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A Model for Analyzing Competition among Intercity Public Transportation Carriers

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Abstract — This paper presents a competition model that captures the short-term competition among multiple transportation carriers providing services between two middle-distance cities and carrying a given number of passengers. The competition model, with flexibility to include competition among carriers providing substitute and/or complementary services and the various setting of passengers' and carriers' attributes, has four major components, including an abstract transportation system model where combinations of attributes describe the passenger carriers, a pricing model that captures how the carriers simultaneously refine their prices to gain competitive advantage, a passengers' choice behavior model that represents how the passengers respond to prices, and profit functions that define the relationship between each carrier's price, market share, and profit. A heuristic solves for the price equilibrium. A set of numerical examples derived from the intercity public transport market in Taiwan demonstrates the model as well as the heuristic, followed by an analysis of the sensitivity of the equilibrium state with regard to passengers' average value of time. The computational results are in line with expectations.

Keywords — high-speed rail, intercity passenger transportation, price competition, pricing, equilibrium

1. INTRODUCTION

The middle-distance intercity public transportation market is often highly competitive. Between a pair of cities that are 300 to 500 km apart, airlines, buses, the conventional rail, and the high-speed rail serve the same pool of passengers traveling from one city to the other, forming a complex market in which all the transportation carriers participate. The carriers differ from each other in cost, price, operating speed, and other attributes. They also interact with each other in complicated ways. While some transportation carriers substitute each other, others might complement each other, with one carrier acting as the feeder of another. It is also not uncommon to have terminals shared by multiple carriers, or one carrier using multiple terminals.

This work is motivated by the domestic transportation market in Taiwan, where several intercity transportation systems connect the two major cities in the country, Taipei and Kaohsiung, which are approximately 350 km apart. There are a newly constructed high-speed rail (HSR) system, a conventional rail (CR) system, a few domestic airlines (before September 2012), and a few bus companies in this market. Due to geographical reasons, all these carriers share the same transportation corridor. Similar situations where parallel systems serve the same corridor also exist elsewhere. In South Korea, the newly-developed high-speed rail (Korea Train Express) competes with the existing CR system along the northwest–southeast corridor (Chang and Chang, 2004; Park and Ha, 2006). In Japan, a new HSR with magnetically levitated trains will provide faster service at over 500 kph along the Tokyo–Nagoya–Osaka (TNO) corridor in 2020, where the famous Shinkansen has been serving since 1964 at a lower speed (Yao and Morikawa, 2005).

Competition among parallel transportation systems in general, and interaction between HSR and CR in particular, have been studied in the past. With a vast capacity and high service level, the appearance of a new HSR typically impacts the existing intercity transportation market significantly. In some systems, HSR even share tracks with CR (Wong, Han et al., 2002). Givoni and Banister (2006, 2007) took London Heathrow airport as an example to examine the potential cooperation of HSR and airlines in UK. They analyzed statistical data provided by the authority and suggested that the airlines can use HSR as additional spokes in the existing hub-and-spoke network. In Western Europe, newly developed HSR lines compete with the existing airline services. Dobruszkes (2011) studied five city-pair cases, namely Paris–Metz, Paris–Brussels, Brussels–London, Paris–Marseilles, and Cologne–Munich, and compared the supply level of air services to empirically examine the influence of HSR Services. The results showed that price, travel time, access time influenced by frequencies, geographical structures of urban regions, and other additional variables such as airlines' hubs are factors relating to the competition between airline and HSR services. A survey (Liu and Zhang, 2012) of the intercity passengers' travel behavior

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in the Beijing-Tianjin intercity transportation system in China, which is approximately 120 kilometers long, showed that the introduction of the Beijing-Tianjin HSR attracts passengers from the existing conventional rail and intercity buses, and causes an increase in business and leisure tourism trips. Yao, Yang et al. (2013) used a nested logit mode choice model to analyze the pricing strategy of HSR in Wuhan-Guangzhou corridor in China with the aim of improving occupancy rates. They suggest that the ticket fare should be set at a lower level on weekdays and at a higher level on holidays to improve the occupancy rates for HSR. Other empirical case studies of the competition between the HSR lines and other transportation system include Taiwan HSR (Cheng, 2010; Jeng and Su, 2013), development of the High Speed/High Capacity rail network in Italy(Cascetta, Papola et al. 2011), various HSR lines operating in China(Fu, Zhang et al. 2012; Shi and Zhou 2013).

