FIELD TESTS OF TRAVEL-TIME FUSION ALGORITHMS UTILIZING REAL-TIME DATA FROM TWO DIFFERENT TRAFFIC DATA GATHERING SOURCES FOR AN ADVANCED TRAFFIC INFORMATION SYSTEM IN SEOUL

Chi-Hyun SHIN
Assistant Professor
Dept. of Transportation Engineering
KYONGGI University
San-94 Yiui-Dong Paldal-Gu
Suwon, Korea
Fax : +82-31-249-9775
E-mail : chshin@kuic.kyonggi.ac.kr

Youngchan KIM
Associate Professor
Dept. of Urban Engineering
The University of Seoul
90 Jeonnong-Dong, Dongdaemun-Gu
Seoul, Korea
Fax : +82-2-2215-5097
E-mail : yckimm@uoscc.uos.ac.kr

Abstract: In Seoul, two primary ATIS services called 'TSD' and 'ROTIS' are in operation. Data collection wise, TSD heavily depends on 500 point-based non-intrusive traffic detectors whereas ROTIS operates beacon-based AVI systems with 12,000 probe cars. According to independent field tests conducted by authors, there found to be noticeable problems in estimated travel time data of both services in terms of accuracy. It was necessary for two systems to improve travel time accuracy through mutual cooperation. After agreeing on forming a consortium, the challenge faced was to improve travel time accuracy by utilizing each partner's travel time data. The resorting approach was to employ a data fusion process. This paper presents some issues exposed in the course of developing the data fusion algorithm and mainly focuses on the methods of improving accuracy of traffic information by utilizing 'data fusion' techniques.

Key Words: Data Fusion, AVI, Algorithm, Travel time

1. INTRODUCTION

As of now, wide spreading ITS technologies are empowering many public road agencies and IP industries especially in their ability to provide drivers with real-time traffic information. Such traffic information provision services, whether it is in primitive form or advanced, are in operation in many major cities over the world. Key elements of such service systems, of course, are the way it collects, processes, and disseminates traffic data to those in need.

Traffic-management-wise, the city of Seoul is far from the vision and level that many cities in western countries and Japan have already realized. With rapid growing telecommunication technologies and market size, however, some private companies have been heavily investing in slightly different fields such as traffic information gathering and disseminating projects of their own. Two primary projects are 'Total Services for Drivers' by SK Corporation and 'ROTIS' by ROTIS Co. Ltd., and both projects are conceived and realized independently. SK Corporation is installing about 500 point-based traffic detection systems along Seoul's major arterial corridors whereas ROTIS Co. Limited is already operating a beacon-based AVI system with 12,000 probe cars providing traffic information to public media and taxi companies.

At present, two companies are forming a consortium that is recommended by city government. And a lead company would be SK Corp. since it has an advantage in telecommunication service and infrastructure traffic-information-dissemination-wise. One of their major concerns is to collect traffic data and process it properly. Even with 500 the-state-of-the-art detector systems deployed and 12,000 tag-installed probe cars, there found to be problems in data reliability and accuracy.

One viable solution is to fuse real-time data obtained from both systems since 1) one system seems to produce superior data to the other or vice versa as traffic condition changes, and 2) both system independently have done almost everything they can in terms of improving data accuracy and reliability. Authors have been heavily involved in selecting and testing of non-intrusive detection systems and developing methods of processing raw data into link travel-times.

As we all know, data fusion is the seamless integration of data from disparate sources. Data fusion techniques were originally applied in battlefield surveillance and tactical situation assessment for military purposes. Many sciences and engineering fields such as robotics, automated manufacturing and remote sensing utilize them nowadays. Transportation field is no exception as, we see, ATIS projects such as Pathfinder, ADVANCE and TravTek are gathering traffic information from different types of collection sources and heavily using fusion methods to enhance the reliability and accuracy of disseminating information.

This paper presents/addresses some issues exposed in the course of developing traffic information service system by the two companies and mainly focuses on the methods of improving quality and accuracy in traffic data such as link travel time by utilizing data fusion technique. This paper also describes a field test conducted to evaluate the final data outcomes that underwent the fusion process.

