An Estimation of Optimal Number of Probe Vehicle of the DSRC Based Traffic Information System Considering Accuracy and Collection Rate

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Abstract: This study aims to estimate the optimal number of probe vehicle in the city of Daejeon where Advanced Traffic Information Systems are deployed. 376 RSE`s were installed in the strategic nodes in Daejeon. According to the result of analyzing the characteristics of collected data, the collection ratio of the whole network in Daejeon is merely 65% due to the limitation of RSE installation. And it is analyzed that the accuracy of the data available links is relatively high as 70%. Also, according to the result of analyzing the number of processing probes in the time interval of 5 minutes, useful information is generated by processing the average of 5.11 probe cars. This study aims to estimate the proper number of processing probes in the time interval of 5 minutes and suggest both reliable and accurate methods. In conclusion, it is shown that when the weighted values of the collection ratio and the accuracy are applied equally, the most effective way to process traffic information rely on collecting 4 or more probe cars. With this study result, it will be possible to generate reliable traffic information in the city of Daejeon.

Keywords: Advanced Traffic Information System, Probe Vehicle, Network Coverage, Accuracy Rate

1. INTRODUCTION

The Advanced Traveler Information Systems (ATMS) is a system to supply traffic information to travelers in moving on the road. The ATIS collects traffic data to generate traffic information to assist travelers. Traditionally, the traffic data has been obtained from spot detectors such as a loop detector, but the ATIS is able to collect them from some probe vehicles equipped on-board device (OBE) using a communication system such as Dedicate Short Range Communication (DSRC) now. The probe vehicle in moving near to a RSE supplies spent travel time of the route from location of the probe vehicle when previously communicated with any RSE to current location. The ATIS estimates real-time traffic information as accurately as possible using the traffic data collected by RSEs. The traffic information includes average travel time of individual links, traffic flow rate and incident as well. The information is presented to users such as individual travelers and traffic management centers (TMC).

The travelers and operators of the TMC would make an important decision on the basis of the offered information. For example, a traveler would consider either the estimated travel time from start location to the desired destination or private experience prior to determine a route. If the information offered by ATIS is not enough accurate to be trusted, the traveler would not trust the ATIS. Therefore, it is very important how much accurate the information is to ATIS. On the other hand, if the ATIS service just covers a confined area, the information could not be usable for travelers to decide the route in many cases. Thus, the coverage level of the ATIS on a network can be one of primary measurements to evaluate efficiency of the system.

As a matter of fact, the relationship between high accuracy and high coverage level of the ATIS is mutually exclusive because of limitation of number of probe vehicles. The accuracy of the information increases in proportion as number of probe vehicles used to estimates traffic information increases (Cetin et al., 2005). However, if the ATIS just use the traffic data of links that detected more than a certain number of probe vehicles for the high accuracy, the coverage level of the ATIS would decrease because number of available links decreases. Therefore, it is required to determine the appropriate criteria value of the minimum number of probe vehicles in order to ensure reasonable accuracy and coverage level of the ATIS.

In this paper, the relationship between number of probe vehicles and accuracy of ATIS are modeled using collected traffic data obtained from ATIS of the Daejeon Metropolitan City, Republic of Korea. The Coverage Level of the ATIS, also, is evaluated by varied critical values of the minimum number of probe vehicles. Consequently, the optimal critical value of number of the minimum number of probe vehicles for accuracy and coverage level for the ATIS is found.

2. LITERATURE REVIEW

Some researchers have found the optimal number of probe vehicles during a certain processing interval (Holdener, 1994; Shrinivasan, 1996; Chen, 2000; Drane, 2001; Li, 2005). Karthik et al. found the optimal number of probe vehicles for the highway by varied processing intervals of 5, 10, 15 minutes (Karthik ea al, 1996). Cetin et al. found the optimal number of probe vehicles to improve confidence level of the estimated travel time (Cetin et al., 2005). They suggested a virtual node to reduce the error caused by some vehicles that made left turn. Jiang et al. simulated a network using the VISSIM, a simulation application, and randomly collected vehicles as probe vehicles. They calculated error by varied numbers of probe vehicles and processing intervals. They found that correlation between number of probe vehicles and processing interval is not remarkable.

In the existing researches above, the optimal number of probe vehicles for not only entire network, but also individual links has been variously studied. However, most of them used data obtained by simulation, and determined the optimal number of probe vehicles based on the accuracy. In this paper, the number of probe vehicles is optimized by not only accuracy but also coverage level of the ATIS using the realistic data.

