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Conflict Risk Assessment Based Framework for Airspace Planning and Design

Fedja Netjasov

Abstract

This chapter presents a conflict risk assessment based framework for airspace planning and design developed for the purpose of preventing aircraft conflicts and collisions. During airspace planning and design process, airspace designers are often guided by the need to increase capacity and/or reduce air traffic controller (ATCo) workload. In order to consider safety risks in a systematic way, the proposed framework contains an additional step—safety risk assessment, performed by safety analysts guided by the risk reduction need. In such a way, they are providing feedback to airspace designers regarding safety issues of their solutions. This chapter presents four conflict risk assessment models, each one developed for different airspace planning level (strategic, tactical, operational, and current day) contained in the proposed framework. Basic development principles for every model were explained together with specific objectives, assumptions, conflict risk concepts, and required input data. Models are illustrated by the simple numerical examples.

Keywords: conflict risk assessment, airspace planning, airspace design, air traffic control, aviation safety

1. Introduction

Air traffic is growing with an average annual rate of about 4–5% in the last 30 years [1, 2]. The increase of the air traffic volume in Europe up to 2050 is forecasted in the European Commission (EC) document “Flightpath 2050” [2] to be almost a threefold relative to the year 2011 (25 million commercial flights in 2050 relative to 9.4 million expected in 2011), i.e., with an expected average annual rate of about 4%. Also, an increase of 25% in aircraft operations is predicted up to 2039 relative to 2019 in the USA [3], i.e., 1,25% annually in average. Simultaneously, an increased level of safety is required [2].

In order to accommodate such a growth, a development of new air traffic operational concepts is expected [4]. But accommodation of growing traffic with requirement to increase safety presents a significant challenge for the research and scientific community since an increase of traffic should not lead to a decrease in safety. That is why a development of new safety measures and system safety performance indicators is also expected [4].

The air traffic system is a complex, socio-technical, safety-critical, and dynamic system with three main components at macro level—airlines, airports, and air traffic control/management services. Those components mutually interact at different

hierarchical levels. At microlevel air traffic system presents a very complicated, highly distributed network of human operators, procedures, and technical/technological systems within different operational environments. Safety of flight operations in such a complex system is influenced by interactions between the various components and elements [5, 6]. Airports and the air traffic control/air traffic management (ATC/ATM) system as an air traffic system infrastructure are expected to be able to support such growth safely and efficiently with adequate capacity.

The research presented in this chapter is focused on the ATC/ATM system and more specifically on airspace planning, design, and organization.

An airspace as main infrastructure resource of ATC/ATM system is characterized by the capacity, which is usually given as the maximum number of aircraft passing through a given airspace in a given time period [7]. Capacity depends on the air traffic flows and the aircraft separation minima applied. One of the possibilities to increase airspace capacity is to reduce the separation minima [8]. This approach is driven by the fact that suitable communication, navigation, and surveillance technology (COM/NAV/SUR) already exist [9]. The reduction of separation minima could increase the traffic throughput but also could affect the safety of the flight operations. This is the reason for the development of models for safety assessment of such a change and for balancing between an increase in capacity and any possible decrease in safety.

The main objective of the research described in this chapter is the development of a framework for airspace planning and design based on a conflict risk assessment. The main purpose of such a framework should be prevention of aircraft conflicts and collisions.

To enable implementation of the proposed framework, it was necessary to develop a risk assessment model for airspace planning, design, and organization purposes at the strategic, tactical, operational, and current day planning levels.

This chapter is organized as follows. Section 2 presents an overview of different risk modeling approaches in air traffic system. Section 3 describes the proposed framework. Section 4 explains the development of a conflict risk assessment model for strategic, tactical, operational, and current day planning levels as well as illustrates their application. Finally, Section 5 draws conclusions and presents further research directions.

2. Risk modeling approaches

2.1 Overview of risk modeling approaches

The main concern in the daily operation of ATC system is prevention of conflicts between aircraft either while airborne or on the ground, which could possibly become a collision [5, 6].

The main reason for developing risk models since the 1960s was the need for increasing airspace capacity (in order to accommodate growing traffic demand) by reducing both space and time aircraft separation minima. However, due to the reduction of this separation, an air traffic safety could be jeopardized. That is why an assessment of the risk of conflicts and collisions has been studied using different models. It was expected from using those models to show whether a reduction of separation would be sufficiently safe. The following models were in use [5, 6]:

- The Reich-Marks model was developed in the early 1960s [10]. It is based on the assumption that both aircraft positions and speeds are random variables. The model computed the probability of aircraft proximity and the conditional probability of collision given the proximity [11, 12].

- The Machol-Reich model was developed in 1966 with the idea of developing the Reich-Marks model as a workable tool, as well as to increase airspace capacity over Atlantic. Consequently, the ICAO adopted the threshold for risk of collision of two aircraft due to the loss of separation [11, 13].
- Intersection models are simplest among collision risk models. They assume that aircraft follow predetermined crossing trajectories at constant speeds. Using the intensities of traffic flows on each crossing trajectory, aircraft speeds, and airways geometry, the probability of collision at the crossing point is computed [14–18].
- Geometric conflict models are similar to intersection models. They are developed in the 1990s with the main assumption that aircraft speed is constant, but their initial three-dimensional positions are random. The conflict occurs when two aircraft are closer than the prescribed separation minimum [19–23].
- The generalized Reich model was developed during the 1990s by removing restrictive assumptions from the Reich model [9, 24–27].

Collision risk models have gradually been developed since the 1960s, but their main purpose has always been to support decision-making processes during system planning and development.

2.2 ICAO risk modeling approach

The ICAO has developed the collision risk model (CRM) as a mathematical tool used in predicting the risk of mid-air collision [28–30]. The CRM model became a crucial part of the Airspace Planning Methodology for the determination of separation criteria [28] which purpose is to determine separation minima based on calculated collision probability.