2. A PROJECT CALLED "TOTAL SERVICES for DRIVERS (TSD)"

For years SK Corp., one of leading companies in energy and logistics industry, has been working with its sister companies such as SK Telecom and SK C&C in developing a service initiative called Total Service for Drivers (TSD). The TDS entails perhaps every aspects of real-time information that drivers in cars wish to obtain through wireless communication. Such information includes traffic and parking conditions, yellow page service, navigation, route guidance, stock prices, weather, game, entertainment, health and etc.

TSD project deploys about 500 point-based non-intrusive traffic detectors along 36 major arterial corridors in Metro-Seoul area in order to collect traffic conditions on roadway links. The project also considers deployment of several thousands of GPS-mounted probe cars to improve data quality on link travel time.

For traffic data collection at stationary points shown as below, TSD uses 200 video image detectors and 300 radar-based multilane detection systems. Each detector is mounted on utility pole such as light poles along streets and will undergo system calibration and wireless communication test. With a goal of commercial service beginning to general public in mid-2001, detailed designs on architecture, service media, services scenarios, necessary algorithms, database, user equipment, and communication network has been completed.

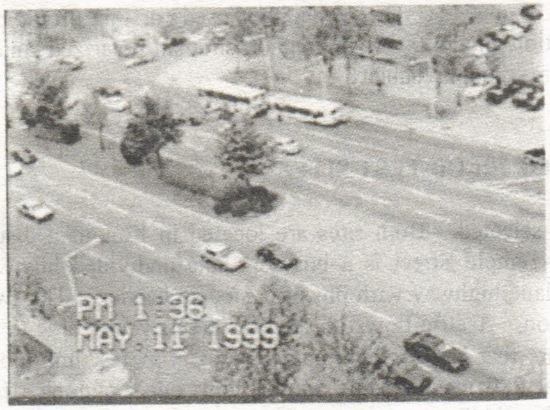

Figure 1. View from A Typical TSD Detectors with Side-firing Position

3. ROAD TRAFFIC INFORMATION SYSTEM (ROTIS) IN SERVICE

For years, ROTIS Co. Ltd. has been doing commercial business in traffic information field. Its real-time traffic information system provides roadway and traffic conditions, for urban freeway, major streets in Seoul metropolitan area via Internet, ARS, PC, and user equipment (OBU). Such information includes link travel speed, travel time, incident, and construction and maintenance activities.

The system employs AVI or DSRC technology and utilizes about 20,000 beacons at urban intersections and 12,000 probe cars that are mostly taxis. A typical system consists of tags, RF modules, antenna, readers, and software. Each tag is attached to a probe vehicle, and encoded with identification information about that vehicle. Communication between beacons and probes, tagged vehicles, is accomplished within CB radio frequency. Travel time for a vehicle, for example, can be easily calculated by comparing entry times recorded at two successive beacon stations.

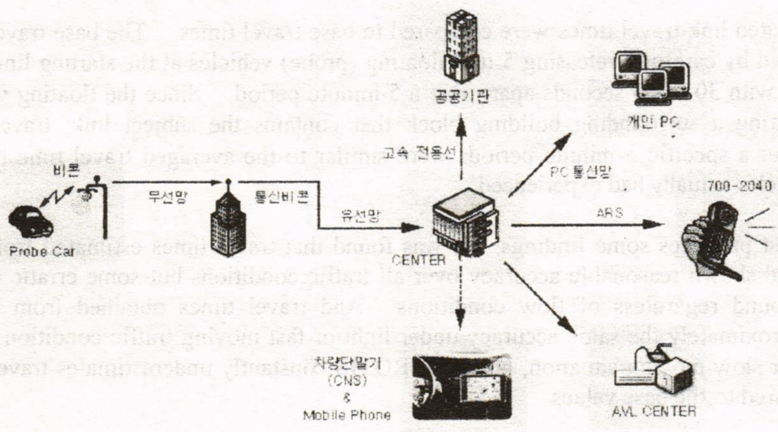

Figure 2. ROTIS System Service Diagram

The maximum data transmission rate is 200 Kbps, and the maximum detection range for high-speed vehicles is 7-10 meters. The technology used for this prototype was a backscatter passive communication method. A high gain circular polarized antenna used gets data from/to a tag with a maximum reliability.

