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Mitigation of airspace congestion impact on airline networks

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ABSTRACT

In recent years European airspace has become increasingly congested and airlines can now observe that en-route capacity constraints are the fastest growing source of flight delays. In 2010 this source of delay accounted for 19% of all flight delays in Europe and has been increasing with an average yearly rate of 17% from 2005 to 2010. This paper suggests and evaluates an approach to how disruption management can be combined with flight planning in order to create more proactive handling of the kind of disruptions, which are caused by congested airspace. The approach is evaluated using data from a medium size European carrier and estimates a lower bound saving of several million USD.

1. Introduction

Running an airline is a complex business where hundreds of aircraft need to be scheduled and maintained. Thousands of flights need to be dispatched every day. Tens of thousands of crew members need to be rostered and millions of passengers need to be transported from one location to another every year. To accomplish this enormous task airlines have for several decades relied on Operations Research (OR) to stay competitive and conduct careful and efficient planning of every single activity in their operation. Unfortunately these efficient plans are hardly ever being executed as originally intended.

In 2010 24% of all flights in Europe and 18% of all flights in the US were delayed more than 15 min and consequently experienced some sort of disruption (Eurocontrol and FAA, 2012). Bad weather, technical problems, crew reporting sick and in recent years to an increasing extent also airspace being congested are all examples of uncertainty elements.

To manage these deviations there has during the last couple of decades been a move in airline related OR research to an increased focus on the real-time execution of the airline. In this paper we take OR based disruption management one step further in the direction toward the actual flight operation as we combine disruption management and flight planning.

The paper initially gives a short introduction to disruption management and the main work processes, which exists in an *Operational Control Center (OCC)* in an airline. The paper provides a literature review on disruption management with a special focus on integrated disruption management as well as flight planning. The paper goes into further detail with Air Traffic Flow Management (ATFM). In this paper we suggest a network representation and a model, which handles integrated recovery decisions with flexible flight trajectories. We describe a framework for using the integrated decision approach and use this to evaluate our suggested approach. Finally we present our findings in terms of a lower bound for the annual saving, which can be obtained by using the approach.

A contribution of this paper is to suggest and evaluate an approach to how disruption management can be combined with flight planning in order to create more proactive handling of the kind of disruptions, which are caused by congested airspace.

The paper suggests a method for increased interaction between Ops Controllers and flight planners in order to make sure that the network effects of any trajectory selection is properly incorporated in the decisions.

The paper introduces a flight planning based aircraft recovery model, which takes into account both passenger misconnections

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and congested airspace constraints.

2. Disruption management

Whenever an event occurs, which makes an airline deviate from its planned schedule or its planned crew rosters, the airline is disrupted. Most larger airlines operate a hub and spoke network, where efficient use of aircraft and crews are causing the airline not to have crew following the aircraft. This is due to the fact that crew work rules are much more restrictive than the rules which can be applied to aircraft. The tight planning of aircraft and crew is causing an airline to become very vulnerable to disruptions, as a delay of a single inbound flight to a hub quickly can propagate to other flights.

Most airlines have an Operational Control Center (OCC). In the OCC *Ops Controllers* monitor the operation of the airline and manage disruptions to the schedule and are responsible for a well-functioning network of flights, crew and passengers on the day of operation.

The organizational setup of an OCC varies from airline to airline and does to a large extent depend on the size of the airline. There are, however, some typical organizational entities, which are present in virtually any OCC. These are:

- Airline Operations Controllers: These are responsible for the overall operation of the airline's schedule on the day of operation.
- Aircraft Controllers: This group of people are responsible for maintaining a feasible schedule and aircraft routing, including that each aircraft is routed back to their scheduled and unscheduled maintenance activities at one of the maintenance stations.
- Crew Controllers: When the recovery of the schedule and aircraft routings inflict changes to the schedule, these changes need to be verified for feasibility with the Crew Controllers.
- Customer Service Representatives: The Customer Service Representatives in the OCC are responsible for maintaining a proper level of service to the airline's passengers, which is especially important to keep in focus during times of irregular operations.
- Maintenance Controllers: This group of people are in contact with the maintenance department of the airline and communicates to the Aircraft Controllers in case a maintenance activity will not be finished on time.
- Flight Dispatchers: A dispatcher is responsible for a number of individual flights and does on a flight-by-flight basis take care of everything from collecting relevant weather information for a flight to calculating the *flight plan* and monitoring the status and potential risks related to the flight while it is en-route.

