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MEASUREMENT OF THE QUALITY OF TRAFFIC ORIENTATION SCHEMES REGARDING FLIGHT PLAN EFFICIENCY

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Abstract–Due to growing traffic volumes in aviation there is a need to distribute the daily traffic demand onto the available capacity to make the airspace system as efficient as possible. These measures are known as Load Balancing within the framework of Strategic Air Traffic Flow Management. Therefore ICAO recommends introducing Traffic Orientation Schemes (TOS) where the demand exceeds the capacity.
These (TOS) are most far-reaching oriented on the ratio of demand and capacity and safety.
But over and above any TOS should take into consideration, that every single flight needs to be as cost or fuel efficient as possible to guarantee the most economic and environmental suitable use of airspace.
In this paper a methodology is shown and exemplary demonstrated on the European Route Availability Document which enables to monitor the economic and environmental efficiency of a Traffic Orientation Scheme.

I. Introduction

Due to continues growth of the traffic volume and consequently a growth of the air traffic capacity demand, it is unavoidable to distribute the air traffic wherever the demand exceeds the airspace capacity. Therefore the introduction of a Traffic Orientation Scheme as a tool of load balancing is needed.
These Traffic Orientation Schemes are published in the regional AIPs. In the European Airspace these so-called Traffic Flow Restrictions are published in the Route Availability Document (RAD).
This paper concludes the basics of state of the art event driven flight optimisation process and gives a short introduction into worldwide Traffic Orientation Schemes and kinds of Traffic Flow Restrictions.
Over and above that a methodology is shown which enables to monitor the quality of Traffic Orientation Schemes and exemplary used to review the Traffic Flow Restrictions of the RAD.

II. Background and Basics

A .Flight Plan Optimisation Process

Goal of the flight plan optimisation process is to find the most optimum route under consideration of different boundary conditions.
A flight is a location change from a defined departure airport to an arrival airport. This change is characterised as a distance which is get through a specific time. Therefore the first two goals of flight plan optimisation are to minimise the distance flown (Minimum Distance Track) or to minimise the time which is needed to reach the arrival airport (Minimum Time Track). The Minimum Distance Track is only considering the distance of every flyable airway segment. Dependent on weather especially wind conditions this route could lead to a very high fuel mass used for the trip. Therefore Minimum Distance Tracks have minor importance for flight plan optimisation.
The Minimum Time Track is considering these weather conditions. Therefore this kind of track is used for very long cruise procedures e.g. when flying over the Atlantic Ocean. But both Tracks will not consider the specifications of an aircraft especially the specific range. The specific range describes the mass of fuel which is needed to fly along a specific distance. If in terms of flight plan optimisation the distance is constant, the goal of the flight plan optimisation process is to minimise the mass of trip fuel. Those tracks are called Minimum Fuel Tracks.
Over and above that state of the art flight plan optimisation has to consider additionally direct and

indirect operation cost and ATC charges. Out of that it is necessary to find a track which leads to a minimum of operational costs. This flight plans are called Minimum Cost Tracks. This most the most complex kind of function used for flight plan optimisation but the only one which considers all boundary conditions of flight operations.

B. Air Traffic Flow Management

"Air traffic flow management is a service established with the objective to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extend possible and that the traffic volume is compatible with the capacities declared by the appropriate ATS Authority." [1]
This task could be provided by measurements like load balancing or re-routeing in the strategic or pre-tactical phase of ATFM. A tool for this task are so-called traffic orientation schemes (TOS). "Where a traffic orientation scheme (TOS) is to be introduced, the routes should, as far as practicable, minimize the time and distance penalties for the flights concerned, and allow some degree of flexibility in the choice of routes, particularly for long-range flights" [2].
The content of these traffic orientation schemes is a set of traffic flow restrictions which must be considered in the flight plan optimisation process.

In principle TOS can be differentiate into Static TOS and Dynamic TOS. Static TOS stipulates the use of one or more defined routes. The airspace user has only the possibility to choose one of the offered routes. Examples for such a traffic orientation scheme are the Coded Departure Routes in Northern America.
The dynamic TOS is more complex due to the fact that single waypoints or airway segments – so-called Flow Elements – are restricted by them. Depending on the restriction the Flow Elements could be forbidden, mandatory or allowed to use. In flight plan optimisation every single segment and waypoint need to be checked if according the traffic orientation scheme or not. This kind of TOS is offering the possibility to use operator preferred routes. An example for such a traffic orientation scheme is the Route Availability Document in Europe.
In principle the dynamic TOS offers more flexibility for flight plan optimisation as the static one which is offering only a set of routes without the possibility to use operator preferred trajectories. Never the less it is not possible to make a decision which kind of TOS offers the possibility to fly most efficient routes due to the fact that this depends on the quality of the single restriction within the TOS.
Figure 1 gives a short overview where important traffic orientation schemes are available.