3. STUDY AREA

The data used in this research was collected by ATIS of the Daejeon Metropolitan City, Republic of Korea in May 16 2011. The ATIS covers entire network of urban area in the Daejeon Metropolitan City. The ATIS includes 378 RSEs communicating with probe vehicles using DSRC technique, and the RSE were installed at the major intersections and knots spread over the urban area. The figure 1 shows the distribution of RSE on the urban area in the Daejeon Metropolitan City. In this paper, the data was used to analyze driving characteristics of probe vehicles such as average travel speed, and collecting characteristics of traffic data such as collection rate. In addition, the collection rate of traffic data of the entire network was analyzed.

Figure 1. Study area and location of RSE

4. OPTIMAL NUMBER OF PROBE VEHICLE

4.1. Accuracy of ATIS for link

To figure out the relationship between the accuracy and the optimal number of probe vehicles, two of links, named as Hanbatdaero and Daedeokdaero, that thirty or more probe vehicles were detected for 5 minutes were selected as sample data. The table 1 shows the selected links. It is assumed that the estimated average speed using all probe vehicles for 5 minutes is the true value of average speed for 5 minutes, and average speed calculated using p probe vehicles randomly selected within them is the estimated average speed by the ATIS. The estimated average speed is computed by the following equation:

$$\widehat{V} = \frac{1}{p}\sum_{i=1}^{p}\widehat{v}_i \tag{1}$$

where,

$\widehat{V}$: average speed (km/h),
$\widehat{v}$: PVs speed (km/h), and
p : number of collected PVs (veh/5min).

Table 1. Characteristic of road traffic

Road name	Peak time volume (veh/hour)	A.M. peak speed (km/h)	P.M. peak speed (km/h)
Hanbatdaero	5,746	17.4	14.7
Daedeokdaero	5,318	25.07	25.71

The value of p was varied from 1 to 10, and compared the accuracy of ATIS corresponding with the value of p, number of probe vehicles detected for 5 minutes. To guarantee high confidence level of the accuracy, this process were repeated thirty times for each value of p, and the thirty values of accuracy were averaged for the final accuracy of the ATIS. The figure 12 demonstrates how the probe vehicles are selected.

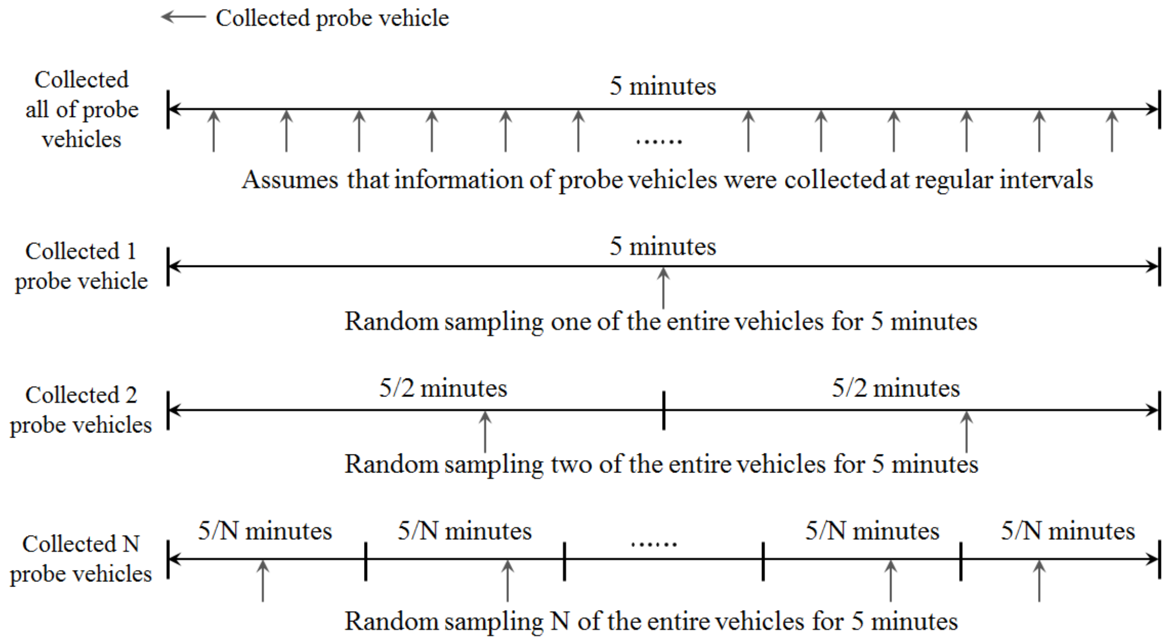

Figure 2. Method for random sampling

The error of ATIS is defined as the difference rates between the true value and the estimated value. Thus, error rate of ATIS is defined as the following formula:

$$\varepsilon_{err}(\%) = \left| \frac{V - \widehat{V}}{V} \right| \times 100 \tag{2}$$

In this paper, Accuracy Rate (AR) in percentage are proposed as a measurement of the accuracy of the ATIS. The AR of the ATIS is defined as the following equation:

$$AR(\%) = \frac{1}{30} \sum_{K=1}^{30} (100 - \varepsilon_{err_k}) \tag{3}$$

where,

ε_{err} : error rate (%),
M : repetition count , and
AR : accuracy rate (%).

