Transportation Research Part B 110 (2018) 160–187

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

A framework for the optimization of terminal airspace operations in Multi-Airport Systems

Stavros Sidiropoulos[a,b], Arnab Majumdar[b], Ke Han[b,*]

[a] Vianair Inc., 3511 Silverside Rd, Ste 105, DE 19810, USA
[b] Center for Transport Studies, Department of Civil and Environmental Engineering, Imperial College London, London SW7 2AZ, UK

ARTICLE INFO

Article history:
Received 3 March 2017
Revised 15 February 2018
Accepted 19 February 2018

Keywords:
Multi-Airport System
Metroplex
Spatio-temporal clustering
Analytic hierarchy process
3-D route design

ABSTRACT

Major cities like London, New York, and Tokyo are served by several airports, effectively creating a Multi-Airport System (MAS), or Metroplex. The operations of individual Metroplex airports are highly interdependent, rendering their efficient management rather difficult. This paper proposes a framework for the design of dynamic arrival and departure routes in MAS Terminal Maneuvering Areas, which fundamentally changes the operation in MAS airspaces for much improved efficiency when compared to the current situation. The framework consists of three components. The first presents a new procedure for characterizing dynamic arrival and departure routes based on the spatio-temporal distributions of flights. The second component is a novel Analytic Hierarchy Process (AHP) model for the prioritization of the dynamic routes, which takes into account a set of quantitative and qualitative attributes important for MAS operations. The third component is a priority-based method for the positioning of terminal waypoints as well as the design of three-dimensional, conflict-free terminal routes. Such a method accounts for the AHP-derived priorities while satisfying the minimal separation and aircraft maneuverability constraints. The developed framework is applied to a case study of the New York Metroplex, using aircraft trajectories during a heavy traffic period on typical day of operation in the New York Terminal Control Area in November 2011. The proposed framework is quantitatively assessed using the AirTOp fast-time simulation model. The results suggest significant improvements of the new design over the existing one, as measured by several key performance indicators such as travel distance, travel time, fuel burn, and controller workload. The operational feasibility of the framework is further validated qualitatively by subject matter experts from the Port Authority of New York and New Jersey, the operator of the New York Metroplex.

1. Introduction

The continuous increase in air travel demand coupled with rapid urban growth during the past century has resulted in the emergence of secondary airports in the proximity of large metropolitan areas (Sidiropoulos et al., 2015). These are in addition to the primary airport serving a given area, and together this gives rise to a Multi-Airport System (MAS) or “Metroplex” (e.g. London, New York, Tokyo). Due to the spatial proximity of the Metroplex airports, their operations are

* Corresponding author.
E-mail addresses: stavros@vianair.com (S. Sidiropoulos), a.majumdar@imperial.ac.uk (A. Majumdar), k.han@imperial.ac.uk (K. Han).

https://doi.org/10.1016/j.trb.2018.02.010
0191-2615/

interdependent and complex, rendering their efficient management a difficult challenge (Lall, 2018). In the absence of an effective centralized coordination of the operations, the prevailing practice in such systems is for Air Traffic Controllers (ATCos) to allocate traffic in an ad-hoc manner based on their experience. This results in a sub-optimal utilization of the potential capacity of the system (Clarke et al., 2010).

There have been a few attempts to optimize the operation of MAS Terminal Maneuvering Area (TMA), primarily through airspace redesign consultations (Los Angeles World Airports, 2014; NATS, 2013; U.S. Government Accountability Office (GAO), 2008). However, such attempts often rely on ad-hoc measures tailored for specific airport systems; for example, Visual Flight Rules (VFR) corridors have been allocated in both the New York and Los Angeles basin Metroplexes. Unsurprisingly, while such measures may result in locally improved solutions for an individual airport, they are often sub-optimal for the system of airports, and pose numerous difficulties in their widespread deployment due to a lack of transferability. In view of this, a number of generic attempts have been made to improve Metroplex operations, including: improved aircraft scheduling, optimized capacity trade-offs and optimized infrastructure planning (McClain, 2013; Clarke et al., 2012; Atkins et al., 2011; Donaldson and Hansman, 2011; Ramanujam and Balakrishnan, 2009; de Neufville, 1995; Hansen, 1995; Hansen and Weidner, 1995; Hansen and Du, 1993). However, all these approaches are limited by the current terminal airspace structure, i.e. its geometry, which is given a priori. In contrast, it is our contention in this paper that the existing static airspace structures may be the main impediment for improving Metroplex operations. We demonstrate this by proposing a novel framework for the new design and planning of terminal airspace in the MAS, based on the *dynamic airspace configuration* (DAC) concept (Kopardekar et al., 2007), together with the improved design of conflict-free arrival and departure routes in order to increase operational efficiency in terms of the travel distance, travel time, fuel burnt, controller workload and cost.

