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Managing reliever gateway airports with high-speed rail network

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ABSTRACT

On the basis of model analysis, this study proposes an effective method for managing reliever gateway airports when the main gateway airport is completely dysfunctional owing to a catastrophe. In particular, we deal with the case where the main and reliever airports are connected by high-speed rail (HSR), and we discuss a desirable and effective support policy for regaining passenger flow from/to the affected area. First, we analyze the market behavior under the usual condition as the base case by adopting the bi-level model, which is a supply-demand interaction model. Second, under the supposition of a catastrophe, we set up some scenarios of management policies, i.e. (i) no special policy and (ii) providing support to HSR passengers to induce them to the reliever gateways. Through such scenario analyses, we show that (i) HSR fare restriction is required to regain sufficient passenger flow and (ii) providing fare support to HSR passengers is an effective way to regain passenger flow using reliever gateways, which can contribute toward building a robust air transport network.

1. Introduction

The last two decades have witnessed a global proliferation of air transport markets. At present, expanded air transport networks contribute significantly toward not only international trade but also local economies. This expansion of air transport networks is attributed to the centralization of functions to specific nodes, i.e., large hub/gateway airports. However, such centralization makes the network somewhat fragile. A centralized node that is severely damaged will propagate this damage across the air transport network, thereby reducing the productivity of the network. In recent years, air transport networks have been frequently exposed to various threats, such as climate change, earthquakes, tsunamis, and acts of terrorism. The 2010 eruption of Eyjafjallajökull, an Icelandic volcano, is regarded as one of the gravest events affecting air transport networks. EU-based air transport networks were severely affected by the eruption; they suffered heavy economic losses and took several weeks to resume services.[1] The 2011 Great East Japan Earthquake[2] had a similar impact on markets in Asia. Thus, there is an urgent need to build robust air transport networks to counter the threat of such catastrophes.

The issues of robustness and hedging against risks associated with air transport have been historically discussed as a family of scheduling problems. Many operations-research-related studies have been conducted in this regard (Arguello et al., 1998; Barnhart et al., 2003; Bard and Mohan, 2008; Janic, 2015; Zhang et al., 2016; Voltes-Dorta et al., 2017). However, most of these approaches

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[1] ICAO reported that because of this eruption, more than 100,000 commercial flights had been canceled and economic losses had reached 1.7 billion US dollars (ICAO, 2013).

[2] Sendai Airport (SDJ), located in nearby Sendai City, was completely destroyed by the tsunami, and both domestic and international flights, except non-scheduled flights, were cancelled for several months.

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focus on reducing delay or estimating short-term costs. Although there is a need to build robust networks by developing physically robust nodes (airports), such an approach entails considerable infrastructural and maintenance costs. Thus, it is financially unsustainable. Therefore, it is important to investigate alternative methods.

Toward this end, Zhang et al. (2015) proposed a unique method for measuring the robustness of transport networks on the basis of topology. Their approach not only enables us to understand the degree of robustness of transport networks but also suggests the importance of origin-destination (OD) connectivity. Furthermore, they proposed some methods for preserving OD connectivity, one of which is to exploit the complementarity of different modes of transport. In this regard, direct/indirect cooperation between air and other transport modes, such as high-speed rail (HSR), is worthy of consideration.

Because HSR is widely known to a transportation mode compatible with air transport services (Dobruszkes, 2011; Jiang and Zhang, 2014; Takebayashi, 2014), establishing a means of cooperation of HSR or integration with air services will be beneficial for passengers.[3] Xia and Zhang (2017) carried out a theoretical analysis of air-HSR integration and concluded that reducing the connecting time for seamless service between air and HSR is always beneficial for passengers; this suggests that ensuring better connectivity between air and HSR strengthens the network workability. In Eastern Asia, Japan, mainland China, and Taiwan have expanded their domestic HSR service networks (Chen, 2010; Fu et al., 2012, 2014), which have larger transport capacity and higher service frequencies than those in EU. However, the connectivity network between air services and HSR might encounter some problems, for example, in a case in which the airport does not have a direct connection to a HSR station. Overcoming such problems can guarantee an ever higher advantage of the air-HSR integration to both carriers and passengers.

The air-HSR integration also demonstrates considerable potential as a method to develop a robust air transport network, which is workable in both ordinary and emergency times. To ensure this, however, it is necessary to develop suitable policies for network management, as management policies play a vital role in formulating middle- and long-term strategies for building a robust air transport network. However, the above-mentioned studies do not address robustness against emergency situations (catastrophic events) from the viewpoint of management policies.

This study aims to propose an effective method of network management when the main gateway airport is completely dysfunctional owing to a catastrophe. In particular, we discuss the policy of managing reliever gateway airports and HSR through model analysis.

2. Model

2.1. Outline

The bi-level air transport market model, which deals with carrier competition from the viewpoint of passengers' route choice behavior (Takebayashi, 2013, 2014, 2015; Hanaoka et al., 2014), is adopted for analyzing the market. We use the following variables in the formula.

Symbols related to network structure			
rs	OD pair of origin r and destination s	k	Service route in rs OD market
Ω	Set of OD pairs	K^{rs}	Set of service routes provided for rs OD market
l^n (l^R)	Commercial link operated by airline n (or HSR)	I^n (I^R)	Set of links operated by airline n (or HSR)
I^{AV}	Set of links available for passengers		
Variables related to carriers			
f_{l^n} (f_{l^R})	Flight frequency on link l^n (or operating frequency on HSR link l^R)	$p_{l^n}(p_{l^R})$	Airfare on link l^n (or rail fare on link l^R)
$\widetilde{\mathbf{f}}^{-n}$ and $\widetilde{\mathbf{p}}^{-n}$	Optimal strategy vectors of competitor against airline n (or HSR), denoted by "–n (or R)"	$C_{l^n}^{OP}$	Operating cost per flight on link l^n
N	Set of airlines	v_{l^n}	Aircraft size, i.e., seating capacity of an aircraft on link l^n
V_h^n	Runway capacity constraint at airport h for airline n	$\Gamma(x_k^{rs})$	Optimal value function for passengers' route choice behavior
$\mathbf{G}(\mathbf{f}^n, \mathbf{p}^n)(\mathbf{G}(\mathbf{p}^R))$	General form of constraints with frequency and/or airfare of airline n (or the constraints for HSR related to the fare)		
Variables related to passengers			
x_k^{rs}	Passenger flow from r to s on route k	$\hat{x}_k^{rs}$	Equilibrium flow of route k in rs OD market

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[3] Some literatures discussed the social benefits of air-HSR integration using empirical relations (Givoni and Banister, 2006; Socorro and Viecens, 2013).