ACCESS MODE COMBINATIONS FOR INTERCITY TRANSPORTATION TERMINALS IN A METROPOLITAN AREA

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Abstract: This paper analyzes the optimal inter-city travelers' access mode combinations to high speed rail (HSR) and air transport (AT) terminals with the objective of minimizing individual's generalized intercity travel cost on both line-haul and access routes. Three types of access way, that is, driving along surface streets, driving along both surface streets and expressways, and driving along surface streets and then riding a train on rail transit lines are considered. The service areas of HSR and AT in the metropolitan area and the residential sites suitable for each type of access way are analyzed and plotted to provide guidance for travelers to choose their optimal line-haul and access mode combinations. The results of the example show that the optimal access way to the AT terminal is driving automobiles via surface streets; while the optimal access way to the HSR terminal depends on the location of travelers' origins.

1. INTRODUCTION

Transportation patterns can be mainly classified into urban transportation and intercity transportation. Previous studies such as Pratt (1970), Quandt and Baumol (1966), Stopher (1969), Florian and Nguyen (1976), Leblanc and Morlok and Pierskalla (1975), Nguyen (1974) and Ruiter (1974) were focused on the topic of urban transportation and aimed at investigating urban travelers' mode and route choices on highway and local street networks in urban area. The expansion of roadway capacities can not catch up the increase of private modes owing to the stimulation of economic growth on travel demand and the encouragement of roadway system on the usage of private modes. This situation results in traffic congestion. To alleviate the intensity of traffic congestion and to restrain the increased usage of private modes, most metropolitan authorities adopt the actions and strategies to encourage public transportation. Therefore, many studies intend to explore the route choices and scheduling decisions on public transportation such as Abdulaal and Leblanc (1979), Florian and Spiess (1983), Florian and Cabrera (1994), Hickman and Bernstein (1997), etc.

On the other hand, studies about conventional rail, high speed rail (HSR) and air transport (AT) mostly emphasized on intercity transportation demand analysis. Wardman (1994) tested the elasticity of travel time, frequency and interchange convenience to examine the relationship between service quality and the demand for interurban rail travel in Great Britain. Hensher (1997) constructed a sequential procedure to estimate the market potential for HSR system serving the Sydney-Canberra corridor currently dominated by AT. Bel (1997) collected cross-sectional data on various routes to analyze the impact of changes in road travel time on the demand for rail. Milan (1993) explored the service quality and the competition condition between HSR and AT based on the physical characteristics of both networks. Nevertheless, most of studies mentioned above aim at exploring the relationship between the line-haul services of HSR and AT and the demand for them. Few studies aim at analyzing access mode and route combinations for HSR stations and AT terminals in a metropolitan area.

Intercity transportation systems such as HSR and AT are usually characterized by few terminals and simple network so as to achieve the objective of fast and mass transport. Urban configurations are transforming from monocentric to multicentric configurations in recent decades with the rise in residents' desire for living quality in suburbs and the development of transportation technology. In this situation, residential locations are scattered around major activity centers in suburbs and urban networks are thus likely to be inefficient in terms of collecting and distributing passengers to and from intercity terminals. When trip origins become dispersed in the metropolitan area, the integrated access networks of different modes are needed to accommodate the overall intercity travel demand and to improve the level of service of intercity transportation systems.

Studies by D'este (1987), Hall (1989) and Campbell (1992) applied the deterministic analytical approach to elucidate travelers' route choice behavior. Hsu and Chung (1997) formulated a new analytical model to estimate the market shares of HSR and conventional rail in a fundamental way and to analyze the competition condition between them. Hsu and Chou (1996) analyzed the market areas of HSR and AT based on the supply and demand attributes such as terminal locations, expressway locations and speeds, travelers' trip lengths, departure times, and origin and destination locations. However, studies mentioned above merely considered surface streets and expressways as the feeder network of intercity transportation systems and neglected the existence of rail transit networks prevailing in major metropolitans in European, Asia and Northeastern United States.

Generally speaking, surface streets, expressways and rail transit networks are commonly deployed in a metropolitan area and can be served as access networks. Each type of access mode and network combination provides different service characteristics suitable for a variety of market areas. Rail transit networks are characterized high volume and high speed. Consequently, it is efficient to design rail transit networks as major access networks and design bus networks as an auxiliary system to rail transit networks. Both networks can then be integrated as a combinatorial access network for intercity transportation systems such as HSR and AT.

This study from the viewpoint of planning assumes surface streets as dense networks and utilizes a two-dimensional coordinate system to represent the study area. The purpose of this paper is to analyze the optimal intercity travelers' access mode combinations to an intercity transportation terminal such as AT and HSR with the objective of minimizing individual's generalized intercity travel cost on both line-haul and access routes. Travelers who travel between two cities connected by AT and HSR may confront three questions. Which intercity transportation mode to choose? How to access AT terminal or HSR station from home? How to reach the destination from the AT terminal or HSR station in the destination city? This research formulated the generalized intercity travel costs for travelers traveling by each of all different line-haul and access mode combination alternatives from any residential sites in the origin city to a specific destination in the destination city. Then, the optimal line-haul and access mode combination from any residential site in the origin city to the specific destination can be determined by choosing the optimal alternative with the least generalized intercity travel cost. Finally, an example of Taipei-Kaoshiung transportation corridor in Taiwan area is used to illustrate the application of the model. The optimal residential sites suitable for each of all different line-haul and access mode combinations are shown, and equi-access time contours and equi-access cost contours from the HSR station and the AT terminal are also plotted. The results not only show the service areas for intercity mode and access way, but also provide useful pre-trip information for travelers to choose the optimal line-haul and access mode combination from their residential sites to the HSR station and the AT terminal in the origin city. These results are also beneficial for rail transit operators on performing transfer facility designs, and on scheduling and routing arrangements so as to serve intercity travelers dispersed in any residential site of a metropolitan area. Moreover, planners may apply the results of equi-access time contours and equi-access cost contours to evaluate the access time and access cost distributions.

