point of view.

B. Risk assessment model for application at the tactical planning level

For the purpose of ATC/ATM planning at the tactical level (e.g. for one season in advance) data about seasonal traffic schedules with designated aircraft types is used as a traffic demand indicator. The supply is similar to the case of strategic planning represented by airspace geometry, but also with equipment characteristics (e.g. aircraft position update rate as feature of surveillance radar). Airspace capacity is approximated by the traffic flow on some or all airways, which depends on the applied separation rules. Influence of Humans – operators (pilots, air traffic controllers, etc.) is not considered at this level.

At the tactical level we are concerned with conflict exposure situations (expressed by duration of single or all conflict situations) and the severity of conflict situations (expressed by the closest point of approach between two aircraft). A model could serve for comparison of different alternative scenarios of operational airspace sectorization from a risk and safety point of view.

C. Risk assessment model for application at operational planning level

On the operational level (one or more days in advance) actual traffic data is used (aircraft types, entry/exit times in/from system) as traffic demand indicators. Also data on aircraft behaviour during the flight, reliability of certain aircraft technical parts, etc. are used. Supply is similar to the previous cases, represented with airspace geometry, but also by characteristics of the COM/NAV/SUR system equipment (technical characteristics and reliability). System capacity is approximated by the traffic flow on some or all airways, which depends on the applied separation rules. Influence of Humans – operators (pilots, air traffic controllers, etc.) at this level is considered through their behaviour, i.e. state (situational awareness, workload, etc.).

At the operational level we are concerned with the exposure (expressed by duration of single or all conflict situations) and severity (expressed by closest point of approach between two aircraft) of conflict situations. A model could serve for comparison of different alternative operational scenarios (different separation rules, delegation of responsibility between pilots and air traffic controllers, etc.) from a risk and safety point of view.

D. Resume

It is apparent from the proposed modelling framework that by approaching the operational planning level models become more detailed and complicated (i.e. level of abstraction is smaller due to availability of specific information) as well as their nature changes (analytical vs. simulation). All models could be applied for both en-route and TMA airspaces.

IV. The Conflict Risk Assessment Model for Application at Strategic Planning Level

A. Objectives And Assumptions

The main objective of this research is to develop a method for risk assessment, which could be used for estimating alternative solutions of the airspace (re)design aiming to increase available airspace capacity. The main starting point is that risk depends on airspace geometry (static element) and air traffic using it (dynamic element). Because of their inherently generic structure, this model could be used as follows:

- Planning purposes at strategic level, i.e. initial assessment of risk and safety of the current, transitional, and future airspace, following slight modifications (in the process of re-planning and re-design of the given airspace); and
- Evaluation of technical/technological feasibility of alternative airspace design, supported by particular technologies.

The following assumptions are introduced in developing the method for safety assessment:

- Airspace geometry and characteristics are known (number and length of the airways, number of intersecting points, available flight levels, etc.);
- Traffic characteristics are known (distribution of traffic flows, portion of level flights vs. climb/descent flights, fraction of specific aircraft category in total traffic volume);
- Human operator’s issues (pilots and air traffic controllers) are not considered.

B. Development of the Model

The model developed in this research is of macroscopic nature. It looks at a given portion of the airspace (en-route sector or terminal manoeuvring area - TMA) and focuses on the geometry of airways. Also, it uses data regarding forecasted traffic flows on specific airways.

Let us consider an airway *i* (i = 1, …, n) of length D_i in the given airspace (sector). It contains *r* flight levels (FL) (r = 1, …, s), vertically separated by 1000 ft. Airways can be uni-directional or bi-directional. Applied horizontal separation (both longitudinal and lateral) is S_{min} and vertical H_{min}. Further, let us assume that the aircraft fleet flying through this airspace consists of *k* aircraft classes (wake turbulence classes) and they are flying along route *i* in either level flight (cruising phase) or they are climbing/descending. The fraction of the aircraft in the fleet mix is given by p_k (k = 1, …, m) and the fraction in different flight phase by p_l (l = 1, …, u).

The model is based on identification of conflict situations and calculation of potential conflict occurrence probabilities. For the purpose of the conflict identification a critical section length and flying time through it (critical time) are defined. Knowledge about the critical time and flight duration through the given airspace allows for the calculation of the probability of conflict occurrence. The average hourly number of conflicts could be estimated by multiplying the obtained probability with hourly traffic flows through the intersecting or non-intersecting airways.

1) Critical Section Length

A conflict situation is a situation when two aircraft come closer then a specified minimum distance both in horizontal and vertical plane. In order to determine whether or not conflict situation exist a cylinder-shaped "forbidden volume" is defined around the aircraft, the dimensions of which are determined by the minimum horizontal S_{min} and vertical separation H_{min} (Figure 1). A potential conflict situation exists between two aircraft if one of them enters the other's forbidden volume. Conflicts could be of crossing or overtaking type, depending on the aircraft trajectory relations.

