Transportation Research Part B 79 (2015) 1–15

Contents lists available at ScienceDirect

Transportation Research Part B

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

Some insights into a sequential resource allocation mechanism for en route air traffic management

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ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form 2 April 2015
Accepted 21 May 2015
Available online 10 June 2015

Keywords:
Air transportation
En route air traffic flow management (ATFM)
Collaborative Trajectory Options Program (CTOP)
Sequential resource allocation
Airline competition
Applied game theory

ABSTRACT

This paper presents a game theoretic model of a sequential capacity allocation process in a congestible transportation system. In this particular application, we investigate the governing principles at work in how airlines will time their requests for en route resources under capacity shortfalls and uncertain conditions, when flights are not able to take their preferred route at their preferred departure time slot due to the shortfalls. We examine a sequential "First Submitted First Assigned" (FSFA) capacity allocation process within an en route air traffic flow management (ATFM) program such as the Collaborative Trajectory Options Program (CTOP), which is a Federal Aviation Administration initiative that aims to manage en route capacity constraints brought on by inclement weather and capacity/demand imbalances. In the FSFA process, flights are assigned the best available routes and slots available at the time flight operators submit their preference requests during the planning period, in a sequential manner. Because flight operators compete with one another for resources, in such an allocation process they would be expected to make their requests as early as possible. However, because weather and traffic conditions – and therefore, the values of resources – can change significantly, flight operators may prefer to request resources later in the process rather than earlier. We use a game theoretic setup to understand how flight operators might tradeoff these conflicts and choose an optimal time to submit their preferences for their flights, as submission times are competitive responses by flight operators looking to maximize their benefits. We first develop a loss function that captures the expected utility of submitting preferences under uncertainty about operating conditions. Then, a conceptual model of the FSFA process is constructed using a simultaneous incomplete information game, where flight operators compete for the "prizes" of having submitted their inputs before others. A numerical study is performed in which it is demonstrated that preference submission times are heavily influenced by the general uncertainty surrounding weather and operational conditions of the ATFM program, and each flight operator's internal ability to handle this uncertainty. A key finding is that, in many of the scenarios presented, an optimal strategy for a flight operator is to submit their preferences at the very beginning of the planning period. If air traffic managers could expect to receive more submissions at the beginning of the planning period, they could more easily coordinate the ATFM program with other ATFM programs taking place or scheduled to take place, and they would have more opportunity to call another FSFA allocation route before the ATFM program begins, should conditions change enough to warrant this. Outputs of the model may provide some general insights to flight operators in planning submission strategies within competitive allocation processes such as FSFA. Also, this

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http://dx.doi.org/10.1016/j.trb.2015.05.016

work may have a broader application to other sequential resource allocation strategies within congestible and controlled transportation systems.

List of acronyms

AFP	Airspace Flow Program
ATFM	Air Traffic Flow Management
CDM	Collaborative Decision Making
CTOP	Collaborative Trajectory Options Program
FAA	Federal Aviation Administration
FCA	Flow Constrained Area
GDP	Ground Delay Program
NAS	National Airspace System
RBS	Ration-by-Schedule
TOS	Trajectory Options Set

List of notation

$V_{n,s}$	utility of slot s to a flight n, where $s \in [1, S]$ and includes all available slots in the en route ATFM program
V_n^*	utility of the highest utility slot to flight n
$U_{n,s}(t)$	estimated utility of slot s to n at time t
$\gamma_{n,r(s)}(t)$	stochastic term representing n's imprecise knowledge about the route conditions of a particular slot at t, distributed type 1 extreme value (Gumbel)
$p_{n,s}(t)$	probability of n choosing slot s at time t
$\omega(t)$	scale parameter of $\gamma_{n,r(s)}(t)$
k	parameter capturing the unpredictability of weather and operating conditions of an en route ATFM program
$L_n(t)$	n's loss in (true) utility resulting from its decisions at t
$l_n(t)$	$L_n(t)/L_n^{max}$, where L_n^{max} is the maximum loss possible for n (due to incomplete information)
$E[\pi_n]$	expected payoff
$R_{x\|t_n}$	true utility that n gains by submitting at t and being xth in the submission order, relative to the utility of submitting last, $R(N)$
$C(t_n)$	cost (due to uncertainty) n incurs in making a preference submission at time t
q_n	time n submits during the planning period as a proportion of the total ATFM program planning period (T), such that $q_n = (T - t_n)/T$
h_n	n's uncertainty level, which determines the rate at which n's uncertainty decreases during the planning period; $h_n \sim U(h_{min}, h_{max})$

1. Introduction

This paper presents a game theoretic model of a sequential capacity allocation process in a congestible transportation system. We investigate the governing principles at work in how airlines will time their requests for resources under capacity shortfalls and uncertain conditions, when an Air Traffic Flow Management (ATFM) program is in place. This particular application involves the allocation of constrained en route resources (in the form of departure time "slots" on specified routes) to flights, when flights are not able to take their preferred route at their preferred departure time slot. In the "First Submitted First Assigned" (FSFA) process, operators of impacted flights submit their en route resource preference requests to air traffic managers during the planning period, which are then used to allocate the best available routes and slots available at the time they make their request, in a sequential manner. Because flight operators compete with one another for resources, in such a sequential allocation mechanism they would be expected to make their requests as early as possible. However, weather and operating conditions can change significantly, which will impact both the true and perceived values of resources to flight operators over time. Weather will change both the set of routes available to a flight, as well as the relative value of each route. Operating conditions that can change include fuel loading requirements, which in turn depend on planned routes as well as passenger counts, the latter which will shift as airlines work to minimize ATFM impacts to customers by reassigning and rescheduling passengers to flights. In addition, crew shift schedules may also be impacted as crews time out with flight delays. As a result of these possible changes, flight operators may prefer to request resources later in the process rather than earlier. Therefore we ask the question: how might uncertainty influence a flight operator's decision about when to make their resource requests in this competitive environment?