2. GENERALIZED INTERCITY TRAVEL COSTS

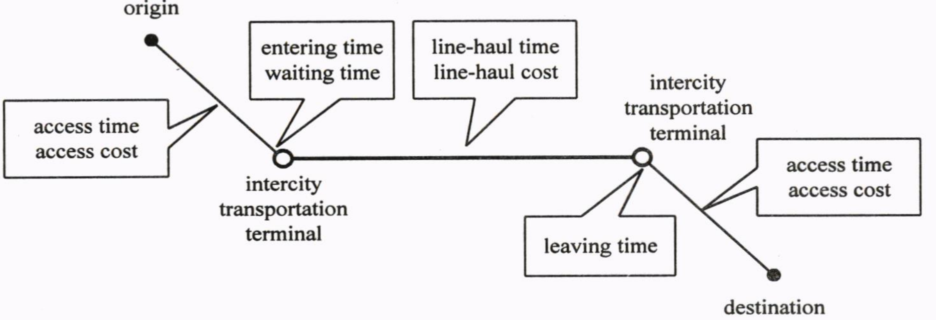

Figure 1. Components of the Generalized Intercity Travel Cost

Factors affecting travelers' mode choices include travel time, waiting time, walking time, out-of-packet cost, individual's preference, car ownership, network constraints, etc. Factors such as travel time, waiting time, walking time and out-of-pocket costs are quantitative. On the contrary, factors such as individual's preference, car ownership and network constraints are qualitative. This study from the planning viewpoint simplifies the travelers' mode choice behavior and merely considers the influence of quantitative factors on the mode choice decision. The intercity travel time consists of three components, that is, traveling by access modes from an origin to the intercity transportation terminal in the origin city, riding by line-haul modes to the intercity transportation terminal in the destination city, and then traveling by egress modes to the destination. This study considers three types of access way in the origin and destination cities, respectively, with the objective of minimizing individual's generalized intercity travel cost in line-haul and access routes. That is, traveling along surface streets, traveling along both surface streets and expressways, and traveling along surface streets and then riding a train on rail transit lines are considered in the access mode and route choice model in this study.

Owing to the alternate usage of access modes and line-haul modes, the generalized intercity travel costs by intercity travelers include the travel time and travel cost both in line-haul and access routes, and the entering, waiting and leaving time at intercity transportation terminals both in the origin and destination cities. Entering and leaving time in this study stand for the average walking time between the access mode terminal (and the parking lot) and the intercity transportation terminal. Figure 1 illustrates the components of the generalized intercity travel cost of intercity travelers.

Let T denote the set of intercity transportation modes considered in this study, Ln_t represent the length of the corridor by intercity mode t, Sd_t stand for the average travel speed of intercity mode t, Fc_t denote the fare per unit distance by intercity mode t. Then, line-haul travel time, LT_t, and line-haul travel cost, LC_t, by intercity mode t can be formulated as equations (1) and (2), respectively.

$$LT_t = Ln_t / Sd_t \quad \forall\, t \in T \tag{1}$$

$$LC_t = Ln_t \cdot Fc_t \quad \forall\, t \in T \tag{2}$$

Let M and M' represent the set of access ways in the origin city and the set of egress ways in the destination city, respectively. Let $ST^O_{m,t}$ and $SC^O_{m,t}$ represent, respectively, the access time and access cost by access way m from the origin to the terminal of intercity mode t in the origin city. Let $IT_{m,t}$ and $OT_{m,t}$ represent the entering and leaving time at the terminal of intercity mode t via access way m. Let $ST^D_{m',t}$ and $SC^D_{m',t}$ represent, respectively, the egress time and egress cost of egress way m' from the terminal of intercity mode t in the destination city to the destination. In addition, let WT_t represent the average waiting time at the terminal of intercity mode t and α denote the value of time for intercity travelers. Then, the generalized travel cost $GC^{m,m'}_t$ for a traveler using access way m in the origin city, intercity mode t, and egress way m' in the destination city can be formulated as equation (3).

$$\begin{aligned} GC^{m,m'}_t &= (SC^O_{m,t} + LC_t + SC^D_{m',t}) + \alpha(ST^O_{m,t} + IT_{m,t} + WT_t + LT_t + OT_{m',t} + ST^D_{m',t}) \\ &\qquad \forall\, m \in M,\ m' \in M',\ t \in T \end{aligned} \tag{3}$$

This study based on utility maximization theory assumes intercity travelers will choose the optimal combination of access way m in the origin city, intercity mode t, and egress way m' in the destination city from all of combinations available to minimize their generalized intercity travel costs. The generalized intercity travel cost for the optimal combination can be formulated as $GC^{*m,m'}_t = \min\limits_{(m,t,m')} \{GC^{m,m'}_t,\ \forall\, m \in M,\ m' \in M',\ t \in T\}$.