CRM calculates probability of collision as the lateral or vertical overlap probability, given the probability density functions of position errors at a given moment [31, 32]. However, [33, 34] CRM is not able to model all situations, especially operational errors.

2.3 Conflict vs. collision risk modeling

What is a conflict? A conflict is an operational situation in which two (or sometimes more) aircraft come closer to each other than a specified separation minimum distance (both in the horizontal and the vertical planes). In order to detect conflict situation, a cylinder-shaped “forbidden volume” [35] (“protected zone” [22] or “conflict cylinder” [34]) is defined around the aircraft. The dimensions of this volume are defined by the minimum horizontal S_{min} (cylinder radius) and vertical H_{min} separation (cylinder height). Whenever one aircraft enters the other’s forbidden volume (**Figure 1**), a potential conflict situation occurs. Conflicts could be of different types—crossing or overtaking—depending on the relations between aircraft trajectories both in horizontal and vertical planes [35].

What are collisions? Collisions are defined by forbidden volumes which are much smaller than in the case of conflicts (**Figure 1**). The dimensions of those volumes are defined by the size of the aircraft [10, 16, 30].

As already mentioned, one of the principal matters of concern in the daily operation of ATC system is the prevention of conflicts between aircraft (incidents) either while airborne or on the ground, which might escalate to collisions (accidents).

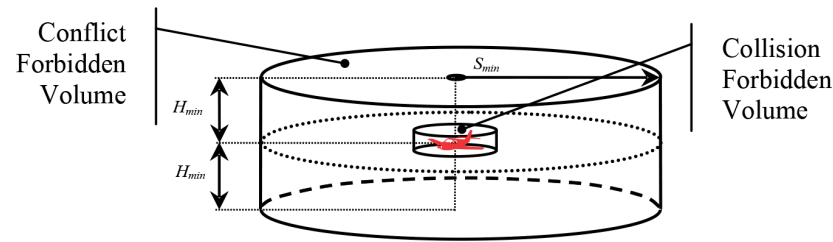


Figure 1.
Conflicts vs. collision forbidden volumes.

3. Conflict risk assessment based framework for airspace planning and design

The basic idea of the proposed framework is that different risk assessment models are required for different planning levels in ATC/ATM system [35, 36]. Their main purpose of those models is to support decision-making during airspace planning and design process through evaluation of safety risks of proposed changes (either in the existing or the new system).

Generally, airspace designers are often guided by the need to increase capacity and/or reduce air traffic controller (ATCo) workload, during planning and design process. Usually, the safety risk assessment is not explicitly performed, but in order to consider safety risks in a systematic way (explicitly), the proposed framework contains an additional step. In this step a safety risk assessment is performed by safety analysts driven by the risk reduction need (**Figure 2**). Safety analysts in such a way are providing feedback (both positive and negative) to airspace designers regarding safety issues of their solutions [9]. It is important for provision of objective feedback that safety analysts are independent of airspace designers.

A proposed conflict risk assessment modeling framework contains four planning levels (strategic, tactical, operational, and current day). It is developed to be complementary to ICAO CRMs and not as its replacement. The main differences between proposed framework and ICAO CRM are the following [37]:

- They are considering different events: the proposed framework considers risk of conflict (incidents) while CRM considers risk of collision (accidents);
- They are used for different purposes: the proposed framework considers airspace designs based on conflict risk, while CRM uses collision risk for determination of separation minima which further allow increase of airspace capacity.

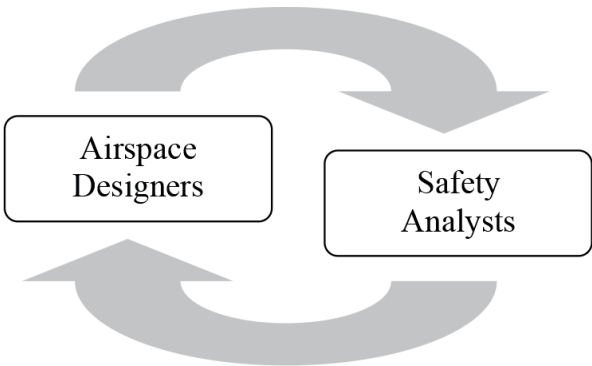


Figure 2.
Iterative process for airspace design and planning (compiled from [9]).

- They use protection volumes of different sizes: the proposed framework considers the forbidden volume around aircraft, while CRM considers the physical dimensions of aircraft.
- They use different separation minima types: the proposed framework uses distance-based separation minima only, while CRM uses both distance- and time-based.
- The resulting risk values are not the same: the conflict risk value is always bigger than collision risk value due to the fact that conflicts are more frequent than collisions.

The proposed framework is intended for use by the safety analysts (as presented in **Figure 2**). For each of the four planning levels, the necessary (not exhaustive) inputs are listed, and possible types of models are proposed (**Figure 3**, **Table 1** [35, 36]).

From **Figure 3** it can be seen that proposed framework is sequential in nature, meaning that outputs obtained after the application of conflict risk assessment models at one planning level are used as inputs into another planning level.

Starting from the initial larger set of scenarios, applying the suitable conflict risk assessment models, a gradually reduced set of scenarios (positively evaluated from the safety point of view) is obtained as outputs from the model application [37]:

- The output at strategic planning level is a list of airspace scenarios A_1, \dots, A_n chosen to be used on the tactical planning level.
- The output at tactical level is a list of airspace scenarios B_1, \dots, B_m ($m < n$ from the strategic planning level) chosen to be used on the operational planning level.

