Progress in Aerospace Sciences xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Progress in Aerospace Sciences

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

An evolutionary outlook of air traffic flow management techniques

Trevor Kistan[a,b,*], Alessandro Gardi[a], Roberto Sabatini[a,*], Subramanian Ramasamy[a], Eranga Batuwangala[a]

[a] RMIT University, Melbourne, Victoria 3001, Australia
[b] Thales Australia Air Traffic Management, Melbourne, Victoria 3001, Australia

ARTICLE INFO

Keywords:
Air Traffic Control
Air Traffic Management
Air Traffic Flow Management
Airspace Management
ATFCM
CFMU
Congestion Mitigation
Decision Support Systems
Demand-Capacity Balance
Dynamic Airspace
Network Model
NextGen
RECAT
Sequencing
SESAR
Slot
Trajectory-Based Operations
Wake Turbulence Separation
Weather Avoidance

ABSTRACT

In recent years Air Traffic Flow Management (ATFM) has become pertinent even in regions without sustained overload conditions caused by dense traffic operations. Increasing traffic volumes in the face of constrained resources has created peak congestion at specific locations and times in many areas of the world. Increased environmental awareness and economic drivers have combined to create a resurgent interest in ATFM as evidenced by a spate of recent ATFM conferences and workshops mediated by official bodies such as ICAO, IATA, CANSO the FAA and Eurocontrol. Significant ATFM acquisitions in the last 5 years include South Africa, Australia and India. Singapore, Thailand and Korea are all expected to procure ATFM systems within a year while China is expected to develop a bespoke system. Asia-Pacific nations are particularly pro-active given the traffic growth projections for the region (by 2050 half of all air traffic will be to, from or within the Asia-Pacific region). National authorities now have access to recently published international standards to guide the development of national and regional operational concepts for ATFM, geared to Communications, Navigation, Surveillance/Air Traffic Management and Avionics (CNS+A) evolutions. This paper critically reviews the field to determine which ATFM research and development efforts hold the best promise for practical technological implementations, offering clear benefits both in terms of enhanced safety and efficiency in times of growing air traffic. An evolutionary approach is adopted starting from an ontology of current ATFM techniques and proceeding to identify the technological and regulatory evolutions required in the future CNS+A context, as the aviation industry moves forward with a clearer understanding of emerging operational needs, the geo-political realities of regional collaboration and the impending needs of global harmonisation.

1. Introduction

Air Traffic Flow Management (ATFM) involves a number of measures to accomplish the mission of supporting a safe, efficient and expedited flow of air traffic. Both long-term and short-term measures are considered to resolve perturbations arising due to unpredicted weather and capacity disruptions. The effectiveness of these measures depends considerably on the amount, accuracy and timeliness of the information exchanged. As a result, human operators depend crucially on technology enablers and Decision Support Systems (DSS) for making better informed and more effective decisions.

ATFM has existed as a component of Air Traffic Management (ATM) for several decades, supported to different degrees by largely bespoke automated systems in a handful of countries (USA, European Union, Japan, Thailand, South Africa, Australia, New Zealand, Mexico, Columbia and Brazil).

In recent years ATFM has become pertinent even in regions without sustained overload conditions caused by dense traffic operations. Increasing traffic volumes in the face of constrained resources has created peak congestion at specific locations and times in many areas of the world. Increased environmental awareness and economic drivers have combined to create a resurgent interest in ATFM as evidenced by the growing number of recent ATFM initiatives mediated by official bodies such as the International Civil Aviation Organisation (ICAO), the International Air Transport Association (IATA), the Civil Air Navigation Services Organisation (CANSO), the United States (US) Federal Aviation Administration (FAA) and the European Organisation for the Safety of Air Navigation (Eurocontrol).

The US Next Generation Air Transportation System (NextGen) and European Union (EU) Single European Sky ATM Research (SESAR) research programs include significant ATFM components [4,6,8,12,15,16,100–106]. Recent ICAO publications (Doc 9971 - Manual on Collaborative ATFM, Doc 9965 Manual on Flight and Flow - Information for a Collaborative Environment, Doc 9854 –

* Corresponding authors.
E-mail addresses: trevor.kistan@thalesgroup.com.au (T. Kistan), roberto.sabatini@rmit.edu.au (R. Sabatini).

http://dx.doi.org/10.1016/j.paerosci.2016.10.001
Received 6 May 2016; Received in revised form 22 October 2016; Accepted 24 October 2016
Available online xxxx
0376-0421/

Please cite this article as: Kistan, T., Progress in Aerospace Sciences (2016), http://dx.doi.org/10.1016/j.paerosci.2016.10.001

Global Air Traffic Management Operational Concept, etc.) indicate a legislative will to harmonise global ATFM and Collaborative Decision Making (CDM) operational concepts and procedures by building on the experience of existing practitioners and expanding their envelope of applicability [1–3].

Broader harmonisation initiatives build on ICAO's 2008 NextGen-SESAR Gap Analysis and various Standards Roundtable discussions since. Developed with industry input, the ICAO Aviation System Block Upgrade (ASBU) modules now form the unifying framework for the evolution of the Global ATM System and it is in this context that any industry-relevant discussion of ATFM/CDM should occur.

For industry these developments mark the maturing of user requirements in an emerging ATFM market segment. For researchers it is a prudent juncture at which to review recent developments in the field of ATFM/CDM and to categorise them by industrial criteria such as technology readiness levels and operational tenability.

This article includes specific sections discussing the fundamental operational settings: airport, approach and enroute operations, as well as a section dedicated to regional ATFM measures and development initiatives.