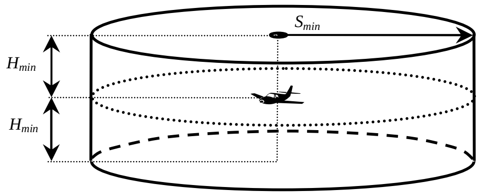

Figure 1. Forbidden volume around an aircraft

Let us consider the situation when two aircraft are flying on the same level and their trajectories are intersecting in horizontal plane, with intersection angle α (Figure 2). Let the speeds of both aircraft be the same V_h. The questions arises, if *Aircraft 1* is in intersection point *O* where *Aircraft 2* should be at the same time in order that (Siddiqee, 1974): a potential conflict is not occurring at this moment, will not develop in some further moment; and would not have occurred in the some previous moment?

In order to answer those questions a "critical section" was defined and its length was determined. The length depends on the plane in which the potential conflicts has occurred (horizontal or vertical) and on the flight phase combination (level flight, climb, descent). In Figure 2 a critical section in the horizontal plane (level flight vs. level flight) is shown. Critical section length for this case d_h (segment X_h-O-Y_h) can be calculated using the following expression:

$$d_h = \frac{2 \cdot S_{min}}{sin\alpha} \tag{1}$$

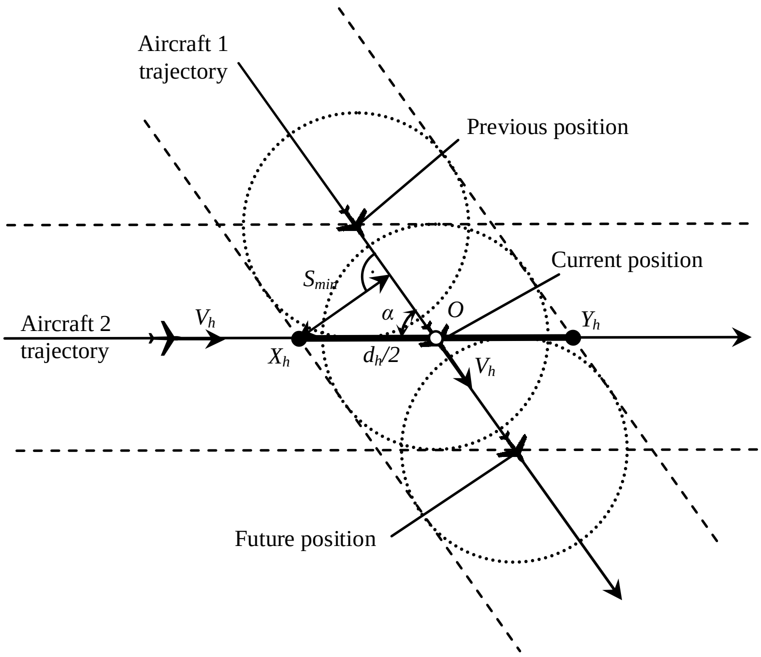

Figure 2. Critical section X_h-O-Y_h in the horizontal plane

2) Critical Time

In general case, if we assume that the average ground speed of the aircraft is V then, in the general case, an aircraft will traverse the critical section length by some average critical time τ. The average time during which an aircraft occupies the critical segment of another trajectory depends on the combination of flights. In case when both aircraft are flying at the same level (horizontal plain) critical time τ_h can be estimated as follows (Figure 2):

$$\tau_h = \frac{2 \cdot S_{\min}}{V_h \cdot sin\alpha} \tag{2}$$

3) Conflict probability

Knowing the length D_i of airway i in the given airspace and average ground speed V, flight time t^i through the airspace over airway i can be calculated. During the flight, aircraft passes through the critical section in time τ^i. The ratio between critical time τ^i and flight time t^i represents the probability of the critical section occupancy $P_{occ}{}^i$. Similarly, for airway j intersecting with airway i, we can calculate t^j and $P_{occ}{}^j$.

The conflict can occur when both aircraft from airway i and j are inside the critical section of the corresponding airways. Assuming that occupancies of critical sections are mutually independent events, the probability of conflict occurrence P_c can be calculated using the following expression:

$$P_c = P_{occ}{}^i \cdot P_{occ}{}^j \tag{3}$$

Theoretically, if we let $S_{min} \rightarrow 0$ and $H_{min} \rightarrow 0$, capacity will increase infinitely and P_c will become accident or collision probability P_a in the following expression:

$$\lim_{\substack{S_{\min}\to 0 \\ H_{\min}\to 0}} P_c = P_a \tag{4}$$

4) Risk of Conflict

In the situation when an aircraft flying on trajectory *i* occupy the critical length of trajectory *j*, a potential for the occurrence of a conflict situation with aircraft flying on trajectory *j* exists. This potential is higher if the traffic flow from trajectory *j* is higher. The situation is worsened when we take into account the traffic flows from both trajectories.

