장 일 준

(삼성 교통안전문화연구소 책임연구원)

6. 네트워크 기반모델을 이용한 서울-부산간 고속철도 개통 후의 교통수단별 시장점유율 예측

A Network-Based Model for Estimating the Market Share of a High-Speed Rail System in the Korean NW-SE Corridor

장 일준

(삼성 교통안전문화연구소, 책임연구원)

Gang-Len Chang

(University of Maryland, Professor)

Table of Contents

Abstract

This research presents a novel application of static traffic assignment methods, but with a variable time value, for estimating the market share of a high-speed rail (HSR) in the NW-SE corridor of Korea which is currently served by the airline (AR), conventional rail (CR), and highway (HWY) modes. The proposed model employs the time-space network structure to capture the interrelations among all competing transportation modes, and to reflect their supply- and demand-sides constraints as well as interactions through properly

formulated link-node structures. The embedded cost function for each network link offers the flexibility for incorporating all associated factors, such as travel time and fare, in the model computation, and enables the use of a distribution rather than a constant to represent the time-value variation among all transportation mode users. To realistically capture the tripmakers' value-of-time (VOT) along the target area, a novel method for VOT calibration has been developed with aggregate demand information and key system performance data from the target area. Under the assumption that intercity tripmakers often have nearly "perfect" travel information, one can solve the market share of each mode after operations of HSR for each O-D pair under the time-dependent demand with state-of-the-art traffic assignment. Aside from estimating new market share, this paper also investigated the impacts of HSR on other existing transportation modes.

1. Introduction

The NW-SE corridor connects major cities in Korea, including Seoul, Daejeon, Daegoo, and Busan. Currently, both the HWY and CR networks are available between every pair of those four cities, and AR is available only between Seoul, Daegoo, and Busan. For convenience of illustration, Table 1.1 converts those trip segments into a sequence of OD pairs along with their current daily demands.

Table 1.2 summarizes the current daily market share among the available transportation modes. As is notable from the summary of statistics, about the same percentage of tripmakers take the HWY and CR modes for short-distance trips (i.e., OD 1). As the trip distance increases, AR becomes increasingly attractive to tripmakers. In contrast, for long-distance trips (i.e., OD 3), tripmakers are rarely taking HWY, and about 78% of the total trips are with AR.

As shown in Table 1.3, the total length of the HWY network from Seoul to Busan along this corridor is 267.5 miles. Seoul and Daejeon are connected through a 95.25 mile-long highway. From Daejeon to Daegoo, a four-lane highway runs about 88 miles. The last segment, from Daegoo to Busan, is a four-lane highway of 83.94 miles. The NW-SE railway network is mostly in parallel with the HWY network, and has about the same trip distance. Travel times of AR and CR are prescheduled except that the waiting time is flow and capacity dependant. Travel time and capacity of each transportation mode by trip segment is summarized in Table 1.4. The HWY capacity is designed to be 2,200 passenger cars per lane per hour, and its travel speed is assumed to be at the free flow level at the initial stage of estimation. The capacity of the AR system is based on its actual schedules and available types of aircraft.

Table 1.1: Converted OD numbers and Current Daily Demand of the NW-SE Corridor

Trip Segment	Seoul ~ Daejeon	Seoul ~ Daegoo	Seoul ~ Busan	Daejeon ~Daegoo	Daejeon ~ Busan	Daegoo ~ Busan
OD	OD 1	OD 2	OD 3	OD 4	OD 5	OD 6
Demand	7,080	15,368	37,037	1,357	2,075	5,230

Note: OD Demand data is based on the Korean Ministry of Construction and Transportation, 1999

Table 1.2: Current Daily Market Share of the NW-SE Corridor

	AR	CR	HWY	Total
OD 1	N/A	3,623 (51.17)	3,457 (48.83)	7,080
OD 2	8,663 (56.37)	5,513 (35.87)	1,192 (7.08)	15,368
OD 3	28,758 (77.65)	7,029 (18.98)	1,250 (3.38)	37,037
OD 4	N/A	676 (49.82)	681 (50.18)	1,357
OD 5	N/A	1,644 (79.23)	431 (20.77)	2,075
OD 6	N/A	2,881 (55.09)	2,349 (44.91)	5,230
Total	37,421 (54.91)	21,366 (31.35)	9,360 (13.74)	68,147

Note: Numbers in parentheses show percentages

Table 1.3: Distribution of HWY Link Lengths between Major Cities in the NW-SE Corridor of Korea

	Seoul	Daejeon	Daegoo	Busan
Seoul	-	95.25	183.56	267.50
Daejeon	95.25	-	88.31	172.25
Daegoo	183.56	88.31	-	83.94
Busan	267.50	172.25	83.94	-

Note: All numbers are in miles

Table 1.4: Travel Time and Daily Capacity of AR and CR by OD Pair

	OD 1	OD 2	OD 3	OD 4	OD 5	OD 6
CR	91 (13,564)	182 (27,128)	250 (38,316)	90 (13,564)	158 (24,752)	66 (11,188)
AR	N/A (N/A)	55 (1,726)	65 (9,500)	N/A (N/A)	N/A (N/A)	N/A (N/A)

Note: *All numbers are in minutes*
All numbers in ( ) are daily capacities
All capacities are in person per day
AR capacity is based on its actual service schedules and type of aircraft

To contend with the increasing congestion along the NW-SE corridor, the Korean HSR system (KTX) has been under construction since 1992. The KTX system connects major cities along the NW-SE corridor (i.e., Seoul, Daejeon, Daegoo, and Busan), and the network is adjacent to the existing CR system. More detail information of the KTX system can be found elsewhere. (Chang, 2001)

Note that the KTX system is designed to reduce the waiting times for the AR and the CR system users, and to provide faster ground services than CR as well as HWY. Hence, the fare of the proposed KTX system is set to be approximately 30% higher than that of CR, and 30% lower than that of AR so as to attract the AR system users. More specifically, KTX is aimed to reduce the overall trip time and congestion along the NW-SE corridor. It is designed not only to provide better service for tripmakers, but also to balance the regional development.

The study is proposed in response to the availability of the HSR system in the near future, and is intended to project the market share of all transportation modes in the NW-SE corridor after the operations of such a new transportation system.

2. Research Methodology

As is notable in the literature (Hensher, 1997 and Hsu and Chung, 1997), fare, VOT, and travel time are the major factors that may affect a tripmakers' choice of transportation modes. For instance, in the market share study for the Sydney-Canberra corridor, Hensher (1997) employed the disaggregate survey method to estimate the VOT of tripmakers along the target area.

Recognizing the vital role of VOT in tripmaking decisions, a large body of research has been focused on this issue over the past several decades, mostly addressing either from understanding of tripmaking behavior (Bruzelius, 1979; Watson, 1974; Moses, 1963; Hensher, 1977; Earp, 1976), or from a microeconomic perspective (Jara-Diaz, 1998; Gonzalez, 1997; Gronau, 1976; Senna, 1993; Stopher, 1976, 1998). Among all existing studies, one of the most popular method for VOT estimation is to use state-preference and/or revealed preference from the disaggregate survey data. Such approaches, although theoretically appealing, may face some difficulties in practice due to the high cost associated with the acquisition of sufficient quality samples.

In contrast to the lack of quality data at an individual tripmakers level for mode choice or route choice studies, most operators of existing transportation modes have well kept their market share information at the aggregate level. Thus, to circumvent the difficulties and costs associated with performing disaggregate surveys, we have developed a network-based method that can take full advantages of those valuable aggregate demand data for VOT estimation as well as the HSR market share prediction. The core concept and principal steps of our proposed aggregate method for market share estimation are illustrated in Figure 2.1.

