SAFETY IN THE TERMINAL AREA – AN APPROACH FOR A QUANTITATIVE ASSESSMENT

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ABSTRACT

This paper shows the development and implementation of valuation model which makes an objective comparison between different alternatives at the airspace design possible. Special importance is given for the influence of the Human Factor, which affect both on-board and ground side.

1. BACKGROUND

1.1. New Safety Awareness

Increasing traffic growth implies the necessity of new concepts and methods as well as innovative technology to be able to ensure a safe and efficient air traffic furthermore, too. To be able to select the most efficient alternative from these new developments, they must be in the position to be compared with each other objectively.

The costs for the implementation as well as the possible capacity increases are not longer only in the foreground, but increasingly also the attainable level of safety. Therefore new valuation models have to be designed not only for the area of capacity profit but also to the judgment of the achieved safety.

As one of the most important components in the system air traffic aerodromes have been for years primarily the limiting factor in Europe and Germany for another growth of the complete system, which is given significantly on the side of the demand again since 2002, too. So the passenger numbers in the year 2005 compared with the previous year of the large German aerodromes Munich, Frankfurt-Main and Düsseldorf increased in the cut by 6%, the flight movements by up to 6% [18], again. To this considerable growth rates still complete themselves the aerodromes with a so-called Low Cost Carrier (LCC) operation like Cologne/Bonn or Frankfurt-Hahn with rates of up to 35% increase in the passenger number or 13% in flight movements, induced by radical price war.

The number of flight movements in the national and international air traffic will rise further also due to the globalisation within the next years. However, a healthy growth is only there possible, where sufficient capacity also will be future availably for the increasing demand. Very complicated approval processes which arise from legal specifications (see air traffic law, air traffic admittance order and others) or from socio-political connections however stand contrary to the extension of existing or the new building of airports primarily in Germany. This shows the running procedures of the aerodromes Frankfurt-Main and Düsseldorf and the completed approval process for the future airport Berlin Brandenburg International, which runs over years.

From the economic point of view, additional workplaces arise from the extension/new building of aerodromes both directly at the aerodrome and furthermore in its environment. The aerodrome Munich particularly documented this with an increase of the number of persons employed of 16% from 2000 to 2003 again - with altogether 24.2 million passengers in the year 2003. This corresponds furthermore well to the approximation formula according to which one million passengers provide about 1000 additional workplaces at the aerodrome.
The advantages like the immediate access to the national and international air traffic and with that a very good accessibility for their business partners or suppliers are a good motivation for companies to settle in the environment of airports. Moreover, the larger aerodromes mostly have very good traffic connections in the form of railway routes and motorways, too. These are, also the essential selling points of the important aerodromes in the eastern part of Germany like the airports of Leipzig and Dresden. These airports also focus strongly on the expansion of the airfreight market and on creation of value aspects of the production chain of the new large-capacity aircraft Airbus A380 [7], [11].

This local traffic concentration is not without adverse consequences for residents and employees in the environment of aerodromes: So, the local loads are increased with regard to noise, pollutants and - latest in the centre of the public interest - the statistical risks for health and lives, despite the

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technological progress in the engine technology within the last few years.

As is well known, the legislator, the participants, and the putative injured of the air traffic system possess an objective assessment catalogue with regard to aircraft noise and pollution (e.g. see law for the protection against aircraft noise, state 25.09.90).

Till now, this instrument formally is not, however, available with regard to the "safety in the air traffic"[2] although now quasi-standardized procedures for the relative judgement of the risks of the involved and the non-involved third parties are available [9]. Alone, the finding of limiting values is still difficult in the moment, also with a view of the European foreign countries[3].

Both groups, residents and employees, attach little value to the probability to get injured by an aviation accident. Till now, the noise and air pollution problematic stands in the foreground for they. Only due to the increasing traffic numbers and thus increasing frequency of flight accidents the safety of the air traffic moves to the centre of the public interest and already "competes" partially with the aircraft noise problematic now.