If we assume that traffic is uniformly distributed along the airway *i*, and that the aircraft are flying with an average ground speed $\overline{V}_h$ on given FL, then the average maximum traffic flow Q_i^{max} per one FL could be estimated by the following equation:

$$Q_i^{\max} = \frac{\overline{V_h}}{S_{min}} \tag{5}$$

For the known average maximum traffic flows on both trajectories Q_i^{max} and Q_j^{max} we can estimate the average maximum number of crossing conflicts per hour N_c^{max} for that intersection point, at given FL:

$$N_c^{max} = Q_i^{max} \cdot Q_j^{max} \cdot P_c \tag{6}$$

The product of traffic flows in expression for N_c^{max} represents the maximum number of aircraft pairs (one aircraft belongs to flow *i*, the other to flow *j*) which could enter into a crossing conflict situation.

In this research, the risk is considered as the product of the probability (or frequency of occurrence) and the magnitude of consequences (or severity) of a hazardous event (Bahr, 1997). According to that definition it is assumed that the average number of crossing conflicts per hour N_c (where is $0 \leq N_c \leq N_c^{max}$) represents the risk of conflict. This is also in line with some results of previous research such as those of Geisinger (1985). In the case of overtaking conflicts, expression (6) becomes simpler.

5) Model Extension

a) Multiple Trajectories Intersection

The situation is made more complicated if the number of trajectories intersecting at one point is increased. Conflict between aircraft can occur at the intersection point for any possible pair of intersecting airways.

An illustration is given in Figure 3 and corresponds to a single FL where $\alpha_{i,i-1}$, α_i, and $\alpha_{i,i+1}$ represents angles between corresponding inbound trajectories to intersection point *O* and γ angle between outbound trajectories. Points E_{i-1}, E_i, E_{i+1} represent entry points into the sector and $E_{i'}$, $E_{i'+1}$ are exit points from it.

For each airway pair a probability of conflict can be estimated. The total probability of conflict P^O_c at intersection point *O*, at the given FL can be estimated using the following expression:

$$P_c^O = \sum_{i=1}^{m-1} \sum_{q=i+1}^{m} P_{c_{iq}} \tag{7}$$

where: $p_{c_{iq}}$ is conflict probability between trajectories *i* and *q* ($q \in (i+1,m)$).

Similarly, a total number of conflicts N^O_c is estimated:

$$N_c^O = \sum_{i=1}^{m-1} \sum_{q=i+1}^{m} N_{c_{iq}} \tag{8}$$

where: Nc_{iq} is the average number of conflicts at the intersection point O between trajectories i and q ($q \in (i+1,m)$).

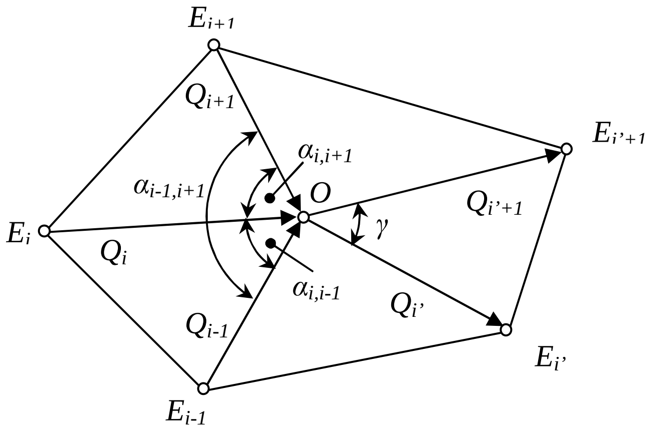

Figure 3. Intersection point O with three inbound and two outbound trajectories. Traffic flows are dependent (intersecting)

b) *Dependant and Independent Airways*

Usually, in a given airspace a numerous dependant airways appear, creating the set with a finite number of intersecting points. So, crossing conflict can appear at every intersecting point. The total number of crossing conflicts per given airspace for all intersecting points $N_c^{T,dep}$ can be estimated using the following expression[1]:

$$N_c^{T,dep} = \sum_{O \in INT} N_c^O \tag{9}$$

where: INT is the set of intersecting points O contained in the given airspace at the given FL. Illustration is given on Figure 3.