As shown in the flowchart, we first formulate a network-based model based on time-space operations of the network served by all transportation modes and their interactions at each O-D pair. With the assumption that all tripmakers are fully aware of the fare, schedule, and travel time of all available transportation modes and intend to minimize their total travel cost, we have proposed a user-optimum objective function to solve the existing distribution of demand among all competing transportation modes on different O-D pairs, considering mainly the travel time and fare in the cost function. Since the actual distribution of the time-varying O-Ds among all existing transportation modes is available from the aggregate statistics, one can use such data as the basis for selecting the best-fit VOT distribution. The new market share of each transportation mode after the operations of HSR can thus be estimated subsequently with the calibrated VOT distribution and the revised time-space operations model that includes the network served by the proposed HSR. A detailed illustration of each principal step in Figure 2.1 is presented in sequence in below.

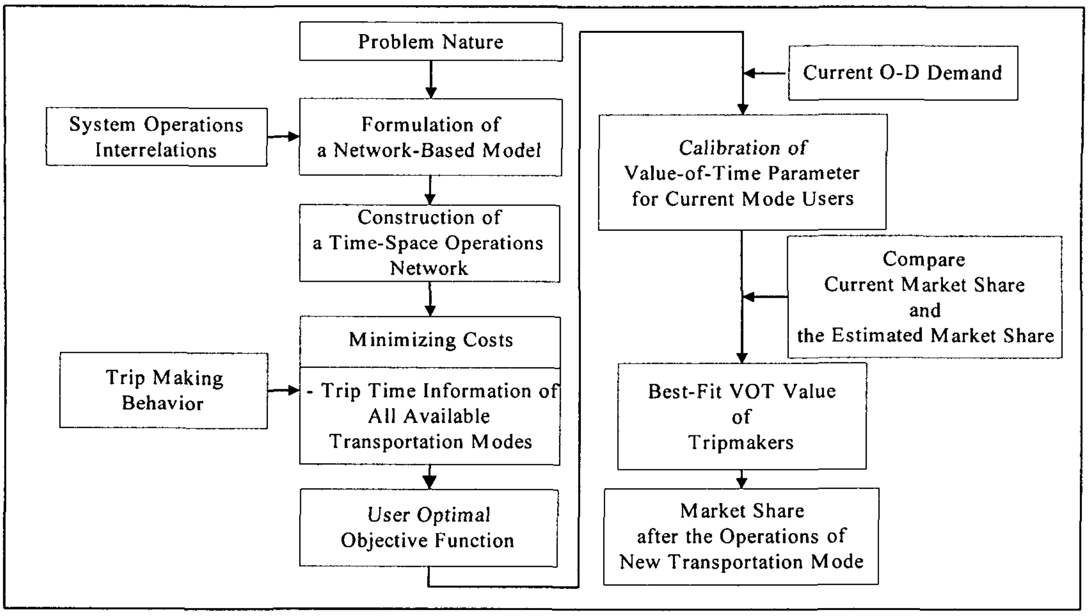


Figure 2.1: Flowchart of the Research Procedures

3. Network-Based Method

3.1 Modeling Concept

As stated previously, to capture the physical capacities and constraints of the network served by each transportation mode, we have developed a network-based model to reflect their actual interrelations. For instance, the link constraint illustrates the capacity of the assigned transportation mode on such a link. The notion of node-capacities can be used to reflect the capacity constraints of a station (or, a tollbooth) for the target transportation mode.

Such a network structure offers the flexibility for researchers to add or drop cities or transportation modes along the target regional corridor without making major changes in the formulation. The network with its graphical feature can easily explain the input and output flows of travelers within a city-node and their spatial distribution. Moreover, the model divides its network links into two types: main and access links.

The main links capture the actual travel time, whereas the access links function to reflect the waiting time of tripmakers along the assigned paths. If more tripmakers than its capacity are coming into a station-node during a given time-period, this input-output mechanism and different types of link will increase the waiting time for those trips. More specifically, the proposed model has been developed to capture the following key features of a target regional corridor that offers several competing transportation modes:

- Considering the trade off between travel time and fare between each transportation mode and among all competing transportation modes;
- Incorporating the capacity and operational constraints of each transportation mode in the model formulation;

- Reflecting the performance level of all transportation modes, the generalized trip cost such as speed, access time, and travel time, and their competing nature;
- Capturing the temporal and spatial relations of trips departing at different origins at different times of a day; and
- Allowing the VOT to vary across population rather than be viewed as a constant.

3.2 Model Formulation

For convenience of illustration, the NW-SE corridor is simplified as shown in Figure 3.1, where three transportation modes (AR, HWY, and CR) and three airports (Nodes 5, 6, and 7) are available in the corridor. Nodes 5, 8, and 12 represent the station-nodes for those three existing transportation modes, and are located at the same city denoted as city-node 1. Between a city-node and station-nodes within a same block represents those located in the same city, and connected together with access links. By incorporating the time-varying demand and the capacity constraint for each transportation mode over each link, one can convert Figure 3.1 into a time-space network that represents the supply-demand relations within each transportation mode and between competing modes.

The time-space network can be illustrated in a two-dimensional plane where X-axis stands for the location and Y-axis for the time. The core modeling components of the time-space operational network are summarized as follows:

- Nodes:

All nodes along the horizontal axis represent locations of different stations or cities in the network, while the vertical axis shows the lapse of time. Thus, connection along the horizontal axis represents the movements between different locations within the same time-period. Links along the vertical axis illustrates the movements between different time-periods at the same

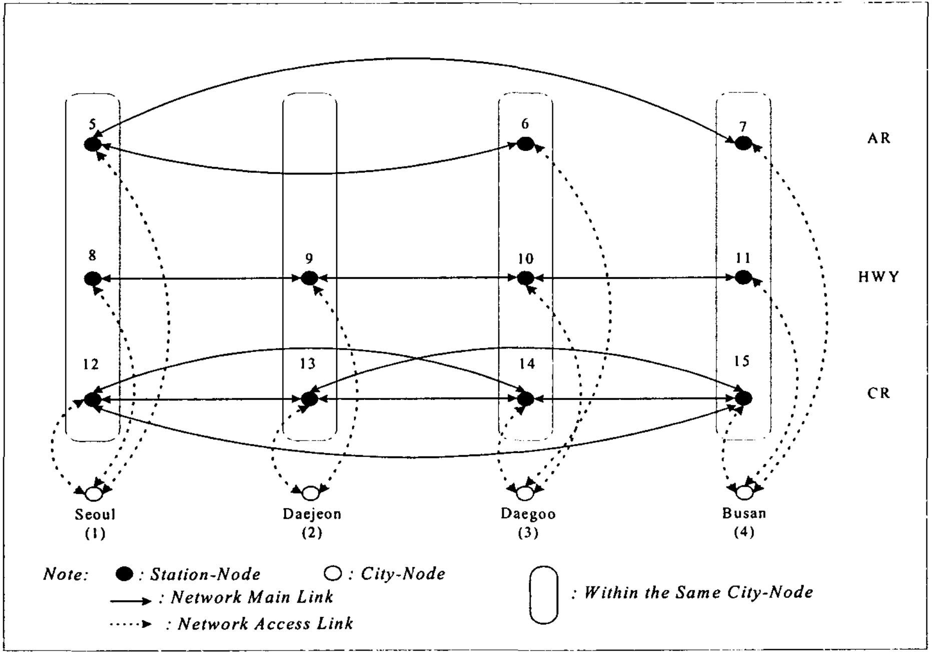


Figure 3.1: Korean Transportation Network Configuration

location. Thus, connection along the diagonal direction stands for the physical evolution of movements over time.

- Links:

  There are two types of links in the network where access links connecting trips from those origin cities to station nodes (and vice versa) are used to capture the access time and waiting time. Main links, representing travel times, are specified for connecting trips between station nodes located in each destination city.