In order to study the interaction between a HSR and other transportation systems, published mode choice models often apply the principle of the discrete choice models (the logit models), network models or variations of them to determine the market share of each mode. Gonzalez-Savignat (2004) applied the logit model to various testing scenarios to predict how a new HSR will compete with the existing Madrid–Barcelona airline service in Spain. In the same context, Roman et al. (2007) developed a nested discrete choice model to analyze potential competition between air transport and the new Madrid-Barcelona HSR line in Spain. Using accessibility as a measurement of travel condition, Yao and Morikawa (2005) also developed a nested discrete choice model to estimate the induced travel demand caused by an alternative new HSR route in Japan's TNO corridor. Dealing with competition among transportation modes, Adler et al. (2010) used a game theoretical model and applied a nested multinomial logit model to analyze the potential effects of a Trans-European HSR network infrastructure by computing equilibria with and without the HSR investments under various scenarios for the year 2020. Yang and Zhang (2012) used differentiated Bertrand model with different objective function of HSR and the airline to analyzed the competition between them. In the demand side, they also applied a nested multinomial logit model. Fu, Oum et al. (2014) used the nested logit model to estimate the travel demand model in Japan's intercity market and therefore evaluated the effects of introducing super high-speed-rail (HSR). Chang and Chang (2004) estimated the market share of the new HSR system in Korea's northwest–southeast corridor by building a time–space network to compute the user-optimum solution under the given fare, capacity, aggregate demand, and performance data. With this tool, they first obtained the best-fit value of time distribution of passengers based on the existing transportation network, and then applied this parameter to predict the future market share after the new HSR joins the network. With a game theoretical model, Hsu et al. (2010) described a competitive market where an HSR competes with CR in a complement network linked two cities with the Hotelling's linear-city setting.

The logit model and its variations are frequently used to study the competition between HSR and other intercity modes in these references. However, these models require a certain pattern of substitution across given alternatives. To allow for more general patterns of substitution and to investigate which pattern is most accurate, more flexible models are needed (Train, 2009). The current work, proposes a competition model that describes the middle-distance intercity public transportation market, develops a numerical heuristic to solve for the price equilibrium, and provides flexibility to investigate how the changes of various characterizes, namely operating cost, travel time, the existence of auxiliary terminals, and location of terminals, influence their competition.

This paper is organized as follows. Following this introduction, the next section sets up our theoretical model of the carriers' price competition and passengers' choice behavior. In section 3, we propose a heuristic to solve for the price equilibrium. Numerical examples are presented and discussed in section 4. Section 5 provides a brief conclusion and directions for possible future research.

2. COMPETITION MODEL

On the supply side of the intercity transportation market, carriers have an array of instruments to compete with each other. Common mechanisms include service frequencies, terminal locations, travel time, and ticket price. Among these, price is often the main tool a firm can use in the short run (i.e., the time frame in which production factors are fixed) in response to competition (Tirole, 1988), as other approaches often require higher cost and/or longer time, and thus are mainly undertaken on a long term basis.

On the demand side, the passengers' origin and destination points are scattered within the two cities; their time values differ from each other, and they have different preferences among available alternatives. Individual passengers make their choice among carriers according to their own origin/destination locations and preferences, and respond to ticket prices set by the carriers. Altogether, their choices drive the price-competition among the carriers.

Our competition model describes how a number of public transportation carriers compete in the transportation market between two cities. Overall, the competition model captures much of the most important attributes of a transportation market, including: (a) price, operating cost, travel time, the existence of auxiliary terminals, and location of terminals that characterize transportation carriers; (b) substitute and/or complementary routes among carriers; (c) the locations of origin/destination points, value of time, and personal preference that characterize individual passengers; and (d) passengers' choice and carriers' profit-maximizing behaviors that drive the market.

The competition model consists of four major components, namely an abstract model of the transportation system, a pricing model that reflects a market where the carriers simultaneously refine their prices to gain competitive advantage, a passengers' choice behavior model that represents how passengers of the transportation system respond to prices, and profit functions of the carriers that define the relationship between each carrier's price, market share, and profit. The carriers affect the passengers' choice by simultaneously altering their own unit distance fares, and the passengers make choices according to their generalized travel cost. The components of the competition model are discussed in more detail below.

