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Data Processing Procedure for DSRC Probe-Based Advanced Traveler Information System on Signalized Arterials

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ABSTRACT

When faced with traffic congestion on the road, drivers are eager to avoid it by diverting to a less congested route using real-life traffic information. To meet the demand from the public, advanced traveler information systems (ATIS) that collect, process, and provide real-life traffic information (travel time or speed) are gaining attraction worldwide. Due to the efficiency and ability to collect link travel times, 5.8 GHz Dedicated Short-Range Communications (DSRC) probe-based ATIS has been actively deployed in South Korea. In this study, the data processing procedure to generate real-life traffic information in the DSRC probe-based ATIS on signalized suburban arterials in Korea is presented. The procedure includes methods for traffic information generation, outlier filtering, and missing data imputation. Real-life traffic information is generated in three sections—the standard, the RSE, and the information—to provide it to the drivers and to relay it to other traffic management centers. Outlying observations are filtered using a coefficient of variation logic. If real-time data are missed, a missing data imputation process is activated. Due to the practical characteristics of the methods presented herein, they could be practically referred by practitioners of probe-based systems of the kind. This article concludes with some discussions on directions towards an improvement in the algorithms.

KEYWORDS: ***ATIS, DSRC, Probe, Traffic information, Travel time***

Introduction

Due to the advancement of modern information and communication technologies coupled with increasing demand for real-life traffic information, advanced traveler information systems (ATIS) that gather, process, and disseminate traffic information have become an essential element in modern traffic systems [1]. Beyond the real-life information provision itself, information accuracy is drawing more attention from the public. Compared to traditional point detectors, probe-based systems are, due to their direct link travel-time collection, gaining more interest in ATIS in Korea, as electronic toll collection systems (ETCS) are becoming popular nationwide [2]. In Korea, 5.8 GHz dedicated short-range communications (DSRC)-based ETCS was deployed on the entire freeway system, and the on-board unit (OBU) for the ETCS is in approximately 60% of the vehicles. Using

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vehicles with the OBU as probes, DSRC probe-based ATISs are actively deployed on signalized suburban arterials in the vicinity of Seoul, Korea [3].

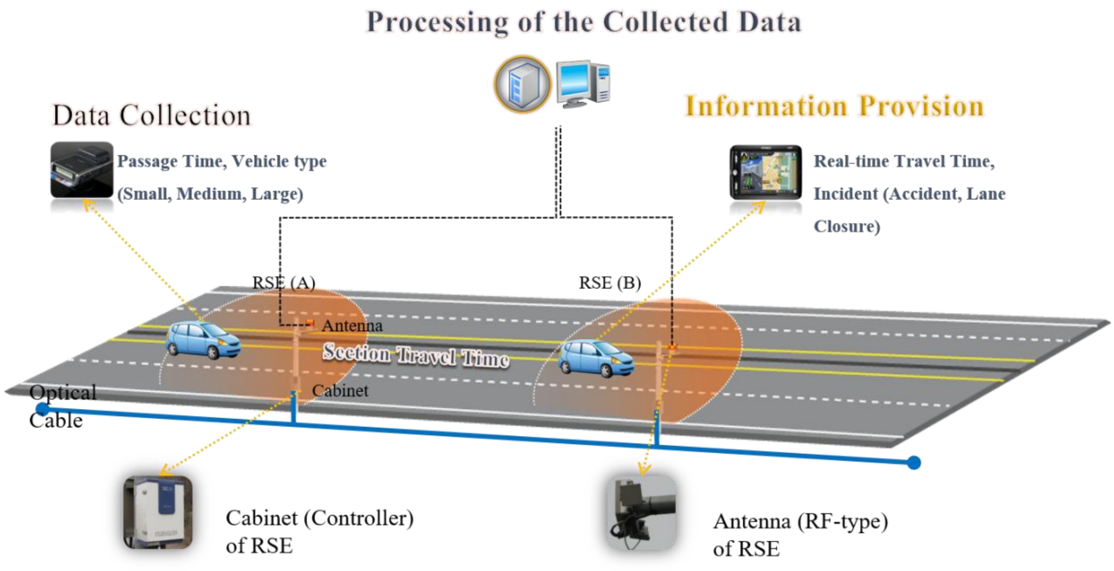

Fig. 1 Schematic of DSRC Probe-Based ATIS

As shown in Fig. 1, two consecutive roadside equipment (RSE) devices collect the coded identification (ID) of the OBUs mounted on passing vehicles and transmit the gathered ID along with the detection time to the traffic management center (TMC); subsequently, the ID is matched in the TMC to produce the travel time between the RSEs. The produced travel time information is subsequently disseminated to drivers through variable message signs (VMS), automatic response system (ARS), the Internet, smart phone applications, and other OBUs [4].