3. ACCESS MODE AND ROUTE CHOICE

This study applies two-dimensional coordinate systems to represent the node and link position of networks in the origin and destination cities with a HSR station and an AT terminal. Formulations for three types of access way in the origin city are discussed sequentially so as to illuminate how the model are constructed. First, assume access way m=1 denotes intercity travelers merely use automobiles to intercity transportation terminals via surface streets. Let $X=(x_1,x_2)$ represent the position of the origin in the origin city and $O^t=(o_1^t,o_2^t)$ represent the terminal position of intercity mode t in the origin city. Then, travel distance $D(X,O^t)$ from origin $X=(x_1,x_2)$ to intercity transportation terminal $O^t=(o_1^t,o_2^t)$ via surface streets by automobiles can be formulated as equation (4).

$$D(X,O^t)=|x_1-o_1^t|+|x_2-o_2^t| \quad \forall\, t\in T \tag{4}$$

Moreover, let v_L represent the average travel speed on surface streets, f_L represent the fuel cost per unit distance on surface streets, pt_t and pc_t represent the average parking time and parking cost at the terminal of intercity mode t, respectively. Then, access time $ST_{1,t}^O$ and access cost $SC_{1,t}^O$ from origin X to intercity transportation terminal O^t via surface streets can be formulated as equations (5) and (6).

$$ST_{1,t}^O = D(X,O^t)/v_L + pt_t \quad \forall\, t\in T \tag{5}$$

$$SC_{1,t}^O = D(X,O^t)\cdot f_L + pc_t \quad \forall\, t\in T \tag{6}$$

The second type of access way represents the intercity travelers driving automobiles on surface streets and then riding rail transit trains to intercity transportation terminals. An intercity traveler firstly drives an automobile from an origin to the nearest rail transit station via surface streets, then transfers to rail transit and rides the train on the shortest transit route until he reaches the transit station nearest to the intercity transportation terminal. This study assumes intercity travelers may walk from the nearest transit station to the intercity transportation terminal in the origin city. Because travel demand of some O-D pairs can not be completely satisfied by rail transit networks with several routes, transshipments of passengers on rail transit routes become quite common. Thus, we consider two situations in this type of access way, that is, passengers with transshipment behavior and without transshipment behavior.

Let access way m=2 denote intercity travelers travel to the intercity transportation terminal via driving automobiles on surface streets and then transferring to a rail transit route without transshipment on rail transit lines. Assume A^t represent the set of rail transit routes directly connected to the terminal of intercity mode t. Further, assume $S_i^{1,t}(i\in A^t)=(y_{1i}^{1,t},y_{2i}^{1,t})$ represent the position of the rail transit station nearest to origin X in rail transit route i which is directly connected to the terminal of intercity mode t. Assume $S_i^{2,t}(i\in A^t)=(y_{1i}^{2,t},y_{2i}^{2,t})$ represent the position of the rail transit station nearest to the terminal of intercity mode t in rail transit route i which is directly connected to that terminal. Then, the distance $D(X,S_i^{1,t})$ from origin X to rail transit station $S_i^{1,t}=(y_{1i}^{1,t},y_{2i}^{1,t})$ via surface streets and the walking distance $D(S_i^{2,t},O^t)$ from rail transit station $S_i^{2,t}=(y_{1i}^{2,t},y_{2i}^{2,t})$ to intercity transportation terminal O^t can be formulated as equations (7) and (8).

$$D(X,S_i^{1,t})=|x_1-y_{1i}^{1,t}|+|x_2-y_{2i}^{1,t}| \quad \forall\, t\in T,\ i\in A^t \tag{7}$$

$$D(S_i^{2,t},O^t)=|o_1^t-y_{1j}^{2,t}|+|o_2^t-y_{2j}^{2,t}| \quad \forall\, t\in T,\ i\in A^t \tag{8}$$

Let $L(S_i^{1,t},S_i^{2,t})(i\in A^t)$ denote the length between station $S_i^{1,t}$ and station $S_i^{2,t}$ on rail transit route i directly connected to the terminal of intercity mode t. Let $v_{Ti}(i\in A^t)$ denote the average running speed of trains on rail transit route i. Let $F(S_i^{1,t},S_i^{2,t})(i\in A^t)$ and $W(S_i^{1,t},S_i^{2,t})\,(i\in A^t)$ denote, respectively, the fare and the total stop delay between station $S_i^{1,t}$ and station $S_i^{2,t}$ on rail transit route i directly connected to the terminal of intercity mode t. In addition, let $c_{S_i^{1,t}}(i\in A^t)$ and $g_{S_i^{1,t}}(i\in A^t)$ represent, respectively, the expected parking cost and the expected parking time around station $S_i^{1,t}$. Let $h_i(i\in A^t)$ stand for the headway of rail transit route i. Let β stand for the average walking speed from station $S_i^{2,t}(i\in A^t)$ to the terminal of intercity mode t. Then, access time $st_{2,t}^i$ and access cost $sc_{2,t}^i$ of access way m=2 can be formulated as equations (9) and (10), respectively.

$$\begin{aligned} st_{2,t}^i = {} & D(X,S_i^{1,t})/v_L+g_{S_i^{1,t}}+h_i/2+W(S_i^{1,t},S_i^{2,t})+L(S_i^{1,t},S_i^{2,t})/v_{Ti}+ \\ & D(S_i^{2,t},O^t)/\beta \quad \forall\, t\in T,\ i\in A^t \end{aligned} \tag{9}$$

$$sc_{2,t}^i = D(X,S_i^{1,t})\cdot f_L+c_{S_i^{1,t}}+F(S_i^{1,t},S_i^{2,t}) \quad \forall\, t\in T,\ i\in A^t \tag{10}$$

We assume that intercity travelers by this access way will select the optimal rail transit route to minimize weighted average of access time and access cost based on their value of time α. That is, the chosen rail transit route i^* will cause the minimal generalized access cost $\min\limits_i\,(sc_{2,t}^i+\alpha\cdot st_{2,t}^i)$. The minimal access cost $SC_{2,t}^O$ and the minimal access time $ST_{2,t}^O$ are denoted by $sc_{2,t}^{i^*}$ and $st_{2,t}^{i^*}$, respectively.

