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Runway capacity management – An empirical study with application to Doha International Airport

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ABSTRACT

This paper examines a three-faceted approach for runway capacity management, based on the runway configuration, a chosen scheduling approach, and an aircraft separation standard. These factors prompt alternative runway settings that are encapsulated using a classical mixed-integer formulation. The optimal solution for each runway setting is compared against our proposed optimization-based heuristic. This integrated approach is applied to investigating the transition from the (Old) Doha International Airport to the New Doha International Airport. Our empirical study based on historical data reveals that the proposed heuristic consistently yields optimal or near-optimal schedules, with considerable savings in fuel cost and reductions in delays, while preserving the spirit of an FCFS sequencing policy.

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1. Introduction

In recent years, new flight patterns – facilitated by the advent of larger aircraft – and ever-increasing air traffic loads have required airlines and airports to seek new frontiers in operations efficiency. In 2012, Airports Council International (ACI) reported over 6 billion passengers in domestic and international flights worldwide. By 2025, it is anticipated that this figure will increase by at least 50%, with over 9 billion passengers in global air traffic. The growing air traffic trends necessitate the construction of new airports, major capacity expansions at busy airports, a commensurate adjustment of aviation infrastructure, and the identification of operational policies and managerial directives that best avail of existing capacity. In particular, airports are faced with persistent challenges related to runway scheduling, a key bottlneck in the air transport system.

The Middle East is serving as a hub for global trade and transport and has witnessed rapid air traffic growth over the last years. According to the *International Civil Aviation Organization* (ICAO), international air traffic amounts to nearly 60% of the total passenger traffic, 10% of which occurs in the Middle East. In this context, the United Arab Emirates and Qatar are making large investments in aviation infrastructure and host three major airlines, *Emirates Airline* based in Dubai, *Etihad Airways* based in Abu Dhabi, and *Qatar Airways* based in Doha.

Our work is predicated on the notion that runway capacity should be analyzed in light of three primary factors: (i) The runway physical configuration and operating mode (segregated vs. mixed); (ii) The adopted aircraft scheduling approach which spans heuristics, metaheuristics, and optimization approaches; and (iii) The specific standard adopted for aircraft separation. Two of the commonly used aircraft separation standards are stipulated by the *Federal Aviation Administration* (FAA)

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and the *International Civil Aviation Organization* (ICAO) and are examined in this paper. To the best of our knowledge, no comparative study has empirically examined such complementary planning factors that influence the performance of runways.

Most of the studies in the literature focus on a specific exact or heuristic solution approach to the aircraft sequencing problem. In this paper we adopt a more integrated approach. As depicted in Fig. 1, we examine the combined effect of the specific runway configuration, including the physical layout of runways and their operation mode (mixed or segregated), the aircraft scheduling policy, and the aircraft separation standards. In particular, we contrast the case of a single-runway airport (as in Doha International Airport, DOH) with the two-runway newly constructed (Hamad International Airport, HIA), under mixed vs. segregated mode. The runway performance under alternative settings is assessed using the proposed optimization-based approach and aims at quantifying fuel burn savings (and accompanying delay reductions). Furthermore, our study demonstrates the importance of assignment decisions, an aspect that is commonly overshadowed by discussions on sequencing decisions. Our results indicate that, even under an FCFS policy within the departure and arrival queues respectively, optimizing aircraft assignment decisions can yield overall very near-optimal solutions. This, in turn, can be beneficial to air traffic controllers, as the focus is not so much on adopting a complex sequencing procedure that could be inhibited by airport layout considerations in practice; rather it is on the benefit of effective aircraft-runway assignment decisions.

The remainder of the paper is organized as follows. Section 2 positions the present work in the context of the extensive literature on aircraft sequencing problems. Section 3 presents a classical optimization model for runway scheduling. This model can readily encapsulate the three-faceted planning approach that we adopt and is enhanced via preprocessing routines. We also propose heuristics that are grounded in the optimization model and the FCFS sequencing policy. In Section 4, we discuss data related to runway operations at Doha International Airport and present our computational results for alternative runway settings using the proposed solution methodology. Section 5 concludes the paper with a summary of our findings and directions for future research.

2. Literature review

At an operational level, runway scheduling problems seek to determine effective aircraft schedules over one or multiple runways using pertinent cost objectives or performance criteria. There exists a large body of literature on aircraft sequencing approaches that is grounded in seminal works on machine scheduling. Bennell et al. (2011) offer a survey of runway scheduling problems, covering modeling approaches, solution techniques, and performance criteria. Popular solution techniques for runway scheduling problems include dynamic programming (Bayen et al., 2004; Brentnall, 2006; Balakrishnan and Chandran, 2006), branch-and-bound/cut algorithms (Brinton, 1992; Abela et al., 1993; Ernst et al., 1999; Beasley et al., 2000), and a broad spectrum of constructive/greedy heuristics and metaheuristics (Bianco et al., 1999; Hansen, 2004; Capri and Ignaccolo, 2004; Hu and Chen, 2005). Most studies tend to focus on either departure or arrival aircraft sequencing, in isolation, with a few exceptions that consider mixed-mode operations.

Literature on optimization models. Noting the similarity between aircraft sequencing problems and machine scheduling problems with sequence-dependent set up times and time-windows for the completion of jobs, Ernst et al. (1999) proposed an optimization model that is tackled using a heuristic based on branch-and-bound algorithms. In a similar spirit, Beasley et al. (2000) proposed a disjunctive mixed-integer program (MIP) for single and multiple-runway aircraft sequencing problems which is widely used in the literature. Further, Ghoniem et al. (2013) presented an asymmetric traveling salesman problem-based (ATSP) model for combined arrival-departure aircraft sequencing problems over a single runway. The computational tractability of this formulation was significantly enhanced using valid inequalities and preprocessing routines.

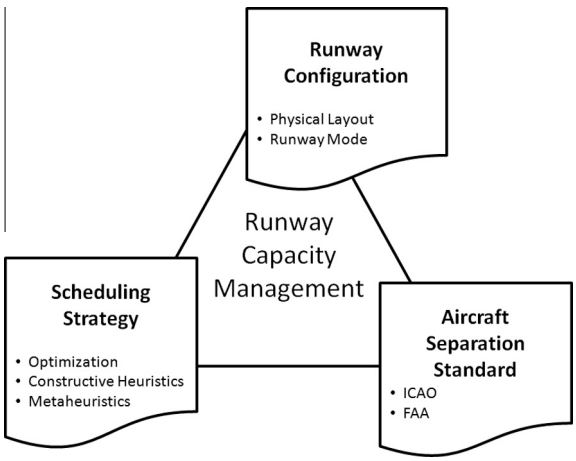

Fig. 1. Key factors related to runway capacity.