This article introduces the data processing procedure used in the DSRC probe-based systems. Compared to other articles that only focus on a small portion of the whole data processing procedure, this article deals with the entire procedure in operation in the DSRC probe-based TMC deployed in suburban arterials in Korea, implying that it could be practically referred by practitioners. The procedure presented in this article is largely categorized into three sub-procedures—traffic information generation, outlier filtering, and missing data imputation.

Traffic Information Generation

Section Configuration

To understand the traffic information generation procedure, prior knowledge of the section configuration, as illustrated in Fig. 2, is required. Due to the signalized arterial characteristics, sections for traffic information provision are typically divided into three sections—standard, RSE, and information section. The standard section is commonly composed of the section between two consecutive traffic signals. The section, constructed and updated by the Korean government, is used for relaying produced traffic information to other TMCs or vice versa. The RSE section is the section where two consecutive RSEs produce travel time data by matching OBU IDs in passing vehicles. Lastly, the information section is the section on which traffic information is produced and disseminated via VMS, the Internet, and so on.

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Traffic Information Generation

Due to the multi-layered sections, the procedure for traffic information generation is somewhat complicated, as described in Table 1. Probe ID (OBU ID) matching comes first. To address the absence of matched probe data possibly caused by the neighboring RSE breakdowns, the procedure matches probes up to four upstream RSEs. Subsequently, an outlier removal sub-procedure is performed. A subsequent chapter will deal with the details on the outlier removal method. If no probe data are observed, an imputation procedure is activated using archived historical data. Next, travel times and speeds of the RSE, the standard, and the information section are calculated in sequence. Finally, the level of congestion of the information section is determined for a graphical indication on the Internet and smart phone applications

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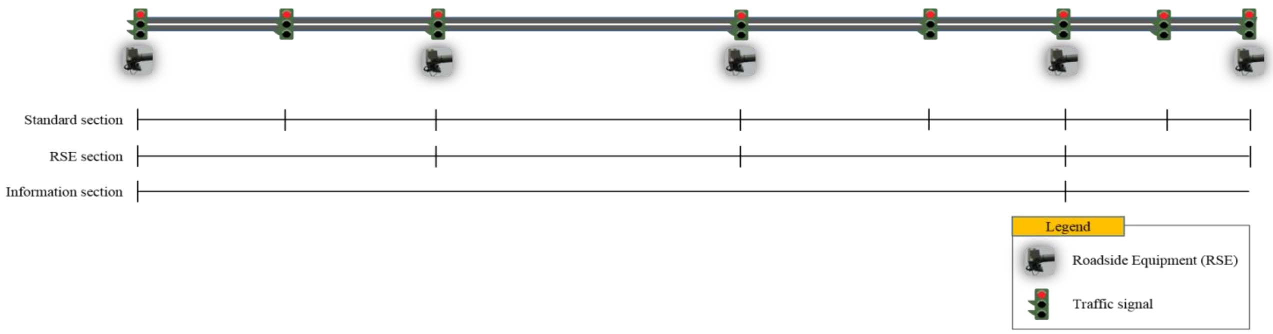

Fig. 2 Section Configuration

Table 1. Procedure for Generation of Real-Life Traffic Information

Step	Content
1	Matching OBU IDs (up to four upstream RSEs)
2	Filtering outliers
3	Imputing missing data (if necessary)
4	Calculating travel time and speed of the RSE section
5	Calculating travel time and speed of the standard sections within the RSE section
6	Calculating travel time and speed of the information section encompassing the standard sections
7	Identifying level of congestion of the information section

The congestion levels are determined by the level of service (LOS) criteria presented in the Korea Highway Capacity Manual (KHCM). The KHCM utilizes average travel speed as the measure of effectiveness (MOE) for signalized arterials. That is, a green indication (uncongested flow) for LOS A to D, a yellow indication (partially congested flow) for LOS E, and a red indication (fully congested flow) for LOS F are represented.

Outlier Filtering

The matched probe data mentioned above inevitably include outlying observations (or outliers) that occur mainly from the parking activities at roadside stores, exit/entry maneuvers between the consecutive RSEs, U-turns, illegal driving on the shoulder during traffic congestion, and so on. If the outliers are included in real-life traffic information, it could be obsolete, causing a decreasing rate of return of the system.

Table 2. Technique for Outlier Removal

Cases	Outlier removal method
CV<0.05	Remove the top 2% and bottom 3%
0.05≤CV<0.1	Remove the top 5% and bottom 5%
0.1≤CV<0.15	Remove the top 8% and bottom 7%
CV≥0.1	Remove the values lying the outside of the mean ± standard deviation

The outlier filtering procedure is largely categorized into two parts; one filters speeds lying

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outside the predefined values (0 and 180 km/h), and the other does so using the predefined coefficient of variation (CV) values (see Table 2). If the number of observations within a collection interval (e.g., 5 m) is greater than seven, the CV method is applied after removing the highest and lowest values to accommodate the signalized arterial features of large number of outlying observations, mainly caused by frequent access points.