Let access way m=3 represent intercity travelers travel to intercity transportation terminals via driving automobiles on surface streets and then transferring to rail transit routes with transshipment on rail transit lines. Let B^t represent the set of rail transit routes that can not directly reach the terminal of intercity mode t. Let $S_k^{3,t}(k\in B^t)=(y_{1k}^{3,t},y_{2k}^{3,t})$ represent the position of transferring station on rail transit route k that can not directly reach the terminal of intercity mode t. This study assumes that the passengers' choices on rail transit routes with transshipment requirements are also based on the least cost principle. In other words, passengers will select a combination of routes to minimize their generalized travel costs on rail transit networks. Let $r_k^t(k\in B^t)$ denote the rail transit route directly connected to the intercity transportation terminal to which passengers should transfer from rail transit route k. Let $L(S_k^{1,t}, S_k^{3,t})(k \in B^t)$ and $F(S_k^{1,t}, S_k^{3,t})$ $(k \in B^t)$ denote, respectively, the length and the fare between station $S_k^{1,t}$ and station $S_k^{3,t}$ on rail transit route k. Let $L(S_k^{3,t}, S_{r_k^t}^{2,t})(k \in B^t; r_k^t \in A^t)$ and $F(S_k^{3,t}, S_{r_k^t}^{2,t})$ $(k \in B^t; r_k^t \in A^t)$ denote, respectively, the length and the fare between transferring station $S_k^{3,t}$ on rail transit route k and the station $S_{r_k^t}^{2,t}$ nearest to the terminal of intercity mode t on rail transit route r_k^t. Let $W(S_k^{1,t}, S_k^{3,t})(k \in B^t)$ denote the total stop delay between station $S_k^{1,t}$ and station $S_k^{3,t}$. Let $W(S_k^{3,t}, S_{r_k^t}^{2,t})(k \in B^t; r_k^t \in A^t)$ denote the total stop delay between station $S_k^{3,t}$ and station $S_{r_k^t}^{2,t}$. Thus, the access time $st_{3,t}^k$ and access cost $sc_{3,t}^k$ by using automobiles, transferring to rail transit route k and further transshipping to rail transit route r_k^t can be formulated as equations (11) and (12).

$$\begin{aligned} st_{3,t}^k = {} & D(X, S_k^{1,t})/v_L + g_{S_k^{1,t}} + h_k/2 + W(S_k^{1,t}, S_k^{3,t}) + L(S_k^{1,t}, S_k^{3,t})/v_{Tk} + \\ & h_{r_k^t}/2 + W(S_k^{3,t}, S_{r_k^t}^{2,t}) + L(S_k^{3,t}, S_{r_k^t}^{2,t})/v_{T_{r_k^t}} + \beta \cdot D(S_k^{2,t}, O^t) \\ & \forall\, t \in T,\ k \in B^t \text{ and } r_k^t \in A^t \end{aligned} \tag{11}$$

$$\begin{aligned} sc_{3,t}^k = {} & D(X, S_k^{1,t}) \cdot f_L + c_{S_k^{1,t}} + F(S_k^{1,t}, S_{r_k^t}^{3,t}) + F(S_{r_k^t}^{3,t}, S_k^{2,t}) \\ & \forall\, t \in T,\ k \in B^t \text{ and } r_k^t \in A^t \end{aligned} \tag{12}$$

The minimal generalized access cost by access way m=3 is specified as $\min\limits_{k, r_k^t} (sc_{3,t}^k + \alpha \cdot st_{3,t}^k)$ which also determines the optimal combination of rail transit routes, k^* and $r_{k^*}^t$, to travel to the terminal of intercity mode t. The minimal access cost $SC_{3,t}^O$ and the minimal access time $ST_{3,t}^O$ are denoted by $sc_{3,t}^{k^*}$ and $st_{3,t}^{k^*}$, respectively.

The third type of access way represents intercity travelers using automobiles via both surface streets and expressways to travel to intercity transportation terminals. This access alternative is specified by access way m=4 in this study. Moreover, let N^t denote the set of expressways that pass through the surrounding area of the terminal of intercity mode t. Let $R_l^{1,t}(l \in N^t) = (e_{1l}^{1,t}, e_{2l}^{1,t})$ represent the position of the interchange on expressway l nearest to the origin X which passes through the surrounding area of the terminal of intercity mode t. By the same way, let $R_l^{2,t}(l \in N^t) = (e_{1l}^{2,t}, e_{2l}^{2,t})$ represent the position of the interchange on expressway l nearest to the terminal of intercity mode t. Therefore, the travel distance $D(X, R_l^{1,t})$ from origin X to interchange $R_l^{1,t} = (e_{1l}^{1,t}, e_{2l}^{1,t})$ and the travel distance $D(R_l^{2,t}, O^t)$ from interchange $R_l^{2,t} = (e_{1l}^{2,t}, e_{2l}^{2,t})$ to intercity transportation terminal O^t can be expressed as equations (13) and (14), respectively.

$$D(X, R_l^{1,t}) = |x_1 - e_{1l}^{1,t}| + |x_2 - e_{2l}^{1,t}| \quad \forall\, t \in T,\ l \in N^t \tag{13}$$

$$D(R_l^{2,t}, O^t) = |o_1^t - e_{1l}^{2,t}| + |o_2^t - e_{2l}^{2,t}| \quad \forall\, t \in T,\ l \in N^t \tag{14}$$

Let $K(R_l^{1,t}, R_l^{2,t})$ denote the length from interchange $R_l^{1,t}$ to interchange $R_l^{2,t}$ on expressway l. Let $v_{H_l^t}$ denote the average travel speed of automobiles on expressway l to the terminal of intercity mode t. Let f_H denote the fuel cost per unit distance on expressways. Then, the access time $st_{4,t}^l$ and access cost $sc_{4,t}^l$ via surface streets and expressways can be formulated as equations (15) and (16), respectively.

