Implicit Relations Between Time Slots, Capacity and Real Demand in ATFM

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Abstract

The motivation of this report is to better understand why there are differences between regulated demand and real demand in ATFM.

We analyze past flight data from two different points of view: First, we take a look on the number of aircraft entering sectors. Visualization gives us intuition on regularities in the data. We interpret regulated and real demand as random variables where the only knowledge we have are the realizations in our database. We infer properties of these variables, especially on how they interact with each other. Secondly, we compare differences in declared and flown length and duration. This gives us an image on how accurate flight plan information is on a daily basis.

Our main hypothesis is that we analyze data of groups of aircraft rather than on a plane to plane basis because deviations of single aircraft are not independent from the others.

We conclude with an outlook on a statistical model of the misbehavior of groups of aircraft dependent on the regulated demand in order to improve current ATFM.

Introduction

The European airspace is a complex system consisting of planes, control-centers, airports, regulations and more. The regulations we are interested in are rules that guarantee that sector capacities are not exceeded. A sector capacity is measured in the number of aircraft that may enter a sector in an hour. Currently these regulations are based on a model of the airspace taking into account flight plan information. A flight plan is essentially a list of way-points. Given all flight plans, one calculates the number of aircraft wishing to enter a sector. Time slots are distributed between aircraft in order to avoid excess of capacities. By consequence some aircraft may be delayed or rerouted before takeoff. One is speaking of initial and regulated demand. The model of the airspace underlying these calculations is of deterministic nature. The above is a summary of the tactical air traffic flow management (tactical ATFM). In reality, the airspace is also governed by events that are not or only partly known in advance. Think of weather conditions, delays due to connecting flights or en-air reroutings for example. We call the number of aircraft entering a sector in reality the real demand. These events may lead to planning differences between the regulated demand and the real demand in certain areas at certain times. As a consequence, safety issues are not always guaranteed and available capacity is not always optimally used. A better understanding of the mechanisms leading to such differences in the system is sought in order to improve the current model. At a first glance, planning differences are the deviation of a single aircraft from its flight plan. The strategy could then be to estimate them. This strategy seems difficult mainly because there are obvious dependencies between the aircrafts: a conflict resolution is made because of the presence of other aircraft, delays due to connecting flights are because other flights arrive too late and so on. From this we motivate our idea to study the planning differences of a group of aircraft rather than of a single aircraft. Dependencies inside a group are implicit and dependencies between groups seem easier to grasp than those between single aircraft, because their number is much lower. Moreover, in tactical ATFM is precisely required to guarantee that no more than a certain number of aircraft enters a sector at a given time. In this report we analyze past flight data from two different points of view: First, we take a look on the number of aircraft entering sectors. Visualization gives us intuition on regularities in the data. We interpret regulated and real demand as random variables where the only knowledge we have are the realizations in our database. We infer properties of these variables, especially on how they interact with each other. Particularly, we are interested in how the measurement timescale affects the interpretability of the planning differences.
Secondly, we compare differences in declared and flown length and duration. This gives us an image on how accurate flight plan information is on a daily basis.

The paper is organized as follows: the next section describes the data that underlies our analysis followed by a description of the experiments. Then, conclusions are drawn and an outlook on a statistical model of the misbehavior of groups of aircraft is presented. Such a model may be used to minimize expected planning differences.

Data

Generally one is classifying traffic demand into weekday (Monday-Thursday), Friday and weekend (Saturday-Sunday) groups. Over the year, summer and winter traffic is distinguished. Special events such as national holidays or strikes may form exceptions. In this report, we assume different days as being independent from one another. We focus on a region in the upper Berlin airspace (EDBB). Reasons for the choice of these sectors is that they are elementary and regulated and that radar data is available for them. For the sector entry study, we use regulated demand (RTFM) and real demand (CTFM) data extracted from COSAAC for a total of 141 weekdays in the period June 2003-April 2004 of the four sectors EDBBUR1-4. For the global study we have data available from all (about 14000) flights entering one of the four sectors EDBBUR1-4 for 11 weekdays in the month of November 2003: More precisely, the following attributes are available for every flight:

- submitted flight length (in NM)
- real flight length (updated profile by radar data)
- submitted flight duration (in minutes)
- real flight duration (updated profile by radar data)

Results

Sector Entry Analysis

In these experiments, descriptive statistics of sector entries are made. All experiments were carried out on all four sectors available, illustrative results are presented from sector EDBBUR2.