- Link Cost:

  The cost of each main link is constituted mainly by fare and travel time of the target transportation mode on that segment. The cost of those access links is designed to capture the waiting time due to insufficient capacity of main links.

- Link Capacity:

  It is specified to reflect the physical capacity constraint of each transportation mode at different time intervals and locations during its operations.

- Origin nodes:

  The set of nodes is designed to capture those trips originated from each city and terminated at a set of potential destination cities over a time horizon.

- Dummy nodes:

  Such nodes are used to capture trips that cannot be finished within an one-day period, serving as the supplemental set of original nodes for tripmakers to continue their journeys on the next day.

3.3 Construction of Time-Space Operations Network

For construction of the time-space operations network, it is essential to have a complete set of system performance data associated with each transportation mode such as travel distance, capacity, and speed. Currently, three transportation modes (i.e., AR, HWY, and CR) are available in the NW-SE corridor as illustrated in the previous section. Tables 1.1, 1.2, 1.3, and 1.4 summarize those data used for construction of the time-space operations network (i.e. current daily OD demand, current daily market share, trip distance, and travel time and daily capacity). Note that daily operational capacities for each transportation mode such as the AR and CR modes are computed based on the actual seat availability and its daily frequencies over each link of the proposed corridor.

With those standard network formation concepts and information presented in previous section, the time-space operational relations for each transportation mode and between competing modes can be developed. For instance, the time-space-operation network of the AR mode for the first three time-periods is presented in Figure 3.2.

Note that for the AR network, its time-space interrelations are identical during all periods since all trips served by AR can be finished within one time-period. In this research, each time-period covers the length of two hours, based on the available aggregation of the OD demand data. In case of sthe CR mode, most trips cannot be completed within one time-period due to its slow travel speed, and

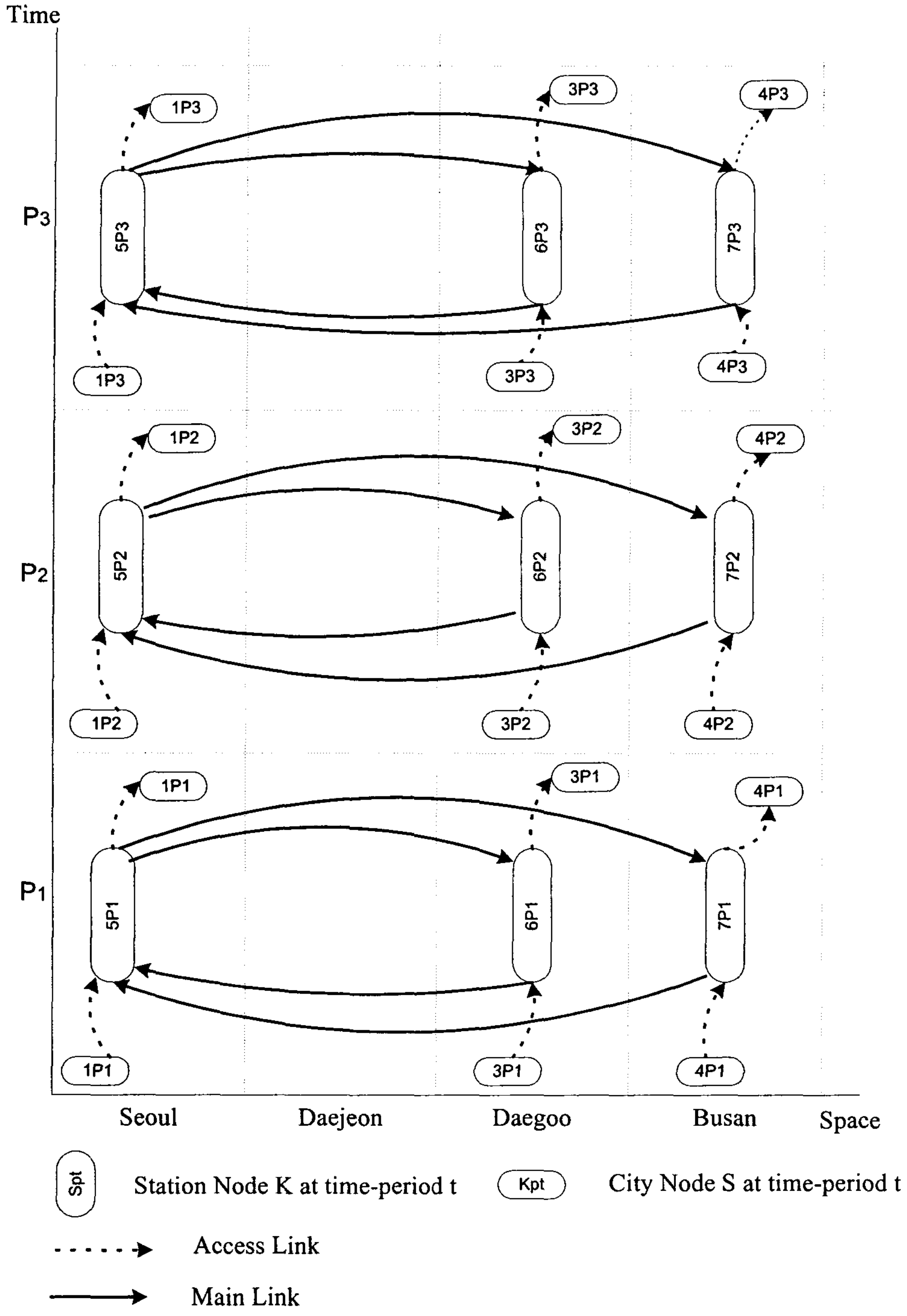


Figure 3.2: AR System Time-Space Diagram for Three Time-Periods

thus its time-space operations vary from one period to the next as shown in Figure 3.3. One can follow the same procedures to construct the time-space-operation network for HWY.

All those three sub-networks are then connected through their common demand nodes as illustrated in Figure 3.4, and constitute the entire operational network for all three transportation modes.