The hub airports are the limiting factor for the growth of the air traffic in the European airspace. Already now they partly work on their utilization limit. There joins that due to the high traffic density, in the area of an aerodrome the danger of an accident provably is the greatest, how numerous studies illustrate [1].

1.2. Accidents in aeronautics: Facts and trends

Although within the last few years the number of accidents moves on a relatively low level [2]. However, the available statistics also point, that there is a direct connection between the number of flight movements and the number of accidents [3]. If the air traffic should increase like numerous prognoses forecast [4], there is a good chance for doubling the volume of traffic till 2015.

Without a strong reduction of the accident rate, these numbers lead to an unacceptably high number of flight accidents in the future. Projected 35 so-called Hull Loss accidents [4] would happen in the year 2015. Due to new methods and developments in the flight guidance it shall turn out well to be able to keep the absolute number of the accidents recorded within the last few years despite the future growth in air traffic[4]. The following illustration shows an evaluation of the worldwide accidents with death consequence [6]. A constant till slightly decreasing accident trend is worldwide recognizable:

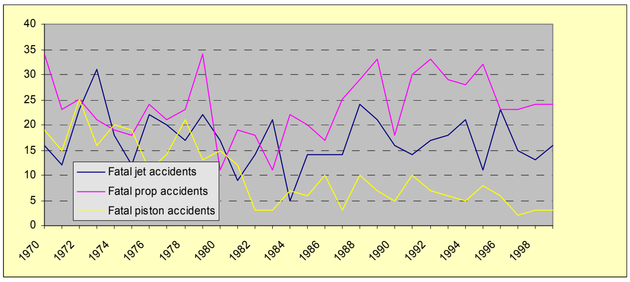

FIG 1. Accident statistics Aviation Safety Network (number of the accidents with death consequence) [6]

The solution of the capacity difficulties of major airports at a simultaneous increase of the level of safety is very difficult with the present arrival and departure procedures and regulations of the airspace structure design. Till now, one usually put on infrastructural measures such as at Frankfurt-Main airport with the making of an additional runway [10].

2. THE RISK DETERMINATION, A PROBABILITY BASED CALCULATION METHOD

2.1. Structure

At the analysis of safety in the air traffic, till now, one distinguish model technically between the potential which there is for non-involved third parties to be endangered by the air traffic (so-called "external risk") and the danger for persons and goods immediately involved in the air traffic (so-called "Level of Safety"). Both areas are examined and judged in separate sub-models. This paper deals exclusively with the endangering of the involved of the air traffic. As a measure for (un-) safety the height of the probability with which it comes to a collision or a dangerous separation infringement of aircrafts during approach or departure.

The bases for the calculation of a risk index

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[2] Also, the ratification of the air security law in September 04 changes nothing to this till now. This law focuses essentially on the security of the air traffic.

[3] Although the Netherlands as well as Great Britain have standardized procedures for the calculation of the external risk with accompanying limiting values whose transgression can result in different, in general economic consequences (such as settlement and use restrictions) for the region. The limiting values being valid in the Netherlands and Great Britain are strictly bound to the respective calculation procedure. Both, limiting values and calculation procedures were highly unstable within the last years and were modified repeatedly lastingly.

[4] The so-called "vision 2020" of the German Federal Government correspondingly demands, in agreement with the aims of the Eurocontrol, the reduction of the accident rate of the air traffic by a factor of five up to the year 2020.

regarding as a Level of Safety (LOS) for the terminal area were introduced in [9] and [12]. FIG 2 shows the essential components of the risk model:

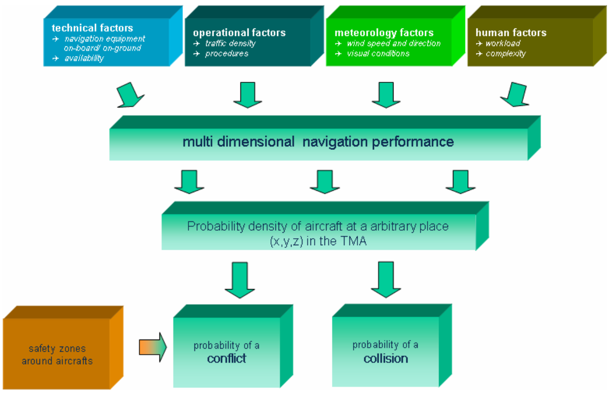

FIG 2. Structure of the Risk Model

2.2. Positional Probability

The ANP values (differentiated in longitudinal, lateral, and vertical direction) are used analogue to the RNP values [13] as the standard deviation σ of the density function to calculate the position probability. The calculation results here for a space grid of pre-defined, three-dimensional raster elements in which the observed airspace is sub-divided. A raster element represents the integration limits for the calculation of the position probability. In the model described here, a raster element corresponds to the dimension of the largest aircrafts within the observed airspace. During each simulation cycle (complies with one second in real time) the position probability for each individual aircraft in the observed airspace is calculated for all raster elements with the following equation:

(1) $$P_{n,i}(x,y,z) = \iiint\limits_{Volumen\ RE} \frac{1}{2\pi\sqrt{2\pi}\sigma_x\sigma_y\sigma_z} \cdot e^{\frac{1}{2}\left(\frac{(x-\mu_x)^2}{\sigma_x^2}+\frac{(y-\mu_y)^2}{\sigma_y^2}+\frac{(z-\mu_z)^2}{\sigma_z^2}\right)} dx\,dy\,dz$$

With:

$P_{n,i}(x,y,z)$ position probability of aircraft n in the raster element (RE) i (coordinates of its centre point: x, y, z) in function of the aircraft reference position

σ_x, σ_y, σ_z standard deviation in longitudinal, lateral and vertical direction of aircraft n

μ_x, μ_y, μ_z reference position of aircraft n (x, y und z coordinates)

2.3. Collision Probability

The calculation of the position probabilities is carried out for all aircraft being in the observed airspace. Under the assumption that the position deviations of the aircrafts are independent of each other, the probability $P_{n,m}$ (x, y, z) of a collision or a dangerous approach of any two aircrafts at a certain point results from the product of the position probabilities of the two aircrafts n and m at this point [5].

(2) $$P_{n,m}(x,y,z) = P_n(x,y,z) \times P_m(x,y,z)$$

The complete collision probability arises from the sum of the individual conflict probabilities of all possible aircraft combinations in the observed airspace.

(3) $$P_{complete}(x,y,z) = \sum_n \sum_m P_{n,m}(x,y,z)$$

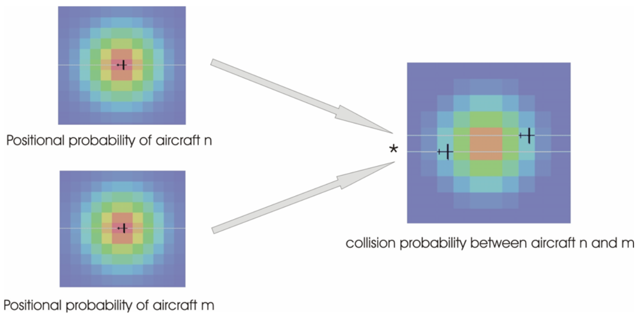

FIG 3. Positional and Collision Probability

2.4. The Safety Zone

The RTCA CD&R Working Group has defined the term „Protected Airspace Zone“ (PAZ) in its work about collision and conflict probability [14]. The PAZ represents an area of the airspace around aircrafts in which no other aircraft is allowed to penetrate. The dimension and shape of this safety zone has an important influence on the calculation of the conflict probability. For this reason, the PAZ chosen from the RTCA CD&R Working was modified. The original PAZ consists of a cylinder with a radius equal to the separation minima. So, each separation infringement represents mandatory a conflict. This modus operandi would lead to an excessive large conflict probability in the here observed airspace with its characteristic high traffic density.
The safety zone used to determine the conflict probability in the here described model is illustrated in FIG 4. The dimensions of this safety zone are deduced from the dimensions of the aircraft, from the values of the actual navigation performance of the aircraft, and from the velocity difference to the potential conflict partner.

