

# A Game theory approach for the operators' behavior analysis in the urban passenger transportation market

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**Abstract.** Urban passenger transportation market in China now is composed by three public transportation modes, including the conventional bus, taxi and subway (or light rail). There are both cooperation and competitive behavior among these three different transportation modes. This paper aims to describe how these three operators make their operational decisions in the competitive environment. A bi-level programming operational model is proposed to model urban passenger transportation operators' decision behavior, which is based on the game theory to describe the behavioral conjectures among the management authority, different operators and passengers. The upper-level model described the management authority' regulation on the fares of each mode, which aimed to achieve the comprehensive social objectives, indexed by the travel time cost, air pollution cost and energy consumption cost. The lower-level model described the three operators' aiming to maximize the profit by determining the service frequency, which can reflect the operators' cooperation and complete behavior under the urban passenger transportation economic policy. A logit model is proposed to analyze passengers' mode choice behavior with the maximization of their travel utilities, which considers the total travel time, waiting time and total travel fare of each mode. This research will provide more evidence for urban passenger transportation development and contribute to urban passenger transportation economic policy establishment and implementation.

## 1. Introductions

Urban passenger transportation service in China now is mainly provided by conventional bus, with the supplementation of taxi service; the rail transit is gradually introduced in large urban area. In 2011, there are twelve cities have operated urban rail transit, and fourteen cities have been constructing urban rail transit. Rail transit can not only provide a more convenient, huge-capacity, punctuality and comfortable service for travelers, but also can meet the urban modernization needs, alleviate the urban road traffic congestion, reduce road traffic air pollution emissions, promote urban passenger transportation sustainable development [1, 2].

There are conventional bus operator, taxi operator and rail transit operator in the urban passenger transportation market, while both cooperation and competitive relationship exist among these different operators [3]. Different operators will make their decision according to their own

development goals; each operator's decision-making process would often be impacted by other operators. How to design and schedule the operational programs to achieve the maximum profit is one of the keys to optimize the urban passenger transport system.

Due to the open and competition in the urban passenger transportation market, the competition and cooperation among different operators have been increasing and more severe; the research on the different operators' competition and cooperation strategies has been paid more attention during recent years, which can be referred to the studies of [4-8].

The aim of this paper is to provide the cooperation and complete behavior analysis among different urban passenger transportation operators, and to apply this study to analyze the reason of the different behavior change among different operators. This research will provide more evidence for urban passenger transportation development and contribute to urban passenger transportation economic policy establishment and implementation.

The paper is organized as follows. Section 2 describes the urban passenger transportation operators' relationship. Section 3 analyzes and models the urban passenger transportation operator's behavior in detail. In Section 4, we summarize this paper.

## **2. The urban passenger transportation operators' relationship analysis**

As a typical complex system, there exists mutual cooperation and mutual competition relationship among the different passenger transportation operators. Each balanced state of the urban passenger transport system is formed when all the operators make their own decision after taking into account the decision-making of other operators.

The cooperative relationship among the urban passenger transportation different operators can be regarded as, the different transportation mode in accordance with its own technical and economic characteristics, playing its own respective role in its reasonable transportation scope; then reasonable convergence with other transportation modes, jointly to accomplish the passengers transport service from the origin to the destination. This cooperative relationship can effectively reduce transportation costs, and improve the passenger transportation efficiency, which make the passenger safety, convenience and fast reach the destination. The coordination and cooperation among the urban passenger transportation operators will meet the different categories passengers travel demand; thereby improve the public's satisfaction and support of the urban passenger transportation system [9]. The cooperative behavior among the urban passenger transportation operators can be referred to [7, 10-12].

The competition relationship among the urban passenger transportation different operators can be achieved when all the transportation modes' services fully reflect its true social cost. The competition relationship will improve the passenger transportation systems productively, save one unit operating costs, and increase the average service number per unit expenditure [13]. Fox (2000) considered that the competitions between the urban passenger transportation are often reflected in the few visible businesses, such as the introduction of new technologies, financial performance and the advanced service function [14]. In China these can be mainly reflected by the electronic bus stop board, taxi GPS dispatching system and the IC card service. At present the competition behavior among the urban passenger transportation operators can be referred to [4-5, 15-17].