2.1. Previous work on disruption management

In order to find good recovery solutions in a limited amount of time OR techniques have been applied to the problem. The full problem of recovering all 3 resource areas of aircraft, crew and passengers is, however, so complex that no work has been published so far, which cover all 3 areas in one single integrated model. The published models are typically inspired by how the airlines do their manual problem solving, and the models usually address one single resource area each. A good introduction to disruption management in the airline industry can be found in Belobaba et al. (2009). Kohl et al. (2007) describes a large scale EU-funded project, called Descartes, which addresses various aspects of disruption management. The reader is also referred to an extensive survey of operations research used for disruption management in the airline industry by Clausen et al. (2010).

Of the 3 resource areas mentioned above, aircraft recovery was the first area to be addressed through the application of OR by Teodorović and Guberinić (1984). This work was merely academic in its scope and only considered flight delays. Jarrah et al. (1993) were the first to publish 2 models, which in combination were capable of producing solutions, which were useful in practice. The drawback of Jarrah et al. (1993) was that cancellations and delays could not be traded off against each other within one single model. This drawback was later on resolved in the work by Yan and Yang (1996). Thengvall et al. (2001) later on extended this model to also include so-called protection arcs, which serve the purpose of keeping the proposed solutions somewhat similar to the original schedule. Rosenberger et al. (2003) present a model based on the set packing problem. Andersson (2006) proposes two meta-heuristics based on simulated annealing and tabu search. Results show that the tabu search heuristic is best and can find high quality solutions in less than a minute. Recently Eggenberg et al. (2010) proposed a generalized recovery framework using a timeband network, where the same model can be used to solve either an aircraft recovery problem, a passenger recovery problem or a crew recovery problem.

The second problem, which has been addressed by the OR community is the crew recovery problem, which was initially addressed in the work by Johnson et al. (1994). Later work include Wei et al. (1997), Stojković et al. (1998), Lettovsky (2000) and Medard and Sawhney (2007).

The third area, passenger recovery, has only been addressed by a very limited amount of published research. The main contribution in this area is done by Bratu and Barnhart (2006), who present a Passenger Delay Model. Vaaben and Alves (2009) does a comparison of sequential passenger re-accommodation with re-accommodation based on an IP model.

3. Air Traffic Control (ATC) and flight planning

The airspace of a country is regulated by the authorities of the country. In the US it is the Federal Aviation Administration (FAA). While the different countries in Europe regulate their own airspace, they have to a large extent agreed on common rules and have also established a common control entity called Eurocontrol. Both Europe and the US have established an overarching control layer for their Flight Information Regions (FIRs) called Air Traffic Flow Management (ATFM). In Eurocontrol ATFM is performed by the Central Flow Management Unit (CFMU).

To coordinate traffic and ensure safety a number of additional elements are defined for the airspace. Among these are *waypoints* and *airways*. Together with waypoints the airways create a directed graph, where waypoints represent nodes and airways represent arcs.

In order to fly from one airport to another it is necessary to calculate a path through the airspace graph. This process is called *Flight Planning*. For further reading regarding airspace and ATC, the reader is referred to Belobaba et al. (2009) and Cook (2007).

A flight plan describes how the aircraft is going to fly from a Point Of Departure (POD) to a Point Of Arrival (POA) and has to be filed with Air Traffic Control (ATC) before the flight is allowed to take off. The route is specified as a sequence of waypoints and altitudes.

Calculating a flight plan is a complex optimization problem in itself. It has, however only been addressed by academia to a rather limited extent compared to other airline related problems. Altus (2012) gives an overview of flight planning related literature and the complexities associated to the problem.