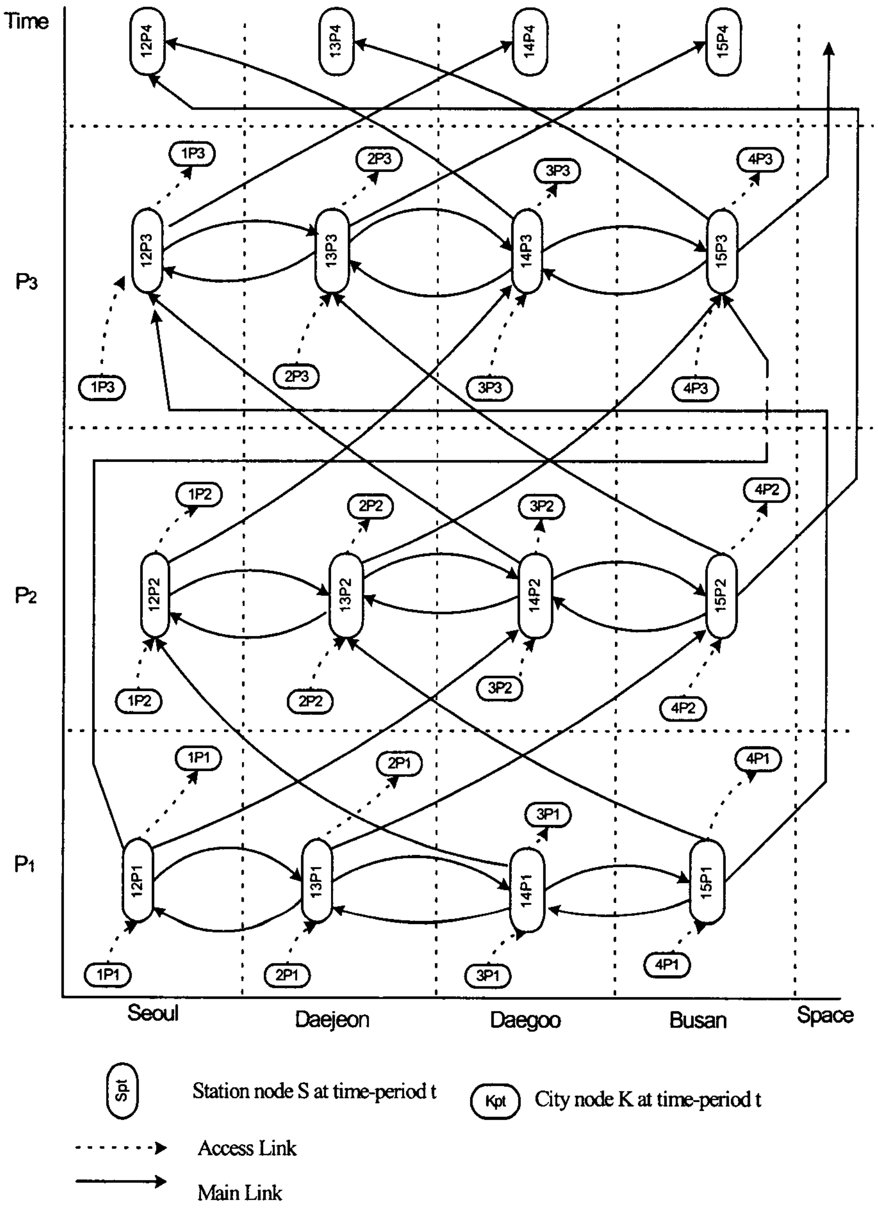


Figure 3.3: CR System Time-Space Diagram for Three Time-Periods

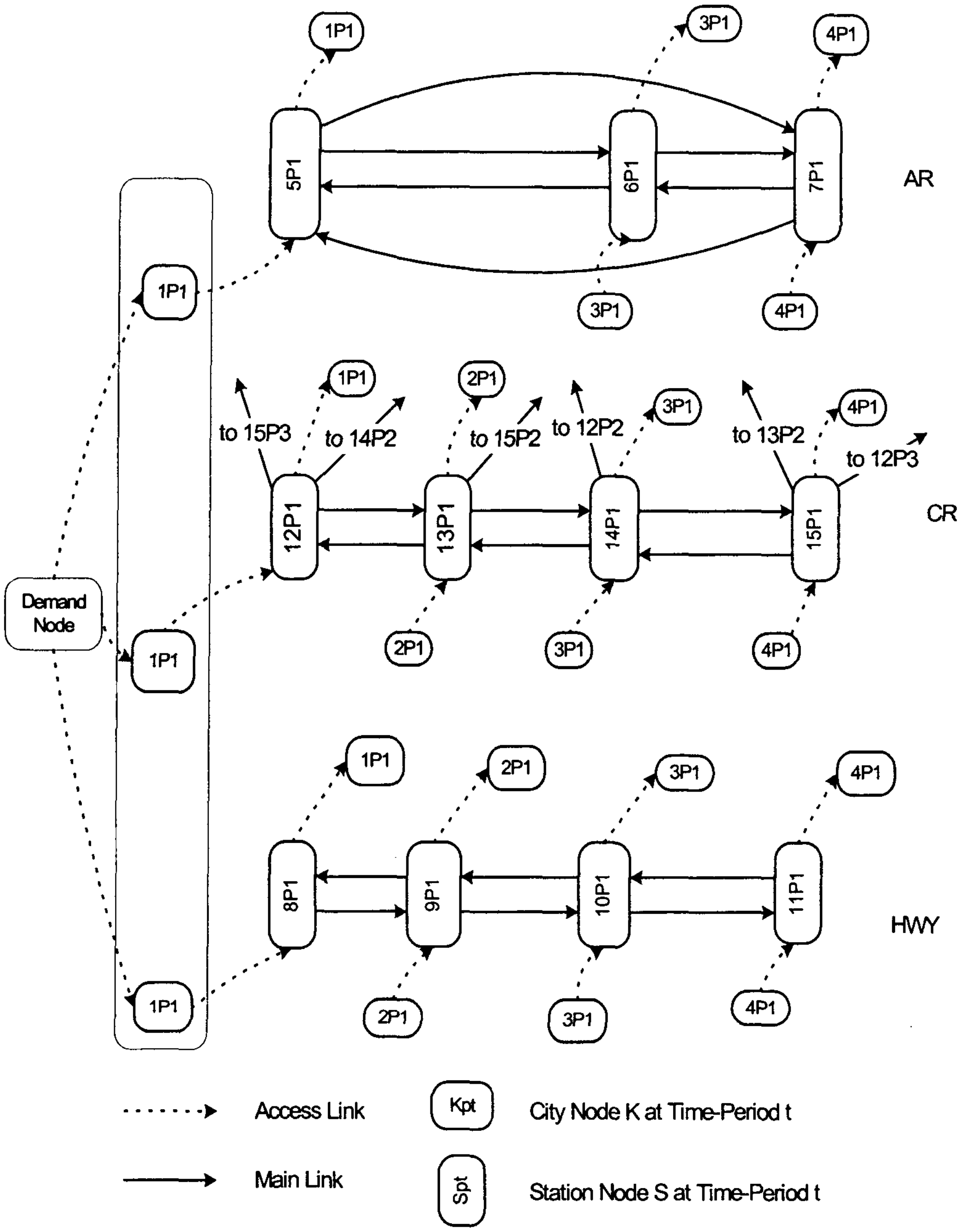


Figure 3.4: Connection of Sub-networks for Time-Period 1 and Location 1

As mainly for illustration, Figure 3.4 only shows the demand from location node 11 and time-period 1. The combination of those three sub-networks reflects the fact that travelers of each OD pair can choose any of those three available transportation modes.

3.4 Objective Function of the Operational Network

Note that to capture the interactions between modes and trips, it is assumed that current network in the NW-SE corridor is under a "state" similar to the "user-optimum" in the context of urban traffic assignment where all users have perfect information regarding the fare, schedule, and travel time of each available mode, and intend to minimize their trip costs. Thus, one can employ similar algorithms for user-optimum solution to solve the large time-space network, and computed all estimated market shares between all O-Ds and transportation modes. The objective function of the proposed operational network is specified as follows:

$$\underset{\text{[Trip on Each Link]}}{\text{Min}} \quad \text{[Total Generalized Cost]} \qquad (1)$$

It can further be expressed mathematically as:

$$\underset{x_{i,j}^{r,s}}{Min} \int_{\alpha} \sum_{r,s} \sum_{i,j} (C_{i,j}^{r,s} + \alpha t_{i,j}^{r,s}(x_{i,j}^{r,s}))d\alpha \qquad (2)$$

Where, $x = x(\alpha)$,

$C_{i,j}^{r,s}$: Out-of-pocket cost from origin r to destination s associated with the path between i and j,

α : Value-of-time,

$t_{i,j}^{r,s}$: Travel time from origin r to destination s associated with the path between i and j, and

$x_{i,j}^{r,s}$: Total number of trips from origin r to destination s associated with the path between i and j.

