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The future relations between air and rail transport in an island country

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ABSTRACT

This paper proposes a bi-level passenger transport market model taking into account competition between air and high-speed rail (HSR) in a domestic market. The paper discusses the characteristics of the relationship between market share and connectivity in domestic and international markets. The result suggests that because of the dominance of HSR in the domestic market, when connectivity between air and HSR is good, international passenger's welfare can be improved. Finally, when considering profitability of the players, there is an incentive for airlines to cooperate with HSR, but there is no incentive for HSR to cooperate with airlines.

1. Introduction

In recent years, the network of high-speed rail, or HSR for short, has been rapidly expanding in Europe and Asia. A trend stimulated by the drive to reduce of greenhouse gas emissions. In Japan, Shin-kan-sen, the Japanese HSR, has been expanding all over the country. In 2011, more than 80% of Tokyo–Osaka passengers used Shin-kan-sen, while the percentage was 70% in 2005 (JR Central, 2012). Thus, HSR has been a strong competitor against air transport (Muto and Uchiyama, 2000) in the domestic market. Moreover, the super-high-speed rail system, linear Shin-kan-sen, will be introduced to Tokyo–Osaka in 2045. Some experts predict a serious decrease of air passengers in this market (Osaka Prefecture Government, 2009). A comparable situation is found in the EU market, where the HSR network has expanded in the last two decades. HSR has played a role of "active" substitute for air transport in the short haul markets and the situation is now competitive (Adler et al., 2010; Dobruszkes, 2011). It is reported that HSR will be developed in North and South American continents in the near future, where the air transport is traditionally dominant in the long haul market, and also to be expanded in mainland China and other Asian countries. The competition between air transport and HSR is therefore intensified in these countries.

Chen (2010) analyzes the situation of Taiwan and states the desirable future relations between these two modes. Air transport is dominant for international transport and the network carrier is the main provider. The network carrier usually operates both international and domestic services and gains by operating a large network of routes.

There is increased concern that the dominance of HSR in domestic markets may affect the operation of network carriers' domestic service and eventually affect the quality of international services in terms of connectivity. Especially, in island countries like Japan and Taiwan, international transport heavily depends on air transport, therefore the policy makers need to consider the relationship between air and HSR transport. Although the relationship between domestic transport and international transport is currently debated in policy circles, there is little research available on this topic; with a notable

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exception of Fu et al. (2012) work on HSR vs. air transport taking international transport into account. They address the case of China and conclude that airlines should strengthen their domestic network to collect more international passengers. Thus, the analysis of airlines' networks considering the effect of domestic competition against HSR on international transport is helpful to understand the relationship between air transport and HSR.

Cooperative relations between airlines and HSR are actually existent in some European markets (Jiang and Zhang, 2012) and effective in securing profits and passenger benefits. So far, Jiang and Zhang theoretically consider the effect of cooperation between airlines and HSR and they show that the cooperation can lead to the effective use of runway with a tight capacity constraint (Jiang and Zhang, 2012). However, they do not deal with the effect of cooperation on network or international (long haul) services and do not discuss the possibility of cooperation. In terms of cooperation, connectivity between air and HSR can be the key because it may affect airline's network design and passenger's route choice behavior.

In view of the benefit for both passengers and transport providers, how to connect domestic and international transport is a severe policy issue in Japan. We, therefore, research into the interaction between domestic and international transport considering the possibility of cooperation between airlines and HSR and the relationship between cooperation and connectivity.

Furthermore, in order to analyze the rail–air cooperation, we apply the bi-level model, which has different features from existing work in this domain. The approach suggested by Fu et al. (2012) cannot be applied to forecasting the effect of HSR–airline cooperation, but the theoretical approach of Jiang and Zhang (2012) allows comprehensive analysis of market behavior under HSR–airline cooperation. However, it is purely theoretical and difficult to apply in an empirical or practical setting. Our approach, the bi-level model approach, is classified as a supply–demand interaction model. The supply–demand interaction model is developed to reflect the realistic structure of the air transport market, and it can be applied to not only theoretical analysis but also applied and practical analysis (Kanafani and Ghobrial, 1985; Adler, 2001, 2005; Adler et al., 2010; Takebayashi, 2011a, 2011b, 2012). In this research, we, therefore, follow the bi-level model approach.

This paper has four sections. In Section 1, we have described the background of this research. In Section 2, we propose a mathematical model with formulation. In Section 3, we carry out numerical computations considering oligopolistic competition to obtain equilibriums, point out some important features of the equilibrium, show the relationship between network design strategy and differences in connectivity through sensitivity analysis, and consider the possibility of cooperation. Finally in Section 4, we summarize outcomes and make suggestions for future empirical research.

2. The model

We apply the bi-level air transport market model. The basic structure of the bi-level model is described in Takebayashi (2011a, 2011b, 2012). In this section, we briefly mention the formulation of passenger's behavior and carrier's behavior focusing on significant modified points. The notations are listed in the Appendix A.

2.1. Passenger's behavior

In the model, passengers choose the best available routes comparing each disutility. For passenger's route choice behavior, we adopt the *stochastic user equilibrium* (SUE) with capacity constraint model. The general formulation of the SUE with capacity constraint (Bell, 1995; Zhou et al., 2005; Takebayashi, 2011a, 2011b, 2012) is

$$\text{Object}: \ \min \Gamma(x_k^{rs}) = \frac{1}{\theta}\sum_{rs\in\Omega}\sum_{k\in K^{rs}} x_k^{rs}(\ln x_k^{rs} - 1) + \sum_{rs\in\Omega}\sum_{k\in K^{rs}} u_k^{rs}x_k^{rs} \tag{1}$$

subject to

$$\sum_{k\in K^{rs}} x_k^{rs} = X^{rs}, \quad \forall rs \in \Omega, \tag{2}$$

$$x_{l^n} = \sum_{rs}\sum_{k} x_k^{rs}\delta_{l^n}^{rsk} \leqslant \upsilon_{l^n} f_{l^n}, \quad \forall l^n \in I^n, \ n \in N^+, \tag{3}$$

$$x_k^{rs} \geqslant 0, \ \text{for} \quad \forall k \in K^{rs} \text{ and } rs \in \Omega. \tag{4}$$

In objective function (1), the first term of right-hand side is the entropy term. Constraint (2) means origin–destination (OD) flow conservation. Constraint (3) is link flow capacity constraint.

The disutility of passenger choosing route k of rs is defined as a function with deterministic costs:

$$u_k^{rs} = \alpha_1\left(t_k^{rs} + w_k^{rs}\right) + \alpha_2 p_k^{rs} + \sum_{l\in I^{A\upsilon}} \frac{\alpha_3}{f_l}\delta_l^{rsk}, \tag{5}$$

where the third term of right-hand side is average waiting time derived from service frequency, which reflects the effect of schedule delay. In our model, generalized time for access/egress to CBD reduces to generalized cost w. Many researches (e.g., Hess et al., 2007) deal with access time and/or cost separated from linehaul time and/or airfare, but in our model w is synthesized with some weight from access time and access cost, therefore Eq. (5) is regarded as equivalent to the traditional manner. Passenger's disutility function including congestion cost U_k^{rs} is described as