In the case of independent airways, an overtaking conflict can appear on each airway. A reference plane is established in order to identify an overtaking conflict (Janic, Tosic, 1991). The total number of overtaking conflicts per given airspace $N_c^{T,indep}$ can be estimated using the following expression:

$$N_c^{T,indep} = \sum_{R_i \in RP} N_c^{R_i} \tag{10}$$

where: $N^{R_i}_c$ is the total number of overtaking conflicts per airway i and the given FL in the case of independent airways; RP is the set of points R_i belonging to the reference plane and within the given airspace, at given FL.

An illustration is given in Figure 4 and corresponds to a single FL. Flows Q_i, Q_{i+1} represent the inbound traffic flow on reference plane, and $Q_{i'}$ and $Q_{i'+1}$ are the outbound flows. Points E_i and E_{i+1} represent entry points into the sector, and $E_{i'}$ and $E_{i'+1}$ are exit points from it.

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[1] Risk is additive according to Campbell (2005).

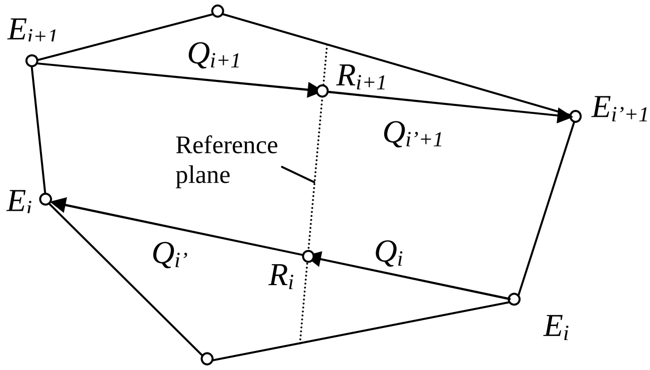

Figure 4. A sector with independent (non-intersecting) flows

c) Number of Flight Levels

Taking into account the fact that one airway contains several flight levels *r*, a total number of conflicts for all available flight levels per given airspace N_c^{air} can be estimated using the following expression:

$$N_c^{air} = \sum_{r \in F} (N_c^{T,dep} + N_c^{T,indep}) \tag{11}$$

where: *F* is the set of available FL's contained in the given airspace.

V. Illustration of the Model Application

In order to illustrate the developed model, two examples are considered: a) a hypothetic en-route sector which was used for sensitivity analysis; and b) a real en-route sector which was used to calculate a risk in a given airspace in peak hour.

A. Hypothetic En-route Sector

The sector (Figure 5) contains two uni-directional and one bi-directional airway as well as four flight levels (e.g. FL320, 330, 340, 350). Total traffic flow through the given sector is Q=28 aircraft/hour of which Q_1=Q_2=10 aircraft/hour on both airway AWY_1 and AWY_2, respectively, and Q_3=8 aircraft/hour on AWY_3. The airways are mutually dependant creating two intersection points $O_{1,3}$ and $O_{2,3}$. The lengths of the airways are: 180 nm, 195 nm and 210 nm respectively for airways AWY_1, AWY_2 and AWY_3.

Average aircraft ground speeds are 450 kt on AWY_1 and AWY_2 and 400 kt on AWY_3. The sector defined in such a way is used as a baseline for sensitivity analysis in further scenarios which analyze the impact of changes in demand (traffic volume) and supply (sector geometry). Distribution of aircraft on FL's, in each airway, is given in the Table II.

TABLE II. Distribution of aircraft on FL's

Airways	Flight levels			
	FL320	FL330	FL340	FL350
AWY_1	0	50%	0	50%
AWY_2	50%	0	50%	0
AWY_3	30%	30%	20%	20%