2.1 Transportation System Model

Consider a set M of all possible carriers that offer a variety of public intercity passenger transportation services between two cities R and S, which can include airlines, buses, HSR, and CR. Carriers have their own terminals in the cities, and some terminals are shared by multiple carriers. Such a system can be modeled as a network (Sheffi, 1985), as illustrated in Figure 1 with an example. The example considers the transportation market from city R to city S, served by six different carriers. In Figure 1, nodes r_1 through r_5 represent the terminals (which are bus/train stations or airport) in city R, and nodes s_1 through s_5 represent their counterparts in city S. Links in the network correspond to transportation services provided by these carriers, which will be selected by passengers. Numbers on the links correspond to transportation routes, which will be explained in more detail later. The link (r_1,s_1) in Figure 1 is an airline; links (r_2,s_2), (r_3, s_3), and (r_4,s_4) represent three parallel bus links representing three different bus companies. Nodes r_5 and s_5 are terminals shared by CR and HSR, where passengers can transfer from one rail to another. The two links connecting nodes r_5 and s_5 correspond to HSR and CR respectively. Finally, the CR in this example has auxiliary terminals r_6 and s_6, and links (r_6,r_5) and (s_5,s_6) are feeder lines operated by CR. This configuration enables the transportation system model to capture the situation where two or more carriers complement each other by one carrier acting as the feeder for another, which is the case in many cities.

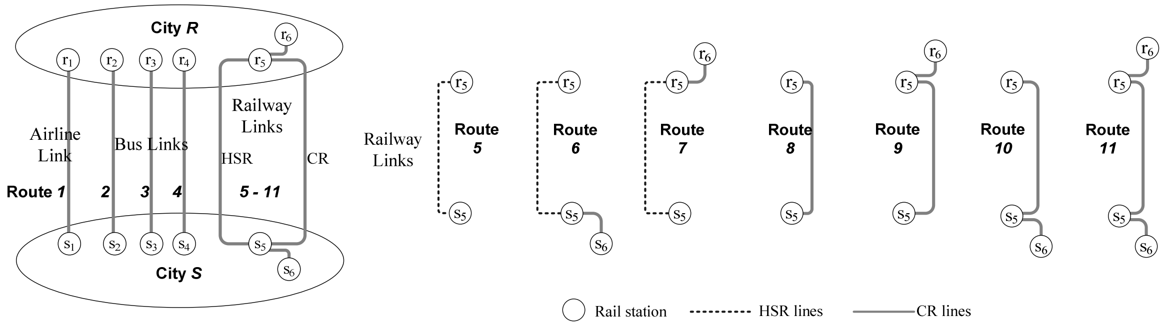

Figure 1. Possible routes of intercity transportation.

This transportation system model allows one to enumerate all the possible combinations of different ways that a passenger can travel from city R to city S, which we shall refer to as travel routes. Using the same example as above, route 1 in Figure 1 is the travel route that takes the airline service to travel from city R to city S, and 2 to 4 are the three routes taking bus services. There are seven different routes, numbered 5 to 11, whose legs are combinations of the CR and the HSR system, as elaborated in Figure 1. Every travel route starts from a terminal in city R and ends at another terminal in city S. The two terminals are referred to as the entrance and exit terminals of the passengers, respectively. Note that the entrance and exit terminals should not be confused with the origin and destination points, which are the locations in the cities where the passengers start and end their trip. One can also observe both competition and cooperation are represented in this model, as these are two essential relationships among transportation carriers in real markets. Competition between carriers is apparent on most travel routes, where a passenger who travels on one carrier will not take another. The two exceptions are travel routes 6 and 7, which represent complementary routes. Passengers taking route 6 travel by HSR and then connect to CR after reaching city S , and those who take route 7 connect to city R by CR and then travel by HSR.

2.2 Pricing Model

In principal, carriers are allowed to set their own prices. However, governments often impose regulations with different degrees of strictness. Reflecting this reality, we employee a rigid cost structure in this pricing model, where, for all the carriers, passengers are charged a unit distance fare proportional to the mileage traveled in that mode. We also consider the case that the unit distance fare charged by each carrier is subject to governmental regulations that specify a ceiling (maximum) and floor (minimum) price. Within this range, every carrier sets its own unit distance fare in order to gain a competitive advantage.

2.3 Passengers' Choice Behavior Model

In our model, passengers choose among the available routes to travel from city *R* to city *S*. They make their choice according to (a) the decision rule, (b) the attributes of the individual, and (c) the attributes of the available alternatives (Ben-Akiva and Lerman, 1985). The decision rule employed in this choice behavior model is a simple one based on the utility maximization hypothesis (Bhat, 1995): an individual selects the available alternative with the least generalized travel cost. We also assume that all passengers gain non-negative consumer surplus while traveling, which is reasonable under the price ceiling assumption. Under this assumption, every passenger can always find a route whose price is within their acceptable range.