### 3. Model formulation

This section presents a bi-level programming model – an operational model for urban passenger transportation market, which describes the operators' cooperation and competition behavior relationship in the urban passenger transportation market.

The game among the urban passenger transport different operators has taken the different transportation mode's service price as objective; modeling the different pricing strategies set, and thus obtains the Nash equilibrium price or a stable equilibrium point. Around the world, the introduction of game theory into the passenger transportation research filed began from Fisk's (1984) study [18]. Different authors apply game theory have achieved more useful research results on the multi-player games [4-8, 10]. With the introduction and development of the subway transit in the urban passenger transportation, existing researches can not be suitable to reflect the cooperation and competition relationship among the three different mode operators, which is difficult to ensure the passenger transport management policy achieve the expected effect.

According to the gaps between previous researches and the reality, this paper will based on the existing studies to explore urban passenger transportation operator's cooperation behavior under the introduction of rail transit service. This paper will be helpful for the cooperation and complete strategy selection among different urban passenger transportation mode operators.

#### 3.1 Model assumptions

Considering in the urban passenger transportation market, existing three public passenger transportation modes (bus, taxi and subway), and the private car mode. For simplicity, each public passenger transportation mode is assumed to be operated by only one operator under a regulated fare. The Nash Equilibrium will be achieved when the bus, taxi, subway and car compete with each other; meanwhile there no one acts as a leader in the four modes' competition. The bi-level operational model is established to determine the optimal fare and service frequency for each mode. The basic model assumptions are as follows:

- i . The management authority aims to regulate the fares and subsidy to achieve overall market equilibrium; the operators determine the service frequency to maximize their profits under the fares restricted by the management authority;
- ii . The Nash Equilibrium among the different operators with the competition with each other in the service frequency, that means the operators behave in a non-cooperative manner in which each operator acts as given the other operators' operational decisions when determining its own strategy;
- iii . The capacity and travel time are fixed for the four passenger transportation modes;
- iv . Passengers based on their personal income and car ownership, they can choose different passenger transportation modes to maximize their utilities, including the conventional bus, taxi, subway and private car; A logit model is proposed to analyze passengers' mode choice behavior with the maximization of their utilities, which considers the total travel time, waiting time and total travel fare of each mode.

#### 3.2 The bi-level programming operational model

The bi-level programming operational model of the urban passenger transportation market can be formulated as follows:

*Upper level*

$$\underset{f_i}{Min} \ SC = TC + AP + EC. \quad (1)$$

$$TC = \sum_{i=1}^3 \left[ b_{i1} \times R \times Pr_i \times (t_{T,i} + t_{W,i}) \right] + b_{41} \times R \times Pr_4 \times t_{T,4} \quad \text{for } i=1, 2, 3. \quad (1.1)$$

$$AP = \sum_{i=1}^3 [b_{i2} \times F_i \times d] + b_{42} \times \frac{R \times Pr_4}{H_4} \times d \quad \text{for } i=1, 2, 3. \quad (1.2)$$

$$EC = \sum_{i=1}^3 [b_{i3} \times F_i \times d] + b_{43} \times \frac{R \times Pr_4}{H_4} \times d \quad \text{for } i=1, 2, 3. \quad (1.3)$$

In the Eq. (1),  $SC$  is the total social cost, where  $TC$ ,  $AP$  and  $EC$  respectively represent the total costs of travel time cost, air pollution cost and energy consumption cost. Where  $b_{ij}$  is the unit cost of social cost index  $j$  ( $j=1$  represents for travel time cost, 2 for air pollution cost, 3 for energy consumption cost) of transport mode  $i$  ( $\text{¥/trip}$  or  $\text{¥/veh}\cdot\text{km}$ ), operator  $i$  for bus ( $i=1$ ), subway ( $i=2$ ), taxi ( $i=3$ ).  $R$  is the ridership of the passengers (trips per hour).  $d$  is the distance between the origin to the destination ( $\text{km}$ ).  $Pr_i$  is the passenger transportation market share of mode  $i$  (%).  $t_{T,i}$  and  $t_{W,i}$  is the travel time and the average waiting time of mode  $i$ . The average waiting time of bus and subway can be assumed as one-half of its headway, that is  $t_{W,i} = (1/2F_i)$ ,  $i=1, 2$ . The average waiting time of taxi can be assumed in the time interval [5, 10] minutes.

