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RESEARCH PAPER

Effect of Road Traffic Congestion on Aviation Passenger's Flight Choice

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Abstract: This paper investigates how passengers choose flight times in view of ground traffic congestion. The departure time choice model of aviation passengers is developed by extending Vickrey's bottleneck model. The conditions are determined for the existence of the user equilibrium in the model. Then, the range of the difference between the airfares is established while the number of aviation passengers choosing the same flight time remains unchanged at the user equilibrium. Moreover, the tendency of the total queuing time and the incremental airfare revenue is derived along with the difference between the airfares. The results show that the number of aviation passengers is jointly determined by the flight time and the bottleneck capacity for different schedules. Under the given passenger volume, the total queuing time (traffic congestion) can be reduced or the incremental airfare revenue can be increased by properly adjusting the airfares difference. Two numerical examples are presented to demonstrate the principle and its application.

Key Words: integrated transportation; flight choice; bottleneck model; air transportation; congestion

1 Introduction

Air travel has become an important intercity transport mode due to the rapid economic growth. However, the fast increase of air travel demand has resulted in traffic congestion on the access roads to major airports during peak hours. Such traffic congestion decreases the quality of air service and the travel efficiency of passengers, who take into consideration the congestion level in ground traffic when making a choice for their air travel. This indicates that the ground traffic congestion affects how aviation passengers choose the departure time for their flights. This phenomenon deserves a careful examination from the academic point of view. Airlines also have to address a practical problem on how to develop pricing strategies that minimize ground traffic congestion and maximize economic benefits from flights departing at different times.

There have been few articles examining how aviation passengers choose their departure times. Many researchers have analyzed and reviewed the travel characteristics of aviation passengers by studying the forecast of demand and volume[1,2], testing on airline customer satisfaction[3], flight time and airfare competition[4,5] in view of maximizing the benefits of airlines and their passengers. All such studies are on the flight characteristics rather than the effect of ground traffic on passenger travel. In this paper, a concise model is used to uncover the relationship between ground traffic congestion and passengers' travel choice. The renowned bottleneck model was developed by Vickrey, one of the Nobel laureates in economics, in 1969. It is the first endogenous departure time choice model built using the deterministic queuing theory with all travelers having the same travel cost[6]. The model clearly reveals the mechanism how travelers choose their departure times. It has been widely recognized by researchers around the world since it was developed. Although similar research has been conducted in an extensively wider area[7−10], little has been carried out on its applications in the departure time choice problem of aviation passengers.

This paper extends the bottleneck model by assuming: (a) an airline has two alternative flights departing at different times; (b) passengers have to access the airport through a road section where a traffic bottleneck exists. It builds a concise departure time choice model by considering ground traffic congestion, and determines the travel pattern of these

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passengers at the user equilibrium. Finally, the paper analyzes how the difference between the airfares can affect the equilibrium and draws a conclusion that the total queuing time of passengers can be reduced or the incremental airfare revenue increased by properly adjusting the difference between the airfares at a given volume of aviation passengers.

2 Basic model and its properties

2.1 Basic model

Given two flights departing from airport A to airport B every day, with the first flight taking off at t_1^* and the second at t_2^*, where $t_1^* < t_2^*$. There are N homogeneous aviation passengers attempting to access airport A through a road containing a bottleneck of traffic capacity s and then take a flight to airport B. Assume that these passengers do not have any preference on the flight time; early arrival is permitted, but late arrival is not; the boarding time is ignored. Traveler category 1 consists of N_1 passengers who choose Flight 1, and category 2 consists of N_2 passengers who choose Flight 2. This paper examines how the aviation passengers choose their departure time.

The travel cost of the passengers includes the cost of queuing time, early-arrival penalty, and airfare. To simplify our model, we first assume that the fares of the two flights are equal to each other, or equal to zero. Therefore, the travel expense of each traveler of one of the two categories is:

$$C_i(t) = \alpha T(t) + \beta[t_i^* - t - T(t)] \qquad i = 1, 2 \tag{1}$$

where t is the departure time of the traveler; $T(t)$ is the queuing time that the traveler departing at time t takes at the bottleneck; α is the cost per unit queuing time; β is the penalty cost per unit time of early arrival ($\alpha > \beta$). In addition, we use t_i^a to denote the earliest departure time of category-i travelers, and t_i^b to denote the time that category-i travelers have to depart if they want to arrive at the airport at exactly the right time (at time t_i^*), which should be the latest departure time of category-i travelers as late arrival is not permitted.