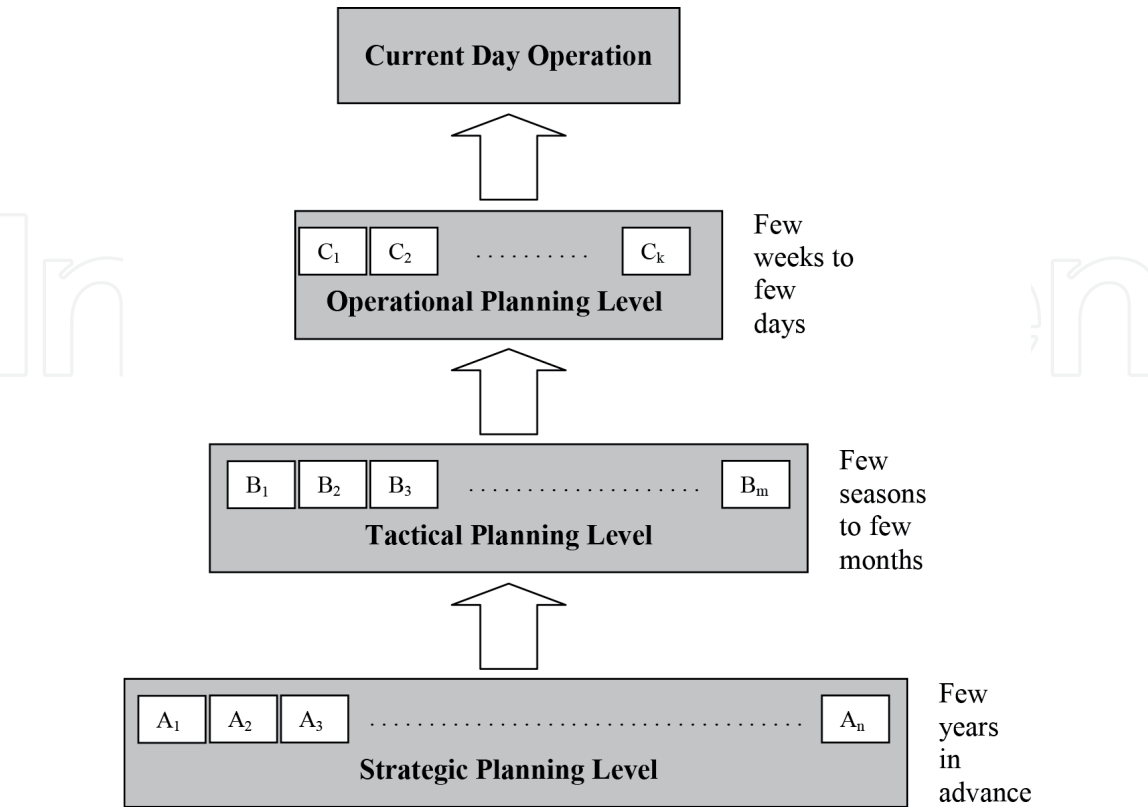


Figure 3.
Planning levels in conflict risk assessment modeling framework (based on [35–37]).

- The output at operational level is a list of airspace scenarios C_1, \dots, C_k ($k < m$ from the tactical planning level) chosen to be used in current day operation.

At the current day level, risk assessment model should help decision-makers to timely organize sectorization based on a given list of sectors and confirmed flight plans.

Planning level	Time horizon	Inputs and assumptions	Flight path characteristics	Nature of the Models
Strategic	a year or more in advance	<ul style="list-style-type: none">- given airway/trajectory network;- assumed aircraft fleet;- estimated traffic flows per airway;- average ground speed per traffic flow;- given separation criteria (horizontal and vertical).	<ul style="list-style-type: none">- intent based (flight plans)- linear propagation	Analytical Models
Tactical	from one week up to a season in advance	<ul style="list-style-type: none">- given airway/trajectory 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).	<ul style="list-style-type: none">- intent based (flight plans)- linear propagation	Simple Simulation Models
Operational	one or more days in advance	<ul style="list-style-type: none">- given airway/trajectory network (fixed/free route);- 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 (ATCo vs. pilots);- human factor issues included (situation awareness, workload, fatigue, ...);- weather conditions;- conflict detection and resolution algorithms.	<ul style="list-style-type: none">- state based- linear propagation	Complex Agent-based Simulation Models (e.g. Petri Nets under TOPAZ methodology or ICAO Collision Risk Model)
Current day	few hours in advance	<ul style="list-style-type: none">- given airway/trajectory network (fixed/free route);- known aircraft fleet;- known temporal and spatial distribution of aircraft on airways;- average ground speed per aircraft type;- given separation criteria (horizontal and vertical);- operational procedures followed (ATC vs. pilots);- human factor issues included (situation awareness, workload, fatigue, ...).	<ul style="list-style-type: none">- intent based (flight plans) + state based- linear propagation	Decision support models

Table 1.
Inputs for conflict risk assessment vs. planning levels.

It is evident from **Table 1** that moving closer to the current day planning level, safety risk assessment models become more detailed and complex. Actually, the level of abstraction is getting smaller due to availability of specific information, while their nature also changes (from analytical models to simulation models and further to decision support systems).

In the following text, a framework is described separately through the developed conflict risk assessment models for each planning level as well as illustration of their application.

(compiled from [35–37]).

4. Conflict risk assessment models

All conflict risk assessment models developed under the proposed framework are sharing the few general characteristics [37]:

1. The main starting point is that the risk depends on airspace geometry (static element) and the air traffic using it (dynamic element).
2. All models are based on the concept of critical sections, as part of the aircraft trajectory, which are traversed by the aircraft during level flight or while climbing or descending through these sections. A critical section was defined as portion of trajectory j in which aircraft should not be at the same time, if other aircraft is in intersection point O flying on trajectory i , in order to prevent occurrence of conflict (similarly is in the case of flying on the same trajectory).
3. A conflict is defined as a situation in which two aircraft are coming closer than a separation minimum distance (both in horizontal and vertical planes).
4. In order to detect conflict situations, around the aircraft a cylinder-shaped forbidden volume (protected zone) is defined (its dimensions are defined by the minimum horizontal S_{min} and vertical separation H_{min}).
5. The following assumptions are introduced in developing the models for risk assessment:
 - Risk is antonym for safety.
 - If there is no traffic, there is no risk.
 - Risk values are not constant.
 - Risk values usually positively correlate to traffic demand and negatively to airspace volume.
6. All models, under certain conditions, could be applied both for en route and terminal maneuvering (TMA) airspace.
7. The risk values calculated using the developed models are only the relative measure of safety. This means that there are intended for the purpose of comparison between numerous scenarios, not for comparison with a Target Level of Safety (TLS) given by the international regulations [38–40].