The figure 3 shows comparison the estimated average speed of each link by each value of p with average speed of all probe vehicles. The average speed of all probe vehicles is assumed as the true average speed. It confirms finding of Cetin et al. that accuracy of estimated value increases in proportion as number of probe vehicles used for the estimation increases (Cetin et al., 2005). The table 2 presents the accuracy rate of the estimates by number of probe vehicles for Hanbatdae-ro and Daedeokdae-ro.

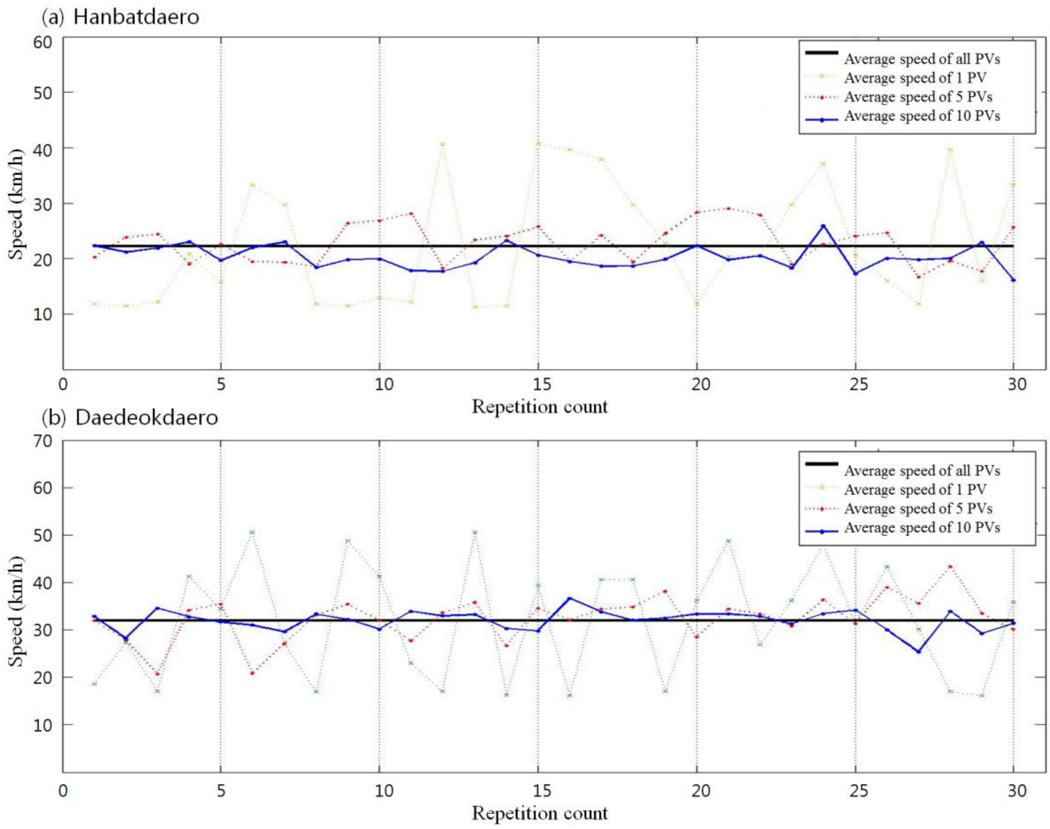

Figure 3 Result of accuracy rate

Table 2 Result of accuracy rate

# of PVs	Accuracy rate (%)		
	Hanbatdaero	Daedeokdaero	average
1	56.88	66.81	61.85
2	64.56	86.38	75.47
3	78.69	87.57	83.13
4	87.76	89.24	88.50
5	85.58	88.53	87.06
6	87.33	88.54	87.94
7	91.44	91.99	91.72
8	89.63	93.21	91.42
9	89.77	93.53	91.65
10	90.41	94.57	92.49

4.2 Coverage level of ATIS for network

The coverage level of ATIS for network, named coverage rate (CR) in this paper, is defined as the ratio of number of links on which more probe vehicles were detected than the critical value for 5 minutes to number of all links covered by the ATIS in percentage. For example, if the critical value is one, the coverage level would be 100%. The figure 4 shows variation of the coverage level by varied critical values, minimum number of probe vehicles to be accepted by ATIS. The variation is different by time period, A.M. peak, P. M. peak and Non peak time. The table 3 presents values of the coverage rate.