Lower level  $i$

$$\text{Max}_{F_i} \pi_i = f_i \times R \times Pr_i - F_i \times c_i \quad \text{for } i=1, 2, 3. \quad (2)$$

s.t.

$$0 < R \times Pr_i \leq F_i \times H_i \quad \text{for } i=1, 2, 3. \quad (2.1)$$

$$0 < F_i \leq F_{\max,i}, \quad F_i \in \text{integer}, \quad \text{for } i=1, 2, 3. \quad (2.2)$$

$$0 < f_i, \quad \text{for } i=1, 2, 3. \quad (2.3)$$

$$Pr_i = \frac{e^{\alpha_1 \cdot t_{T,i} + \alpha_2 \cdot t_{W,i} + \alpha_3 \cdot f_i}}{\sum_{i=1}^3 e^{\alpha_1 \cdot t_{T,i} + \alpha_2 \cdot t_{W,i} + \alpha_3 \cdot f_i} + e^{\alpha_1 \cdot t_{T,4} + \alpha_3 \cdot f_4}} \quad \text{for } i=1, 2, 3. \quad (2.4)$$

$$Pr_4 = \frac{e^{\alpha_1 \cdot t_{T,4} + \alpha_3 \cdot f_4}}{\sum_{i=1}^3 e^{\alpha_1 \cdot t_{T,i} + \alpha_2 \cdot t_{W,i} + \alpha_3 \cdot f_i} + e^{\alpha_1 \cdot t_{T,4} + \alpha_3 \cdot f_4}} \quad \text{for private car.} \quad (2.5)$$

Where  $f_i$  is the fare rate of passenger transportation operator  $i$  ( $\text{¥/trip}$ ) for bus ( $i=1$ ), subway ( $i=2$ ), taxi ( $i=3$ ), and for private car, respectively.  $F_i$  is the service frequency of operator  $i$  (number of scheduled buses, scheduled subway trains, and scheduled taxi per day).  $f_i$  and  $F_i$  are the decision variables at upper level and lower level, respectively.  $H_i$  is seat capacity of mode  $i$  (passengers per bus, passenger per train, or per taxi).

Eq. (2) is the profit ( $\pi_i$ ) of operator  $i$  ( $\text{¥}$ ) for bus, subway and taxi.  $c_i$  is the average operational cost per service of operator  $i$  for bus, subway and taxi. Restriction (2.1) means that the seat capacity of operator  $i$  must equal or exceed its passenger demand of bus, subway and taxi. Eq. (2.4) and (2.5) represent the Logit-choice model for the mode  $i$  (%) market share.  $v$  is the time of value of different categories passenger ( $\text{¥/hour}$ ).  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$  are three negative parameters for the travel time, average waiting time and fare, respectively, which can be obtained by the parameter calibration method [19].

The upper level model is to determine the optimal fare for each passenger transportation mode, which is based on the management authority's objective. Once the fares are fixed at the upper level, the lower level of the model is to determine the optimal operational service for each mode.

### 3.3 Model solution

As a bi-level programming model, the presented operational model can be solved by kinds of method, referring to the research of [20, 21], this model can be solved by Branch-and-bound method, Complementary pivoting method, Descent methods, Penalty function methods, and Trust-region methods. The Genetic Algorithm can also be introduced to solve this model; the detail can be referred to the research of [8] and [19] to solve this problem. Meanwhile, the software GAMS can also be adopted to solve this model [6].

## 4. Summary

In order to describe and analyze different kinds of passenger transportation operators operational decision behavior, this paper based on game theory to establish a bi-level programming operational model. The upper-level model described the management authority' regulation on the fares of each mode, and the lower-level model described the three operators' aiming to maximize the profit by determining the service frequency, which provides the cooperation and complete behavior analysis among different urban passenger transportation operators. The future work is to set parameters and analyze the operators' competition behavior under different strategies.

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