Equation (2) itself cannot explain temporal and spatial relations. However, its temporal relations are well captured by the constructed time-space operational network. Note that each path in the time-space network represents not only the transportation mode select by tripmakers, but also the temporal and spatial evolution of those trips up to their destination. The model constraints consist of the following two main groups:

- Demand Constraints:

1) Non-negative flow conditions; $x_{i,j}^{r,s} \geq 0$

2) [Trips on Link] $\leq$ [Total Outflow]; $x_{i,j}^{r,s} \leq x^{r,s}$

3) [Total Trips]

$$= \int_{\alpha} \sum \text{[Trips over Each Link on the Designated Link Path]};$$

4) Link Usage Condition; $\delta_{i,j}^{r,s} = 1 \text{ or } 0$

5) Continuity Conditions;

$$x_{r,i}^{r,s} = x_{i,j}^{r,s} = x_{j,s}^{r,s} \text{ for } \forall\, i, j, r, s;$$

$$x_{r,i} = \sum_{s} \delta_{r,i}^{r,s} \cdot x_{r,i}^{r,s} \text{ for } \forall\, i;$$

$$x_{j,s} = \sum_{r} \delta_{j,s}^{r,s} \cdot x_{j,s}^{r,s} \text{ for } \forall\, j;$$

- Capacity Constraints:

  1) $x_{i,j}^{r,s} \le K_{i,j}^{r,s}$

  2) $x_{r,i}^{r,s} \le M$

  3) $x_{j,s}^{r,s} \le M$

  4) $\sum\sum \delta_{i,j}^{r,s} x_{i,j}^{r,s} \le K_{i,j}$

Where, $K_{i,j}^{r,s}$ is the given capacity on the path, and M is a very large number.

Note that $x_{r,i}^{r,s}$ and $x_{j,s}^{r,s}$ show the total number of flows over access links. As the number of trips on these access links increases, the trip-waiting times will increase. Unlike those main links, their capacities on access links should capture all waiting times in travel. Therefore, the proposed model assumes that the capacities of access links are sufficiently large to accommodate all flows under the waiting state.

Based on the constructed network model and the objective function, we now can apply the existing software T-2 to estimate the market share (Dial 1997). Note that T-2 assignment model allows incorporation of VOT as a distribution, rather than a constant, by taking lower and upper limit of VOT to determine the probability of taking each transportation mode. A detailed description of the T-2 algorithm is available elsewhere (Dial, 1993; 1996; 1997).

4. Calibration of the VOT Distribution for Current Mode Users

Based on the developed time-space operations network, the objective function, key system characteristics, and current OD trip demand, one can calibrated the VOT distribution of the tripmakers along the NW-SE corridor of Korea. The calibration is grounded on the assumption that all tripmakers intend to minimize their total travel costs which consists of both fares and travel times. Thus, as mentioned previously, the current market distribution among available transportation modes for all OD demands can be viewed as under a nearly "user-optimum" state, similar to that in the urban traffic assignment context. The method described hereafter is to employ the "user-equilibrium" notion from traffic assignment, but use a time-space network to capture temporal and spatial interactions among different competing transportation modes and OD demands. A detail discussion of the proposed method for the VOT calibration in the Korean NW-SE corridor is presented below.

4.1 Calibration Steps

A set of systematical steps for calibrating the VOT distributions is illustrated as follows.

Step 1: Selecting the initial VOT parameters for the target population.

Step 2: Designing a set of experimental scenarios with a list of candidate VOT parameters.

Step 3: Estimating the "user-optimum" state of trip distribution among current transportation modes with the existing software (T-2) under each experimental scenario based on the developed time-space operations network.

Step 4: Computing the best-fit VOT parameters for current users, based on the discrepancies between the projected and actual market shares of all transportation modes over all O-D pairs under all candidate experimental scenarios.

4.2 Selection of the Initial VOT Distribution

As an initial step for searching the optimal mean VOT parameter, we assume that it must lie within the range between the low 10% and the high 10% of the income of the Korean residents in the NW-SE corridor. The monthly income of Korean people along the NW-SE corridor (Korean Statistics Summary, 1999) is $2,248 in 1999, equivalent to the average income of $0.20 per minute. The low-end 10% of labor forces make $563 per month, about $0.05 per minute, where the high-end 10% is $5,295 per month and is about $0.46 per minute.

Note that with the same assumptions for trip choice behavior and identical system performance data, conceivably, the scenario that yields the best-fit of the current demand distribution must have best captured the actual VOT distribution among tripmakers. Thus, with the network-based method, given system characteristics illustrated previously, and the fare of each transportation mode as shown in Table 4.1, one can perform the preliminary search of the optimal parameters for the VOT distribution. To investigate the best-fit VOT parameters, seven carefully designed scenarios have been used and are listed in Table 4.2.

Case-1: Mean VOT of the system users is $0.05/min (the low 10% of the average resident income in the target area) with a standard deviation of 0.02.

Case-2: Mean VOT of the system users is $0.10/min with a standard deviation of 0.02.

Case-3: Mean VOT of the system users is $0.20/min (the average resident income in the target area) with a standard deviation of 0.02.

Case-4: Mean VOT of the system users is $0.25/min with a standard deviation of 0.02.

Case-5: Mean VOT of the system users is $0.35/min with a standard deviation of 0.02.

Case-6: Mean VOT of the system users is $0.40/min with a standard deviation of 0.02.

Case-7: Mean VOT of the system users is $0.46/min (the high 10% of the average resident income in the target area) with a standard deviation of 0.02.

Table 4.1: Actual Fare (or Toll) of Each Transportation Mode by OD Pair

	OD 1	OD 2	OD 3	OD 4	OD 5	OD 6
HWY	5.25	9.50	12.92	4.25	7.67	3.42
AR	N/A	34.17	42.08	N/A	N/A	N/A
CR	8.25	16.17	21.92	7.92	13.67	5.75

Note: All numbers are in US dollars and all fares are for one-way trips.

Table 4.2: Experimental Scenarios

Case	1*	2	3**	4	5	6	7***
Mean VOT	0.05	0.10	0.20	0.25	0.35	0.40	0.46

Note: Mean VOT is measured by \$/min, and assumed to be normally distributed with a standard deviation of 0.02 *based on the wage distribution in the target service area*

* *shows the low 10% of the average resident income in the proposed area*

** *shows the average resident income in the proposed area*

*** *shows the high 10% of the average resident income in the proposed area*

4.3 Selection Criterion

To identify the best-fit VOT, we have employed the weighted-average error of estimation as the criterion. It is proposed to compute the discrepancy between the estimated market and the current market shares, and is defined as follows:

- Weighted-average error for mode m on OD pair *k* in scenario:

$$[Error]_{k,m} = \frac{ABS(\overline{V}_{k,m} - V_{k,m})}{\overline{V}_{k,m}} \tag{3}$$

Where, k = Origin-destination pair k;

m = Transportation mode (i.e., AR, CR, and HWY);

$\overline{V}_{k,m}$ = Actual volume of transportation mode m on OD pair k;

$V_{k,m}$ = Estimated volume of mode m on OD pair k in scenario; and

ABS = Absolute value.

As such, the total weighted-average error in the scenario can be expressed as:

$$[Error] = \frac{\sum_{m}[\sum_{k}[Error]_{k,m} * \overline{V}_{k,m}]}{\overline{V}} \tag{4}$$

Where, $\overline{V}$ = Total actual volume of the entire system, and is denoted as $\overline{V} = \sum_{m}\sum_{k}\overline{V}_{k,m}$

4.4 Experimental Results

As shown in Figure 4.1, among all candidate sets Case 4 (i.e., the mean VOT equal to \$0.25/min) has yielded the lowest estimation error. However, it is noticeable that the slope connecting the error rate of Cases 2 and 3 is steeper than that of Cases 4 and 5. Thus, it is expected that the actual minimum should lie between Cases 3 and 4.

To further identify the best-fit mean VOT value, we have divided the range between Cases 3 (i.e., mean VOT=\$0.20/min) and 4 (i.e., mean VOT=\$0.25/min) into four additional cases. With the same estimation procedures, it has been found that Case 3-4 (i.e., mean VOT is \$0.24/min) has yielded the lowest estimation error, as presented in Figure 4.2. Thus, for the purpose of market-share prediction, it seems that mean VOT of \$0.24/min can reasonably represent the travel time value of transportation system users in the NW-SE corridor of Korean.