Passengers' choice behavior is often affected by spatial aspects. Some important factors are the spatial distribution of the passengers' origin and destination points in the two cities, and the physical location of the transportation terminals. For example, a bus terminal that is close to passengers' origin or destination points helps the company gain a competitive advantage, and the remote location of an HSR terminal can be compensated for by well-located auxiliary CR terminals. To capture these spatial aspects, we divide the two cities into grids, and the origin and destination points of the passengers are treated as if they concentrated at the centers of the cells they belong to.

The trips of passengers who travel from city *R* to city *S* consist of three segments. They access the transportation system by going from their origin points in city *R* to the entrance terminals of their choice, travel to city *S* via the chosen travel routes, and finally go to their destination points from their exit terminals of the transportation system.

Table 1 Definitions of parameters, sets and variables.

Parameter and set	Definition
n	Number of possible routes.
d	Number of passengers.
y	Number of airlines.
z	Number of bus companies.
A	The set of airlines $\left\{a_1,\ldots,a_y\right\}$.
B	The set of bus companies $\left\{b_1,\ldots,b_z\right\}$.
R	The set of railroads $\left\{HSR, CR\right\}$.
M	The set of all carriers $\left\{A,B,R\right\}$.
N	The set of all possible routes $\left\{1,\ldots,n\right\}$.
D	The set of all passengers $\left\{1,\ldots,d\right\}$.
$\left(Pu_i, Pl_i\right)$	The upper and lower bound of the unit distance fare for carrier i, $i \in M$.
C_i	Operating cost per passenger-kilometer of carrier i, $i \in M$.
T_i^j	The travel distance of carrier i on route j, $j \in N, i \in M$.
TC_i^j	The travel time cost of carrier i on route j, $j \in N, i \in M$.
TC_{tra}^j	The transfer time cost on route j, $j \in N$.
$GTCO_k^j$	The generalized cost for a passenger to access the intercity transport network from his or her origin point, $j \in N$, $k \in D$.
$GTCD_k^j$	The generalized cost for a passenger to access his or her destination point from the intercity transport network, $j \in N$, $k \in D$.
Variable	**Definition**
p_i	Unit distance fare of carrier i, $i \in M$.
gtc_k^j	Generalized travel cost of passenger k for route j, $j \in N$, $k \in D$.
q^j	The ridership of route j, $j \in N$.
π_i	The profit of carrier i, $i \in M$.

The passengers pay a cost for each of the three segments of their trips. Consider a passenger *k* who travels from city *R* to city *S*, and refer to Table 1 for the definition of parameters and variables, and Figure 1 for the system model. The total generalized travel cost gtc_k^j that passenger *k* realizes if they choose to travel along route *j* is the sum of the cost to access the transportation system, ticket price, travel time cost, transfer time cost (if applicable), and the cost to egress from the transportation system, which can be expressed as Equation (1).

$$gtc_k^j = \left(\sum_{i \in M} p_i \times T_i^j + \sum_{i \in M} TC_i^j + TC_{tra}^j \right) + \left(GTCO_k^j + GTCD_k^j \right) \quad \forall k \in D, \quad j \in N . \tag{1}$$

The two pairs of parentheses on the right-hand side of Equation (1) are the system-related cost and passenger-related cost of passenger *k*, respectively. System-related cost depends solely on the travel route, which includes the ticket price $\sum_{i \in M} p_i \times T_i^j$, the in-vehicle travel time cost $\sum_{i \in M} TC_i^j$, and the transfer time cost TC_{tra}^j. The second pair of parentheses consists of the passenger-related cost, including the generalized access cost $GTCO_k^j$ and the generalized egress cost $GTCD_k^j$. These two items reflect the locations of the individual passenger's origin/destination points, which in turn determine the travel time spent to access/egress the travel route. Here we define the generalized access cost $GTCO_k^j$ as the time that passenger *k* spends to travel from her origin point to the entrance terminal of travel route *j*, multiplied by their value of time. The generalized egress cost $GTCD_k^j$ is defined similarly. When desired, the passenger-related cost can also include individual passenger's preference for travel routes as an additional cost item. The more a passenger prefers to take a travel route, the lower this corresponding cost becomes. As stated earlier, passengers always choose the least generalized travel cost route among available choices.