In terms of mathematical modelling, this article reviews the fundamental problems, the key mathematical models and the solution approaches that have been explored as part of several ATFM research and development programs undertaken in recent years. Five aspects are discussed in particular: the sequencing problem, the arrival-departure problem, the gate-to-gate problem, as well as dynamic models of traffic flow and airspace capacity. Global solution approaches are explored to promote optimised flows across a sizable network of airports and regional airspace.

2. Ontology of ATFM techniques

The continuous growth in air traffic demand underscores the limitations of conventional ATM and ATFM procedures and operational paradigms. Novel operational concepts, technology enablers and DSS are being developed to accommodate this growth trend as part of extraordinary aviation modernisation initiatives currently taking place around the globe [4–9,12,16,100–106,115]. The new systems expected to emerge from these initiatives shall address the multiple superimposed problems that characterise the operation of airports and airspace sectors in the highly interconnected and interdependent air route network. Perturbations or disruptions occurring locally due to a variety of reasons can quickly affect a growing number of airports, airspace sectors and flights unless effective mitigation measures are put in place. ATFM is specifically tasked to continuously match the air traffic demand with the available capacity of airspace and airport resources. A number of ATFM reaction measures have been developed over the years, addressing both the strategic (i.e. long-term) and pre-tactical/tactical (short-term) timeframes.

ATFM measures can be modelled as mathematical optimisation problems in which either an individual solution or a set thereof is to be identified. Optimal solutions are those where the model resembles the real scenario and all assumptions are valid. Uncertainties in input data and estimation models necessarily void some key assumptions, therefore typical solutions are pseudo-optimal.

Uncertainties in input data originate from the limited amount and timeliness of information shared amongst flight crews, ATM operators, Air Navigation Service Providers (ANSP) and Airline Operations Centres (AOC).

Airport capacity is often variable and dependent on weather conditions, traffic composition, infrastructure conditions and human factors. Meteorological factors that significantly impact capacity include wind direction and intensity, precipitation, visibility, hazardous clouds and more severe hazards. The variability introduced by meteorological factors is exacerbated by the fact that aircraft have different weather capabilities ranging from almost all-weather to completely inhibited from operating. The resulting airport capacity, in terms of arrival and departure rates, can vary considerably and abruptly.

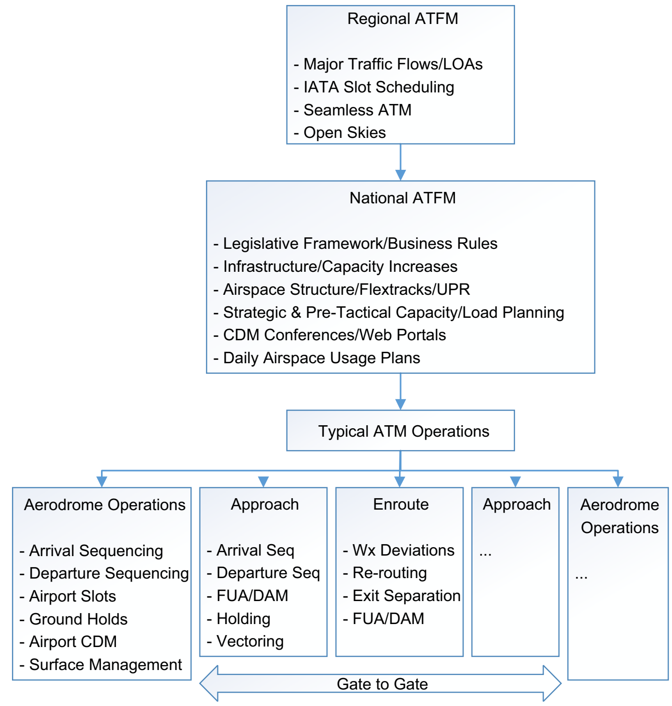

Fig. 1. Relationships between ATFM and ATM.

Fig. 1 illustrates that while certain techniques can be considered unique to ATFM, many of the sample shown are typical ATM techniques that are applied either to implement a broader ATFM strategy locally or invoked in the pre-tactical or tactical phase of operations in order to compensate for failings in that strategy or in its upstream implementation. ATFM can therefore be seen as a subset of ATM, with some blurring of distinctions as technological advances (in trajectory prediction, load estimation, System Wide Information Management (SWIM) etc.) progress towards the implementation of gate-to-gate concepts.

With reference to the academic literature, various ICAO, SESAR and NextGen industry documents, including the minutes of recent ICAO ATFM workshops, established ATFM operational practice (predominantly FAA and Eurocontrol) and vendor-supplied product information it is possible to construct an up-to-date ontology of ATFM techniques.

Since there are several operational improvement imperatives with overlapping focus areas, the most expedient approach is to classify the ATFM techniques by phase of flight (Fig. 2). Indeed, the networked nature of ATFM means that tactical measures applied locally at one point of the network are perceived to be pre-tactical measures by actors at another location in the network. For comparison, a more traditional categorisation of ATFM techniques by time and separation criterion (vertical, horizontal, longitudinal or time) is given in the ICAO Manual on Collaborative ATFM [1]:II-6-2.

One acknowledged consequence of departing from the traditional categorisation of ATFM techniques into planning/strategic, pre-tactical, tactical and post-operations analysis phases is that the ontology in (Fig. 2) is missing the identification of the post-operations analysis to planning loop that is meant to gauge the efficacy, efficiency and equitability of past ATFM measures and lead to their improvement [1]:II-2.

3. Airport

Airports frequently represent logistical bottlenecks and a source of