4.1 Conflict risk assessment model for airspace strategic planning

4.1.1 Objectives and assumptions

The conflict risk assessment model for the airspace strategic planning level [35, 37] is intended to facilitate comparisons and sensitivity analyses of different airspace designs (sector shapes) and organizational scenarios (sector configurations) under different air traffic flow levels a year or more in advance. Conflict risk is assessed using two variables [35, 37]: the conflict probability and the number of conflicts in the given airspace under the given circumstances.

In order to detect conflicts, length and flying time through critical section (critical length and critical time) are defined. Those two values enable calculation of the conflict probability, which is (for a given pair of aircraft) defined as the product of the probability that an aircraft is in a given critical section of its own trajectory and the conditional probability that another aircraft is simultaneously in a corresponding critical section of its (crossing) trajectory. The number of conflicts is defined as the product of conflict probability and estimated traffic flows for the given airway [35, 37].

Taking into account all available flight levels and airway combinations in the given airspace, it is possible to calculate total conflict numbers. Details of the model development are provided in [35, 37].

Proposed conflict risk assessment model is intended for airspace planning purposes at the strategic level, based on risk assessment of the current, and future airspace, following its modifications (changes of sector shapes or sector configurations).

The main inputs for conflict risk assessment using the proposed model are [35, 37]:

- Airspace geometry and characteristics (sector shape/boundaries, number and spatial distribution of available airways, length of the airways, number of intersecting points, available flight levels, etc.)
- Traffic characteristics (special and temporal distribution of traffic flows, proportion of level flights (in cruising phase) vs. flights in climb/descent, share of specific aircraft category in total traffic volume, etc.)

Human operator (pilots and ATCos) issues and behaviors are not considered.

4.1.2 Illustration of the model application

In order to illustrate the developed model, a hypothetical en route sector is used containing two unidirectional airways, one bidirectional airway, and four flight levels (**Figure 4**).

In this example traffic flow increase (e.g., on AWY₃) as well as airspace volume change (e.g., length extension of AWY₃) was considered together with the change in separation minima applied. Details of the model application illustration are provided in [35].

Experimental results show the following:

- Higher risk of conflict can be obtained in the case of traffic demand increase in airspace volume that does not change (sector volume and airway length, **Figure 5**).
- Decrease in risk of conflict can be obtained in the case of an increase of airspace volume (sector volumes and airway lengths), with traffic demand that does not change (**Figure 6**).

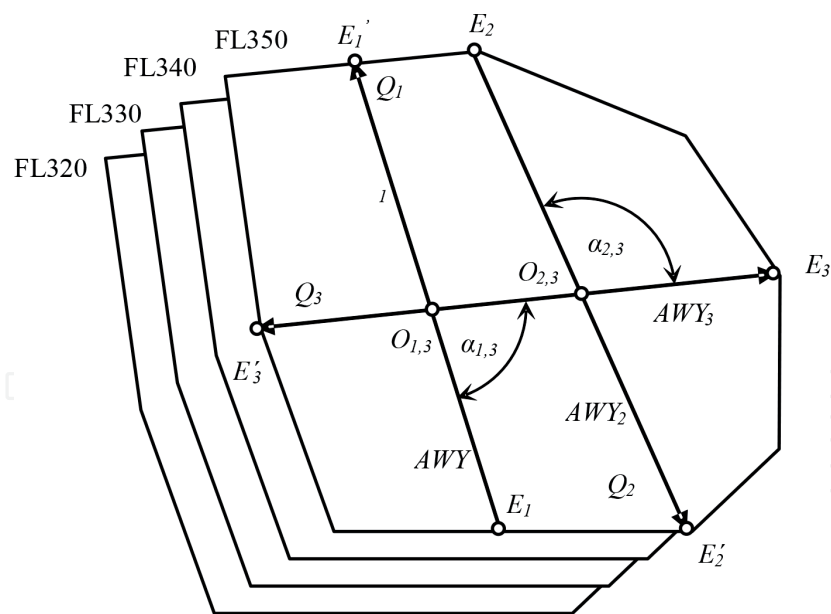


Figure 4.
Sector geometry (compiled from [35, 37]).

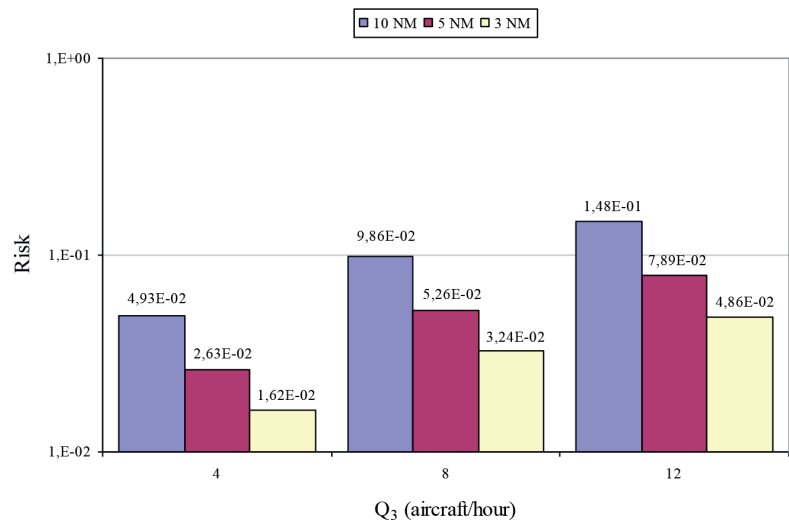


Figure 5.
Risk for the given sector dependent on traffic flow on AWY_3 [35, 37].