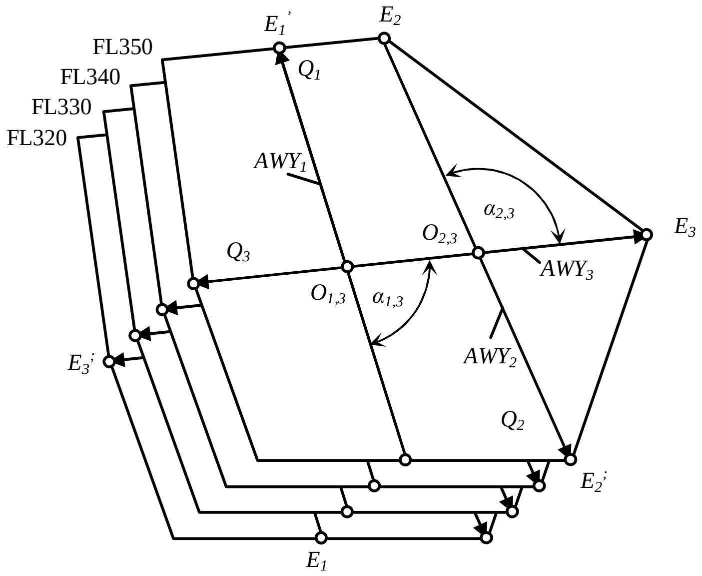

Figure 5. Sector geometry

1) Scenario 1 – Demand change

Traffic flow on AWY_3 is varied in order to see how sensitive risk values are to demand change. For illustration purposes traffic flow values of Q_3 = 1, 4 and 8 aircraft/hour are considered. S_{min} values are also varied taking the following values: 10, 5, 3 and 0.038[2] nm while H_{min} was unchanged (1000 ft).

Figure 6 represents the hourly number of conflicts (risk) for the given sector dependent on traffic flow on AWY_3. It can be observed from figure that an increase of traffic flow as well as S_{min} yields an increase of hourly number of potential conflicts. This fact is in relation with the conclusions of some previous papers (Datta, Oliver, 1991; Sherali et al, 2000; Willemain, 2003). In the case of separation minima equal to 0.038 nm, obtained result presents an hourly number of potential collisions and their values are $6.01 \cdot 10^{-7}$, $2.74 \cdot 10^{-6}$, $6.39 \cdot 10^{-6}$ for Q_3 = 1, 4 and 8 aircraft/hour, respectively.

2) Scenario 2 – Supply change

Length of AWY_3 is used to represent a supply side change. Changing the length of the airway, it is assumed the shape of the airspace is also changed. Length of D_3 = 60, 135 and 210 nm are considered for illustration purposes. Separation minima values are the same as in Scenario 1.

Figure 7 represents the hourly number of conflicts for the given sector, dependent on airway length D_3. It can be observed that an increase in airway length as well as decrease of S_{min} produce decrease of hourly number of conflicts for unchanged demand. This fact is in relation with the conclusions of some previous work (Datta, Oliver, 1991; Sherali et al, 2000). In the case of separation minima equal to 0.038 nm, the obtained result presents hourly numbers of potential collisions and their values are $2.24 \cdot 10^{-5}$, $9.94 \cdot 10^{-6}$ and $6.39 \cdot 10^{-6}$ for D_3 = 60, 135 and 210 nm respectively.

This experiment shows that an increase in traffic demand a without change of infrastructure (sector volume and airway length) leads to higher risk of conflict. Similarly, increases in sector volumes and airway lengths, without a change in traffic demand, lead to a decrease of the risk of conflict. Balancing infrastructure changes together with traffic demand changes could enable a reduction of conflict risk, while increasing airspace capacity at the same time.

[2] Current longitudinal separation minima values in en-route and TMA airspaces are 3, 5 and 10 nm. Value of 0.038 nm represents a dimension of an aircraft (approximately of 70 m in length and wing span).

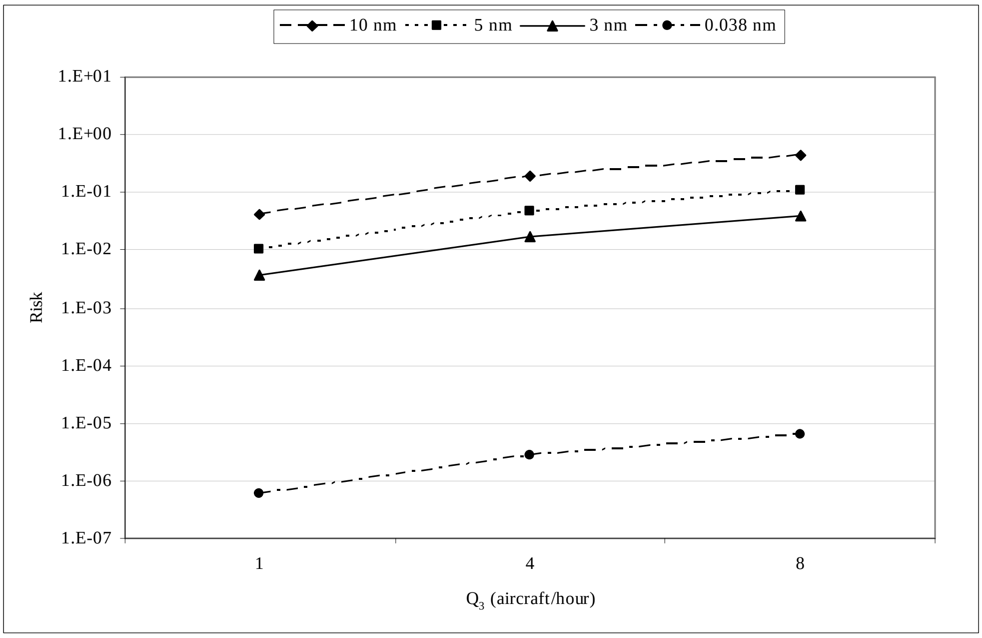

Figure 6. Hourly number of conflicts (risk) for the given sector dependent on traffic flow on AWY_3

