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Conflict-free arrival and departure trajectory planning for parallel runway with advanced point-merge system

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ABSTRACT

In this paper, an efficient trajectory planning system is proposed to solve the integration of arrivals and departures on parallel runways with a novel route network system. Our first effort is made in designing an advanced Point Merge (PM) route network named Multi-Level Point Merge (ML-PM) to meet the requirements of parallel runway operations. Then, more efforts are paid on finding a complete and efficient framework capable of dynamically modelling the integration of arrival and departure trajectories on parallel runways, modelling the conflict detection and resolution in presence of curved trajectory and radius-to-fix merging process. After that, a suitable mathematical optimization formulation is built up. Receding Horizon Control (RHC) and Simulated Annealing (SA) algorithms are proposed to search the near-optimal solution for the large scale trajectories in routine dense operations. Taking Beijing Capital International Airport (BCIA) as a study case, the experimental results show that our system shows good performances on the management of arrivals and departures. It can automatically solve all the potential conflicts in presence of dense traffic flows. With its unique ML-PM route network, it can realize a shorter flying time and a near-Continuous Descent Approach (CDA) descent for arrival aircraft, an economical climbing for departure aircraft, an easier runway allocation together with trajectory control solutions. It shows a good and dynamic sequencing efficiency in Terminal Manoeuvring Area (TMA). In mixed ML-PM mode, under tested conditions, our proposed system can increase throughput at BCIA around 26%, compared with baseline. The methodology defined here could be easily applied to airports worldwide.

1. Introduction

1.1. Motivation

Flight delays lead to many negative impacts, such as increasing passengers trip costs, airlines operation costs, environmental damage due to more fuel consumption and gas emissions (Ball et al., 2010; Ryerson et al., 2014). The key cause of delays is the disequilibrium between the high traffic flow demand and the low capacity. In 2015, China's total civil aviation turnover, passenger turnover, and cargo-mail turnover reached 85.165 billion ton-kilometers, 728.255 billion passenger-kilometers, and 20.807 billion ton-kilometers, a year-on-year increase of 13.8%, 15.0%, and 10.8%, respectively (CAAC, 2016). However, less than 30% of the airspace is reserved for civil aviation operations in China, compared to about 80% of the airspace in the US. Meanwhile, a large

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amount of radar vectorings are frequently used by approach controllers to manage dense arrivals and departures in China. The current Standard Instrument Departures (SIDs) and Standard Instrument ARrivals (STARs) route design method does not provide a good use of airspace. rea Navigation (RNAV)/Required Navigation Performance (RNP) routes are not being fully exploited in today's baseline operation. As a result, there is an inefficient conflict resolution with a number of low-level radar vectoring, a low runway utilization, and a low flight efficiency in Terminal Manoeuvring Area (TMA). Consequently, at the first seven busiest airports in China, their peak traffic volumes exceeded their capacities by more than 30%. Average landing delay at the ten busiest airports is around 26 min, and average flight holding time on-ramp from closing door to pushing back is around 12 min (CAAC, 2016). The air traffic bottleneck in the terminal airspace around the busy airport is an important issue nowadays.

On the other hand, parallel runways are the main structure of Chinese Top 16 airports, for example Beijing Capital International Airport (BCIA) with 3 parallel runways, Shanghai Pudong airport with 4 parallel runways, Guangzhou Baiyun airport with 3 parallel runways, Chongqing airport with 3 parallel runways. More and more parallel runways are being built in existing or new hub airports, such as Beijing DaXing airport with 5 parallel runways. Facing high demand in the near future, there is an urgent need to develop a novel approach to efficiently manage departing and arriving flows at busy airports with parallel runways, to significantly improve flight efficiency and increase capacity.