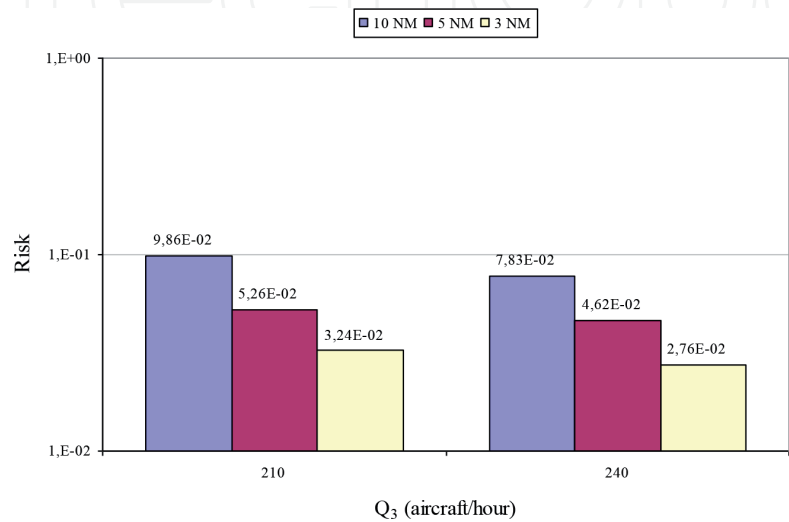


Figure 6.
Risk for the given sector dependent on length of AWY_3 (change of sector volume) [35, 37].

- Reduction of separation minima is causing higher conflict risk values (**Figures 5 and 6**).

4.2 Conflict risk assessment model for airspace tactical planning

4.2.1 Objectives and assumptions

The conflict risk assessment model for airspace tactical planning level is intended for evaluation and comparison of different alternative flight scheduling scenarios for a given airspace sectorization, or comparison of different alternative airspace sectorization scenarios for a given flight schedule, from 1 week up to a season in advance [36, 37].

Assessment of conflict risk is based on two variables [36, 37]: duration and severity of conflict situation in the given airspace. Both, duration and severity, depend on different factors: aircraft entry time into given airspace, aircraft speed, relative speed between conflicting aircraft, trajectory crossing angle, separation minima, etc. The conflict risk is defined as the ratio between the “elementary risk” and the observed period of time. “Elementary risk” is calculated as the ratio between [36, 37] (1) the surface limited by minimum separation line (from above) and function representing the change of conflicting aircraft separation (from below) and the surface limited by minimum separation and time moments presenting the conflict duration (beginning and ending of conflict) and (2) abscissa. Conflict risk is being calculated for each aircraft pair, as well as for all conflicting pairs, i.e., total conflict risk in the given airspace. Details of the model are provided in [36, 37]. The proposed conflict risk model is intended for [36, 37]:

- Assessment of conflict risk in given airspace under given flight schedules
- Approval of filed flight plans or suggestions for their modifications (flight re-scheduling or slot assignments with the aim to reduce conflict risk)

The main inputs for conflict risk assessment using this model are [36, 37]:

- Known airspace geometry and characteristics (e.g., sector shape/boundaries, number and length of the airways, airway tracks, number of intersecting points, available flight levels, etc.)
- Known traffic demand characteristics (flight plans—planned routes, speeds, altitudes, aircraft types, temporal and spatial distribution of air traffic flows over specific airspace entry points, etc.)

The main assumption of this model is that flight perfectly follows their planned routes (trajectories) and altitudes. Also, human operator (pilots and ATCos) issues and behaviors are not considered.

4.2.2 Illustration of the model application

In order to illustrate the developed model, a hypothetical en route sector is considered containing two unidirectional airways and one flight level (**Figure 7**).

For illustration purposes only, flights on one flight level are considered. Five flights entering the sector in a 6-minute period are considered (**Figures 8–10**). For each flight, an entry time, together with aircraft type and assigned airway, was the input.

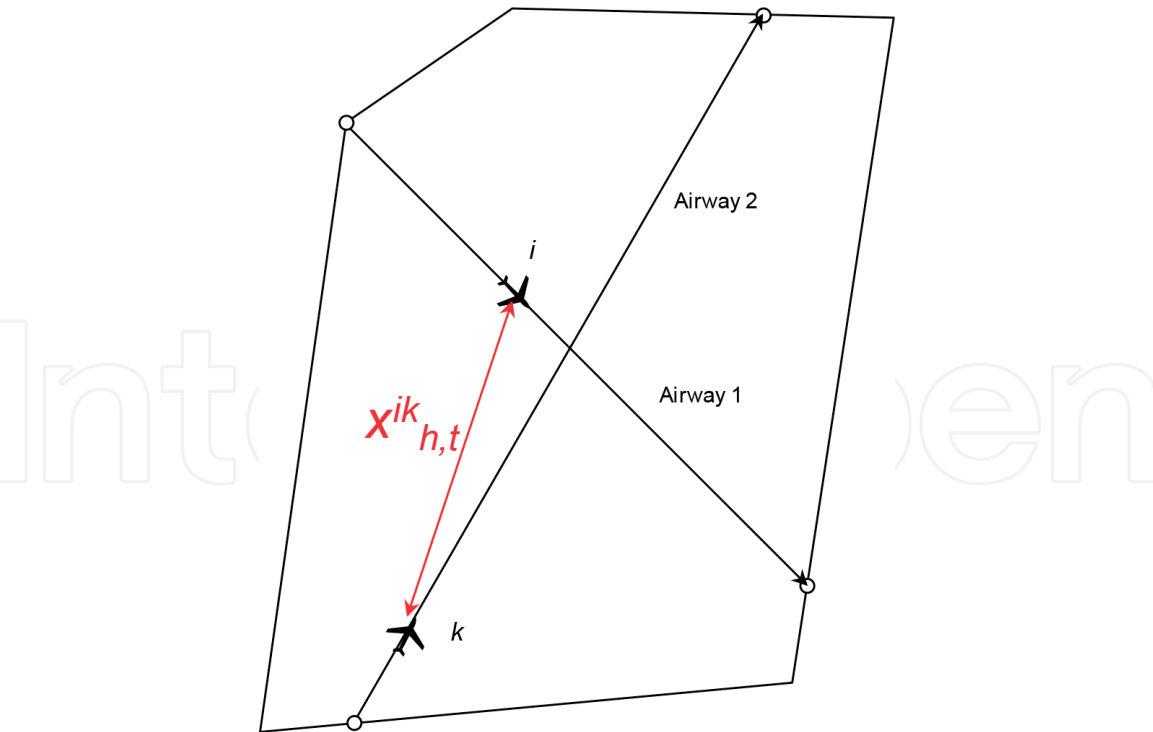


Figure 7. Sector geometry with flights (compiled from [36, 37], $x^{ik}_{h,t}$ is horizontal separation between flights i and k at time t).

