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Procedia - Social and Behavioral Sciences 138 (2014) 602 – 611

Procedia
Social and Behavioral Sciences

The 9th International Conference on Traffic & Transportation Studies (ICTTS'2014)

Time Value Distribution and Multi-modal Intercity Travel Network Shape: Theoretical Analysis for the Typical Setting

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Abstract

In a period of declining demand, should we sustain some intercity transport even if it is unprofitable? And in which situations should we sustain the plurality of modes of transport? In this paper, we analyze the relationship between time-value distribution and multi-modal network shapes. The network shapes considered are dual-mode or single-mode, and a random parameter model is used to describe the route choice of travelers, which takes the time-value distribution into account. First, the relationship between parameters of time-value distribution (i.e., average and dispersion) and the optimal network shape is analyzed; we find that a dual-mode network is optimal when the time-value dispersion is large. Second, as demand declines, the optimal network may change from a dual-mode network to a single-mode network. Third, the conditions in which an equilibrium dual-mode network can be established in a given transport market are described. From a comparison between the equilibrium and optimal conditions for a dual-mode network, we find that dual-mode networks may be in equilibrium even though they are not optimal. It follows that we need not sustain unprofitable mode service in order to realize the optimal network shape. Moreover, in a period of declining demand, it may be beneficial to move from a dual-mode network to a single-mode network from a market driven dual-mode network.

Peer-review under responsibility of Beijing Jiaotong University(BJU), Systems Engineering Society of China (SESC).

Keywords: heterogeneity of time value; multi-modal network; intercity transportation; optimal network; equilibrium network

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doi:10.1016/j.sbspro.2014.07.244

1. Introduction

The demand for intercity travel in Japan is currently decreasing because of a diminishing population. This decline in demand may result in some public transport operations becoming unprofitable, particularly in rural areas. In Japan, some unprofitable intercity transport services are supported by government subsidies, but it may not be practical to sustain all transport services forever. In particular, with a multi-modal network, some services may no longer be required. The relationships between some modes (e.g., high-speed rail (HSR) and air travel) have become increasingly competitive because of appearance of low-cost carriers and/or the construction of HSR. This means that we can make the intercity transport network more efficient by cancelling some services without seriously affecting the regional economy, because competitive modes can cover the terminated service.

In some cases, however, it may be socially efficient to sustain dual-mode networks, considering the heterogeneity in travelers' preference (i.e., their time-value) and congestion. First, in the case of larger heterogeneity in travelers' preference, it may be socially optimal to sustain dual-mode networks, in which they can choose their favorite mode. For example, when travelers have both high and low time-value, the optimal network is often dual-mode, and passengers can choose different modes: a fast but expensive service, or a slow but inexpensive service. Therefore, it is important to determine the relationships between the heterogeneity of travelers' preferences and optimal network shape for intercity transport. Second, when transport is limited by congestion, we should sustain a dual-mode network. However, in Japan congestion is not a significant problem because of the declining population (with a few notable exceptions, for example, Haneda Airport in Tokyo).

Few studies into intercity public transport have focused on heterogeneity in travelers' preferences. Many theoretical studies involving airline networks (e.g., Brueckner (2004) and Flores-Fillol (2009)) assume that travelers' preferences are identical. Adler *et al.* (2010) considered the heterogeneity of travelers stochastically using a nested multinomial Logit model, but they did not analyze the relationship between variance in travelers' preferences and the network shape.

Kawasaki (2008) analyzed airline networks to consider two types of travelers: business travelers with high time-value, and leisure travelers with low time-value. He concluded that, in the case of large heterogeneity, the optimal strategy for airlines is to operate two types of service: high-frequency services (i.e., a hub-and-spoke network) for business travelers and low-frequency but direct services (i.e., a point-to-point network) for leisure travelers.

In this paper, we first examine the robustness of Kawasaki's 2008 analysis by considering a multi-modal network with different cost functions and time-value distributions. The time-value distribution is assumed to be a uniform distribution with a certain range, in contrast to the assumption that there are two types of travelers, each with a single time-value. Second, the optimal network shapes are analyzed in response to a decline in demand. Third, optimal and equilibrium networks in a transport markets with a given set of time-value distributions are compared. As a result of these analyses, we find that 1) a dual-mode network is optimal when the time-value dispersion is large, in agreement with the results of Kawasaki (2008); 2) in a period of declining demand, the optimal network may change from dual-mode to single-mode; and 3) based on a comparison between the optimal and equilibrium networks, we find that a dual-mode network may be in equilibrium even though it is not optimal.

The reminder of the paper is organized as follows. In Chapter 2 we describe the model used to analyze the relationship between the time-value distribution and the network shape. In Chapter 3 we present the results of our analyses of a typical setting: the network shape is either single-mode or dual-mode, and the time-value distribution is assumed to be uniform and limited to a given range. Chapter 4 concludes the paper.

2. Model

In this chapter, we describe the models used to analyze the relationship between the time-value distribution, and the optimal and equilibrium network shapes. The model consists of a description of the travelers' route choice and a description of the network, in which public transport operators determine link fares and the network shape. In section 2.1 we describe the travelers' route choice model; in Section 2.2 we describe the network model to analyze the optimal network shape; and in Section 2.3 we describe the network model for analysis of the equilibrium network shape.