SHORT TERM TRAVEL TIME PREDICTION USING CUMULATIVE TRAFFIC COUNTS AND UPLINK INFORMATION COLLECTED ON EXPRESSWAYS

Hironobu Otaka
Department of Engineering, Japan Highway Public Corporation
3-3-2 Kasumigaseki Chiyoda-ku Tokyo, 100-8979, Japan
TEL +81-3-3506-0404, FAX +81-3-3506-8870
E-mail: hironobu.otaka@jhnet.go.jp

Ryota Horiguchi
Representative Director
i-Transport Lab. Co., Ltd
2-12-404 Ageba-cho Shinjuku-ku Tokyo, 162-0824, Japan
TEL/FAX +81-3-5261-3077
E-mail: horiguchi@i-transportlab.jp

Hirokazu Akahane
Professor
Department of Engineering, Chiba Institute of Technology
2-17-1 Tsudanuma Narashino Chiba, 275-8588, Japan
TEL +81-47-478-0444, FAX +81-47-478-0474
E-mail:

ABSTRACT

This paper proposes a methodology to predict travel time in short term using uplink information of equipped vehicles. The prediction is based on a simple queuing model, of which traffic conditions are defined with two cumulative traffic flow curve at upstream and downstream ends of roads. The downstream cumulative curve is drawn with traffic counter, and the upstream curve, as the imaginary cumulative flow curve, is derived by horizontally shifting the downstream curve with the section travel time. Both cumulative curves can be predicted by using historical data. A couple of methods to predict cumulative curve are proposed in the paper. The performance of proposed prediction methods are validated through the experiments with observed data, which is collected on Keiyo-Road in Chiba.

INTRODUCTION

This research develops a methodology to predict travel time in short term using uplink information of equipped vehicles. Travel information system on the expressways in Japan now provides travel times of major designated sections at every five minutes based on detector speed information. The travel times are so-called ‘instantaneous’ travel time that are simple accumulations of the travel times of ‘unit sections’ at the present time and are provided to drivers through variable message signs (VMSs).

Figure.1 Ex. The travel time provided a driver through variable message signboard

Travel times of a unit section, which is covered by one detector, are estimated by assuming uniform travel speed measured by the detector. However, the travel times may include some error against the actual travel time, because the traffic conditions of the unit section may not be uniform in real.

Nowadays, the ETC (electronic toll collection system) was installed on the expressway in Japan. If the issues on privacy are solved, we may expect to utilize uplink information to identify individual vehicle for the purpose of the road administration. It must be more accurate to measure the section travel times with uplink information than the detector-based ones.

We have, so far, examined the advantages of uplink-based travel times over detector-based travel times [1] and concluded that uplink-based travel times are much robust for the sizes of unit sections than the detector-based travel times. For example, through the experiment on Keiyo-Road, the uplink-based travel times with a long unit section of which length is 13km will be accurate as much as the detector-based travel time with unit sections of 3km.

It is, however, pointed out that instantaneous travel times are another problems. It will differ from the actual travel time when the traffic congestion is changing the status of itself. There is some time lag between the times when a driver receives information at the upstream end of subjective section and when he/she reaches the tail of the congestion section. During the time lag, the traffic condition may not be the same as the previous status, on which the instantaneous travel time provided to the driver is based. This difference is coming from the intrinsic nature of instantaneous travel time and may not be removed unless the predicted travel times are provided to the driver at the upstream end.