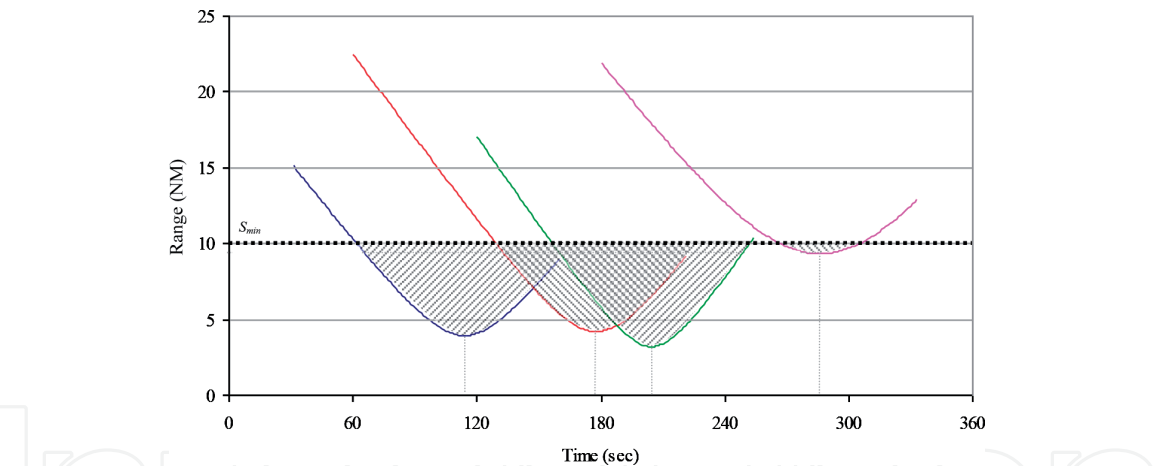


Figure 8. Change of spacing between aircraft pairs and the potential conflicts in the horizontal plane ($S_{min} = 10$ NM), compiled from [36, 37].

Potential traffic separation violations in the horizontal plane between succeeding aircraft pairs are observed in the simulated situations for the case of separation minima of $S_{min} = 10$ NM (only intersecting conflicts are presented (shaded areas in **Figure 8**)). The calculated total risk was $3.08 \cdot 10^{-3}$.

In order to examine the influence of changes in flight entry time on the individual and total risk values, a simple change is introduced.

Namely, allowing one flight to enter into the system 30 seconds earlier (red line, **Figure 9**), the total risk value is reduced from $3.08 \cdot 10^{-3}$ to $2.86 \cdot 10^{-3}$.

Additionally, a previous situation is simulated with a lower separation minima $S_{min} = 5$ NM resulting in lower total risk. The risk value is now reduced from $2.86 \cdot 10^{-3}$ to $1.39 \cdot 10^{-3}$ (**Figure 10**). Details of the model application illustration are provided in [36, 37].

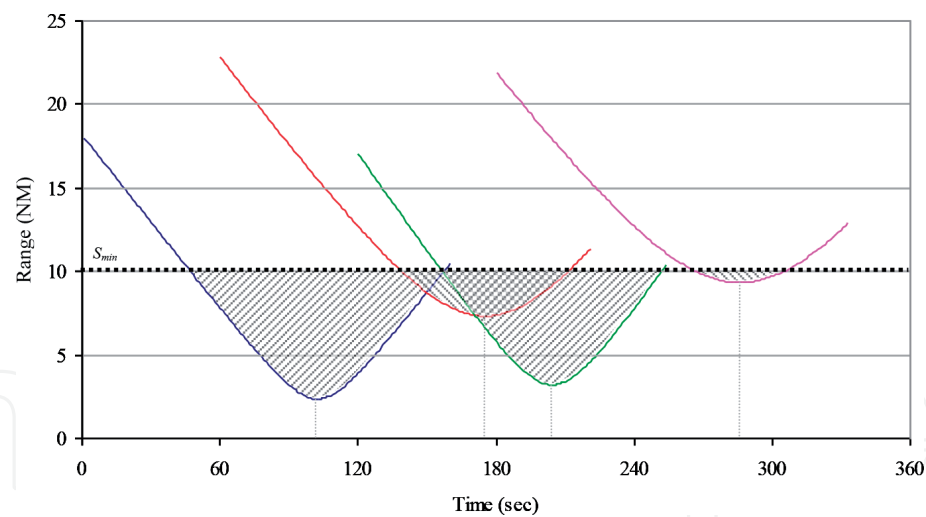


Figure 9.
Change of spacing between aircraft pairs and the potential conflicts in the horizontal plane ($S_{min} = 10$ NM) with modified entry time case, compiled from [36, 37].