Similarity of Demand

In order to compare daily traffic figures with the declared capacities of the sectors, the regulated and real demand data is visualized for hourly values. For visualization purposes, we only display the data from the same 11 week days in November 2003 as in the experiments above.

Figure 1 displays the 11 days. On the 'time' axis you see the time of the day, the 'day' axis stands for the date and the 'Planes' axis counts the planes entering the sector. Daily peaks are observed between 7-8h and 19-20h in the regulated and the real demand figures.

![Figure 1. Regulated Demand in UR2 (Hourly)](image)

On the 'time' axis, you see the time in hourly intervals. The 'day'-axis displays the different days (here 11), the 'Planes'-axis the number of aircraft entering the sector in the given hour.

Taking the differences of regulated and real demand, however, does not reveal visible regularities (Figure 2). The pattern seems chaotic. A more detailed study of the statistical properties of this pattern on a five minutes interval has been carried out in [1]. A result is that some statistical

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1 both are point profiles for single flights; CTFM is an update according to information in the correlated position report (CPR)
2 an ATFM simulator software developed at EEC Bretigny
3 a resectorization has taken place in December 2003; our four sectors changed their names but we will refer to them in their origin names
4 the data source is the PRISM data-warehouse
properties of this pattern do not vary over time. We will address the question of consequences of increasing the time scale below.

Figure 2. Planning Differences in UR2 (hourly)
On the 'Error'-axis you see the difference between regulated demand and real demand.

Correlation vs. Time Scale Study
In this experiment, we’d like to find out the relation between the time scale (e.g. hourly values, five minutes values) and the correlation between the regulated demand and the real demand. This is important to know when analyzing the propagation of the differences in the whole airspace network. At this point, we interpret regulated and real demand as discrete random variables\(^5\). We can then formulate questions about the nature of the quantities as the identification of (joint) probability distributions and use tools from statistics to infer new knowledge.

The Figures 3, 4, and 5 display the number of regulated demand on the x axis and the number of real demand on the y axis. A linear trend can be seen when working on hourly values (Figure 3). The line is the corresponding regression line. The r-square coefficient has a value of 0.89. When comparing the values based on a five minute interval (Figure 5), no correlation may be seen. The threshold between linear correlation and no correlation is about 15 minutes (Figure 4) (r-square=0.53). We observe that below 15 minutes intervals, associations between regulated demand and real demand look arbitrary. This lets us conclude that on a plane-to-plane basis, no simple pattern is visible in the difference between flight plan information and reality. This is not surprising, since there are numerous causes for such differences (lost slots, flight plan incoherency, weather condition, controllers actions, ...). On the other side, when counting a number of aircraft in a larger time interval, high (linear) correlation exists between the number of aircraft supposed to enter and the number of aircraft that really entered the sector. This information can be useful for ATFM, since one of its objectives is to protect sectors from over-delivery.

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\(^5\) for definitions of concepts from statistics and probability theory, the reader is referred to [2, 3] or any introductory book on statistics and stochastic processes.
Figure 4. Correlation REGULATED and REAL Demand: 15 Minutes Values
The axes are as above, a weak linear correlation is visible.

Figure 5. Correlation REGULATED and REAL Demand: 5 Minutes Values.
No more correlation is visible.

Shape of Histogram vs Time Scale Study
In another study, we showed that some statistical properties of the planning differences do not vary over time, when the time interval is 5 minutes [1]. In this experiment we’d like to know whether they vary when the size of the time interval is increased. Figure 6 shows the typical distribution of planning differences with 5 minutes time interval and Figure 7 displays the histogram for a 60 minutes interval.