This framework takes both a systematic and holistic approach for a paradigm-shifting design of MAS terminal airspaces, through the seamless integration of a:

- demand characterization method that identifies major traffic flow patterns during the operational horizon (24 h), and derives dynamic routes accordingly (see Section 3);
- route prioritization framework that enables the decision maker to influence the design based on a set of demand characteristics essential for MAS operations (see Section 4.2); and
- 3-D routing problem for constructing the airspace structures (arrival and departure routes) in accordance to the dynamic routes (see Section 4.4).

This framework embraces a novel Concept of Operations (CONOPs), namely the *dynamic route* concept, which shifts from the traditional ad-hoc, First-Come-First-Serve (FCFS) service policy that handles aircraft individually, towards a strategic service policy based on the systematic assignment of aircraft to a set of dynamic routes. A dynamic route is defined to be a group of flights that share similar spatial and temporal characteristics. In addition, we let each dynamic route be associated with exactly one MAS airport and consist of either arrival or departure flights to/from that airport.

The proposed CONOPs recognize significant traffic flow patterns as they evolve in both space and time; and the designed routes are meant to dynamically accommodate such demand patterns. The dynamic route service policy allows the MAS operations to achieve a higher level of efficiency, which is demonstrated in this paper by the use of fast-time simulation modeling (see Section 6). Furthermore, it enhances the First-Come-First-Serve (FCFS) principle, which can be applied to existing flights already assigned to specific dynamic routes, thus promoting equity. In order to do this either, the air traffic controllers can either handle the established traffic on a FCFS basis, or schedule flights along each dynamic route in order to further optimize the operations. The dynamic route service policy can be applied to operations at either the strategic (a few days prior to flight) or pre-tactical (up to 3 h prior to flight) levels. A hallmark of the research presented in this paper is the generic nature of the proposed methodology and its compatibility with subsequent, case-specific designs. The complete framework for developing and assessing the proposed concept is summarized in Fig. 1.

Previous research typically overlooks the operational feasibility of the proposed solutions for a Metroplex. It is worth noting that the focus of the previous research is either on arrival or departure operations in isolation, or on the operation of a subset of the Metroplex airports irrespective of the others. Isolating a subset of operations fails to represent the complexity of the full-scale problem, and thus the feasibility and effectiveness of any proposed solutions may be compromised. This paper bridges this gap through a comprehensive assessment of the proposed framework using fast-time simulation modeling (FTS) (AirTOp soft) of the entire New York MAS, comprising of the airports of John F. Kennedy (JFK), LaGuardia (LGA), Newark Liberty International Airport (EWR) and Teterboro (TEB), arguably among the most complex Metroplex systems in the world in terms of the number and proximity of the airports, as well as its current airspace design. In addition, qualitative confirmation of the operational feasibility of the proposed framework is obtained through structured interviews with Subject Matter Experts (SMEs) from the Port Authority of New York and New Jersey (PANYNJ) and the Federal Aviation Administration (FAA).[1] FTS is a useful technique for rapidly evaluating the feasibility and efficiency of airspace design scenarios based on realistic and accurate inputs. In this paper, the current operational features in the New York MAS are accurately replicated in the FTS using the Performance Data Analysis and Reporting System (PDARS) data provided by the PANYNJ. The simulation results of the proposed design indicate a substantial improvement over the current MAS operations,

[1] PANYNJ is responsible for the administration of the New York MAS airports; the FAA is responsible for the provision of air traffic control over the MAS.