2.4 Profit Functions

The profit of a carrier is the difference between its revenue and its operating cost. The passengers pay p_i for each unit distance they travel on system *i*, and the corresponding per-unit distance cost to the carrier is C_i. Therefore, a passenger who takes travel route *j* generates $(p_i - C_i) \times T_i^j$ revenue for carrier *i*, where T_i^j is the mileage on travel route *j* that is served by the carrier. When different legs of a travel route involve different carriers, the route generates revenue for each of them. Let q^j be the ridership of route *j*, then the problem of maximizing profit for carrier *i* can be modeled as equations (2) to (4), where P_i^l and P_i^u are the floor and ceiling prices for carrier *i*.

$$\max \ \pi_i = \sum_{j \in N} \left(p_i - C_i \right) \times T_i^j \times q^j , \tag{2}$$

subject to

$$P_i^l \le p_i \le P_i^u , \tag{3}$$

$$q^j = \left| \left\{ k \;\middle|\; gtc_k^j < gtc_k^{j'} \ \forall j' \in N, k \in D, j' \ne j \right\} \right| \qquad \forall j \in N . \tag{4}$$

Here, the objective function (2) is the total revenue of carrier *i*, constraint (3) limits the floor and ceiling of its price as regulated by the government, and in equation (4) q^j equals the number of passengers who, according to their attributes, conceives travel route *j* as the one that has the least generalized cost to complete their journey. Note that q^j is a function of p_i.

3. SOLVING FOR THE PRICE EQUILIBRIUM

The price equilibrium is a situation in which each carrier sets their price in a way that maximizes their own profit in response to the anticipated actions of other carriers. The price equilibrium condition then can be expressed as:

$$\pi_i \left(p_i^*, p_{-i}^* \right) \ \ge \ \pi_i \left(p_i, p_{-i}^* \right) \qquad \forall \ i \in M . \tag{5}$$

The price equilibrium is frequently obtained by solving systems of partial differentiation equations of the profit functions of the carriers with respect to prices. In our model, the profit functions, which are described by equations (2), (3), and (4), depend on passenger counts, which in turn are determined by the distribution of value of time among the passengers, as well as the locations of their origin and destination points among the grids that divide the cities. None of these functions are assumed to be continuous. Moreover, the model contains several discrete aspects: the passengers are divided into groups of different time value, the two cities are divided into grids, and a fixed number of alternative routes connecting different terminals. As such, we propose an iterative numerical algorithm to solve for the price equilibrium and use a golden section search approach to obtain the set of price for carriers in each iteration.

To generate the initial price, the heuristic set $p_i^0 = C_i$ for all carrier *i*, where all the carriers' profits are zero. All the carriers' prices are updated one at a time in each iteration. In iteration *t*, carrier *i* optimizes its own price $\bar{p}_i^t$ while treating the prices of all the other carriers as if they are fixed at the previous level p_i^{t-1}. After finding the price $\bar{p}_i^t$, the heuristic then sets the price of carrier *i* in iteration t, p_i^t to $\frac{1}{2}(\bar{p}_i^t + p_i^{t-1})$. Instead of a simple replacement, this setting moves p_i^t from its value at the previous iteration halfway towards its new value, a design that stabilizes the heuristic's search path. An iteration ends when every carrier updated its price. The equilibrium condition implies that all carriers have a local maximum profit $\pi_i^*\left(p_i^*, p_{-i}^*\right)$ and the gradients near the equilibrium are zero. Because of the numeric nature, we define convergence as $\frac{\left|\pi(\bar{p}_i^t) - \pi(p_i^{t-1})\right|}{\left|\bar{p}_i^t - p_i^{t-1}\right|} \le \varepsilon$ with a computation precision of ε =0.001, which should be sufficient for practical purposes.

4. NUMERICAL EXAMPLE AND COMPUTATIONAL RESULTS

The numerical examples demonstrate the ability of the proposed competition model, as well as the solution method, to predict the interaction among carriers of various attributes in an intercity market. These numerical examples investigate how different combinations of transportation carriers representing different market structures interact with each other, as well as how their equilibrium states react to changes in passengers' value of time. The numerical examples are derived from the market in the north-south transportation corridor in Taiwan. The 350-km corridor connects Taipei and Kaohsiung. The travel distance, riding time, operating cost, and ceiling price of the carriers for a passenger traveling between these two cities are listed in Table 2. The solver is coded in the C programming language, and executed on personal computers equipped with 3.46GB memory space and CPUs of clock speed ranging from 3.16 to 3.42 GHz.

Table 2 Distance, riding time, operating cost, and ceiling price of the carriers in Taiwan.