4. DESCRIPTION OF FIELD TEST SITES

Two test sites were selected. Both sites are located in Kangnam district near the KOEX building. Bongeun-Temple Street is a busy six-lane undivided highway while Yongdong Street is a busy ten-lane highway with physical median barrier. The two streets intersect at the KOEX intersection. Traffic flows on the two streets varies time to time. Traffic peaks in evening rush hours that last for minimum 3 hours. A test link along Bongeun-Temple street stretches about 300 meters while another link on Yongdong street 400 meters with pedestrian signal in the middle.

Table 1. Description of Test Sites

Site	Street Name	Subject Test Link
A	Bongeun-Temple St.	Samjung Hotel → Kyongbok Apt.
B	Yongdong St.	AEM Building → Samsung Subway St.

5. FIELD TEST OF THE ACCURACY OF THE TWO TRAVEL TIMES

A test of data (travel times produced by the two services) accuracy was conducted. The need for accuracy test was obvious: it was reported many times that travel times produced by two service systems weren't quite accurate and both systems needed to be evaluated to changing traffic conditions in terms of travel time estimation accuracy.

At first travel times from the two different data collection modes are in a raw data format and subsequently undergo data screening process and travel time conversion algorithms finally producing estimated link travel time.

These estimated link travel times were compared to base travel times. The base travel times were obtained by carefully releasing 5 to 7 floating (probe) vehicles at the starting line of the subject link with 30 to 60 seconds apart over a 5-minute period. Since the floating vehicles kept circulating a surrounding building block that contains the subject link, travel times obtained over a specific 5-minute periods were similar to the averaged travel time that 2-3 floating vehicles actually had experienced.

The field test produces some findings. It was found that travel times estimated from TSD detectors had shown reasonable accuracy over all traffic conditions but some erratic outliers had been found regardless of flow conditions. And travel times obtained from ROTIS showed approximately the same accuracy under light or fast moving traffic condition. Under congested or slow moving situation, however, ROTIS constantly underestimates travel times when compared to the base values.