Furthermore, the total volume of airspace for civil aviation in China will not be changed in the near future, due to state security reasons. The volume of TMA in China is usually very small, but with huge traffic demand. To solve this problem, firstly, it is necessary to design an efficient and integrated RNAV/RNP-based SID/STAR route network. It should not only reduce the traffic complexity, but also adapt the constraint of small airspace, and support an optimized descent and climb in TMA. Secondly, a more dynamic re-sequencing optimization should be studied to achieve an integrated arrival and departure optimization. It should improve the predictability at busy airports on the strategic level, further increasing capacity. Thirdly, in dense traffic cases, automated conflict resolution by planning conflict-free trajectories in advance could potentially be a good solution. It should provide a good way to continuously reduce the traffic complexity and increase capacity. Especially, in a complex traffic situation, a good and feasible automation solution for controllers and pilots without requiring specialized equipage is crucial from an operation point of view. The system developed in this paper will be applied to BCIA, aiming to alleviate the heavy delay in China in the near future.

1.2. Traffic at BCIA

BCIA is the most important, largest and busiest international aviation hub in China. Everyday, around 1700 flights from 94 airline companies operate at BCIA, which makes Beijing in a close bond with 244 cities in 54 countries around the world. There are three parallel runways at BCIA: runway 01–19, runway 18L-36R, and runway 18R-36L. According to published Aeronautical Information Publication (AIP), runway 36L-18R is used for departure and arrival, runway 36R-18L is mainly used for departure, runway 01–19 is mainly used for arrival. Three runways could be all used for landing in case of dense traffic demand. The declared operation capacity at BCIA is 88 movements per hour, including departures and arrivals. As shown in Fig. 1, its peak traffic period is from 6:00 to 24:00. From 6:00 to 9:00, there is a heavy demand for departure. From 21:00 to 24:00, there is a heavy demand for arrival. Between 9:00 to 21:00, the arrival and the departure almost equals each other.

In Beijing TMA, there are designed SID routes for guiding the departing aircraft into the airways, and STAR routes for helping the arrivals aircraft to approach the airport. There are six entry points in Beijing TMA for arrival flights. Among which, there are four entry points in the South: JB, BOBAK, VYK and DOGAR, two entry points in the North: KM and GITUM. The traffic flows are very heavy in the South. Meanwhile, there are seven exit points for departure flights, including YV, CDY, TONIL, LADIX, RENOB, SOSDI, and KM. The significant point KM is special, it serves both for departure and arrival flights. To understand baseline traffic at BCIA, several days of real flight data in the June, 2017 (see Fig. 2) were collected. We chose South-inbound arrivals and departures to study. Furthermore, we filtered out the 10th day traffic to study the South-inbound traffic characteristic at BCIA. In order to reduce the noise

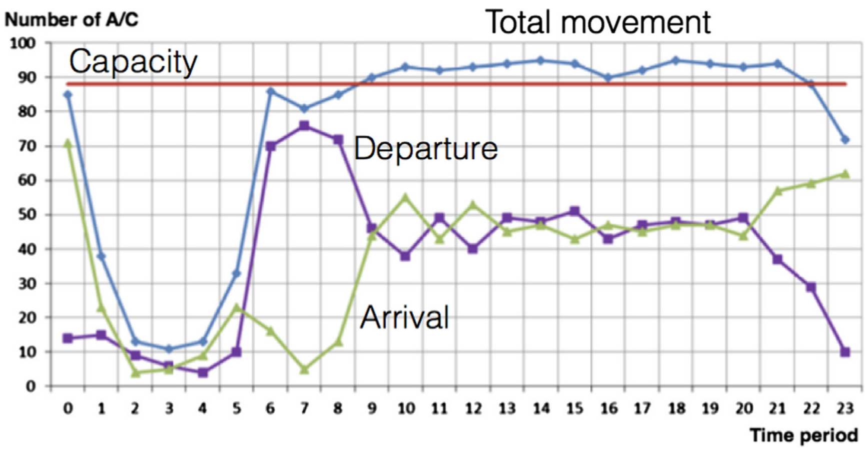

Fig. 1. Hourly movements at BCIA on 07/09/2015.