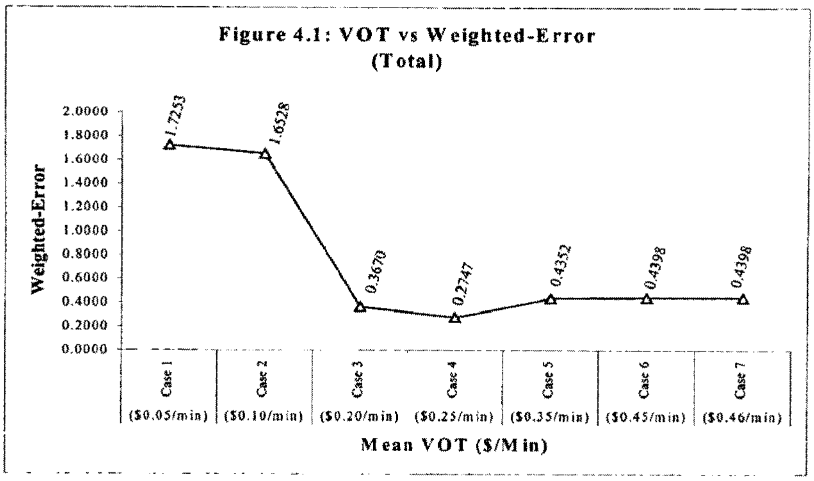


Figure 4.1: VOT vs Weighted-Error (Total)

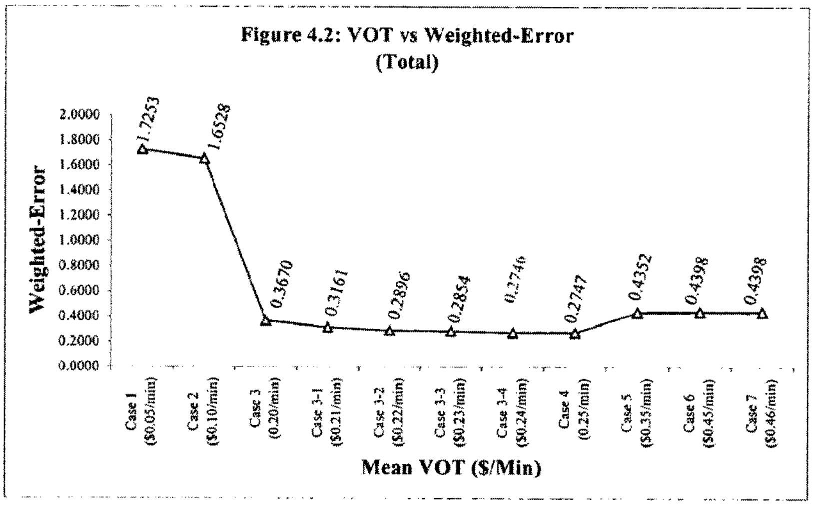


Figure 4.2: VOT vs Weighted-Error (Total)

4.5 Estimation of the Best-Fit Standard Deviation

Given the best-fitting mean VOT of $0.24/min, this section focuses on identifying the best-fitting standard deviation for the system users along the NW-SE corridor with four carefully identified cases: Cases A, B, C, and D, and are summarized in Table 4.3.

Note that theoretically one should vary both the mean and variance concurrently in search of the optimal parameters for the VOT distribution. But practically, the mean value of the VOT has much more significant impact than its variance on the estimation results. Thus, for efficiency of computation we have employed the method of sequential rather than concurrent search in identification of the best-fit parameters.

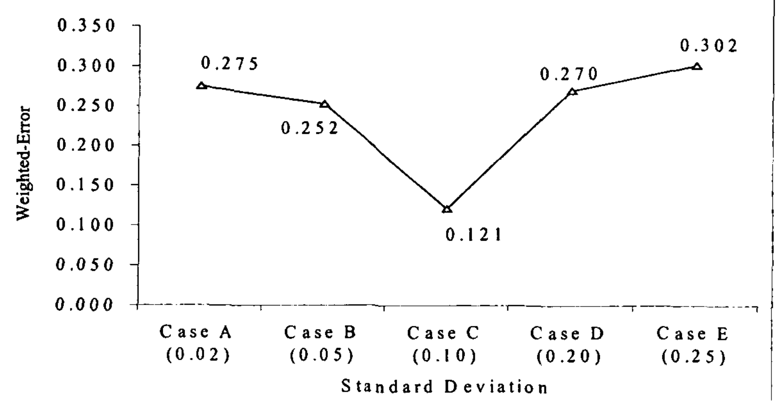
Table 4.3: VOT Distribution Tests with Different Standard Deviations

	Case A*	Case B	Case C	Case D	Case E
Mean VOT	$0.24/min	$0.24/min	$0.24/min	$0.24/min	$0.24/min
Sd	0.02	0.05	0.10	0.20	0.25

Note: *Sd = standard deviation*
**: Base-case*

Also note that the design of those four cases is based on the collected statistics which have shown that the standard deviation of the residential income in the target area is 0.02. Thus, we have chosen 0.02 as an initial standard deviation and 0.25 for the upper bound. The estimation results of all those four cases are illustrated in Figures 4.3.

Figure 4.3: Standard Deviation vs Weighted-Average Error



It is noticeable that Case C (i.e., sd=0.10) has yielded the lowest weighted-average error of estimation, comparing to the initial and all other cases. Additional explorations with a small increment of standard deviation have also confirmed the best-fit of the Case C results.

With all the above explorations, one may conclude that VOT of tripmakers along the NW-SE corridor of the Korean transportation network can best be approximated with a distribution of its mean equal to \$0.24/min (i.e., Case 3-4) and standard deviation of 0.10 (i.e., Case C). The estimated trip distributions of all transportation modes and O-D's with the best-fit VOT parameters along with its weighted-average errors are presented in Table 4.4.

Table 4.4: Estimated Daily Trip Distribution and Weighted-Average Error with Best-Fit VOT

	AR	CR	HWY	Total
OD 1	N/A	5711 (0.2557)	1369 (0.1267)	7080
OD 2	6794 (0.7387)	5604 (0.1614)	2970 (0.2698)	15368
OD 3	26496 (0.7081)	3384 (0.0950)	7157 (0.7644)	37037
OD 4	N/A	1176 (0.0409)	181 (0.0167)	1357
OD 5	N/A	1674 (0.1654)	401 (0.0405)	2075
OD 6	N/A	4443 (0.1464)	787 (0.0027)	5230
Total	33290 (0.1104)	21992 (0.0292)	12865 (0.3745)	68147 (0.1212)

Note: Numbers in ( ) are weighted-average error of estimation

5. Estimation of the New Market Share and Its Impacts on Other Modes

It is notable that with the estimated VOT distribution and available system features, one can now reconstruct the entire corridor network with the HSR system, and employ the same solution procedures to estimate the market share of HSR as well as other existing transportation modes. One can also employ the same network relation to explore the impact of various operating policies, such as fare structure, on the potential market share of all competing transportation modes.

Tables 5.1 and 5.2 summarize the trip distances and the designed speeds of the proposed KTX between each station. According to the KTX authority, the average travel time by the KTX system is designed to be longer than that by AR but shorter than those by CR and HWY. The KTX travel time from Seoul to Busan takes about 55% of CR. From Seoul to Daejeon (i.e., OD 1), the KTX travel time is about 50% of CR. Thus, the travel time by the KTX system is about 50% of CR in general. Comparing to the AR mode, travel time by the KTX is 36% longer than that by AR mode from Seoul to Daegoo (i.e., OD 2), and about 71% longer than from Seoul to Busan (i.e., OD 3).