$$st_{4,t}^l = D(X, R_l^{1,t}) / v_L + K(R_l^{1,t}, R_l^{2,t}) / v_{H_l^t} + D(R_l^{2,t}, O^t) / v_L + pt_t \quad \forall t \in T,\ l \in N^t \tag{15}$$

$$sc_{4,t}^l = D(X, R_l^{1,t}) \cdot f_L + K(R_l^{1,t}, R_l^{2,t}) \cdot f_H + D(R_l^{2,t}, O^t) \cdot f_L + pc_t \quad \forall t \in T,\ l \in N^t \tag{16}$$

According to the principle of minimizing generalized access costs, the optimal access route l^* on expressway networks is the route yielding the least generalized access cost, e.g. $\min_l\ (sc_{4,t}^l + \alpha \cdot st_{4,t}^l)$. The minimal access cost $SC_{4,t}^O$ and minimal access time $ST_{4,t}^O$ by access way m=4 are denoted by $sc_{4,t}^{l^*}$ and $st_{4,t}^{l^*}$, respectively.

The above descriptions formulate access times and access costs for travelers from any residential site to intercity transportation terminals by each of four access ways in the origin city. On surface streets and expressways, we assume travelers merely use automobiles. However, it is very common to use buses and taxies as access modes in an urban area as well. When travelers travel to intercity terminals by taxis instead of automobiles, several modifications should be made on the formulation of access costs and access times for three types of access ways mentioned above. Firstly, the fuel cost per unit distance of automobiles should be replaced by the fare per unit distance of taxies in equations (6), (10), (12) and (16). Secondly, the parking cost and the parking time at rail transit stations also should be removed from equations (9), (10), (11) and (12). Finally, the parking cost and the parking time at intercity transportation terminals ought to be removed from equations (5), (6), (15) and (16). On the other hand, when travelers travel to intercity transportation terminal via buses instead of automobiles, the pattern of bus routes connected to intercity transportation terminals and rail transit stations should be further considered to analyze travelers' route choices and transferring behavior between buses and rail transits. Formulations of access times and access costs from intercity transportation terminals to the destination in the destination city are similar to those in the origin city.

4. EXAMPLE

Taipei-Kaohsiung transportation corridors for HSR and AT in Taiwan are adopted to examine the application of the models proposed in this study and to illustrate the service areas of these two intercity transportation systems in Taipei metropolitan area. This study analyzes the access mode and route choice behavior for travelers living in Taipei metropolitan area and traveling to Kaohsiung metropolitan area. Realistic and planned data on networks of rail transit system and expressways in Taipei and Kaohsiung metropolitan areas include lengths of rail transit lines and expressways, positions of rail transit stations and expressway interchanges, etc. Rail transit lines considered in this example include Tamshui line, Panchiao line, Tucheng line, Chungho line, Hsintien line, Mucha line, Nankang line and Nehu line in Taipei metropolitan area, and Orange line and Red line in Kaohsiung metropolitan area. Moreover, expressways explored in this example include Hwanher Expressway, Shoeyuan Expressway, Shinsheng Expressway, Jangwo Expressway, and Civil Boulevard in Taipei metropolitan area and the planned expressway system in Kaohsiung metropolitan area (Kaohsiung Municipal Government, 1998). Study areas for Taipei and Kaohsiung metropolitan are shown in Figure 2 and Figure 3, respectively.