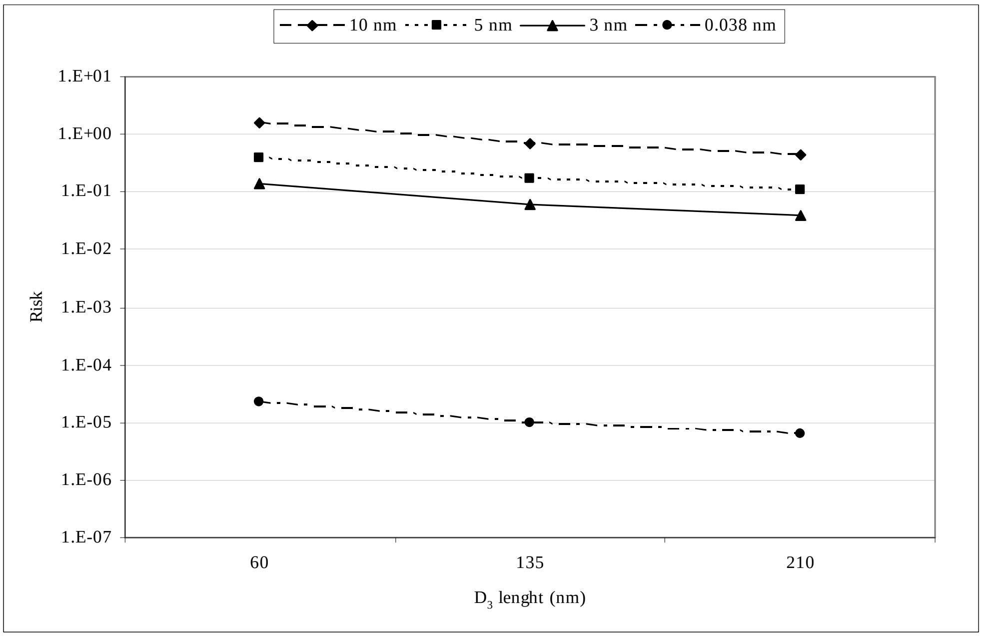

Figure 7. Hourly number of conflicts (risk) for the given sector dependent on length D_3

B. Real En-route Sector

The North-East sector of the Serbian airspace is chosen to illustrate how to determine a risk in a given airspace during a given period of time. The airway structure, entry/exit points as well as traffic load are presented in Figure 8. Traffic load of 22 aircraft per hour represents a highest hourly load on a peak day in 2005.

Also, it is assumed that the average aircraft speed is 430kt and that aircraft do not change FL during flight. Distribution of traffic on airways and FLs, together with lengths of airways, is given in Table III.