Table 5.1: Trip Distances of KTX between Each Station

	Seoul	Daejeon	Daegoo	Busan
Seoul	-	99 mile	176 mile	257 mile
Daejeon	99 mile	-	76 mile	158 mile
Daegoo	176 mile	76 mile	-	130 mile
Busan	257 mile	158 mile	75 mile	-

Table 5.2: Designed Average Speeds of KTX for Each Trip Segments

	Seoul	Daejeon	Daegoo	Busan
Seoul	-	135 mile	141.25 mile	138.75 mile
Daejeon	135 mile	-	150 mile	141.25 mile
Daegoo	141.25 mile	150 mile	-	133.75 mile
Busan	138.75 mile	141.25 mile	133.75 mile	-

The capacity of KTX is designed to be about 50% higher than that of CR from Seoul to Daejeon (i.e., OD 1) only. Its daily capacities from Seoul to Daegoo (i.e., OD 2) and to Busan (i.e., OD 3) are 6.5% and 2.8% lower than the CR capacities, respectively. For other trip segments, between Daejeon, Daegoo, and Busan, the daily capacities of KTX are about 80% to 90% lower than that of CR. The reason for the lower capacity for other trip segments is due to the fact that the expected travel demands for those origin-destination trips are to be lower for KTX. Table 5.3 summarizes the designed daily capacity of the KTX system by trip segment computed from its actual seat availability and designed daily frequency.

Note that the proposed fare of KTX is approximately 30% higher than that of CR, and 30% lower than that of AR. Table 5.4 summarizes the proposed fare for KTX for each OD pair. The fare is designed to attract the AR users. Thus, KTX is expected to reduce the waiting times for the AR travelers by reducing the total number of users, and also to minimize the excessive waiting time for KTX passengers.

Table 5.3: Designed Daily Capacities for the KTX System by Trip Segments

	Seoul	Daejeon	Daegoo	Busan
Seoul	-	26,760	25,371	37,264
Daejeon	26,760	-	2,636	2,151
Daegoo	25,371	2,636	-	6,047
Busan	37,264	2,151	6,047	-

Note: All numbers are in Trips per Day

Table 5.4: Expected Fares of the KTX System by Trip Segments

	Seoul	Daejeon	Daegoo	Busan
Seoul	-	11	21	29
Daejeon	11	-	10	18
Daegoo	21	10	-	8
Busan	29	18	8	-

Note: All numbers are in US $

To estimate the market share under the current demand, we have adopted the VOT distribution to be normally distributed with a mean of $0.24/min and a standard deviation of 0.10 for the entire system users, based on the VOT calibration results in the previous section. The first step of estimation is to construct its time-space operations network, based on key system characteristics illustrated in previous tables. Figure 5.1 presents its time-space-operations network over two time periods. By iterating the operational network of HSR with the existing three-mode network, one can construct a complete time-space operations network of all available transportation modes for the NW-SE corridor.

Given the completed time-space-operations network and calibrated VOT distribution, we have computed the optimal trip distributions from the perspective of the existing corridor users based on the objective function proposed in Equation 1. Table 5.5 summarizes the estimation results of the new market share of each mode without considering the potential induced demand. With those preliminary results, it seems that the proposed HSR system will attract more than 60% (i.e., 60.56%) of tripmakers along the proposed corridor.

By performing the before-and-after comparison, it has been found that with the HSR system, the AR demand will decrease about 23 percent points (PP), where the CR and the HWY demands will drop by 31 PP and by 6 PP, respectively. All comparison results are presented in Figure 5.2. For short-range trips (i.e., OD pair 2), as shown in Figure 5.3, the market share has been decreased about 9.32 PP for the AR, 8.09 PP for the CR, and 0.32 PP for the HWY users.

For long-range trips, it has been decreased by 13.77 PP for the AR and 10.31 PP for the CR users. In contrast, the market share of the HWY users for long-range trips has been increased only 0.17 PP. The relations between the current and estimated percentage of market share for OD pair 3 is presented in Figure 5.4. Thus, given the current market demand (i.e., without induced trips), the operations of HSR, as expected, can significantly decrease overall share of AR and CR for intercity trips, and reduce the current level of congestion on the intercity travel.

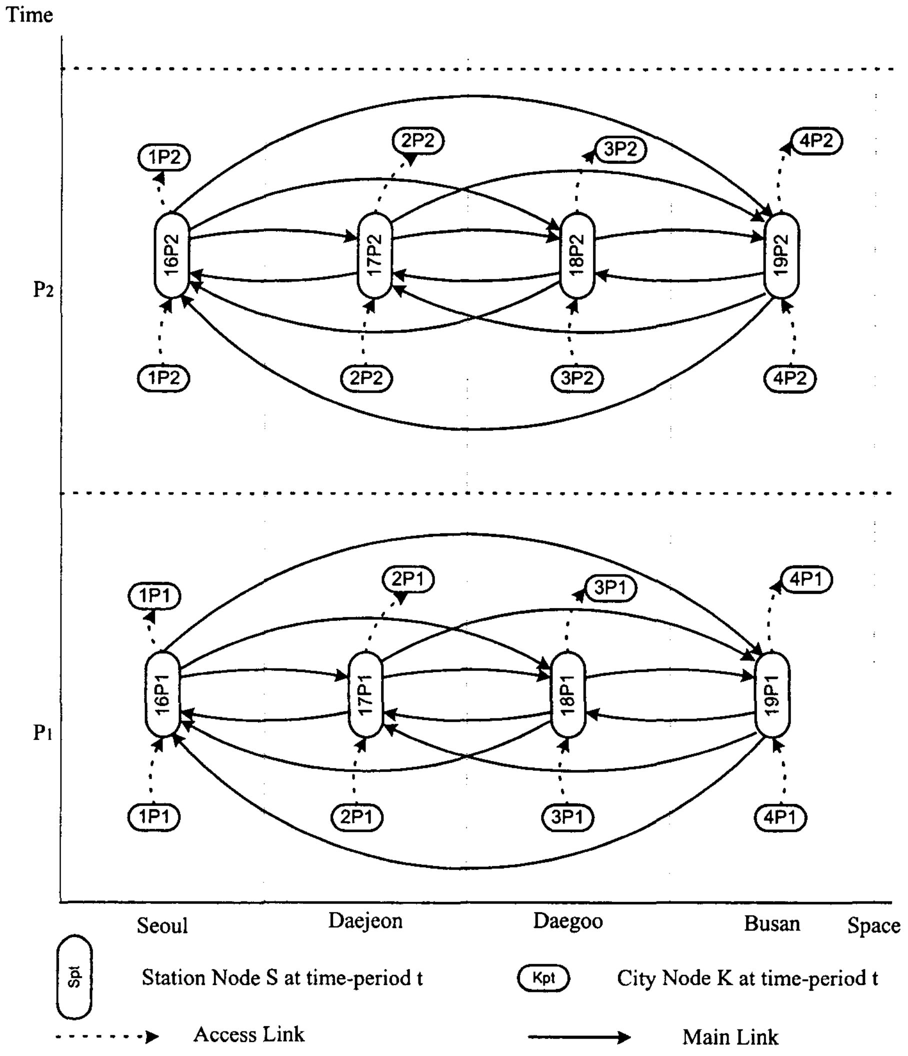


Figure 5.1: Time-Space Diagram for Two Time-Periods of the Korean HSR System

Table 5.5: Percentage of the Estimated Market Share of the NW-SE Corridor

OD	Pair		AR	CR	HSR	HWY	Total
Seoul ~	Daejeon	OD 1	N/A	2.15	78.55	19.31	100
Seoul ~	Daegoo	OD 2	15.11	0.00	78.55	6.34	100
Seoul ~	Busan	OD 3	52.31	0.00	44.00	3.69	100
Daejeon~	Daegoo	OD 4	N/A	10.24	76.42	13.34	100
Daejeon~	Busan	OD 5	N/A	0.00	84.96	15.04	100
Daegoo ~	Busan	OD 6	N/A	0.00	86.63	13.37	100
Total Market Share			31.83	0.43	60.56	7.18	