Parameters	Value				
	Airline	Bus	HSR	CR	Feeder
Travel distance (Km)	350	360	345.2	363.1	20
Riding time (Min)	60	300	90	262	15
Operating cost (NT$ / passenger-kilometer)	6	1.5	5	2	2
Ceiling price (NT$ / passenger-kilometer)	18	4.5	15	6	6

(Department of Statistics, 2010)

4.1 Numerical Examples and Values of Parameters

Using the above-mentioned Taipei-Kaohsiung transportation market in Taiwan as a guide, a transportation system model is developed for the numerical examples. There are two cities *R* and *S*, each of which is represented with a square with features as shown in Figure 2. Node A in Figure 2 represents the airport, nodes B_1, B_2, and B_3 are the bus terminals of the three companies, node *J* is the HSR/CR joint terminal, and node *C* is the CR auxiliary terminal. The HSR/CR joint terminal is right in the city center, the three bus terminals are slightly away from this point, and the airport and the auxiliary terminal are located away from the city center. The dimensions of each city is measured in minutes of travel time, where each side of the square is 100 minutes long, and the travel time between any two points within the same city is measured proportionally according to the Euclidean distance between the two points. We assume that traveling within the same city takes time, but incurs no additional charges.

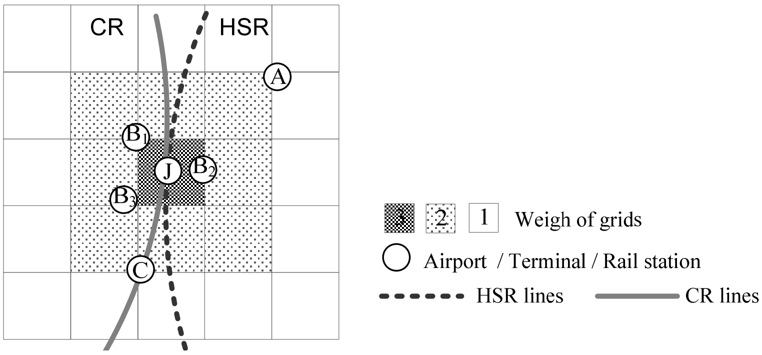

Figure 2. Weight of grids and locations of terminals in cities R and S.

There are a number of passengers traveling from city *R* to city *S*. The square representing each city is divided with a grid into 25 equal cells, also shown in Figure 2. We assume that the passengers' origin and destination points are concentrated at the center of the cells. In all the examples, the number of passengers for each cell is determined in the following fashion. First, a weight of 1, 2, or 3 is assigned to each cell in the way shown in Figure 2, where the one at the center has weight 3, those at the outermost have weight 1, and the rest have weight 2. The two squares for the two cities are treated in the same way. The number of passengers who travel from one origin cell to another destination cell is ten multiplied by the weight of the two cells. For example, the number of passengers who travel from the lower-left corner in city *R* (with weight 1) to the center grid in city *S* (with weight 3) is 10*1*3=30. In this way, the population of passengers is distributed more densely near the city center than at the outskirts. It is also easy to calculate that the total number of passengers in the system is 12,250. The total generalized travel cost for a passenger to complete their trip is thus composed of the time spent traveling from the center of their origin cell to their chosen entrance terminal multiplied by the value of their time, the cost paid to their chosen service provider (bus, airline, and so on), and the time spent traveling from the exit terminal to the center of her destination cell multiplied by the value of their time. This generalized travel cost depends on the service a passenger chooses, which is assumed to be the lowest possible one among all choices.

Each of the following examples are tested a number of times to see how changes in the value of time affect the price equilibrium. With the reference to real estimated passengers' value of time (Chiang, 2003), each run is given an average value of time, and 70% of the passengers are randomly selected to have a value of time of 0.3 above average, while the value of time of the remaining 30% is 0.7 below average. For example, if the average value of time is set at 2.0, then the value of time of 70% of the passengers is 2.3, and the value of time of the remaining 30% passengers is 1.3. The average value of time used in the examples ranges from 1.5NT$/min to 6.0NT$/min (New Taiwan Dollars per minute, roughly ranging from half to twice that of business travelers in 2001) with a step size of 0.1. The following figures display the testing results, where each data point is the average of ten repeated runs using different random number seeds (which results in the assignment of different time values to individual passengers). The results are both interesting and agree with expectations.

4.2 Sensitivity Analysis and Impact of Passengers' Time Value

This section demonstrate that the proposed competition model allows us to investigate the influence of various attributes of carriers and passengers by examining how the location of terminals, operating cost, and travel time affect the price competition result. Firstly, the competition between carriers with different terminal locations is examined. Assuming that CR, HSR, and the airline are absent, Figure 3 shows the competition between the three bus companies, which share the same attributes except the location of their terminals, as previously shown in Figure 2. The terminal of the second bus company is closest to the city center where more passengers reside, therefore gains the competitive advantage, resulting in the highest profit.