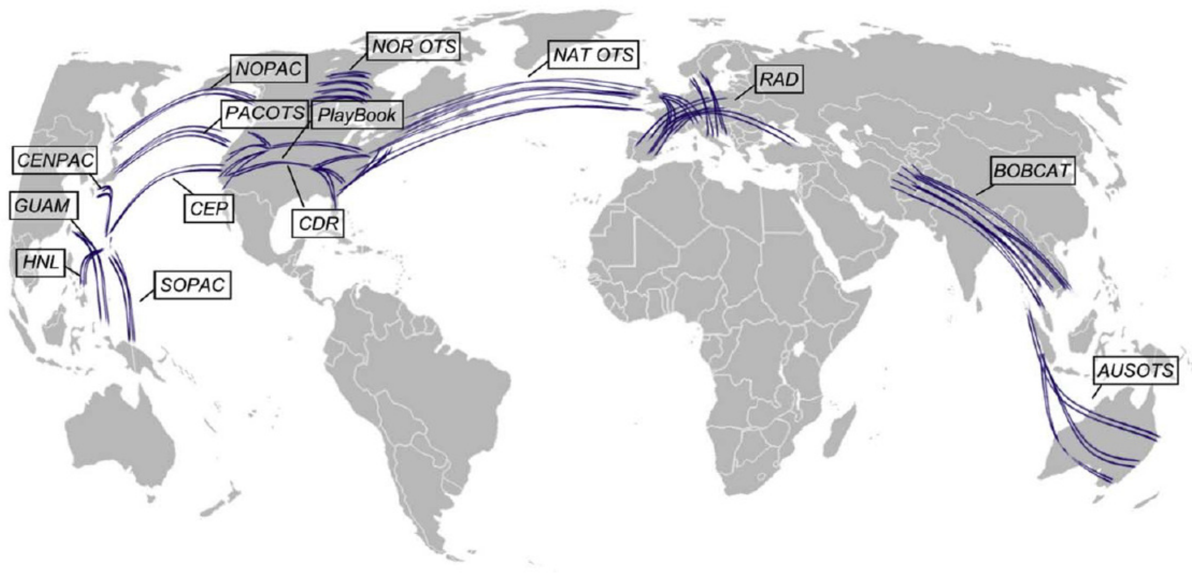

Figure 1: Distribution of traffic orientation schemes

III. Methodology of Measuring the Quality of a Traffic Orientation Scheme

A. Focus of the Analysis

The analysis of traffic flow restrictions, especially of restrictions published in the RAD, showed that there are two major elements of a flight route which are affected by regulations.
At first the airway segments and waypoints that are available within the airspace are regulated by restrictions. These segments can be not available, only available or compulsory for traffic fulfilling

defined conditions. This first kind of restriction – the route restrictions – has a direct effect on the route which is usable from one airport to another and may lead to higher detour factors.
The second element is the maximum flight level which is available on a defined city pair. This kind of restrictions – the City Pair Level Cappings – affects the profile or maximum flight level which is available between defined departures and destinations.
Both kinds of restriction lead to additional effort when operating a flight. In general these restrictions lead to higher detour factor, a longer time of flight, more required fuel or higher operating costs.
This higher operational effort should be as low as possible to make sure that flight operations are as efficient as possible.

B. Determining of the effects of a TOS on a single flight event

The methodology for analysing the effects of a TOS has the goal to quantify the value of additional effort resulting from fulfilling all these regulations.
Therefore routes, which are optimised under consideration of all restrictions of a TOS (FPL+TFR), are compared with flight plans which are established without taking care about restriction published in a TOS (FPL-TFR). The result of such a process is an absolute difference or a relative deviation factor of the optimisation criteria which is one of distance, time, fuel or operational costs. From this point of view only the optimisation criteria of the used optimisation function is decisive for the analysis.
The comparison of both kinds of flight plans is done by using the following formulas for absolute or relative deviations:

$$d_{abs\ i} = d_{i\ +\ TFR} - d_{i\ -\ TFR} \qquad (1)$$

$$d_{rel\ i} = d_{i\ +\ TFR} / d_{i\ -\ TFR} \qquad (2)$$

Dependent on the optimisation criteria d_i represents the route distance, time, trip fuel or costs for flights i = 1…n.
For a sample of flights the total deviations D are calculated by the formulas:

$$D_{abs\ i} = d_{abs\ i} / n \qquad (3)$$

$$D_{rel\ i} = d_{rel\ i} / n \qquad (4)$$

If the overall influence of a TOS should be measured, a set of flights is needed which is based on the totality of all flights affected by the respective TOS. Due to the fact that some city pairs are flown in a higher frequency and other with lower frequency all flights i could be weighted by a factor g_i. The sum of all weight factors should be one or 100%.

The measured relative deviation or absolute difference of the optimisation criteria is now adapted by the following formula:

$$D_g = \sum_{i=1}^{n} (g_i * d_i) \qquad (5)$$

Using this methodology it is possible to measure the additional effort in terms of flight efficiency of static as well as dynamic TOS and to compare different TOS.

IV. Example Route Availability Document

A. Overview

As it is the focus of this analysis the Route Availability Document is introduce is this paragraph.

"The Route Availability Document (RAD) is a sole-source-planning document which integrates both structural and Air Traffic Flow and Capacity Management (ATFCM) requirements geographically and vertically." [3]

The RAD includes traffic flow restrictions of 32 European Countries. But about 61% of the restrictions are published by the Countries Germany (ED), France (LF), Great Britain (EG) and Spain (LE).
Figure 2 shows the countries which are affected by the RAD.
The RAD is published every AIRAC-Cycle as a pdf-document via the EUROCONTROL CFMU web page.

Figure 2: Geographical overview of the RAD.

The RAD includes a set of different restrictions and limitations affecting the flight plan optimisation process. The main types of restriction are Route Restrictions and City Pair Level Cappings. The City

Pair Level Cappings only affect the maximum FL which is usable on specific City Pairs. This kind of restriction leads to a higher specific fuel consumption and therefore to higher operational costs for affected flights. Route Restrictions affect the trajectory of the route horizontally and vertically. These restrictions can lead to more operational effort depending on the published restrictions.

V. Focus of the Analysis

The focus of the analysis is a comparison of routes which are optimised in consideration of all restrictions published in the RAD with routes which are optimise without taking care of these restrictions.
The quality of the FPLs+TFR was analysed for eleven airports which are used as departure and arrival hub.

A. Used Software and Algorithm

All flight plans used for this analysis were calculated with the flight planning system LIDO OC developed and offered by Lufthansa Systems AG. This state of the art flight planning tool is used by about 40 known airlines like KLM, Lufthansa, easyJet and Air Berlin.
The tool itself offers the possibility to optimise routes in consideration actual weather, NOTAMs, CRAM, specific load and performance of the used aircraft and over and above that Traffic Flow Restrictions. Therefore it is not only possible to find preferred trajectories but also to measure the efficiency of possible trajectories influenced by a TOS. Therefore the TFR Module was developed which allows considering of all Traffic Flow Restrictions when optimising routes. That means that these requirements are automatically considered in the optimisation process.
The core algorithm which is used for optimisation is the Dijkstra Algorithm which was adapted and modified to ensure best optimisation results in shortest periods of time.

B. Setting of the System

For all calculations an aircraft of the type Airbus A3210-200 was used. The payload of this aircraft was set to 75%. To avoid differences in the results of the calculations for different city pairs every flight was calculated with a stated Alternate Fuel which was limited to a 2 hour holding procedure.

The analysis was performed between the 29th of June 2007 and the 28th of July 2007. All restrictions from the RAD, NOTAMs etc. were observed during the analysis.
Over and above that all calculations were done in consideration of the actual weather.
All optimised routes were calculated under most realistic conditions.

C. Sample of Flights

The sample of flights is oriented on airports. Therefore a random sample of 90 European airports was established. Figure 3 shows the distribution of the used airports across the European area.

Figure 3: Distribution of Airports used for the Analysis.