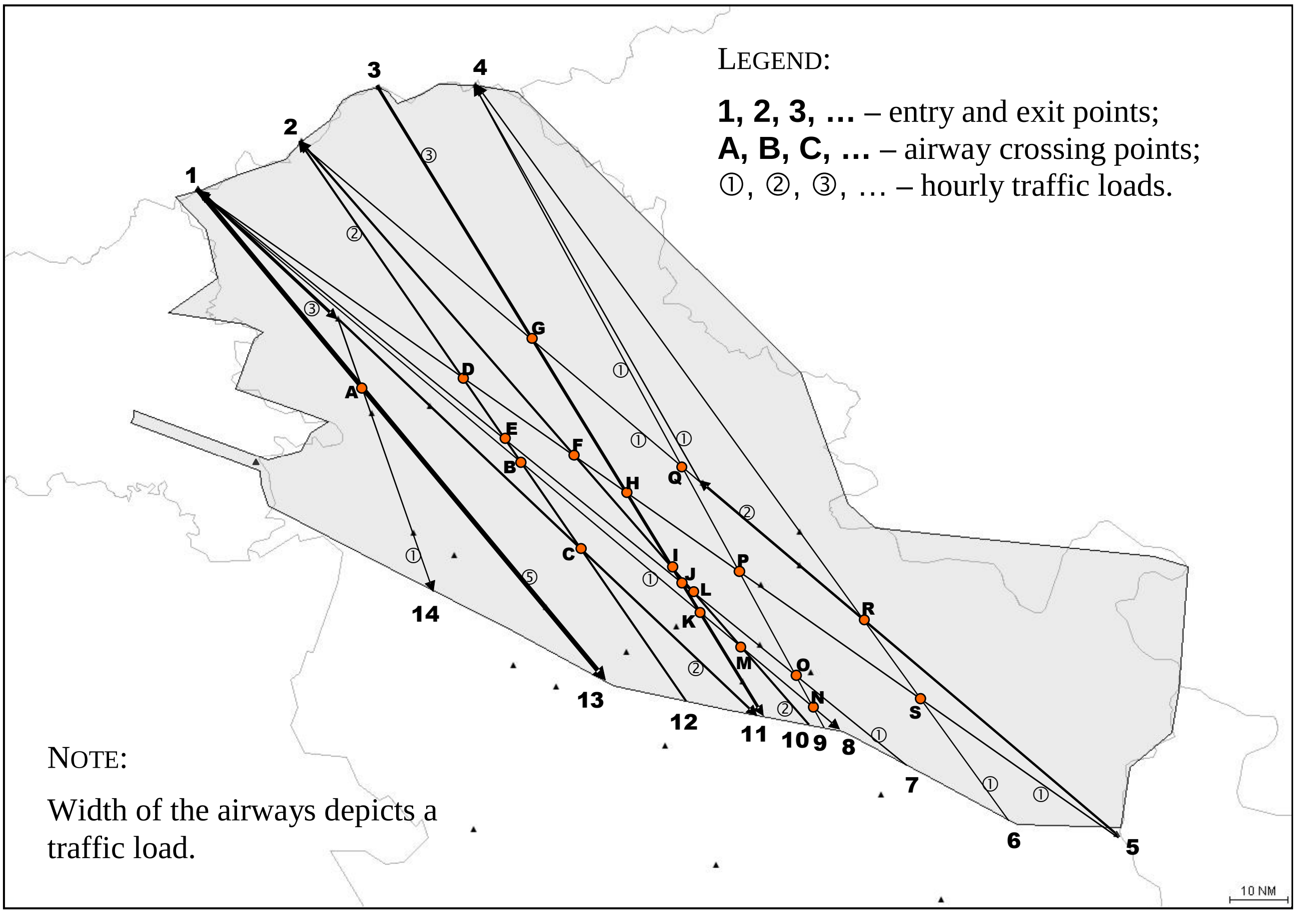

Figure 8. Sector North-East

The results are presented in Table IV. Table IV contains a probability of conflict for each crossing point and the corresponding value of risk of conflict for various S_{min} values (10, 5, 3, 0.038 nm). Accepting the assumption that risk is cumulative (Campbell, 2005) the total risk per sector is calculated (Table IV) and presented in Figure 10, as well as the functional relationship between risk and separation minima for given example.

It is apparent from Table IV that at certain airway crossing point probability of conflict exists but this doesn't mean that risk exists. If there is no traffic, there is no risk. However, the fact that traffic fluctuates over time lead us to the conclusion that risk values are not constant and that they too change in time.

The probability figures in Table IV can also serve to identify the airway crossing with the highest probability of conflict, i.e. with highest potential to have the highest risk. Also, from the same table it can be seen how the risk is allocated among the set of airway crossings for a given input condition.

Therefore, the change of the traffic flows over time produces a changes of the individual (risk per airway crossing point) and total risk values as well as changes in risk allocation within the given airway network.

TABLE III. DISTRIBUTION OF TRAFFIC ON AIRWAYS AND FL'S

Routes	Route length (nm)	Average flight time t_d (sec)	Hourly traffic load	Traffic distribution on FL's			
				FL320	FL330	FL340	FL350
1-8	141.98	1188	1	-	-	-	1
1-11	130.29	1090	2	-	1	-	1
1-13	109.22	914	5	-	3	-	2
1-14	82.57	691	1	-	1	-	0
3-11	127.59	1068	3	-	1	-	2
5-1	195.65	1638	1	1	-	-	-
5-2	187.19	1567	1	-	-	1	-
5-4	175.58	1470	1	-	-	1	-
6-4	145.13	1215	1	-	-	1	-
7-1	154.45	1293	1	1	-	-	-
9-4	125.92	1054	1	-	-	1	-
10-2	134.02	1122	2	-	-	2	-
12-2	118.39	991	2	1	-	1	-