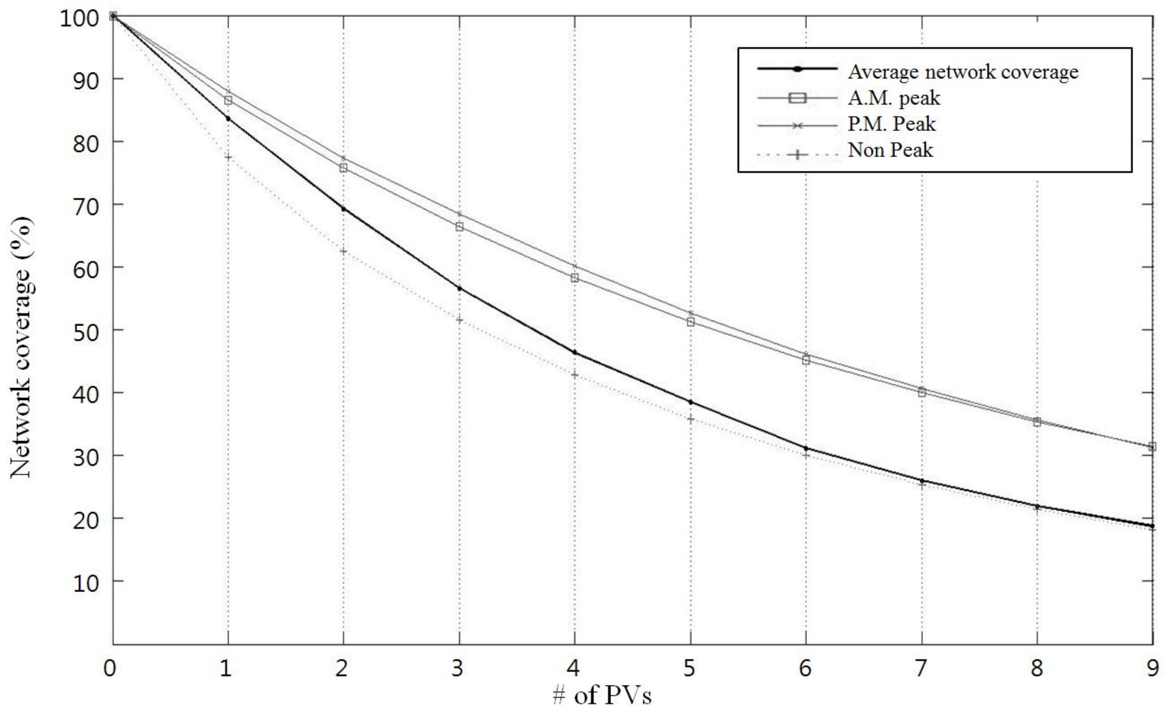

Figure 4 Result of network coverage

Table 3. Result of network coverage

# of PVs	Network coverage (%)			
	Average	A.M. peak	P.M. peak	Non peak
1	100.00	100.00	100.00	100.00
2	83.58	86.55	87.90	77.48
3	69.23	75.68	77.30	62.51
4	56.63	66.37	68.37	51.50
5	46.35	58.27	60.13	42.87
6	38.53	51.18	52.72	35.88
7	31.16	45.11	46.09	30.08
8	26.05	39.97	40.61	25.29
9	21.98	35.40	35.60	21.41
10	18.75	31.37	31.20	17.68

4.3. Result of optimal number of PVs

The number of minimum probe vehicles with largest summation of coverage rate and accuracy rate is determined as the optimal critical value of minimum number of probe vehicles. The coverage rate and accuracy rate were separately standardized using Z-Score, and the Z-score was converted to T-score with mean of 70 and standard deviation of 15 as the following:

$$Tscore = Zscore \times 15 + 70 \tag{4}$$

The summation of them was calculated using two ways: non-weighted method and weighted method. The weighted method is to apply weight of 0.6 for the coverage rate and 04 for the accuracy rate, labeled as α=0.4. The non-weighted method is equally to apply weight of 0.5 for the both of them, labeled as α=0.5. As a result, the optimal critical value is 4 vehicles for the non-weighted method, and 3 vehicles for the weighted method. The figure 5 graphically shows the process to determine the optimal critical value for each method, and the table 4 presents values of the results.