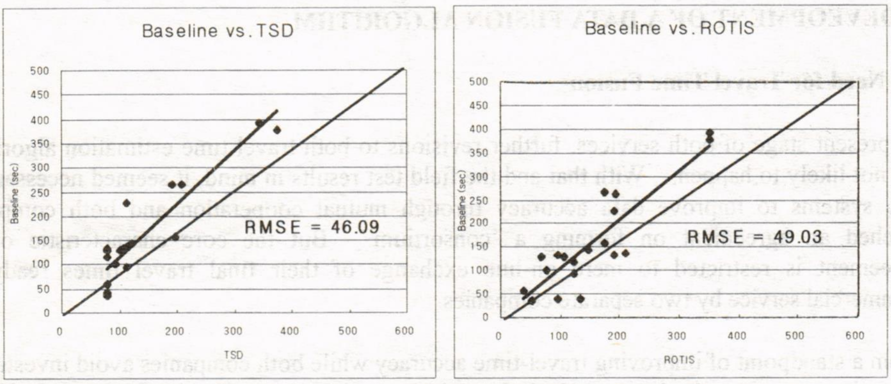

Figure 3. Comparison of Travel Times to Baseline Data at Test Site A

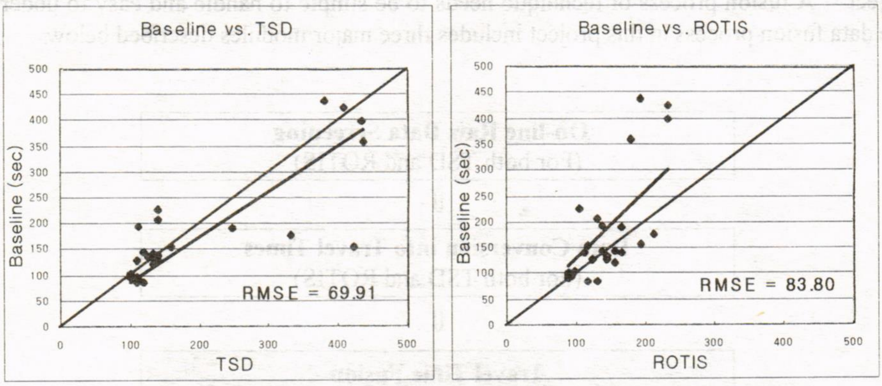

Figure 4. Comparison of Travel Times to Baseline Data at Test Site B

Possible reasons to problems would be as follows;

1) Since for both services, a travel time provided for a subject link represent a traffic flow condition averaged over 5 minutes, travel times bears high fluctuations due to traffic signals including a pedestrian signal. Depending upon traffic signal cycle lengths, flow conditions in a link could differ significantly one period to another.

2) Because typical TSD's IDS collects data in terms of spot speed at a mid-link, the position of tail of queue significantly influences a travel time conversion formula such as a FETTOS which relates the occupancy and speed collected to calculation of final travel times.

3) For ROTIS, a limited number of probes restrict the number of available travel time reports transmitted from a subject link RF antenna. In most case, the number of reports ranges form 1 to 5 over a 5-minute period. Less the reports, lower the travel time reliability.

4) The communication lag or failure between tag and ROTIS antenna in a 5 minute period due to very slow moving traffic situation seems to produce preset maximum travel times. This often causes the underestimation of travel times. It is believed that ROTIS perhaps imposed inadequate maximum travel times depending upon link length.

6. DEVEOPMENT OF A DATA FUSION ALGORITHM

6.1 Need for Travel Time Fusion

At present stage of both services, further revisions to both travel time estimation algorithms are not likely to happen. With that and the field test results in mind, it seemed necessary for two systems to improve data accuracy through mutual cooperation and both companies reached an agreement on forming a 'consortium.' But the core characteristic of the agreement is restricted to mere on-line exchange of their final travel times ready for commercial service by two separate companies.

From a standpoint of improving travel-time accuracy while both companies avoid investing of extra time, money and other resources, the resorting approach was the development of a travel time estimation algorithm utilizing "data fusion technique" similar to that of ADVANCE project. A fusion process or technique needs to be simple to handle and easy to understand. The data fusion process in this project includes three major modules described below.

On-line Raw Data Screening
(For both TSD and ROTIS)

⇓

Data Conversion into Travel Times
(For both TSD and ROTIS)

⇓

Travel Time Fusion
(Fuse using the weighted average formula)

Figure 5. Data Fusion Process

The first is on-line raw data screening module that eliminates inadequate raw data lying outside preset criteria. The preset criteria have allowable minimum and maximum values. The second process is the conversion of screened data into travel times (TT_T and TT_R). In this conversion process, TSD uses VOS (volume, occupancy and speed), distance to detector, cycle length and the number of phases as independent variables in order to produce travel time while the conversion technique of ROTIS is concealed. Finally, two types of travel times undergo the data fusion utilizing a simple mathematical equation. The equation itself has a form of a weighted average. The weight factors such as represent the relative degree of significance or reliability of travel times calculated from two different services.

$$\text{Final\_Travel\_Time} = \frac{f_T \cdot TT_T + f_R \cdot TT_R}{f_T + f_R} \qquad \text{EQ (1)}$$

where, TT_T and TT_R = travel times calculated by TSD and ROTIS in order
f_T and f_R = fusion weight factors for TSD data and ROTIS in order

6.2 Handling of ROTIS Data

Before embarking on a core part of data fusion such as application of fusion formula, an extra treatment of ROTIS data seemed necessary since in many cases underestimation of actual travel times was obvious. Figure 6 shows ROTIS' tendency of travel time underestimation particularly under heavy flow condition.