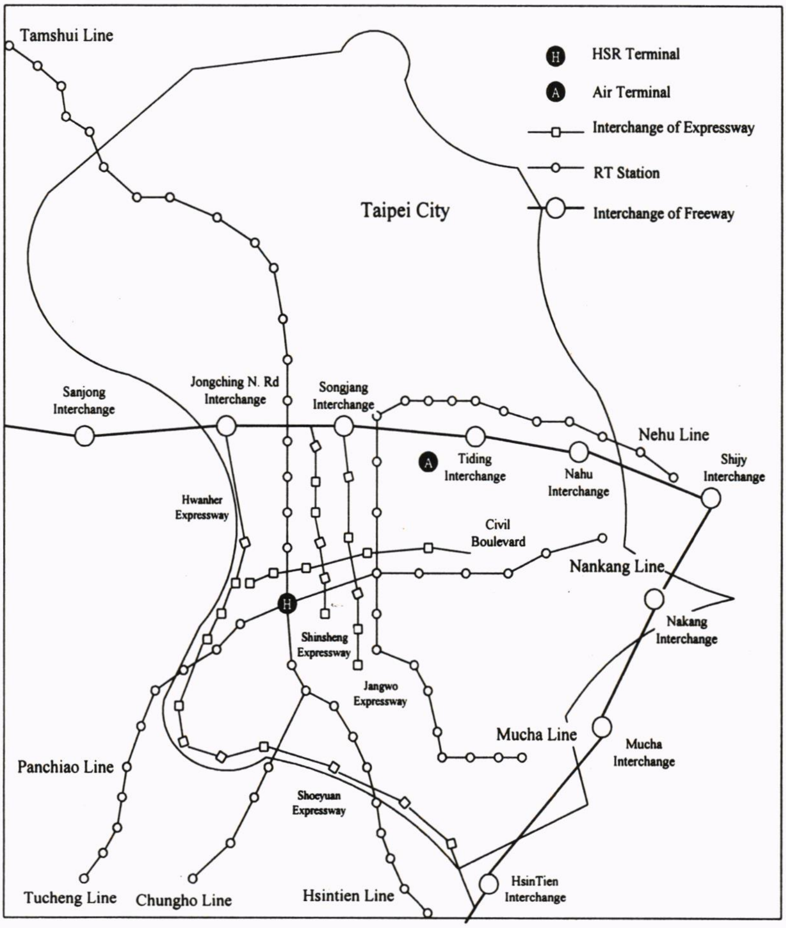

Figure 2. Study Area in the Taipei Metropolitan Area

With regard to parameters used in formulas of access times and access costs, this study assumes v_L, f_L and f_H equal to 25km/hr, NT$5.8/km and NT$5.8/km, respectively. Travel speeds on expressways bound for the HSR station and the AT terminal are assumed to be 40km/hr and 42km/hr, respectively. Average parking times at the HSR station and the AT terminal are postulated to be 30 minutes and 15 minutes. Parameter β is assumed to be 2km/hr. For the rail transit network, average running speeds of Tamshui line and Mucha line are equal to 35km/hr and 33km/hr. Average running speeds of other lines are postulated to be 33km/hr. Moreover, this study assumes the average stop delay at each rail transit station to be 15 seconds and determines fares and rail transit lengths from each rail transit station to the HSR station and the AT terminal by referring the results of Lan (1990). Data about ticket prices and travel times by HSR and AT are collected from periodically official reports. These reports announce that the ticket price and the travel time between Taipei and Kaohsiung by AT are NT$1400 and 50 minutes, while the fare and the travel time between Taipei and Kaohsiung by HSR are estimated to be NT$1000 and 90 minutes.

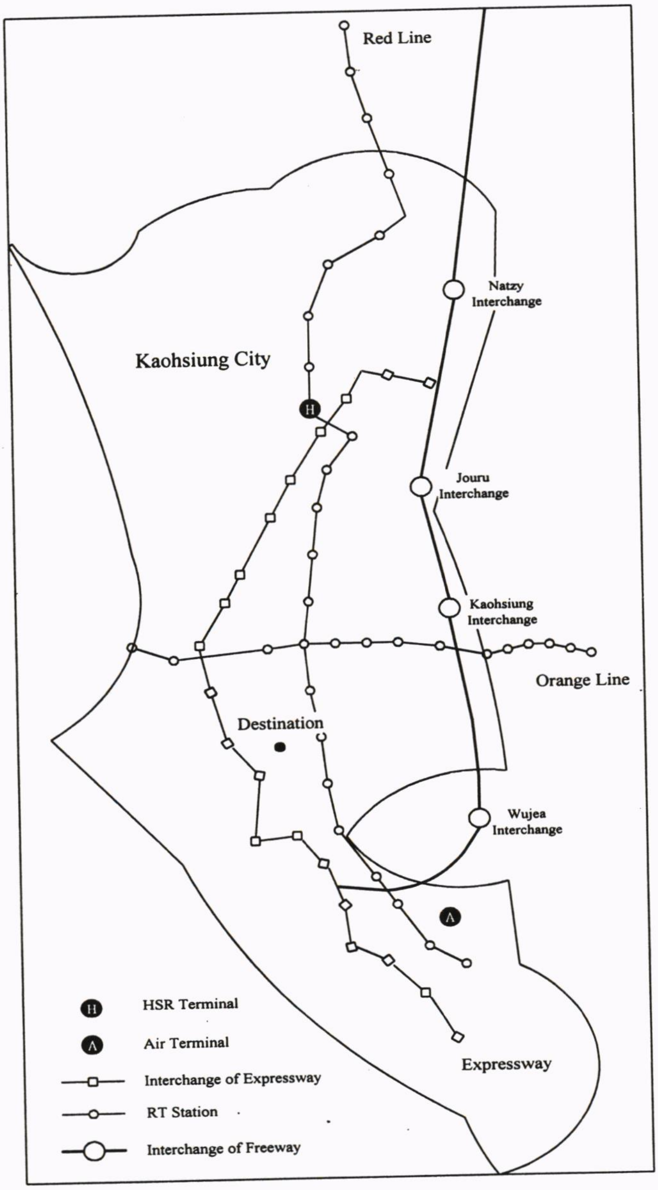

Figure 3. Study Area in the Kaohsiung Metropolitan Area

A selected destination in Kaohsiung metropolitan area shown in Figure 3 is used to illustrate the application of the model. The results of applying the access mode and route choice model based on the parameters described above are the optimal intercity travelers' choices of access ways at each residential location in Taipei metropolitan area. The service areas for each access way are illustrated in Figure 4. These results are further incorporated into the formulation of intercity travelers' generalized intercity travel cost expressed in equation (3) so as to determine the optimal choice of intercity mode for travelers traveling from each residential site in Taipei metropolitan area to the specific destination in Kaohsiung metropolitan area. The service areas of AT and HSR are shown in Figure 5.

The results shown in Figure 4 indicate that intercity travelers living in the area served by AT can not directly travle to the AT terminal via rail transit lines. Therefore, the optimal access way in this area is applying automobiles via surface streets. On the other hand, intercity travelers living near the HSR terminal and living in the area served by HSR will tend to use automobiles to the HSR station via surface streets with the closeness to the HSR station. The merger of traffic flows from expressways and surface streets occurs at interchanges for the sake of access control of expressways. Accordingly, intercity travelers living in vicinage to expressways tend to use automobiles to the HSR station via surface streets and expressways. Intercity travelers living in outlying areas are more likely to choose automobiles and then transfer to rail transit to reach the HSR station.