TABLE IV. CONFLICT PROBABILITY AND RISK VS. SEPARATION MINIMA

Point	Conflict probability				Risk			
	10 nm	5 nm	3 nm	0.038 nm	10 nm	5 nm	3 nm	0.038 nm
A	3.79 E-01	9.48 E-02	3.41 E-02	5.47 E-06	1.14 E+00	2.84 E-01	1.02 E-01	1.64 E-05
B	3.55 E-01	8.88 E-02	3.20 E-02	5.13 E-06	0	0	0	0
C	6.00 E-01	1.50 E-01	5.40 E-02	8.66 E-06	0	0	0	0
D	1.70 E-01	4.26 E-02	1.53 E-02	2.46 E-06	1.70 E-01	4.26 E-02	1.53 E-02	2.46 E-06
E	2.27 E-01	5.68 E-02	2.05 E-02	3.28 E-06	2.27 E-01	5.68 E-02	2.05 E-02	3.28 E-06
F	2.61 E-01	6.52 E-02	2.35 E-02	3.76 E-06	0	0	0	0
G	1.75 E-01	4.38 E-02	1.58 E-02	2.53 E-06	0	0	0	0
H	9.69 E-02	2.42 E-02	8.72 E-03	1.40 E-06	0	0	0	0
I	7.76 E-01	1.94 E-01	6.98 E-02	1.12 E-05	0	0	0	0
J	5.58 E-01	1.39 E-01	5.02 E-02	8.05 E-06	0	0	0	0
K	2.08 E-01	5.21 E-02	1.87 E-02	3.01 E-06	4.17 E-01	1.04 E-01	3.75 E-02	6.02 E-06
L	6.41 E-01	1.60 E-01	5.77 E-02	9.25 E-06	0	0	0	0
M	8.59 E-01	2.15 E-01	7.73 E-02	1.24 E-05	0	0	0	0
N	1.59 E-01	3.99 E-02	1.43 E-02	2.30 E-06	0	0	0	0
O	1.35 E-01	3.37 E-02	1.21 E-02	1.95 E-06	0	0	0	0
P	7.88 E-02	1.97 E-02	7.09 E-03	1.14 E-06	0	0	0	0
Q	1.32 E-01	3.30 E-02	1.19 E-02	1.91 E-06	1.32 E-01	3.30 E-02	1.19 E-02	1.91 E-06
R	2.52 E-01	6.29 E-02	2.26 E-02	3.63 E-06	2.52 E-01	6.29 E-02	2.26 E-02	3.63 E-06
S	1.33 E-01	3.32 E-02	1.20 E-02	1.92 E-06	0	0	0	0
Total Risk					2.34 E+00	5.84 E-01	2.10 E-01	3.37 E-05

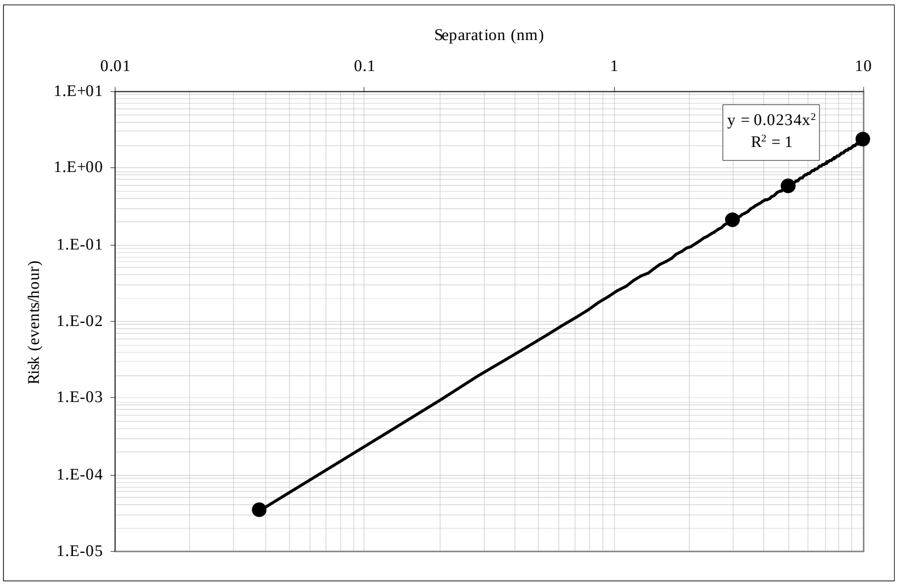

Figure 9. Total Risk vs. Separation minima

VI. CONCLUSION

The aim of the developed risk assessment model is to be used for comparison purposes at the strategic planning level. Namely, during the process of airspace design and organization one can seek to find design with lower risk of conflict and higher capacity. The model developed in this research allows for the estimation of the number of conflicts at intersections or along airways as well as probability of conflicts. Also, the model allows for the determination of the most suitable combination of demand and supply which will be balanced with risk and capacity requirements (less risk, more capacity). The model is intended for use both in en-route as well as TMA's airspace. Further research will consider application of the developed model on real life cases as well as development of planning models for tactical and operational levels.

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