In order to develop a data handling process to improve accuracy of ROTIS, it was determined that heavy statistical analyses be avoid and rather an intuitive judgment based on data trend was employed. Since underestimation occurs mostly under heavy traffic condition such when the condition requires travel time to be more than 250 seconds, 20% increase of travel time was adopted while, under light traffic condition, small but linear increase of travel times depending upon ROTIS travel time quantity was used.

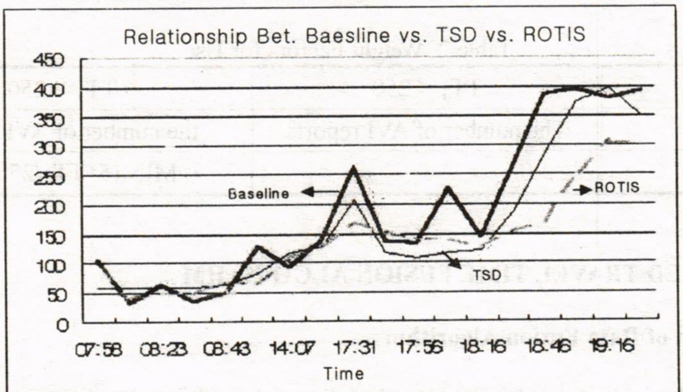

Figure 6. Comparison of Three Travel Times on Daily basis

The 250 seconds is a quantity that resulted from doubling the conventional traffic signal cycle length (110–130 seconds) on busy urban intersection in Seoul. And maximum 20% of increase was used because even though visual observations of limited data sets justified 20 to 40 % increase of ROTIS data when compared to baseline data, most conservative value should be adopted. This 20% limits unnecessary blow-up of travel times when ROTIS travel times are considered quite accurate even under heavy traffic condition.

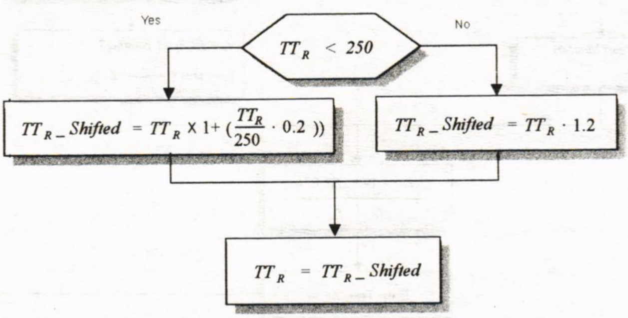

Figure 7. Handling Process of ROTIS Data (Data Shifting)

As shown above, TT_T = 250 seconds was used as a threshold value to differentiate heavy flow from light to moderate flow since TT_T data show relatively high credibility travel-time-accuracy-wise. For some cases, TSD travel times seem to be inadequate or inaccurate. But with no true travel times available when service is in operation one has to choose a less worse candidate. Of course, if ROTIS' probe population grows up to a reasonable number such as 2-3% of total traffic volume, the choice of candidates is a completely different story.

6.3 Determination of Weight Factors

In producing final travel times from the fusion formula, the most important step is to determine the weight factors. Determination of the factors is two-folded. TT_T= 250 determines which weight factors are for use. The number of AVI reports was found in the range of 0 to 9, but in most of links observed the AVI report number was below 5. MIN ($5*TT_T/250$, 10) was used to increase the weight of TT_T as discussed earlier.

Table 2. Weight Factors for Use

Case	$TT_T < 250$	$TT_T > 250$
f_R	The number of AVI reports	the number of AVI reports
f_T	3	MIN ($5*TT_T/250$, 10)

7. A PROPOSED TRAVEL TIME FUSION ALGORITHM

7.1 Final Form of Data Fusion Algorithm

The algorithm basically executes EQ (1) calculation. In addition, handing process of ROTIS data is included with intension of travel time increase under heavy flow condition, and a process that differentiate the data credibility of two collection sources by bestowing the weight factors based on the value of travel times and the number of AVI reports as well.