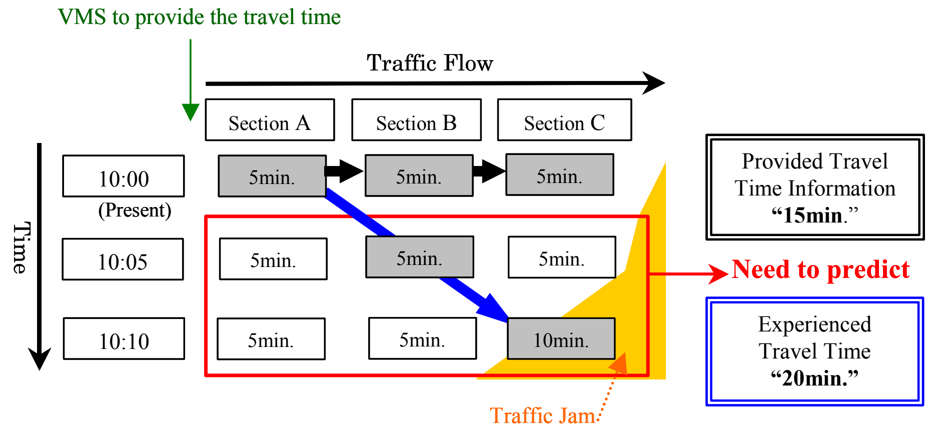

Figure.2 Ex. Difference between actual travel time and provided information

In this paper, we will introduce a basic concept of travel time prediction at first. The prediction is based in on simple queuing model, of which the status is determined with two cumulative traffic flow curve at upstream and downstream ends. The downstream cumulative curve is drawn with traffic counter, and the upstream curve, as the imaginary cumulative flow curve, is derived by horizontally shifting the downstream curve with the section travel time. Both cumulative curves can be predicted by using historical data. The detail of the prediction methodology is described at second. A couple of methods to predict cumulative curve is proposed in the following chapters. Then the performance of proposed prediction methods are validated through the experiments with observed data, which is collected on Keiyo-Road in Chiba. At the end of this paper, we will conclude the commendable prediction method and will state the future scope.

PROPOSED METHODOLOGIES OF PREDICTION

OUTLINE OF THE PREDICTION BASED ON QUEUING MODEL

The idea of travel time prediction [2] is based on queuing model, of which status is determined by two cumulative flow curves, the arrival curve $\boldsymbol{A} = \{A_i \mid i = 0, 1, ...\}$ at the upstream section and the departure curve $\boldsymbol{D} = \{D_i \mid i = 0, 1, ...\}$ at the downstream section, as shown in Figure 3. Assuming flow conservation row, the vertical distance N_j of two curves means the number of vehicles existing in-between two sections at time t_j. Under first-in-first-out principle, the horizontal distance T_j means the section travel time of which the vehicle arriving at the upstream section at time t_j will take. Similarly, T'_k , which is equal to T_j, is denoted as the travel time of which the vehicle leaving out of this section at time t_k has taken. In this paper, let us call T_j as 'arrival-based' travel time to be predicted. On the other hand, T'_j is called 'departure-based' travel time, which can be measured at every time period.

Simple way to obtain two cumulative flow curves is to install traffic counters at both upstream and downstream ends. It is, however, difficult to precisely estimate section travel time because it is hard to adjust vertical levels of two 'independent' cumulative curves. When there are some resource or sink of traffic flow within the section, the flow conservation row will not observed any more; i.e. N_j is not equal to $(A_j - D_j)$. Even though there are no resources or sinks, it is often the case that some errors may be included in each traffic count data. The flow conservation row may not be always guaranteed with the real world data.

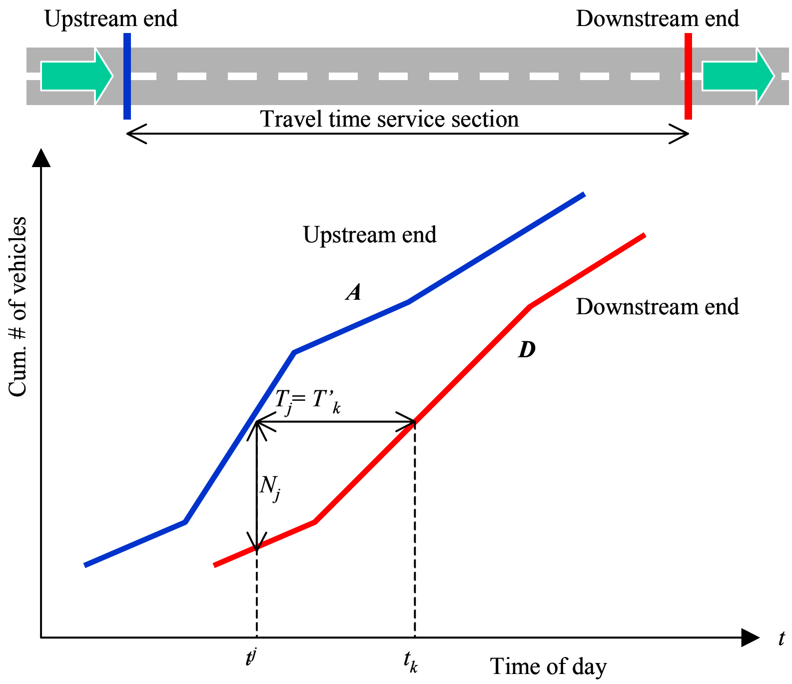

Figure 3: Queuing status described by two cumulative curves.