Assume aviation passengers are completely informed of the departure times. Therefore, all passengers incur the same travel cost under the equilibrium state and no one can reduce his/her travel cost by changing the departure time. Under the condition that the travelers of one category travel independently from those of the other, we have the following formulas for category-1 travelers.

Those departing earliest do not spend queuing time and incur the travel expense of:

$$C_1(t_1^a) = \beta(t_1^* - t_1^a) \tag{2}$$

Those departing latest arrive at the exact time (without early-arrival punishment) and incur the travel expense of:

$$C_1(t_1^b) = \alpha(t_1^* - t_1^b) \tag{3}$$

The bottleneck runs at full capacity throughout the departure period. Therefore,

$$t_1^* - t_1^a = \frac{N_1}{s} \tag{4}$$

By combining formulas (2) to (4) and the equal-cost condition, it is obtained that:

$$t_1^a = t_1^* - \frac{N_1}{s},\, t_1^b = t_1^* - \frac{\beta}{\alpha} \cdot \frac{N_1}{s},$$

$$T(t) = \frac{\alpha}{\alpha - \beta}(t - t_1^a), t \in [t_1^a, t_1^b],\, C_1 = \beta \frac{N_1}{s} \tag{5}$$

Similarly, the following formulas for category-2 travelers are obtained:

$$t_2^a = t_2^* - \frac{N_2}{s},\, t_2^b = t_2^* - \frac{\beta}{\alpha} \cdot \frac{N_2}{s},$$

$$T(t) = \frac{\alpha}{\alpha - \beta}(t - t_2^a), t \in [t_2^a, t_2^b],\, C_2 = \beta \frac{N_2}{s} \tag{6}$$

2.2 Properties of model

The following paragraphs discuss the condition under which the equilibrium state can exist in respect of the volume of aviation travelers N, and analyze the pattern for the existence of the equilibrium. All passengers incur the same travel cost under the equilibrium state, i.e., $C_1 = C_2$. Set the flight time difference to $\Delta t = t_2^* - t_1^*$. Lemma 1 and Lemma 2 present how the equilibrium can be affected by N_2, the number of category-2 travelers, due to the existence of ground traffic bottleneck.

Lemma 1: If $N_2 > \Delta t \cdot s$, the user equilibrium does not exist.

Prove: given the limited traffic capacity at the bottleneck, the travelers arriving between t_1^* and t_2^* cannot be more than $\Delta t \cdot s$. If $N_2 > \Delta t \cdot s$, then it is inevitable that some of the category-2 travelers would arrive before time t_1^* and some travelers of one category would depart at the same time and travel together with those of the other category because late arrival is not permitted. If the travelers of the two categories depart together with each other at time t, they must have the same queuing time $T(t)$, where $t + T(t) < t_1^*$. Therefore, their travel costs are respectively:

$$C_1(t) = \alpha T(t) + \beta[t_1^* - t - T(t)] \tag{7}$$

$$C_2(t) = \alpha T(t) + \beta[t_2^* - t - T(t)] \tag{8}$$

It should be noted that $C_1 < C_2$. This contradicts the statement that all travelers incur the same travel expense under the equilibrium state. End of proof.

Lemma 1 indicates that the aviation passengers choosing flight time t_2^* (category-2 travelers) would not be more than $\Delta t \cdot s$ due to the limited traffic capacity at the bottleneck under the equilibrium state.

Lemma 2: Assumes that $N_2 < \Delta t \cdot s$. The user equilibrium exists if and only if $N_1 = N_2$.

Prove: Given $N_2 < \Delta t \cdot s$. It is derived from Eq. (6) that

$$t_2^a = t_2^* - \frac{N_2}{s} < t_1^*$$