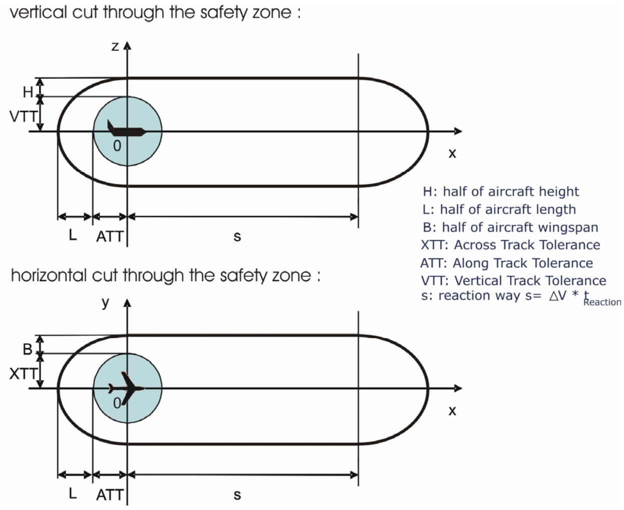

FIG 4. Definition of the Safety Zone

Based on the actual navigation performance expressed by the values along, cross and vertical track tolerance (ATT, XTT, VTT), which are illustrated as blue surfaces in the FIG 4, the safety zone is defined, that the aircraft is in 95 per cent of the flight duration complete inside the zone. This complies with the two sigma value of a standard distribution. For this the track tolerance values are added to the dimensions of the aircraft (length, height, and wingspan). Furthermore, the safety zone is extended in flight direction at the length of the reaction way of the aircraft. This is calculated from the product of the reaction time and the velocity difference Δv to the potential conflict partner. The reaction time $t_{reaction}$ is composed of the time, which the pilot needs to detect the potential conflict, the time to find a solution to solve the conflict, the time to initiate an avoid manoeuvre, and the time the aircraft needs to realise the control inputs.

2.5. Conflict Probability

A conflict is defined as a contact or penetration of the safety zones of two aircrafts. The calculation of the conflict probability is carried out in three steps. First, it is calculate if there is a contact or penetration between the safety zones of every aircraft pair n and m.

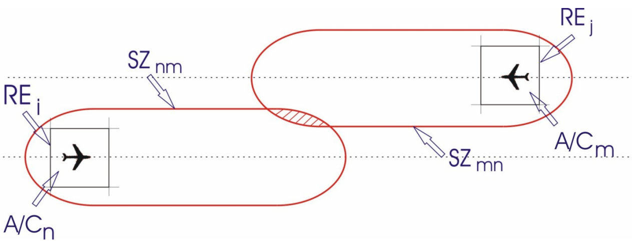

FIG 5. Conflict Situation between two Aircrafts

If there is a contact between these aircrafts, then the conflict strength S_{con} is calculated as the ratio between the penetration volume and the volume of the smaller safety zone.

Then the conflict probability is calculated for the pairs of aircraft from the product of the positional probabilities and the conflict strength.

(4) $$P_{con,nm,ij}(x,y,z) = P_{n,i}(x,y,z) \cdot P_{m,j}(x,y,z) \cdot S_{con}$$

with:

$P_{con,nm,ij}$ conflict probability between the aircrafts n and m with aircraft n in RE i and aircraft m in RE j

$P_{n,i}$ position probability of the aircraft n in RE i

$P_{m,j}$ position probability of the aircraft m in RE j

S_{con} conflict strength ($0<S_{con}\leq 1$)

Because of the probability approach, it is possible, that an aircraft can be in any raster element. At this, the probability decreases heavily with increasing distance of the raster element to the reference position of this aircraft in dependency of the actual navigation performance. So, it is necessary to calculate the conflict probability for every possible spatial configuration of the aircrafts n and m. The sum of these conflict probabilities is the probability of a conflict between the both aircrafts:

(5) $$P_{con,nm} = \sum_{i,j} P_{con,nm,ij}(x,y,z)$$

with:

$P_{con,nm}$ conflict probability between aircraft n und m

$P_{con,nm,ij}$ conflict probability between aircraft n und m with aircraft n in RE i and aircraft m in RE j

3. USING THE FAA 'DYNAMIC DENSITY MODEL' TO RESPECT THE INFLUENCE OF THE HUMAN FACTOR CONTROLLER WORKLOAD

The ability to measure and predict complexity is one of core elements of future concepts such as dynamic airspace configuration and advanced traffic flow management. In an operational setting, if an accurate measurement and prediction of complexity for a particular airspace is available, changes in traffic flows and airspace will be better managed, both strategically and tactically. Additionally, higher levels of automation are proposed for future operations. However, provisions for degradation and graceful recovery may be designed for future systems. Should automation degrade and if the design calls for human operator to manage the situations, the measures of complexity are very crucial so that human workload limitations are not exceeded.

From the research perspective, the use of a DD metric in fast-time simulation models would provide a dynamic indicator of sector capacity and possibly workload. Most current fast-time models use the Monitor Alert Parameter (MAP) as a sector capacity indicator [15]. A problem with using the MAP values is that they are usually generated by the facility that controls the sector and are not based on objective measures [16]. Although these values can be adjusted dynamically, there is no scientific basis for doing so [17]. A more objective measure would be a DD metric which would base the sector capacity and/or workload on the current traffic situation and not on a static MAP value. This would provide a better way to calculate potential workload and the ability to dynamically reroute aircraft around saturated sectors with more fidelity than current fast-time simulation models.

In 1999, the FAA William J. Hughes Technical Center (WJHTC), NASA Ames Research Center, and Metron Aviation formed a partnership to research DD. Each organization had its own ideas about what variables contributed to DD, although many similarities existed. The analysis therefore considered all of the proposed DD variables. A unified DD model (i.e., one containing variables from each organization) performed the best.

4. MODEL IMPLEMENTATION

Probability based procedures are suited for the objective judgement of the safety in the air traffic (here the terminal area as an examination room) in a special way, because the deterministically forecast of conflicts or even accidents does not seem possible till now.

The described model is implemented as a prototype called Safety Korrelator (SK) using the JAVA programming language. Beside modules for modelling the actual navigation performance of each individual aircraft and the modules for calculating the positional, collision, and conflict probabilities, the Safety Korrelator also has a graphical user interface illustrated in FIG 6.
With this interface, the user is able to set the constraints and it also shows him the results of the calculations. Furthermore, the SC has some interfaces to connect external sources of traffic data. In this way, for example, one can explore real traffic data with an ADS-B receiver with the SK.

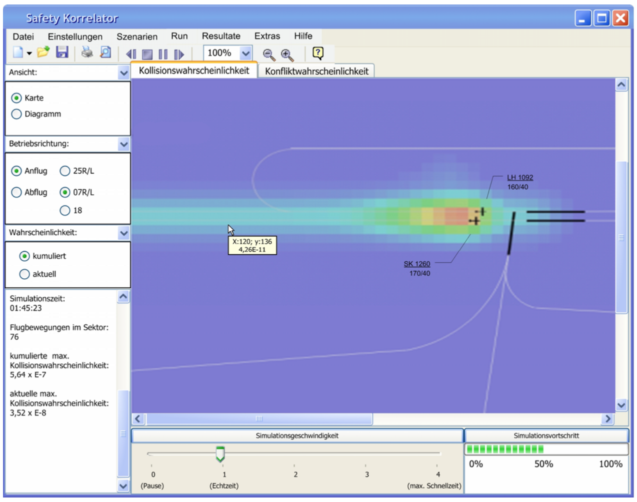

FIG 6. Graphical User Interface of the Safety Korrelator

First results of simulations for the airport Frankfurt/Main show the correct operating mode of the elected model and of the implementation. Next step of developing will be the validation of the prototype during real and fast time simulations in cooperation with the German and European ATC (DFS and EUROCONTROL-CRDS).