These airports are used to define the city pairs used for analysis. Due to the fact that more than 8000 city pairs can be established from the sample 11 airports are selected which were used for deeper analysis. Every of the 11 airports are used as global departure (departure star) and arrival (arrival star) location to fly to or from all other 89 airports of the sample. The 11 airports are Paris Charles De Gaule (LFPG), Frankfurt Rhein/Main (EDDF), London Heathrow (EGLL), Amsterdam Schiphol (EHAM), Madrid Barajas (LEMD), London Gatwick (EGKK), Brussel National (EBBR), Istanbul Atatürk Intl. (LTBA), Oslo Gardermoen (ENGM), Airport Köln/Bonn (EDDK) and Warsaw Okecie (EPWA). In the end more than 1800 flights are analysed. Figure 4 gives a short overview of all relations.

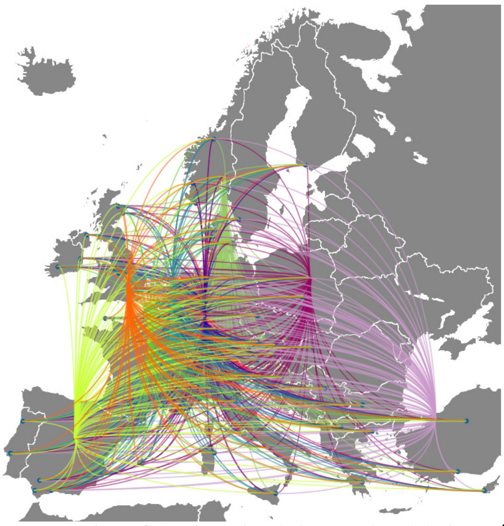

Figure 4: Overview of the city pair relations analysed during 29th of June 2007 and the 28th of July 2007

VI. Results

A. Relative Cost Deviations as result of Traffic Flow Restrictions

The comparison of the flights plans which are calculated using the TFR Module (FPL+TFR) and the flight plans which are calculated without using this module (FPL-TFR) results in the average Cost Deviation D_{RAD} for the Route Availability Document:

$$D_{RAD} = 0{,}76\%.$$

This Cost Deviation is between 0,28% (LTBA) and 1,09% (LFPG). Figure 5 shows the measured Cost Deviation for every of the 11 airports.

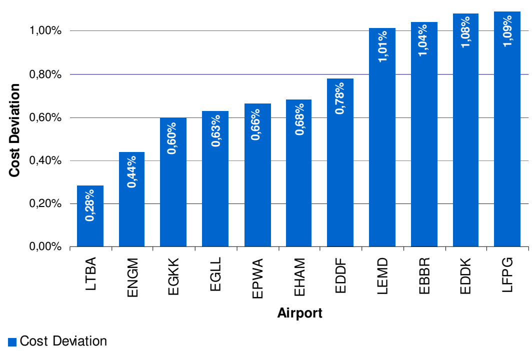

Figure 5: Average Cost Deviation for Analysed Airports

B. Frequency of Different Cost Deviations

If the Cost Deviation of all route is sorted and distributed into Cost Deviation classes it becomes visible that more than 56% of the flight plans have a Cost Deviation lower than 0,5%. Only in a minor number of cases a very high Cost Deviation is expectable as figure 6 shows.

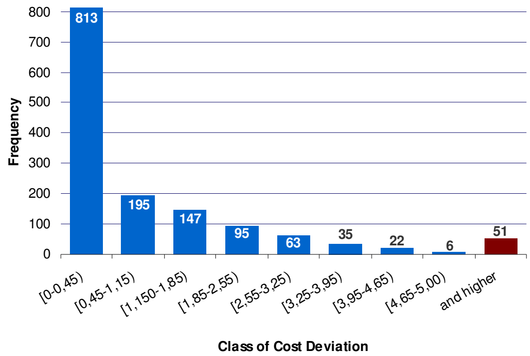

Figure 6: Frequency of Cost Deviations sorted by Classes

C. Interdependencies between route distance and Cost Deviation

If all calculated flights are sorted and distributed into distance classes, interdependencies between Cost Deviations and route distances become visible (see figure 7)

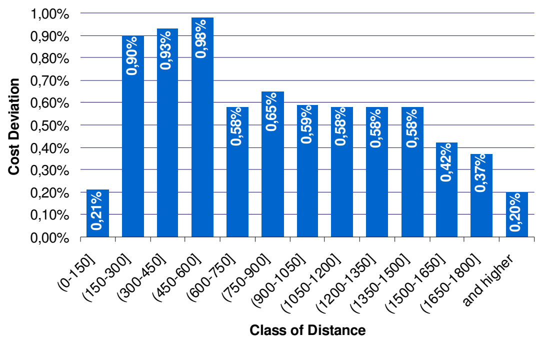

Figure 7: Cost Deviation dependent on route distances

Routes shorter than 150NM have a very low Cost Deviation. Only 13% of these flights have a Cost Deviation higher than 0,00%. In many cases the STARs started with the last waypoint of the used SID.