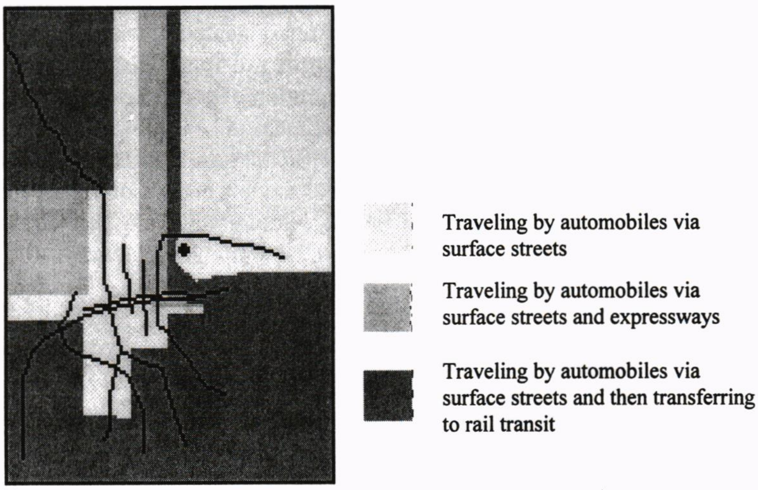

Figure 4. Service Areas of Access Ways in the Taipei Metropolitan Area

The results shown in Figure 5 possess two implications interpreted as follows. Firstly, intercity travelers living in the coverage of rail transit networks and expressway networks tend to reach the closer and more accessible HSR station in an attempt to minimize their generalized intercity travel costs. Relevant costs include the access time and access cost by access ways, waiting time, entering time and leaving time at the HSR station, and line-haul time and line-haul cost of HSR between Taipei and Kaohsiung metropolitans. Secondly, AT terminals are usually situated at the outlying area with low residential density due to location constraints and the requirement of ample land area. The service area of AT in Taipei metropolitan area is beyond the coverage of rial transit networks and expressway networks. Consequently, the service area of AT is far less than that of HSR due to lower accessibility.

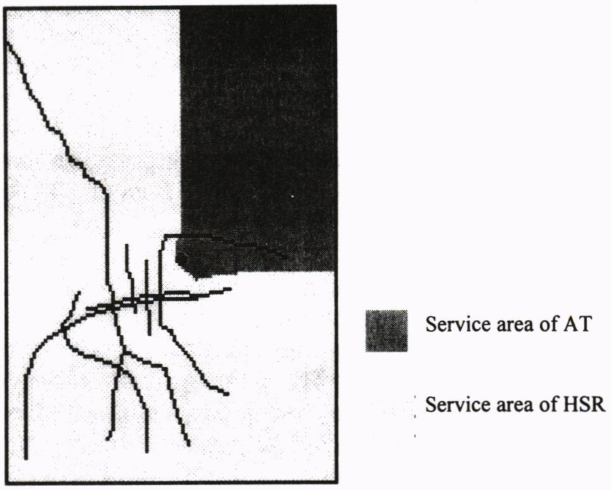

Figure 5. Service Areas of AT and HSR in the Taipei Metropolitan Area

Figure 6 and Figure 7 illustrate, respectively, equi-access time contours and equi-access cost contours from the HSR station and the AT terminal in Taipei metropolitan area. The results show that there is a complementary relationship between rail transit networks and expressway networks. The radiated pattern of rail transit networks with a center at the HSR station can alleviate the spatial concentration of traffic flows bound to the city center and provide efficient access ways to the HSR station. The equi-access time contours and equi-access cost contours centered at the HSR station are shown dispersed rhomboidly. On the contrary, the AT terminal is located at the left bottom of the area served by AT and the optimal access way in this area is using automobiles via surface streets. Thus, the equi-access time contours and equi-access cost contours centered at the HSR station are shown dispersed obliquely.

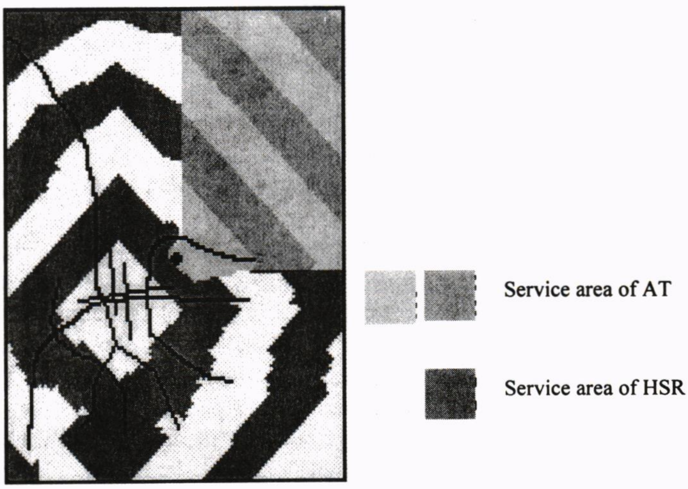

Figure 6. Equi-access Time Contours Centered at the HSR Station and the AT Terminal

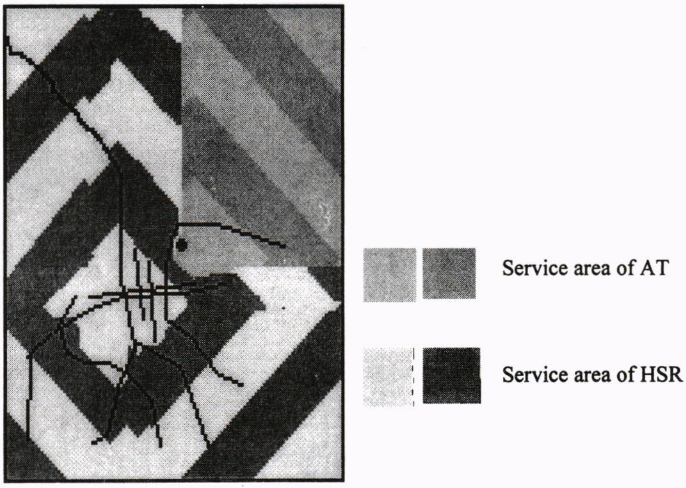

Figure 7. Equi-access Cost Contours Centered at the HSR Station and the AT Terminal

Figure 8 illustrates the service areas for each of all different rail transit lines. The result shows that the service area of Hsintien Line is larger than those of other rail transit lines and implies that Hsintien Line is more competitive than Chungho Line and Mucha Line. The service areas of all rail transit lines are shaped into quadrangle form approximately. The position and shape of service boundary between two rail transit lines depend on the configuration of rail transit networks and the locations of rail transit stations.