5. INFLUENCE OF THE PROCEDURES ON THE SAFETY

Up-to-date and within the next years the instrument landing system (ILS) is and still remains sure at the large airports the prior-ranking navigation support system for the final approach with its technical specifications.

RNAV approaches have already gained some acceptance in the area of the Initial Approaches. However, at many aerodromes Radar Vectoring is still used to lead the aircrafts to the final approach individually.

A short summary of different systems, their maximal achievable precisions, and RNP values is given in TAB 1.

System	*Precision*	*RNP*
VOR/DME	>0,2 NM	0,3-20
DME/DME	>0,2 NM	0,3-20
GNSS	>0,2 NM	0,3-20
SBAS/GBAS	>0,1 NM	0,1-20
INS	>1 NM	1-20

TAB 1. Precision of Navigation Systems [18], [3]

The values to be gathered in TAB 1 represent the maximum precision of the individual systems which are reached partly only under certain conditions. For VOR/DME the values are depending on the distance between the single stations to the aircraft and from its altitude. So, one reaches RNP 0.3 only up to a maximum distance of 20 NM and RNP 1 to 40 NM. For DME/DME navigation, moreover, the attainable RNP value is depending on the number and position of the stations as well as their age (plants which were installed before 1989 have a lower precision). The maximum distances amount here to 25 NM for RNP 0.3 and 55 NM for RNP 1.

The navigation with satellite systems like GPS, GLONASS and future Galileo is independently of the ground infrastructure and therefore globally applicable. The attainable precision is dependent on the short-term integrity of the system which depends from the number of receiving satellites and whose position to the receiver, though. Furthermore the complete precision results from the precision of the partial systems space segment and receiver as well as the calculating precision of the system. Another rise of the precision is possible by the use of SBAS[5] or GBAS[6] systems. Here, correction signals are sent by geostationary satellites or ground stations so that the improvement on the precision is limited spatially on certain local areas. Such systems typically will be used in the terminal area of airports to reach the above-mentioned demanded RNP values (e.g. 0.3).

The precision of the completely infrastructure independently working Inertial Navigation System (INS) decreases continuously with the time since the last position update, so the RNP 1 value is reached so only during the start and the take-off (characteristic of the coupled navigation).

Changes of the prevailing regulations for the design of safety areas (such as obstacle clearance surfaces to ICAO PANS OPS) as well as separations limits (lateral as longitudinal) under a possible use of the aforementioned systems is one possibility for the more effective usage of the available airspace. This is, however, only practicable if one can prove first of all reliably that furthermore also under these new boundary conditions a (socially) acceptable level of safety remains.

With this effort the model on hand can also do a contribution for a comparison of different alternatives e.g. at the airspace structure design.

6. SUMMARY

The also for the future predicted further increase of the air traffic and the increasing safety awareness of the population require systematic and not longer often intuitive dealing with the concept safety in the air traffic.

With the attempt for the quantification of the air safety in a defined examination room introduced here, it becomes possibly to compare different alternatives of the airspace structure design and used approach and departure proceedings with each other objectively.

Particularly the RNPx-RNAV procedure offers from its systematic a high transparency concerning the attainable safety in airspace. Till now, this was not possible with the methods of PANS-OPS (Obstacle Assessment Surfaces).

The aim of the SK is to enable the user to assess different alternatives of traffic flow management procedures on the basis of the quantitative criteria collision and conflict probability. For this, the user can explore, for example, different routings, traffic flow allocations for each route and the influence of new technologies and ATC procedures with the SK. In this way he is able to identify the safest alternative. Furthermore the user can, using the SK, investigate potentially existing areas with high risk potential ("hot spots") and find a solution to mitigate the local risk. In this manner, the SK can be a part of a Safety Management System like recommended from ICAO and EUROCONTROL.

[5] SBAS Satellite Based Augmentation System

[6] GBAS Ground Based Augmentation System

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