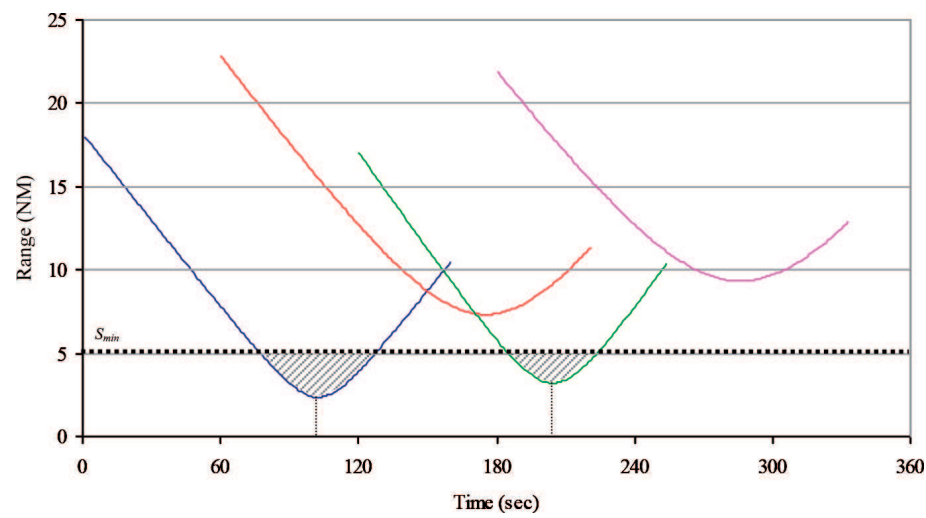


Figure 10.
Change of spacing between aircraft pairs and the potential conflicts in the horizontal plane ($S_{min} = 5$ NM), compiled from [36, 37].

4.3 Conflict risk assessment model for airspace operational planning

The conflict risk assessment model for airspace operational planning level is intended for evaluation and comparison of different alternative operational scenarios (different separation minima, delegation of responsibility between pilots and ATCos, introduction of different ground and/or airborne-based decision support systems and tools, etc.) one or more days in advance [37].

In order to assess conflict risk, two variables are used [37]: duration of single or all conflict situations and severity of conflict situations.

The main inputs for this model are [37]:

- Airspace geometry
- Characteristics of the COM/NAV/SUR system equipment (technical characteristics and reliability)
- Actual traffic data (aircraft types, entry time in the airspace, exit time from the airspace)

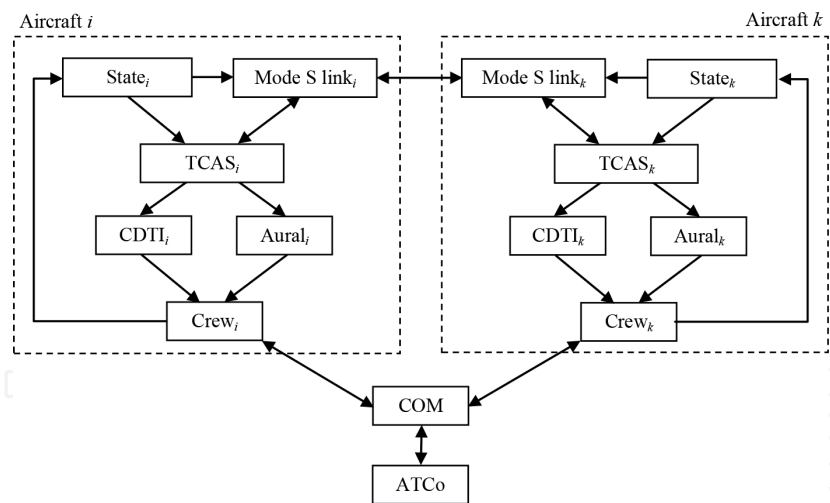


Figure 11.
High-level representation of TCAS agents [37, 43].

- Data on aircraft behavior during the flight, reliability of certain aircraft technical parts, etc.

The influence of human operators (pilots, ATCos, etc.) at this level is considered through the modeling of their state (situational awareness, workload, etc.) [37].

An example of conflict risk assessment model for airspace operational planning level (one or more days in advance) is presented in the work of [41–43]. Although those papers are not directly related to the developed framework, they are showing the type of models which could be used for risk assessment at operational planning level. The goals of the research described in those papers were to assess the potential collision risk reduction for a historical en route mid-air collision event by using traffic collision avoidance system (TCAS).

This model (**Figure 11**) contains the technical elements (Cockpit Display of Traffic Information (CDTI), speakers for aural annunciation, TCAS, Mode S airborne-airborne communication link, airborne-ground communication link (COM)), human elements (pilot crews and ATCos), and procedural elements of TCAS operations (change of ATCos and pilots' roles during TCAS encounters) and fully supports mathematical analysis as well as rare event agent-based Monte Carlo simulation of aircraft encounters [43].

4.4 Conflict risk assessment model for airspace current day planning

4.4.1 Objectives and assumptions

A final step of the proposed framework is presented by the conflict risk assessment model for airspace current day planning level [37, 44].

The main objective (purpose) of this model is to support decision-making processes during sectorization (for a given set of available elementary sectors determined at operational planning level) through evaluation of the number of conflicts, the conflict probability, and the risk of conflict as well as their distribution at intersections or along airways, and ATCo task-load according to the approach of [45] for a given airspace and traffic load [44], few hours in advance. Decision-makers, using the proposed model and the results obtained, could decide whether or not to accept the estimated risk with a certain specified probability as well as the estimated task-load. Based on these results, they could decide, in advance, to keep the existing sectorization or not, at current day level [37, 44].

The following input data are used in this model [37, 44]:

- Known traffic data (confirmed flight plans and flight schedules with known aircraft types)
- Known airspace geometry (sector shapes and boundaries, number and length of airways, as well as airway tracks) determined as the most appropriate from a conflict risk point of view at the operational level

The influence of humans is considered through the ATCo task-load. Details of the model are provided in [37, 44].

Apart from the main assumptions, an additional one is introduced here: risk is a random variable and one aircraft at an airway can be simultaneously in conflict with only one aircraft from another airway.

The objectives and assumptions of this model show that the main difference between this model and models presented in previous subsections [35, 36] is that risk is assumed to be random variable and that consequently the developed conflict risk assessment model should now be able to serve as a decision support tool.