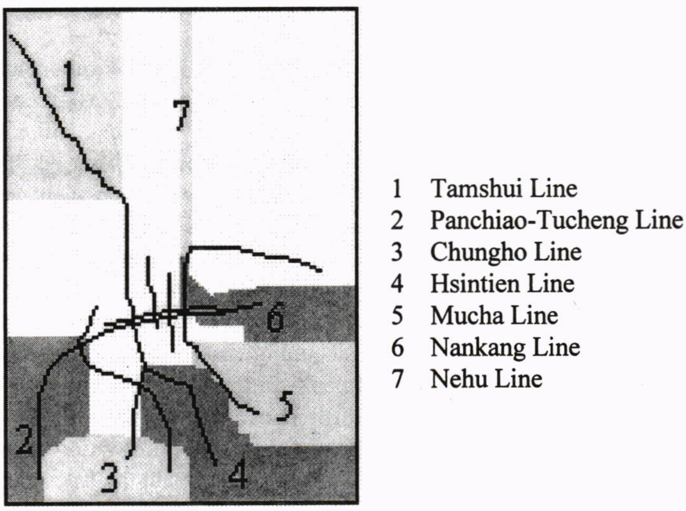

Figure 8. The Service Areas of Transit Lines in Taipei Metropolitan Area

Figure 9 shows the service areas for each of all rail transit stations along Tamshui Line, Panchiao-Tucheng Line and Hsintien Line. Based on the assumption of dense networks in surface streets, Figure 9 shows that the service areas of each rail transit station along these three rail transit lines are distributed stripily. These results imply well-located stations and extensive networks are more attractive to intercity travelers, thereby increase the patronage of intercity transportation systems. These concepts are also demonstrated by the results of Figure 5 and Figure 9. That is, the service area of HSR is larger than that of AT because intercity travelers to the HSR station are well served by the rail transit network and expressways, while those to the AT terminal are merely served by local streets.

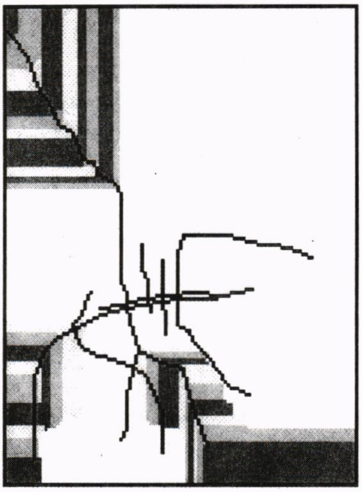

Figure 9. The Service Areas of Stations in Several Rail Transit Lines

5. CONCLUSIONS

This study decomposes the generalized intercity travel cost into three components, that is, the line-haul travel time and cost, the access travel time and cost in the origin city, and the access travel time and cost in the destination city. An intercity travelers' route and mode choice model is constructed to explore the optimal intercity mode and the optimal access way for travelers at each residential site in the study area by minimizing their generalized intercity travel costs. Surface streets approximated by dense networks, actual expressway networks and rail transit networks are applied in the study. Results of the Taipei-Kaohsiung corridor example show that the service area of HSR is larger than that of AT owing to the locations of the HSR station and the AT terminal, and the configuration of expressways and rail transit networks. The HSR station in Taipei metropolitan area is located adjacent to the confluence of rail transit lines such that the accessibility of the HSR station is enhanced with the service of rail transit networks. On the other hand, the location of AT terminal in Taipei metropolitan area is away from downtown. The inconvenient access to the AT terminal by rail transits makes automobiles become the optimal access mode in the service area of AT. In the service area of HSR, intercity travelers with shorter access distance will prefer to travel by automobiles via surface streets to the HSR station. Intercity travelers living around expressways then will tend to travel by automobiles via both surface streets and expressways. The access way of using automobile then transferring to rail transit is mainly chosen by intercity travelers living in outlying areas. Equi-access time contours and equi-access cost contours centered at the HSR station and the AT terminal in Taipei metropolitan area are affected by the configurations of expressways and rail transit networks and positions of these two intercity transportation terminals. The position and shape of service areas of each rail transit line depend on the configuration of rail transit networks and locations of rail transit stations. The results of service areas for each rail transit station imply well-located stations and extensive networks are more attractive to intercity travelers, thereby increase the patronage of intercity transportation systems.

The choice of the intercity mode and the access way in this study is decided by selecting the alternative with the least generalized intercity travel cost. Changes in the optimal choice decision at each residential site can be further analyzed when key parameters in the model are varied. The results of the optimal intercity mode and access way at each residential site can be utilized to preview the service areas of HSR and AT, and the competition condition between them. Moreover, these results can illuminate the optimal transportation system at different locations in the metropolitan area and facilitate the planning and operation of new intercity transportation systems and their access networks. However, the value of the generalized intercity travel cost depend on the variations of waiting times at the HSR station and the AT terminal, and the randomness of travel time on surface streets and expressways. Therefore, future studies exploring the traveler's mode and route choice from the viewpoint of operating should incorporate these variations.

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