Missing Data Imputation

In real-world ATIS systems, the missing data problem is inevitable due to field device breakdowns (or malfunctions), communications interruptions, and errors in center systems. To accommodate these undesirable situations, a missing data imputation strategy is essential for seamless information provision.

The imputation algorithm, as shown in Fig. 3, is executed every 5 min (aggregation interval). If the number of matched travel times (TTs) after filtering outliers are more than one observation, the algorithm does not activate. When only one sample exists, the effectiveness of the value is verified by comparing the neighboring temporal and spatial observations. If the value is considered valid, no imputation is performed and vice versa.

$$imputed\ (t) = hist.\ (t) \times \left(1 + \frac{curr.\ (t-1)}{hist.\ (t-1)}\right) \quad (1)$$

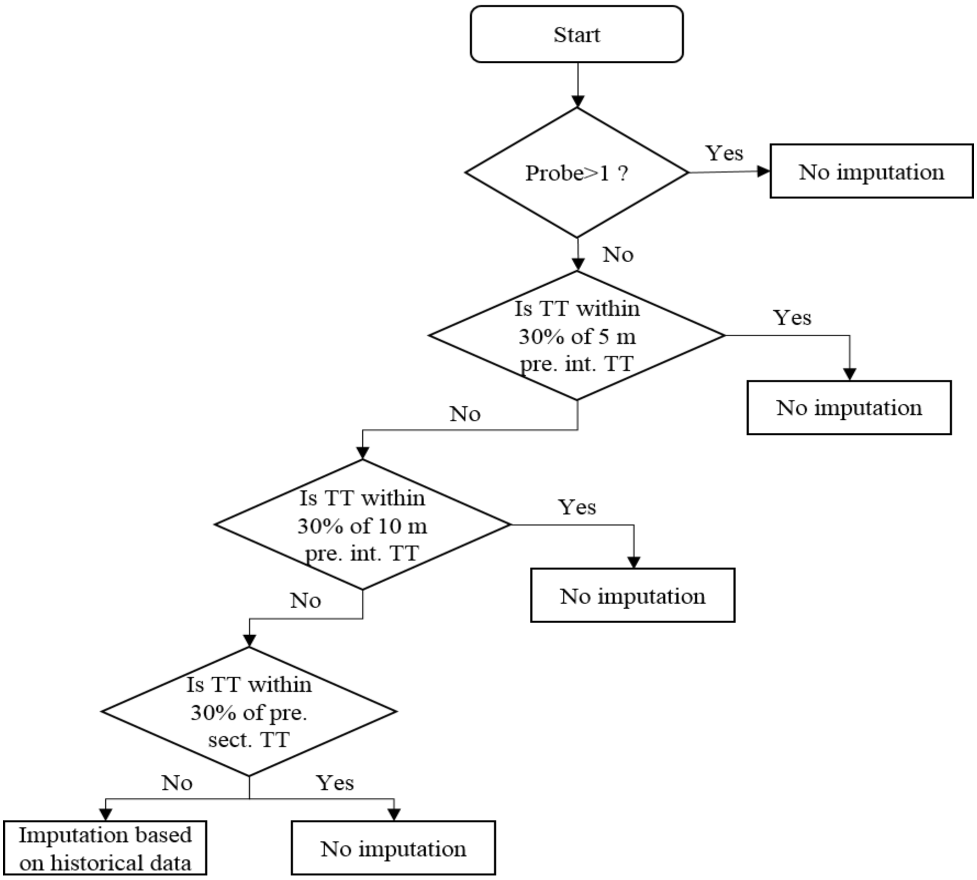

Fig. 3 Algorithm for Imputing Missing Data

If the algorithm determines that the imputation process is necessary, the missed data are imputed using the Equation 1. All the imputed values can be obtained based on the historical data. Here, the historical values are obtained from the data at the same time of day. Fig. 4 shows the whole procedure for the probe data processing that includes the three sub-procedures stated above.

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Discussion

A comprehensive procedure for the probe data processing for generating real-life traffic information is discussed. The procedure is categorized into three sub-procedures—traffic information generation, outlier filtering, and missing data imputation. The traffic information generation sub-procedure produces real-life travel time and speed information of the three sections including the standard, the RSE, and the information section. Outlier filtering sub-procedure censors outlying observations using a min/max value logic and the CV technique. The missing data imputation sub-procedure identifies the necessity for imputation when there is only one filtered probe. The entire procedure is illustrated in Fig. 4.

