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Robust aircraft sequencing and scheduling problem with arrival/departure delay using the min-max regret approach

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ABSTRACT

This study considers the aircraft sequencing and scheduling problem under the uncertainty of arrival and departure delays for multiple heterogeneous mixed-mode parallel runways. To enhance runway resilience, runway operations should remain robust to mitigate the effects of delay propagation. The main objective of this research was to identify an optimal schedule by evaluating the robustness of feasible solutions under its respective worst-case scenario. A novel artificial bee colony algorithm was developed and verified by experimental results. The proposed efficient artificial bee colony algorithm can obtain close-to-optimal results with less computational effort in regard to a one-hour flight traffic planning horizon.

1. Introduction

1.1. Problem description

With the introduction of low-cost carriers in Western countries and the remodelling of airport-airline relationships, air transport demand has been significantly increased due to the capacity bottlenecks (Francis et al., 2004; Gelhausen et al., 2013). The performance of the aircraft turnaround process and the airport-airline relationship affects the decision-making of the objective function in the aircraft sequencing and scheduling problem (ASSP) model. The common First-Come-First-Served (FCFS) approach creates unnecessary spare capacity in the ASSP model (Bennell et al., 2017; Ng and Lee, 2016a). The most relevant operational problem in the aircraft scheduling literature often considered the global optimality in practice within a reasonable computation time (Samà et al., 2015). It is frequently observed that real-time aircraft re-scheduling in runway operation occurs. Air Traffic Control (ATC) obtains the latest information on flights to determine a schedule. The ATC workload has dramatically increased due to rising air transport demand. The estimated time of arrival/departure may not be close to the true operation time, which may lead to disruption of planned flight schedules and subsequent ground operation schedules (Sinclair et al., 2014). In fact, the introduction of a robustness optimisation technique in the ASSP problem improves the resilience at busy airports and leverages the possible workload of re-scheduling effort.

This paper aims to improve the runway operations by considering the solution quality, computation time, the resilience level of runway operation and the degree of robustness in makespan optimisation of aircraft scheduling in hedging uncertainties. In this model, we considered the aircraft sequencing and scheduling problem with multiple heterogeneous

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mixed-mode parallel runways. In mixed-mode runway operation, the runway is used for both aircraft landings and take-offs. The arrival and departure rate in an airport usually does not have a stationary distribution subjected to the landing/take-off demand patterns, which implies inefficient runway capacity usage, solely for landing or take-off in independent runway operation (Jacquillat and Odoni, 2015a, 2015b; Jacquillat et al., 2017). Mixed-mode parallel runway operations further enhance the capacity to handle airborne and airport traffic, but also increase the degree of ATC workload. Uncontrollable delays also increase the vulnerability to disruptions. To enhance the robustness of a flight schedule and reduce the possibility of a re-scheduling effort by ATC, the objective of this research was to minimise the maximum makespan deviation from optimality over all worst-case scenarios using the min-max regret approach.

The iterative relaxation framework is the standard procedure to solve the min-max regret problem (Aissi et al., 2009). Aissi et al. (2009) addressed that the computational complexity for min-max regret optimisation is a great challenge in the field. Meta-heuristics in min-max regret optimisation have been successfully applied to parallel machine scheduling, job shop scheduling and other related problems (Feng et al., 2016; Hu et al., 2016; Xu et al., 2013). Therefore, we propose the Efficient Artificial Bee Colony (EABC) algorithm to enhance the computational efficiency for obtaining a robust schedule with close-to-optimal condition.

1.2. Literature review

Runway capacity is the major bottleneck in air traffic management (Balakrishnan and Chandran, 2010; Ghoniem et al., 2014). In order to maintain a smooth airport operation, managing aircraft landing and take-off procedures has become a key component in air transport systems. Runway operation includes the flight approach operation/Aircraft Landing Problem (ALP) (see, e.g., Beasley et al., 2001; Bencheikh et al., 2009; Caprı and Ignaccolo, 2004; Hancerliogullari et al., 2013; Hansen, 2004; Liu, 2011; Ng and Lee, 2017; Pinol and Beasley, 2006; Salehipour et al., 2013; Vadlamani and Hosseini, 2014), departing operation/Aircraft Take-off Problem (ATP) (see, e.g., Atkin et al., 2008; Hancerliogullari et al., 2013) and mixed-mode parallel operation/ASSP (see, e.g., Bennell et al., 2011; Lieder and Stolletz, 2016). Mixed-mode parallel operation allows simultaneous runway operations for a pair of flights on different runways (Beasley et al., 2000).