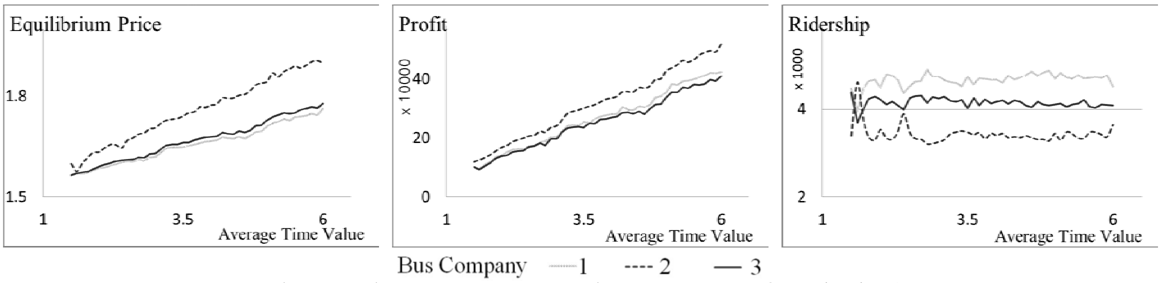

Figure 3. Competition between bus companies: equilibrium price, profit and ridership versus time value.

Next we examine the influence of the operating costs. Since the bus companies have similar attributes, they can be collectively considered one company when investigating the competition among the CR and the bus companies. Figure 4 shows the competition between the CR and the bus company with response to the change of the CR operating cost, which is presented as the ratio to the original value. For example, 0.5 on the horizontal axis corresponds to the situation where the operating cost of CR is one half of its present level. As shown in the Figure, the model predicts that when the CR operating cost increases, both the CR and the bus increase their price but profit and ridership of the bus company gradually increase due to its relatively lower cost.

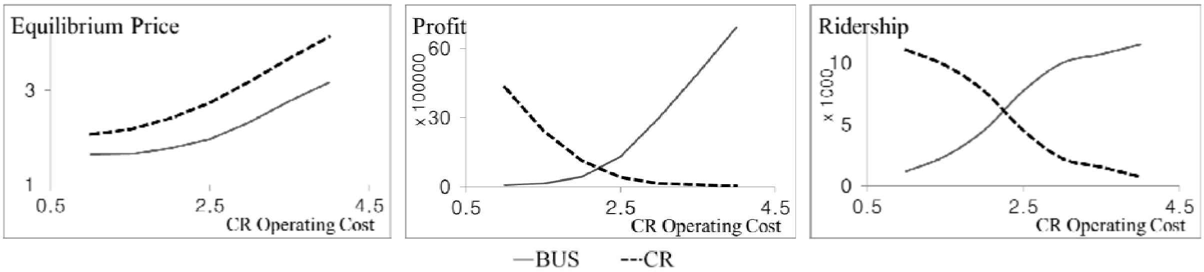

Figure 4. Competition between Bus and CR: equilibrium price, profit and ridership versus CR operating cost.

The next example demonstrates how the change in time value affects the competition of HSR against CR or airline. Figure 5 shows how the competition between the HSR and the CR respond to changes in time value. The interaction between these two rail systems is more complicated than others due to the setting that the CR feeder line offers complementary services for HSR. However, a general trend is evident as displayed in Figure 5. The localized variation in the curves is the result of discrete effects, namely, the finite-grid cities and a two-level time value population. Because passengers travel either by HSR or by CR, the ridership curves in Figure 5 are in symmetry. Passengers' time value is related to the economy, since the higher the income, the higher the passengers' time value. The HSR has a higher operating cost, but, because of its faster speed, one would expect that it becomes more attractive as the passengers' time value increases. This expectation agrees with the test results displayed in Figure 5. As the time value increases, the HSR gains a competitive advantage and raises its price. At the same time, the CR responds by decreasing its price. While the price changes smoothly, changes in profit and market share are much more dramatic as the time value increases. The ridership of feeder lines, which the passengers use to access HSR at one or both ends of their trip, also increases with time value.