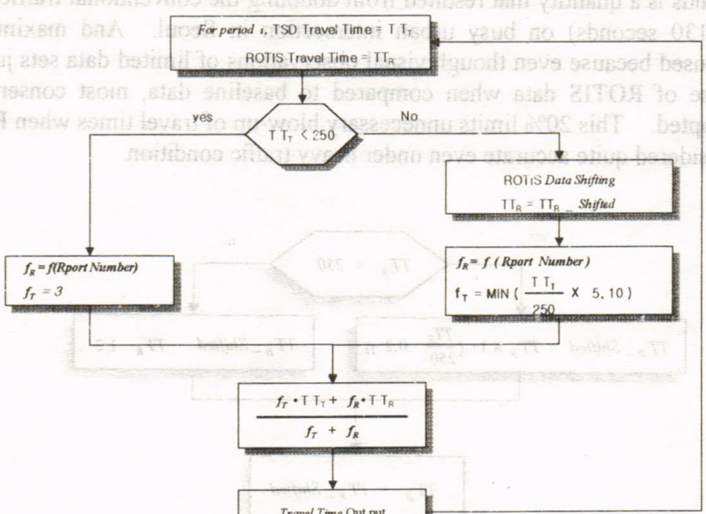

Figure 8. Fusion Algorithm Flow Chart

- Input Data: Travel times by TSD and ROTIS, the number of reports by ROTIS
- Input Parameter: 3 for TSD travel time weight factor under light to moderate flow
- Output Data: Fused travel time
- Algorithm's Data Process Interval: every 5 minutes

7.2 Execution Results of Fusion Algorithm

As results of executions, following outcomes has been issued. Figure 9 describes the comparisons of baseline travel times to fused travel times without handling of ROTIS Data for site A and site B. Figure 10 describes the comparisons of baseline travel times to fused travel times with handling of ROTIS Data for both sites. As stated before, relatively lower accuracy shown in site B is believed to stem from the existence of a mid-link pedestrian signal that makes travel time characteristics more complex.