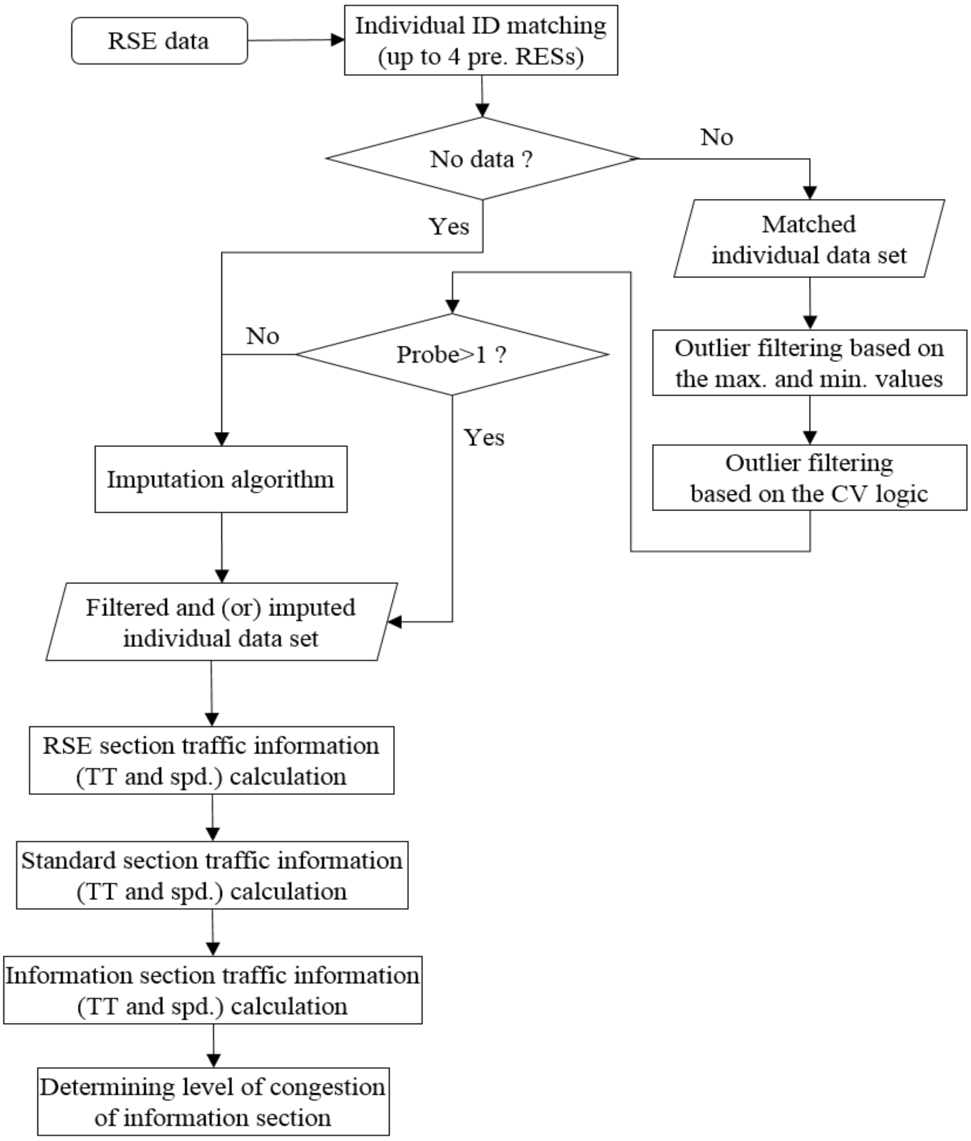

Fig. 4 Entire Procedure for Probe Data Processing

Conclusions and Future Studies

The algorithms for outlier filtering and missing data imputation appear to be quite simple compared to other sophisticated methodologies found elsewhere [5-10]. However, in real-world situations, complicated algorithms that contain many parameters and assumptions cannot be effectively applied due to various unexpected

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situations. Nonetheless, the proposed algorithm could be further improved to produce more reliable traffic information in the following perspectives.

First, the outlier filtering algorithm needs to be enhanced due to its innate limitations. The CV technique has limited theoretical background. The threshold values of 2, 3, 5, 7, and 8% are quite arbitrary. Furthermore, one extremely aberrant value can make unnecessary large effective range, causing outliers to be considered valid. Lastly, the technique determines valid values as outliers when all the observations in a collection interval consist of valid ones. To resolve these problems, the effective range for outlier filtering needs to be determined using values in previous and current interval values. More concrete theoretical background is also necessary.

Second, the imputation logic could be further enhanced by analyzing the substantial archived data in the database. The current algorithm does not allow for atypical weekdays, such as national holidays, vacation days, and so on. Another problem is that 5 min travel times (speeds) could not be closely related to historical data. Hence, a more sophisticated algorithm needs to be developed using different aggregation intervals.

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