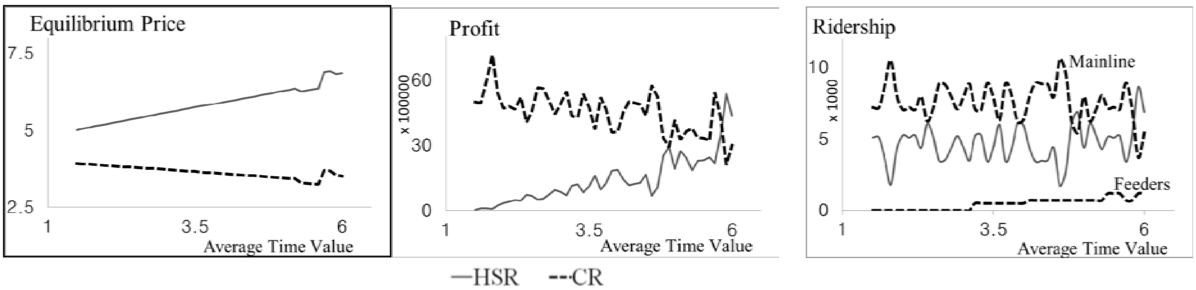

Figure 5. Competition between HSR and CR: equilibrium price, profit and ridership versus time value.

As shown in Figure 6, in the case of the market composed of only the airline and HSR, the equilibrium price of the former is higher than that of the latter, yet the profit of the airline is far lower, due to the higher operating cost of the airline and its remote terminal location, which is further away from the city center.

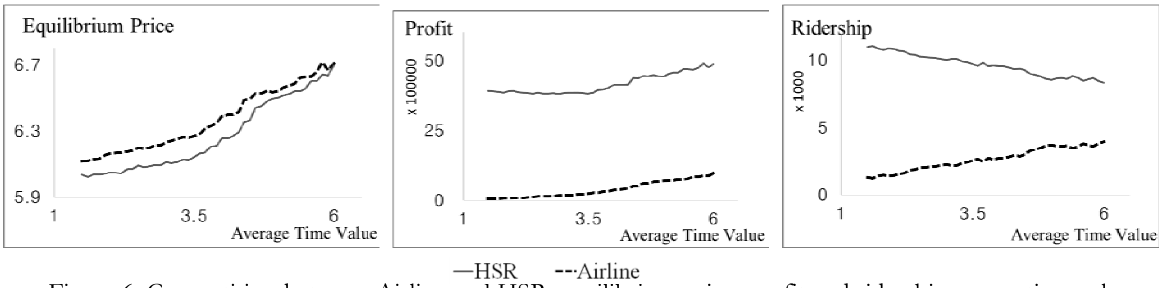

Figure 6. Competition between Airline and HSR: equilibrium price, profit and ridership versus time value.

4.3 Management Implication

The current model can provide important suggestions regarding the management of transportation systems. Many HSR lines rely on CR as feeder lines to gain access to cities (Shi and Zhou, 2013). As demonstrated in the numerical examples, one can use the model to predict how the market might response to different scenarios, which could be very helpful when planning the feeder lines. On the competition between the airline and the HSR, our model correctly predicted that ridership for the airline will drop significantly following the launch of HSR (Cheng, 2010; Jeng and Su, 2013), and that a low-price strategy will not raise the airline's profit. In the real market, all air services did retreat from the Taipei-Kaohsiung market by September 2012. The airline companies are still providing service to places out of reach of the HSR, such like off-shore islands and the east coast. This model can be used to analyze the future of this remaining market, as well as the best operation strategy for the managers.

5. CONCLUSIONS AND FUTURE WORK

This paper presents a competition model describing the price competition among intercity passenger carriers with flexibility to include the competition among carriers providing substitute and/or complementary services, which serves as a tool to investigate the important trend of public transport integration, especially for the transportation market after the launch of HSR. On the supply side, the model allows the use of combinations of multiple attributes to characterize different carriers. In addition to price, these attributes include operating cost, travel time, the existence of auxiliary terminals, and location of terminals. On the demand side, a grid-based model captures the spatial distribution of the passengers' origin and destination points in the cities. Passenger choice behavior is determined by the individual's generalized travel cost, which includes factors that depend on the carriers as well as factors that depend on the individual passenger. The carriers offer substitute and/or complement routes, compete in the market, and seek to maximize their own profits by adjusting their prices.

Numerical examples derived from the Taipei-Kaohsiung transportation market demonstrate the ability of this model. Competing carriers in the examples include an airline, three bus companies, a conventional rail system and a high-speed rail system, representing combinations of attributes like price, cost, travel time, the existence of auxiliary terminals, and the locations of terminals. Various scenarios are tested under a range of value of time levels, and the computational results are in line with expectations.

Market equilibrium studies considering service frequency and system capacity are rare in the literature, which are important and promising directions for this model to extend into. The capacity to handle complicated discrete aspects enhances its ability to model real-world markets. Finally, in future work there will be a demand for more powerful numerical solution techniques as the model incorporates more and more complicating factors.

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