Robust Optimization Model for Runway Configurations Management

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ABSTRACT

The Runway Configuration Management problem governs what combinations of airport runways are in use at a given time for an airport or a collection of airports. Runway configurations (groupings of runways), operate under Runway Configuration Capacity Envelopes (RCCEs) which limit arrival and departure capacities. The RCCE identifies unique capacity constraints based on which runways are used for arrivals, departures, and their direction of travel. When switching between RCCEs, due to a change in weather conditions or a change in the demand pattern, a decrement in arrival and departure capacities is incurred during the transition. This paper reports computational experience with two distinct models—a robust optimization model that addresses uncertainty in the arrival demand, and a previously studied model that does not include uncertainty in any of the parameters. Test case scenarios are based on data from the John F. Kennedy international airport in New York.

Keywords: Air Traffic, Airport Runway Configurations, Mixed Integer Programming, Robust Optimization

1. INTRODUCTION

The dynamics of a metroplex, a grouping of airports in close geographic proximity, are governed by a complex underlying framework of airport regulatory guidance, competition, and feasibility constraints. Efficiency is gaining increased importance in metroplex operations, since up to three times the current traffic demand for the U.S. national airspace is expected by 2025 (Technology Pathways, 2005; FAA and MITRE Corporation, 2007). Expanding existing or building new airports is not only an expensive and time consuming task, but more critically it is often geographically infeasible due to space limitations in high demand city centers and urban areas. In order to alleviate congestion while maintaining connectivity to desired destinations, airport operations must be tuned as closely to optimal conditions as possible. Moreover, future airspace management systems are likely to consolidate air transportation decisions at the metroplex rather than individual airports. Efficient operation of a metroplex introduces several challenging, dependent, sub-problems at each individual airport including, runway

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configuration management (Provan and Atkins, 2010), surface operations (Tsao and Pratama, 2011), arrival and departure scheduling (Atkin, Burke, Greenwood and Reeson, 2008) and gate assignments (Das, 2009).

This paper addresses the Runway Configuration Management (RCM) problem. Air traffic controllers must make decisions regarding when to change from one configuration of runways to another. Runways are numbered between 01 and 36. Runway numbers are found by rounding one tenth of the magnetic azimuth of the runway’s heading. For example, a runway numbered 09 points east (85-95°). If there is more than one runway pointing in the same direction (parallel runways), each runway is identified by appending Left (L), Center (C) and Right (R) to the number. Figure 1 shows the FAA airport diagram for the John F. Kennedy (JFK) International airport. There are two pairs of orthogonal runways: 4L, 22R, 4R, 22L, 13R, 31L, 13L and 31R. Each runway may be used for arrivals only, departures only, or a mixed arrival and departure pattern. For example, 31R | 31L, is a runway configuration in which 31R is used only for arrivals and 31L is used only for departures. Usually, runways before “|” are used for arrivals and those after it are for departures.

We call an RCM problem strategic if the planning window is five hours or more and tactical if the planning window is less than five hours. The tactical RCM problem requires detailed information about each planned arrival and departure in the time window and does not lend itself to a closed form performance metric. Thorne and Kincaid (2012) describe a heuristic search procedure for the tactical RCM problem that relies on a scenario based Monte Carlo simulation to evaluate each proposed configuration change. The focus in this paper is the strategic RCM problem in which the use of aggregate arrival and departure information leads to a closed form performance metric. For a five hour planning time scale, determining when to change from one runway configuration to another does not require detailed information of individual flights. Instead, aggregate arrival and departure demand is sufficient. There are two reasons for this. First, cumulative overall system performance rather than individual flight performance is the objective of interest in strategic RCM. Second, system uncertainties prohibit a fine level of detail for future planning. Hereafter, when we refer to the RCM problem we mean the strategic RCM problem.

Changing runway configurations impacts airport arrival and departure capacities since each runway configuration has a different RCCE. Determining when to change from one configuration to another is complicated by a dynamic system rich with uncertainty. It is therefore not possible to deterministically forecast configurations in which to operate throughout the day. Weather conditions such as wind speed, wind direction, and cloud cover ceiling are among the most influential characteristics governing configurations available for use. The demand for aircraft arrivals and departures in each time period further limits the number of feasible configurations. Additionally, environmental constraints such as noise and no-fly restrictions over populated areas are often present at varying times of the day. Regardless of the system’s dynamic nature, the ability to generate a schedule of configuration changes is essential. RCM models are an attempt to provide air traffic controllers with a tool to assist in the scheduling of configuration changes. The main goal of this paper is to develop an RCM model that provides a mechanism for addressing uncertainty in the arrival demand in each planning time period.

The paper is organized as follows. In section 2 key terms and definitions needed to describe the optimization models for RCM are provided as well as a summary of a previous RCM model (Weld, Duarte, and Kincaid, 2010). This model is extended in section 3 by adding uncertainty to the arrival demand in all planning time periods via a robust optimization approach. Section 4 contains a description of how our computational experiments are conducted. A small example is provided in section 5 to illustrate both the robust optimization model described in section 3 and the computational experiment procedure.
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