Regarding the objectives in formulating the ASSP model, various objective functions can be found in the literature. These include: minimising the makespan (Balakrishnan and Chandran, 2010; Harikiopoulo and Neogi, 2011; Ma et al., 2014; Ng and Lee, 2016a), minimising total/weighted tardiness of all flights (Ng and Lee, 2016b; Pinol and Beasley, 2006; Sabar and Kendall, 2015; Salehipour et al., 2013), and minimising total/average/weighted delay of all flights (Lieder and Stolletz, 2016; Liu, 2011; Samà et al., 2015). The FCFS approach is a policy that maintains fairness among flights in a schedule (Farhadi et al., 2014). Dear and Sherif (1989) revealed that the FCFS approach is undesirable as the ASSP solution must be updated promptly to cope with real-time needs. Beasley et al. (2004) proposed a displacement rule for ASSP to absorb the perturbations in a predefined schedule. Farhadi et al. (2014) introduced Constrained Position Shifting (CPS) based on the FCFS schedule in mixed-mode parallel runway operation. Soomer and Koole (2008) evaluated the trade-off between total cost, delay and fairness to obtain a schedule that compromises different stakeholders' interests.

Microscopic air traffic flow modelling enhances the level of practical usage and robustness of the solution, which provides detailed control of the practice of air traffic control, including air segments, holding patterns, runway operation and ground operation. Detailed characteristics of airport infrastructure and flight paths facilitate the modelling accuracy regarding the on-time coordinates, status and speed profile (Samà et al., 2017). Bianco et al. (1997) formulated microscopic modelling in runway scheduling with blocking and a no-wait version of job-shop scheduling using an alternative graph for managing the streaming of Terminal Manoeuvring Area (TMA) operations. Regarding airport layout and the structure of air segments, sophisticated characteristics and real-world constraints have been proposed in runway scheduling using the extensive versions of microscopic modelling (D'Ariano et al., 2015, 2012; Samà et al., 2017, 2014, 2013). Artiouchine et al. (2008) and Eun et al. (2010) considered the discrete holding patterns and airborne delays to maintain a smooth landing schedules. Providing the latest information assists ATC to resolve the potential conflict detection and collusion-free guidance within the TMA. The current research progress is still mired in the static approach. The aforementioned literature is static in nature, which means that all variables and information are known in advance.

Most international airports find that the associated financial costs caused by airborne delays are significant so they try to moderate the cost by reducing the flight delay times (Ball et al., 2010; Hansen and Zou, 2013; Ng and Lee, 2017; Zou and Hansen, 2012). The sensitivity of an airport network is remarkable as all the airport resources are highly linked (Beatty et al., 1999). The delay of a flight leads to delay propagation of various airport activities and scheduling (Campanelli et al., 2016; Churchill et al., 2010; Kafle and Zou, 2016; Pyrgiotis et al., 2013). It is known that aircraft approaching and take-off times are not precisely determined in advance due to the dynamic changes of the environment. Risk analysis in the ASSP model is lacking in the current literature. According to the decision theory of risk analysis, uncertainties are defined as the outcome of a decision remaining unknown when an alternative is selected (Bell, 1982). Various uncertainties, practical constraints and the changes in the dynamic environment are considered in the model, which leads to an increase in the practical complexities in the decision-making for ATC. There are two types of methods for handling uncertainty: stochastic and robust modelling. In the stochastic approach, the uncertain variables in a model are designed as a known probability distribution by the historical data. Nonetheless, the expected outcome may not be able to be derived from past records in certain situations. Therefore, robustness analysis has become of more interest under the risk-adverse approach than optimal performance. Robustness analysis provides a paradigm supporting the decision-making considering imprecision so as to