4.4.2 Illustration of the model application

In order to illustrate the developed model, a hypothetical en route sector is used (Figure 4). For each flight the following inputs were used: the entry points into the airspace, entry time, entry flight level, heading, ground, and vertical speed. Values for those inputs were assumed to remain constant during the flight [37, 44].

In real operations, the decision on specific sectorization usage in a certain time period is based solely on the forecasted number of aircraft in the sector. But, other factors exist as well, one of which is the number of potential conflicts. This number indicates an ATCo task-load and conflict risk in the sector. Correct assessment of those indicators is the responsibility of air traffic managers, and it serves them to adjust the existing airspace capacity by changing the sector configuration [37, 44].

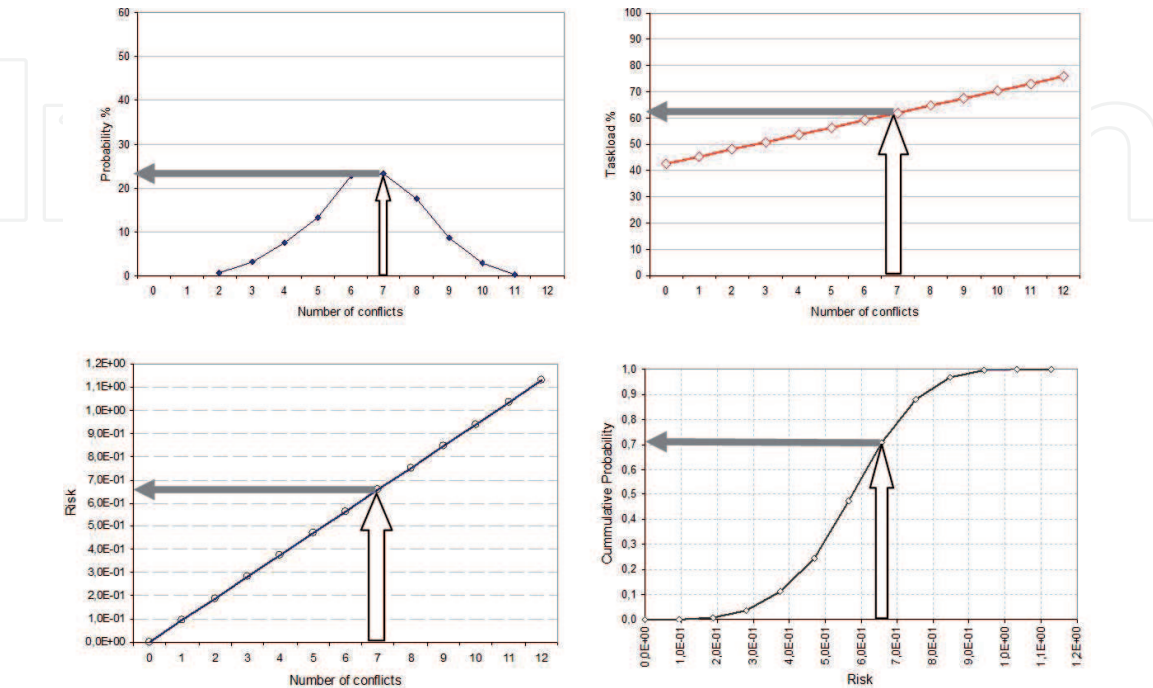


Figure 12. Example showing possible usage of outcomes of developed model by the air traffic managers [37, 44].

Based on the values for the number of conflicts, the risk of conflict, the risk probability, and the task-load determined by the simulation, their possible usage by air traffic managers is explained.

Let the number of conflict $N_c^* = 7$, with a horizontal separation minima of 10 NM and 12 aircraft/hour on AWY₃. **Figure 12** (upper left) enables the determination of a frequency (probability) of seven conflicts (23%), while **Figure 12** (upper right) enables the determination of ATCo task-load of 63%. This task-load value could be compared with critical threshold values which are usually used to define an overload situation [37, 44]. A conflict risk value of $R^* \approx 6.6 \cdot 10^{-1}$ was read from **Figure 12** (lower left) for given N_c^* , while **Figure 12** (lower right), for a risk value $R \leq R^*$, shows a cumulative probability of 0.71.

Figure 12 presents a value which could serve air traffic managers to decide whether or not a specific merging or partitioning of sectors is necessary within a certain time period (e.g., 30–90 minutes), allowing them in such a way to perform real-time analysis on a regular basis (e.g., every half an hour) [37, 44].

5. Conclusion

This chapter presents a framework for airspace planning and design based on conflict risk assessment developed for the purpose of preventing aircraft conflicts and collisions. The proposed framework is hierarchical by nature, containing four planning levels: strategic, tactical, operational, and current day.

During airspace planning and design process, airspace designers are often guided by the need to increase capacity and/or reduce air traffic controller (ATCo) workload. In order to consider safety risks in a systematic way, the proposed framework contains an additional step—safety risk assessment performed by safety analysts guided by the risk reduction need. In such a way, they are providing feedback to airspace designers regarding safety issues of their solutions.

This chapter presents four conflict risk assessment models, each one for different airspace planning level (strategic, tactical, operational, and current day), contained in the proposed framework.

Each of those models defines conflict risk on a different way and also has different objectives. The idea behind every model, i.e., basic development principles, was explained together with specific objectives, assumptions, and conflict risk concepts.

All models are illustrated by the simple numerical examples. The illustration of the model application shows that in addition to airspace geometry (airways length and airways crossing angles), conflict risk in the given airspace also depends on traffic flows/traffic demand, average flow speeds/aircraft speed, average aircraft inter-arrival times, spatial and temporal distribution of aircraft in the airspace, as well as separation minima in horizontal plane.

Experimental results confirmed that conflict risk values are sensitive on traffic demand and airspace volume changes.

A plan for further research considers application of the proposed framework in real-life systems and on large-scale cases. Special attention will be given to investigation of air traffic managers' behavior during decision-making process.

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