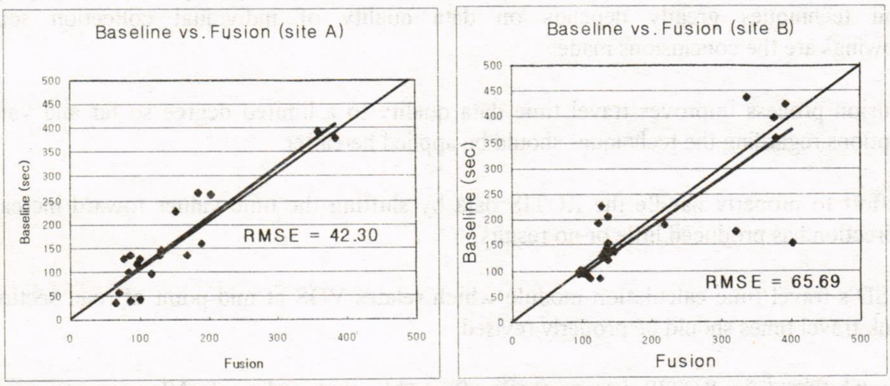

Figure 9. Comparison of Baseline Data to Fused Data Without ROTIS Data Handled

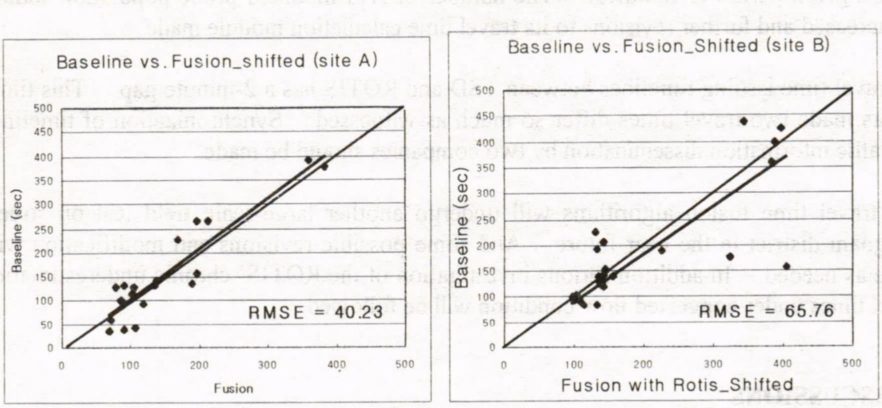

Figure 10. Comparison of Baseline Data to Fused Data With ROTIS Data Handled

The following table shows the changes of Root Mean Square Errors (RMSE) resulted from executing the proposed fusion algorithm. Clearly fusion improves the accuracy of estimated travel times lowering the RSME values. But handling of ROTIS data seems to contribute little or none in improving the accuracy.

Table 3. Changes of RMSE Resulted from Fusion Process

Classifications	Travel Time_Raw Data		Fusion without	Fusion with
	TSD	ROTIS	ROTIS_handled	ROTIS_handled
Site A	46.09	49.03	42.30	40.23
Site B	69.91	83.80	65.69	65.76

8. CONCLUSIONS

As an effort to improve accuracy of travel times a travel time estimation algorithm utilizing "data fusion technique" was developed herewith. Using this, data from two distinctive data sources (Image Detection Subsystems by SK Corps. and beacon-based AVI Systems by ROTIS Co.) were properly handled to produce adequate travel times or fused travel times.

Application of fusion techniques seems promising showing some or noticeable improvement in travel-time estimation. Of course, the level of data quality improvement employing fusion techniques greatly depends on data quality of individual collection source. Followings are the conclusions made.

1) Fusion process improves travel time data quality to a limited degree so far and various options regarding the techniques should be applied hereafter.

2) Effort to properly handle the ROTIS data by shifting the time values toward increasing direction has produced little or no results.

3) TSD's travel time calculation module which relates VOS at mid-point of road section to link travel times should be properly revised.

4) Credibility of the ROTIS data is greatly affected by the number of AVI reports transmitted in a given period (5 minutes). The number of AVI-mounted probe population should be increased and further revisions to its travel time calculation module made.

5) Travel time issuing timelines between TSD and ROTIS has a 2-minute gap. This time lag has made two travel times differ so much as witnessed. Synchronization of timelines of traffic information dissemination by two companies should be made.

The travel time fusion algorithms will undergo another large-scale field test on streets in Kangnam district in the near future. And some possible revisions and modification will be made as needed. In addition serious investigation of the ROTIS' chronic underestimation of travel times under congested flow condition will be followed.

9. DISCUSSIONS

In the course of paper reviewing process, authors have received many good comments. As one reviewer pointed out, conclusions may be premature since this study is based on small-scale database in only 2 test sites. Transferability of the algorithm is also problematic as another reviewer pointed out since data used for model building and validation is same. Authors completely agree with them. But a large-scale test scheduled in near future will help us present more statistically justifiable results.

Aside from data fusion, the quality of travel time from the two collection sources should be enhanced independently from fusion techniques since the underestimation of travel times do occur frequently. But this problem should be solved through more extensive algorithm fine-tuning and recruiting more probe vehicles. The effort made up until now is surely far from enough.

REFERENCES

(1) D. Fenichell, P. Alling, and M. Douglas (1994) **Electronic Toll Collection: Technology Update and Market Analysis.** Waters Information Service, London.
(2) ITS Architecture Development Program Phase I Summary Report (1994) **USDOT & ITS America**, Washington, DC.
(3) Stanislaw Berka, Xin Tian and Andrew Tarko (1995) Data Fusion Algorithm for ADVANCE Release 2.0. **ADVANCE Working Paper Series # 48.**
(4) Sumner, R. (1991) "Data Fusion in Pathfinder and TravTek", **Vehicle Navigation and Information Systems Conference Proceedings**