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Integrated sequencing and merging aircraft to parallel runways with automated conflict resolution and advanced avionics capabilities ☆

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ABSTRACT

Congestion in Terminal Maneuvering Area (TMA) in hub airports is the main problem in Chinese air transportation. In this paper we propose a new system to integrated sequence and merge aircraft to parallel runways at Beijing Capital International Airport (BCIA). This system is based on the advanced avionics capabilities. Our methodology integrates a Multi-Level Point Merge (ML-PM) system, an economical descent approaches procedure, and a tailored heuristic algorithm to find a good, systematic, operationally-acceptable solution. First, Receding Horizontal Control (RHC) technique is applied to divide the entire 24 h of traffic into several sub-problems. Then in each sub-problem, it is optimized on given objectives (conflict, deviation from Estimated Time of Arrival (ETA) on the runway and make-span of the arrival flow). Four decision variables are designed to control the trajectory: the entry time, the entry speed, the turning time on the sequencing leg, and the landing runway allocation. Based on these variables, the real time trajectories are generated by the simulation module. Simulated Annealing (SA) algorithm is used to search the best solution for aircraft to execute. Finally, the conflict-free, least-delay, and user-preferred trajectories from the entry point of TMA to the landing runway are defined. Numerical results show that our optimization system has very stable de-conflict performance to handle continuously dense arrivals in transition airspace. It can also provide the decision support to assist flow controllers to handle the asymmetric arrival flows on different runways with less fuel consumption, and to assist tactical controllers to easily re-sequence aircraft with more relaxed position shifting. Moreover, our system can provide the fuel consumption prediction, and runway assignment information to assist airport and airlines managers for optimal decision making. Theoretically, it realizes an automated, cooperative and green control of routine arrival flows. Although the methodology defined here is applied to the airport BCIA, it could also be applied to other airports in the world.

1. Introduction

With rapid economic growth, the demand for air services in China has significantly increased, the number of aircraft movements grew at an average rate of 9.9% per year between 2006 and 2015. However, the on-time performance of flights in this period dropped from 81.48% to 68.33% (CAAC, 2016). In 2013, the average delay of 23 min caused direct cost of more

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than 6.4 billions US Dollars to passengers and airlines reported by Minsheng Securities. Moreover, in the last few years, frequent and long delays have already generated passenger discomfort, which lead to complaints towards airlines and airport staff. Obviously, air traffic booming has put enormous pressure on the Chinese transportation system, and has even threatened air safety and deteriorated efficiency.

The key factor causing delays in Chinas is the unbalance between the high traffic flow demand and the low capacity. Only around 20% airspace is reserved for civil aviation operations. In the en-route part of this civil airspace, the average traffic flow in the 13 busiest airways in China is more than 500 flights per day in year 2014. At the hub airport, the capacity is also near saturated or even overloaded. For example, the seven busiest airports in China at 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).

Civil Aviation Administration of China (CAAC) reported that poor performance of Air Traffic Management (ATM) is now the most important cause of delay, producing 30.68% of air delays in 2015, ahead of all the other factors like weather, airport, passenger and airlines etc. With the successful implementation of some projects, for example the Reduced Vertical Separation Minimum (RVSM) between 8900 m (29,100 ft) and 12,500 m (41,100 ft), the en-route traffic capacity has been significantly enhanced. Therefore, the air traffic bottleneck is shifting from en-route segments to TMA at the busy airport.

Despite the already overloaded ATM system, the Chinese airplanes fleet is continuing to expand. Boeing (2015) forecasts that over the next 20 years, China's commercial airplane fleet will nearly triple: from 2570 airplanes in 2014 to 7210 airplanes in 2034. Airbus (2016) forecasts that domestic China will become the largest traffic flow before the end of the forecast period 2035, supplanting domestic USA. However, the airspace for civil aviation operation in China is still expected to be very limited due to state security concerns. Parallel runway is the mainstream structure of Chinese hub airports. More and more parallel runways are built in existing or new hub airports, such as Beijing DaXing international airport with 6 parallel runways. Facing the high demand in the near future, to benefit from the emerging Communication, Navigation and Surveillance (CNS) techniques, there is an urgent need to develop a novel approach to efficiently sequence and merge arrival flows to parallel runways. As BCIA is now the busiest airport in Asia and the second busiest airport in the world, taking it as a case to study the optimization of arrival flows on parallel runways will not only help to alleviate the serious delay of China air transportation, but also provide a good example for the management of multiple parallel runway operations in China.

Some attempts have been done to alleviate the airspace congestion by improving the Trajectory-Based Operation (TBO) in TMA, such as strategic de-confliction in the presence of a large number of 4D trajectories (Ruiz et al., 2014, 2013), avoiding non-efficient holding procedures by efficient path shortening/path stretching techniques (Zúñiga et al., 2013); or by scheduling of airport runway operations to find optimal sequences (Slveling and Clarke, 2014). However, several challenges remain before finding a systematic, operationally-acceptable, and good solution for efficiently sequencing and merging arrivals to multiple runways. The first challenge is to integrate aircraft sequencing, merging and runway assignment to support a real-time traffic operation. The second challenge is to make an automated, cooperative, and green control of trajectories. Here, automated control means that this system has a steady automated de-conflict performance under different routine traffic situations; cooperative control means that different actors could make a collaborated decision for the management of trajectories; green control means less fuel consumption, less CO_2 emission comparing with the conventional radar vectoring approach. The last challenge is to overcome the constraint of "MPS less than 3" which has limited the optimization of airport scheduling problem for a long time. This paper has three main objectives:

1. To formulate the optimization problem of integrated sequencing and merging arrival flows on parallel runways in terms of multi-objectives: under the hard constraint on collision avoidance, soft constraint on the average delay, optimized fuel consumption with continuous descent approach, balanced runway landing rate.
2. To design an efficient RNP route network to support our concept, and to meet the requirements of the unbalanced and mixed multiple runway operation.
3. To automatically derive a good and feasible solution to handle the routine traffic in busy TMA both at the pre-tactical and tactical levels in a dynamical fashion.

Several preliminary efforts have been done by the authors (Liang et al., 2015, 2016). Liang et al. (2015) introduced the framework of an autonomous system with Multi-Layer Point Merge (ML-PM) for BCIA. Based on the classic PM route structure for single runway operation, the designed ML-PM route network aimed at adapting to the segregated parallel runway operation. Hybrid algorithm with Receding Horizontal Control and SA (RHC-SA) is applied to find the solution, however the runway re-assignment problem was not considered. Liang et al. (2016) made a brief evaluation of this ML-PM potential operational benefits in terms of flight efficiency and runway throughput, but the airspeed model and the fuel consumption model needs to be further improved. Based on previous researches, the contribution of this paper are the followings:

1. An advanced modelling is proposed to handle high-density arrivals to mixed parallel runways operation in the transition airspace at busy airports. It is based on an efficient model of the route network, the BADA[1]-based multi-phase trajectory generation, the automated conflict detection and resolution;

[1] BADA (Base of Aircraft Data) is the world's leading aircraft performance model, managed by EUROCONTROL for use by the aviation community. The main application of BADA is trajectory simulation and prediction.