In both figures, the x axis displays the value of the difference between the number of aircraft supposed to enter the sector and the number that really entered the sector. The y axis shows the relative number of occurrences of these values at any time during the day. Both histograms have a similar shape. Mean of the first is -0.03 and of the second -0.4. The standard deviation is higher in the 60 minutes case (3.34) than in the 5 minutes case (1.48). This makes sense since much more aircraft are counted in a time interval of one hour than in five minutes. Note that the underlying values are discrete (differences of counts of aircraft), so even
if they look like normally distributed, it is not correct to speak about normal distributions.

Also note that the values of the 60 minutes measurement are sums of values of the five minutes measurements. We know from their autocorrelation, that the five minutes measurements are not independent random variables [1]. We observe that their empirical distributions look similar. Theoretically, we are thus confronted with a convolution problem of discrete, dependent random variables. It is not the scope of this paper to go in more details here, but we think that more has to be found out on this topic.

As a conclusion we strengthen the hypothesis that the shape of the distribution of the differences between planned and realized sector entries does not change with the measurement time interval. This should be further investigated in more detail.

**Repeated Flight Plan Inaccuracy Analysis**

In this experiment we investigate how much the flight lengths and flight durations differ between the information on the initial flight plan and reality. Other studies with similar scope (e.g. [4, 5]) normally analyze only one traffic day. Our focus is on the regularities on a day to day basis rather. We split the data into the two groups: 'difference in flight length' and 'no difference in flight length'. We refer to the first group as 'rerouted', but we admit that the difference must not necessarily be the result of controllers actions. We report three observations: one for the lengths of rerouted flights and each one for the durations of non-rerouted and rerouted flights. Each of Figures 8, 9, and 10 consists of 11 boxes, one for each day. About 2 percent of the flights are rerouted. Moreover, there is nearly no difference between the length initially planned and really flown (Figure 8)

Examining the durations of non-rerouted flights (Figure 9), two effects may be observed: firstly, the real flown duration is generally up to 10 % below the initial one. This is seen in the thick diagonal. It may be explained by the fact that airlines add a time buffer to their length calculation in order to absorb delays [5]. And secondly, from a duration of 400 minutes on, a cluster of planes exceeds the initial flight duration. This is the group of points in the upper right part of every box. It might be the effect of incorrect repetitive flight plans but merits to be investigated in more detail.

The situation is less clear for rerouted flights: while the time buffer effect may still be seen, the cluster effect is not visible on every day (Figure 10).
As a conclusion, we state that the flight length indicated on the initial flight plan is accurate. Daily repeating differences in flight durations, however, may be seen. These findings correspond to controllers observations [6]. Translated in our context, we found non arbitrary reasons for the planning differences.

Conclusions and Future Work

We showed that on a plane-to-plane basis, no simple pattern is visible in the differences between flight plan information and reality. On the other side, when counting a number of aircraft in time intervals larger than 15 minutes, high linear correlation exists between the number of aircraft supposed to enter the sector and the number of aircraft that really entered the sector. Next, we observed that the shape of the distribution of the differences between planned and realized sector entries does not change with the measurement time interval. Theoretically, increasing the measurement interval corresponds to a convolution of discrete, nonindependent random variables. We like to further clarify the probabilistic structure of the planning differences. We found also that differences between flight plan information and reality are in durations rather than in flight lengths. For the former, systematic, daily repeating patterns may be seen. In another study, we showed that there are no linear relationships between the differences in adjacent sectors [7]. From this we conclude the following: We think of a model of the misbehavior of groups of aircraft rather than of single aircrafts. In more detail, if we know the probability distribution of this misbehavior dependent on the regulated demand of sectors that are connected via the routes, we can identify patterns of regulated demand that minimize the planning differences. Such an approach would use the current infrastructure of the whole airspace system and would not assume the modification of the behavior of its users.

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References