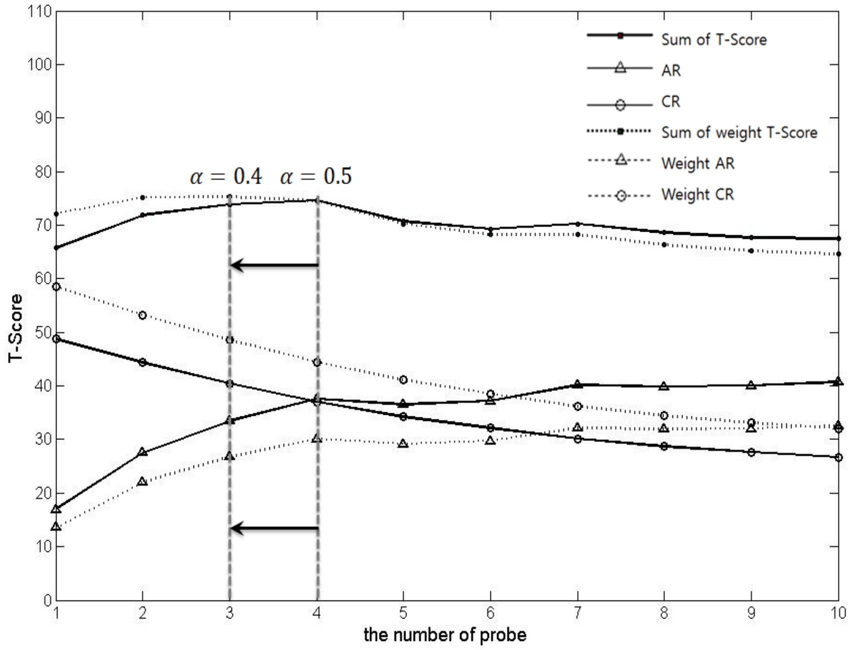

Figure 5. Result of optimal number of PVs

Table 4. Result of optimal number of PVs

# of PVs	α=0.5			α=0.4		
	t-score		Sum	t-score		Sum
	AR (%)	NC (%)		AR (%)	NC (%)	
1	16.95	48.78	65.74	13.56	58.54	72.10
2	27.51	44.33	71.84	22.01	53.19	75.20
3	33.45	40.43	73.88	26.76	48.52	75.28
4	37.62	37.01	74.63	30.09	44.41	74.51
5	36.50	34.22	70.72	29.20	41.06	70.26
6	37.18	32.10	69.28	29.75	38.52	68.26
7	40.12	30.10	70.21	32.09	36.12	68.21
8	39.88	28.71	68.59	31.91	34.45	66.36
9	40.06	27.60	67.67	32.05	33.12	65.17
10	40.71	26.73	67.44	32.57	32.07	64.64

5. CONCLUSION

This paper aimed to determine the optimal critical value of number of probe vehicles with consideration of the both of accuracy and coverage level of ATIS. The realistic data obtained by ATIMS installed on the Daejeon Metropolitan City was used to estimate average speed for 5 minutes in each link. The average speeds of probe vehicles detected on two links, Hanbatdaero and Daedeokdaero, were separately used to figure out relationship between accuracy of estimated average speed and number of probe vehicles. The average speed of all vehicles detected on each link was assumed as the true average speed of each link, and the average speed of probe vehicles randomly selected on the sample links were assumed as the estimated average speed. The accuracy of the estimated average speed was evaluated by varied number of selected probe vehicles, from 1 to10 vehicles with accuracy rate in percentage using suggested measurement, accuracy rate (AR) in percentage. The coverage level of the ATIS was evaluated using the coverage rate in percentage defined as the ratio of number of links with more probe vehicle than critical value to number of entire links covered by the ATIS. The coverage rate was assessed by varied critical values. The number of probe vehicles with largest summation of coverage rate and accuracy rate was chosen as the optimal critical value of number of probe vehicle. Each rate was standardized using Z-score, and the Z-score was converted to T-Score with mean of 70 and standard deviation of 15. And then the summation of T-scores of the both was compared with each other to find the optimal value. As the results, the optimal critical value of number of probe vehicles was 4 for the non-weighted method (α=0.5), and 3 for weighted method (α=0.4). It represents that the optimal value could be changed depending on the weights, and it is required to find the appropriate weight in the future. In addition, accuracy of ATIS was evaluated using only average speed. Thus, it is necessary to evaluate the accuracy using various estimated information such as flow rate in the future work. We hope that this research contributes not only to evaluate efficiency of the Advanced Traveler Information System established in another city, but also to improve the ATIS. Furthermore, this study could be guideline for design and planning of new ATIS for other cities.

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