Note: *All numbers are in % of Trips/Day*
N/A stands for not available

Figure 5.2: Changes on Market Share

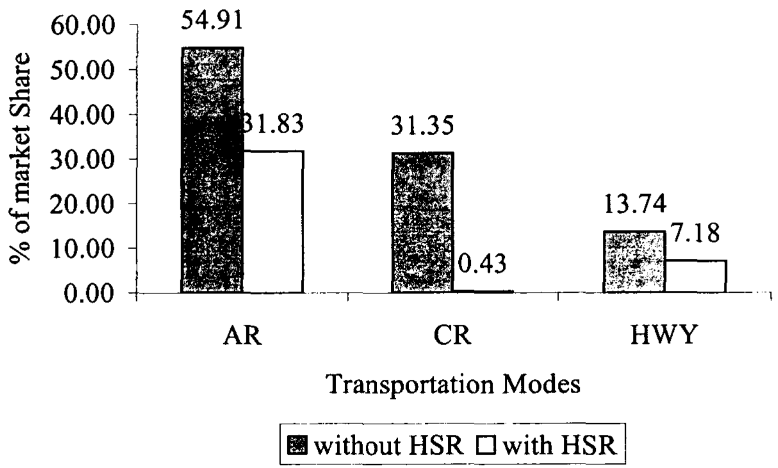


Figure 5.3: Changes on Market Share
(OD 2)

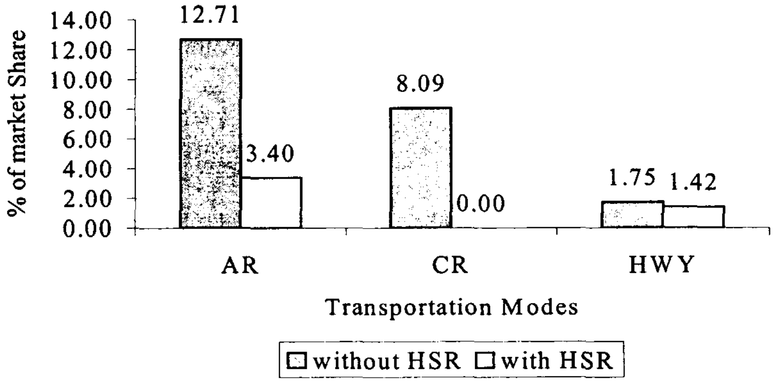
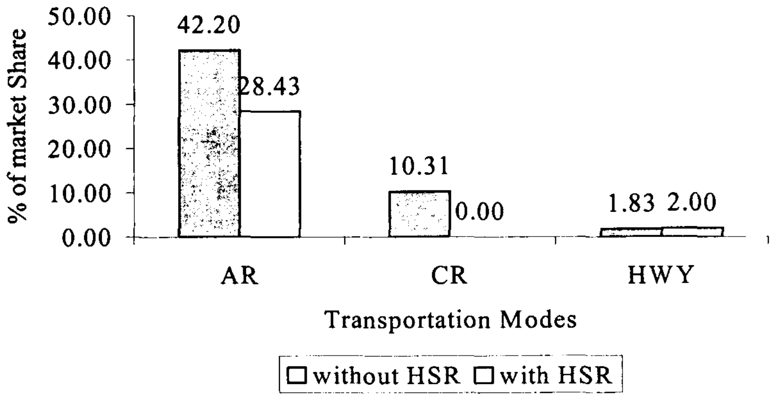


Figure 5.4: Changes on Market Share
(OD 3)



6. Concluding Comments

This study has presented a novel application of the network-based method for market share estimation in a regional corridor of multiple O-Ds and multiple competing transportation modes. The proposed method enables each transportation operator (i.e., HSR) to project its market share under the given fare structures and capacity constraints of all competing transportation modes with available aggregate demand and performance data. The underlying assumption is that all tripmakers intend to minimize their trip costs that involve both fare and trip time.

The proposed model has taken full advantages of available aggregate demand data and the time-space network formulations that can capture the interrelations among competing transportation modes and their impacts on trip distributions. By constructing time-space operating network, the proposed network method can explicitly model the temporal and spatial evolution of trips among transportation modes and between each O-D pair.

The proposed model also allows the VOT to vary across all system users, rather than viewed as a constant in the market share estimation. It is expected that the research methodology and method proposed in the study will enable policymakers to effectively evaluate their policies prior to implementation, and to best utilize available resources so that the entire transportation system can evolve toward an optimal state.

REFERENCES

1. Bruzelius, N., The Value of Travel Time: Theory and Measurement, Croom Helm, London, 1979.

2. Dial, B. R. "A Multicreteria Equilibrium Traffic Assignment Model: Theory and Algorithms", Federal Highway Administration Research Paper, Dec. 1993.

3. Dial, B. R. "Bicreterion Traffic Assignment: Theory and Elementary Algorithms", Transportation Science, May 1996 Vol. 30 n 2, p. 93.

4. Dial, B. R. "Network - Optimized Road Pricing: Part I: A Parable and a Model", Federal Highway Administration Research Paper, March 1997.

5. Chang, I. J., "A Network Based Model for Market Share Estimation Among Comepting Transportation Modes in a Regional Corridor", Ph.D. Dissertation, 2001.

6. Earp, J. H., Hall, R. D., McDonald, M. "Model Choice Behaviour and the Value of Travel Time: Recent Empirical Evidence", Model Choice and the Value of Travel Time, Edited by Heggie, I.G., Clarendon, Oxford, 1976.

7. Gonzalez, R. M., "The Value of Time:Theoretical Review", Transportation Reviews Vol. 17, No. 3, 245-266, 1997.

8. Gronau, R. "Economic Approach to Value of Time and Transportation Choice", Transportation Research Record No. 587, 1-11, 1976.

9. Hensher, D. A., "A Practical Approach to Identifying the Market Potential for High Speed Rail: A Case Study in the Sydney-Canberra Corridor", Transportation Research A, Vol. 31 n 6, pp. 431-446, 1997.

10. Hensher, D. A., Value of Business Travel Time, Pergamon, New York, 1977.

11. Hsu, C-I. And Chung, W-M. "A Model for Market Share Distribution Between High-Speed and Conventional Rail Services in a Transportation Corridor", The Annals of Regional Science, 1997 Vol. 31 n 2, p. 121.

12. Jara-Diaz, S. R., "Time and Income in Travel Choice: Towards a Microeconomic Activity-Based Theoretical Framework", Theoretical Foundations of Travel Choice Modeling, Elsevier, New York, 1998.

13. Moses, L. M. and Williamson, H. F. Jr., "Value of Time, Choice of Mode, and the Subsidy Issue in Urban Transportation", Journal of Political Economy, Vol. LXXI, p.p. 247–264, 1963.

14. Senna, L. A. D. S., "The Influence of Travel Time Variability on the Value of Time", Transportation Vol. 21, 203-228, 1994.

15. Stopher, P. R., "Derivation of Values of Time From Travel Demand Models", Transportation Research Record No. 587, 12-18, 1976.

16. Stopher, P. R., "Household Travel Surveys: New Perspectives and Old Problems", Theoretical Foundations of Travel Choice Modeling, Elsevier, New York, 1998.

17. Watson, P. L., The Value of Time: Behavioral Models of Modal Choice, Lexington, Mass., 1974.