In the classes between 150NM and 600NM the Cost Deviation is between 0,90% and 0,98%. A deeper analysis showed that about 35% of the Cost Deviation in these classes is caused by City Pair Level Capping restrictions.

Between 601NM and 1500NM the Cost Deviation is about 0,58% and degreases starting by 1500NM down to about 0,20%. The longest route of the sample was 1879NM.

Figure 8 shows the Cost Deviation of the single distance classes influenced by the type of restriction.

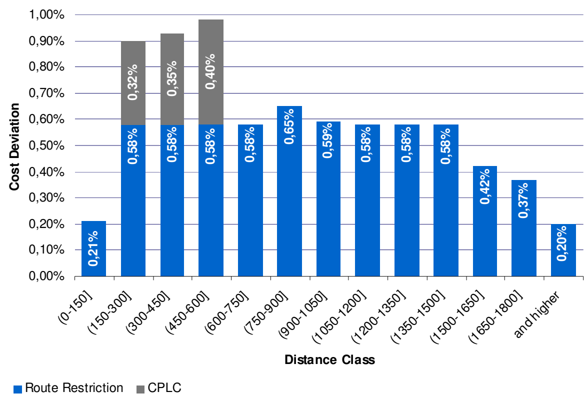

Figure 8: Specific Cost Deviations of Different Types of Restrictions dependent on route distance

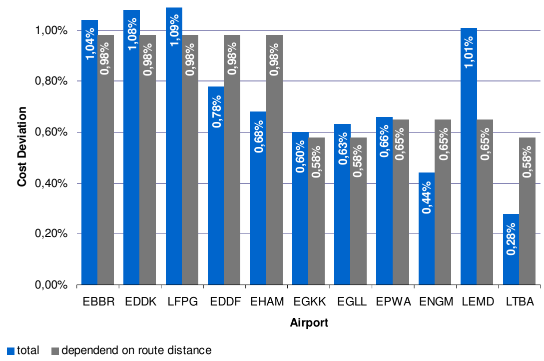

Figure 10: Average Cost Deviations for Analysed Airports

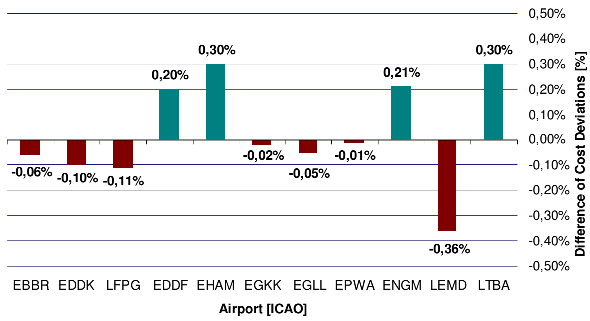

Figure 11: Differences between Distance Based Cost Deviation and Measured Cost Deviation for Analysed Airports

D. Specific Cost Deviations of the Analysed Airports

Due to the fact that not only airports from the centre of the European airspace but also airports from the periphery of this airspace are used, all results should be influenced by average route distance of the respective flights. Therefore the average flight distance should be calculated for these 11 Airports.

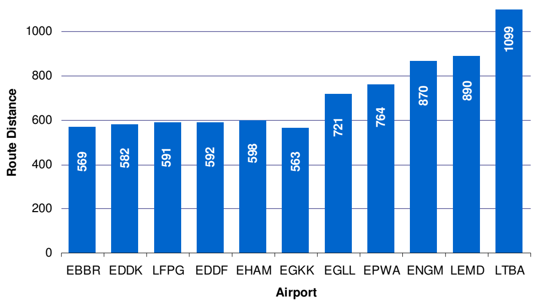

Figure 9: Average Route Distances for the Analysed Airports

As shown in figure 9 the average distances of the flights vary a lot from one airport to another. Therefore a comparison of these airports is only possible if the calculated Cost Deviations are compared with the average Cost Deviations which result from the route distances. Figure 10 compares both the measured Cost Deviation of the airports with the respective Cost Deviation resulting from the average route distance. The differences between both Cost Deviations are shown in figure 11 for every airport.

