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A data-driven approach to modeling high-density terminal areas: A scenario analysis of the new Beijing, China airspace

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Abstract Airports are being developed and expanded rapidly in China to accommodate and promote a growing aviation market. The future Beijing Daxing International Airport (DAX) will serve as the central airport of the JingJinJi megaregion, knitting the Beijing, Tianjin, and Hebei regions together. DAX will be a busy airport from its inception, relieving congestion and accommodating growth from Beijing Capital International Airport (PEK), currently the second busiest airport in the world in passengers moved. We aim to model terminal airspace designs and possible conflicts in the future Beijing Multi-Airport System (MAS). We investigate standard arrival procedures and mathematically model current and future arrival trajectories into PEK and DAX by collecting large quantities of publicly available track data from historical arrivals operating within the Beijing terminal airspace. We find that (1) trajectory models constructed from real data capture aberrations and deviations from standard arrival procedures, validating the need to incorporate data on historical trajectories with standard procedures when evaluating the airspace and (2) given all existing constraints, DAX may be restricted to using north and east arrival flows, constraining the capacity required to handle the increases in air traffic demand to Beijing. The results indicate that the terminal airspace above Beijing, and the future JingJinJi region, requires careful consideration if the full capacity benefits of the two major airports are to be realized.

1. Introduction

The Chinese aviation system is in a period of rapid growth. In the 30-year period from 1980 to 2009, China's civil aviation system grew at a rate of 17.6% per year, with the number of airports growing from 77 to 166 and annual passenger traffic volume increasing from 3.43 million to 230 million. The Civil Aviation Administration of China (CAAC), the aviation

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authority in the Ministry for Transport, is planning to greatly expand their network of airports across China.[1] One of these new airports is planned to be the Beijing Daxing International Airport (DAX), a brand new international airport 30 miles to the south of Beijing.[2] The airport will relieve some congestion – and some projected growth – at Beijing Capital International Airport (PEK), which is the second busiest airport in the world in terms of passengers moved.[3] Daxing also serves the important purpose of integrating the region of Beijing and Tianjin into the larger megaregion of JingJinJi and anchoring the megaregion centrally with the new airport. The new Daxing airport currently under construction is planned to be a very large international airport with between four and nine runways, depending on the final design, complicating airspace operations within the Beijing terminal airspace. In the following study, we investigate airspace structures in high-density MASs and project future trajectories and conflicts in the Beijing airspace with the goal of aiding ground and airspace planning for Daxing.

In the following study, we present and utilize the data-driven and mathematical methodology developed by the authors to investigate future airspace scenarios of the Beijing terminal airspace, an airspace that will encompass a Multi-Airport System (MAS) with two highly proximate major international airports, DAX and PEK. Furthermore, this MAS is a subset of the larger airport infrastructure in the JingJinJi megaregion. We begin by introducing the current and future Beijing MAS. We next investigate spatially how existing highly complex terminal airspaces over Chinese MASs are structured. We find, by comparing historical track data with standard arrival procedures in Chinese MASs, that the airspaces above the Beijing and Shanghai MASs are highly congested and complex; this illustrates that understanding terminal airspaces and airport interactions requires visualizing real, historical trajectories and not simply standard arrival procedures. We then seek to model current trajectories in the PEK terminal airspace in order to study future interactions with arrival trajectories bound for DAX. We introduce our data-driven trajectory modeling and visualization methodology, mathematically modeling current trajectories into PEK. We see that the modeled trajectories – which are themselves functions of individual historical flight tracks – do not well adhere to standard arrival procedures, thus justifying the need to evaluate modeled trajectories when considering new airspaces. Finally, we use the modeled trajectories for PEK and abstract them into future arrival trajectories for DAX, moving towards understanding airspace conflicts when the two airports will be operating in tandem. We find that, given the current operating configurations at PEK and the location of the under-construction new Daxing airport, the new airport may be restricted to using north and east flow solely, possibly limiting the potential of DAX to handle the increases in air traffic demand to Beijing.

2. Background and literatures

2.1. Background on airports in Beijing

Fig. 1 shows the two major airports in Beijing and the future JingJinJi region. The left panel is the runway and terminal diagram for PEK, currently the major domestic and international airport serving Beijing. It is a three-runway airport with two 12500 ft. (1 ft = 0.3048 m) runways capable of serving the largest aircraft currently in operations. The right panel of Fig. 1 shows the planned layout for the new Daxing Airport. This layout shows 6 parallel north-south runways and 2 parallel east-west runways with no runway intersections.

Daxing will be built approximately 30 miles south of PEK. Both will be large hub airports, central to the national airspace of China. PEK will continue to serve both domestic and international flights and Daxing will also handle domestic and international flights. Once the new Daxing Airport is opened, the Chinese authorities plan to reallocate flights between PEK and Daxing based on airline alliance membership. Current plans are to move flights operated by airlines belonging to the SkyTeam and Oneworld alliances to Daxing, with Star Alliance and other airlines remaining at PEK.[6]

2.2. Relevant literature on modeling MASs

The airspace is highly complex and built on multiple components, all which can introduce uncertainty into the practice and study of air traffic management (ATM). In a comprehensive look at applying complexity science to air transportation, Cook et al.[7] explore how data uncertainty and unavailability, along with operational, equipment, and weather uncertainty lead to tremendous challenges in modeling, predicting, and improving the performance of the ATM system. This is particularly true for the modeling of complex terminal airspaces. Indeed, because of this, much of the ATM literature focused on the terminal airspace seeks to optimize the trajectory for individual flights[8,9]; optimize one variable at the airport-level to optimize airspace efficiency[10]; or shift terminal area delays upstream to the en route portion of the flight.[11] A notable exception is Sidiropoulos et al.[12] The authors propose a framework for the prioritization of arrival and departure routes in the terminal area of MASs. The study found that fewer terminal area fixes can serve a complex MAS efficiently if they are dynamically allocated based on demand fluctuations at each airport throughout the day. In response to the challenge of modeling the terminal airspace and the preponderance of complex, proprietary models, Manataki and Zografos[13] call for more flexible and intuitive decision support tools for modeling the terminal area of MASs in order to explore airspace structures. We showcase a methodology to build flexible and intuitive models for MASs by unlocking publicly available data. In doing so, we move the field towards addressing the call of Manataki and Zografos[13] and build on the vast body of research that examines aviation system demand (passenger demand, counts and times of flight operations, etc.) using publicly available data.[14,15]

3. Examination of MASs within China

The terminal airspace surrounding a major airport is largely defined by the established arrival and departure procedures for that specific airport. This may be further complicated by additional airports which share the same terminal airspace. We seek to investigate a way to design airspace structures serving two or more collocated major airports. Prior to examining and modeling possible airspace structures for the Beijing terminal airspace once the new Daxing airport is completed, we qualitatively assess similar airspaces with large collocated air-

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