It is visible that the airports EBBR, EDDK, LFPG, EGLL and LEMD have a higher Cost Deviation as they should have regarding the average of route distances. On the other hand there are the airports EDDF, EHAM, ENGM and LTBA which have a lower cost deviation as they should have.

E. Absolute Values of Additional Effort Trip Fuel

The analysis shows that in 60% of all cases less than 25kg Fuel are needed to fulfil all constraints from the Route Availability Document. In 95% of all cases the additional trip fuel is below 225kg. This mass of fuel is not enough to fly 5 minutes with the used aircraft.

Figure 12 shows the classified additional trip fuel mass frequency and distribution.

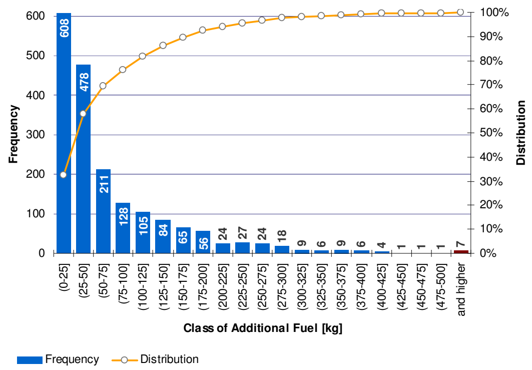

Figure 12: Distribution and Frequency of Additional Trip Fuel

F. Distance

Similar to the results of the analysis of the additional trip fuel the additional route distances are minor. As figure 13 shows in about 50% of cases the additional route distance is below 10NM. In 80% of the cases the additional distance is below 20NM. The statistical maximum (95% of cases) is below 50 NM.

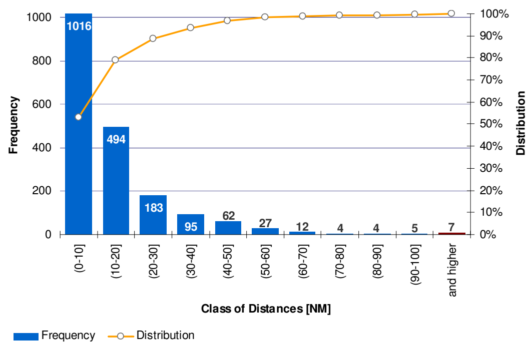

Figure 13: Distribution and Frequency of Route Extension

VII. Conclusion

This study was performed from Marcus Hantschke during his diploma thesis at University of Dresden. The goal of the thesis was to develop a procedure to measure key performance indicators for a Traffic Orientation Schema. By using the flight planning tool Lido OC from Lufthansa Systems, the calculations of Minimum Cost Tracks taking traffic flow restrictions into account were compared with the results of Minimum Cost Tracks neglecting traffic flow restrictions from the RAD document.
The analysis shows that a flight in Europe needs minor than 1% of additional costs if all constraints of the RAD are considered. This value proofs the high quality of the RAD document, which is valid for the European airspace. The given method to measure the performance of any TOS schema should be used in future from airlines regularly to proof the quality of the active schema. This procedure would enable any ATC authority to keep the active TOS schema on a high level of quality.

References

[1] EUROCONTROL: Performance Review Report, PRR2006, Brussels, May 2007

[2] International Civil Aviation Organization, ICAO: Procedures for Air Navigation Services – Air Traffic Management DOC4444 (PANSATM DOC4444): 14th Edition, Montréal, 2001

[3] EUROCONTROL: EUROCONTROL RAD User Manual, Edition N°:1.0, 2006

Author Biographies

Marcus Hantschke studied transport engineering at Technische Universität Dresden from 2001 until 2007. He received his engineer's degree (Dipl.-Ing.) after having finished a diploma thesis about the Influence of Traffic Orientation Schemes on Flight Plan Optimisation which was conduct in cooperation with Lufthansa Systems. Today, he works as system engineer in the Lido OC research and development department of Lufthansa Systems in Raunheim, specialised on trajectory optimisation under consideration of dynamic ATM traffic flow restrictions.

Urban Weißhaar is currently team-leader in the product development of Lufthansa Systems Aeronautics GmbH. He is responsible for planning and steering of strategic projects for the development of the flight planning software Lido OC. He represents Lufthansa Systems Aeronautics at international conferences and committees, dealing with ATM and environmental issues. Urban studied physics at the University of Freiburg where he received his Bachelor degree. After this he moved to the Institute of Meteorology and Climate at University of Karlsruhe where he finished his Diploma of Meteorology.