Instead of using traffic counters at both ends, let us premise the sensor configuration as shown in Figure 4. The sensor installed at upstream end works as a beacon that collects uplink information to identify individual vehicle. The downstream sensor has the function of a traffic counter and a beacon to collect uplink information, while the upstream sensor has only the function of beacon. We may know the travel time of individual vehicle by matching uplink information at these two sections.

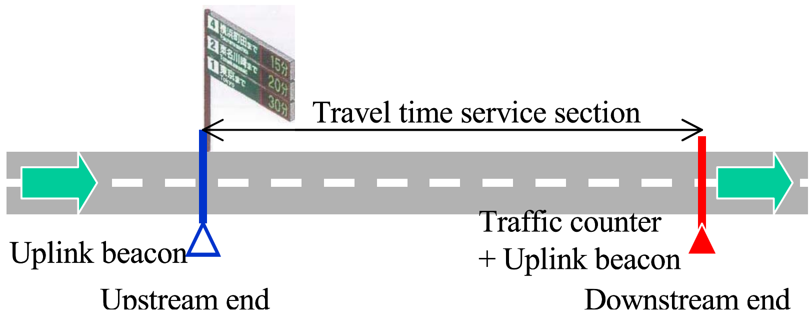

Figure 4: Sensor configuration assumed in this research.

With this sensor configuration, we may generate 'imaginary' cumulative flow curve of the upstream section with the subsequent procedure illustrated in Figure 5.

i) Plot the current value of the cumulative departure traffic count D_k at the downstream section. Here, t_k means the present time.
ii) Measure the ‘departure-based’ travel time T'_k by the recent uplink pairs.

iii) Shift D_k, the current point of ***D*** to the left (= past) by T'_k, and obtain the latest point on 'imaginary' arrival curve A'_k. Remember that A'_k represents not the present data but the some past data.

iv) Repeat i) - iii) for m times, where m means the number of data used for the prediction method explained later. Then the imaginary arrival curve $\boldsymbol{A'} = \{A'_i \mid i = k, k\text{-}1, ..., k\text{-}m\text{+}1\}$ is obtained

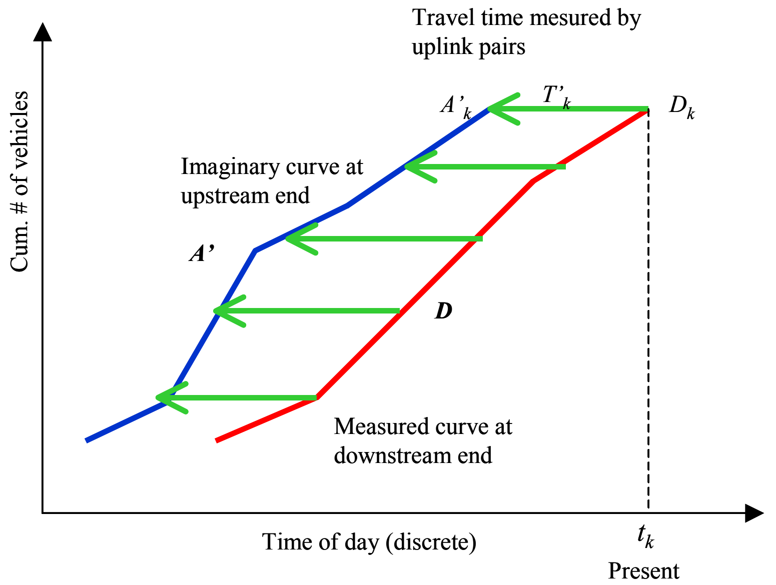

Figure 5: Generation of imaginary arrival cumulative curve at upstream end.

Once the imaginary arrival cumulative curve ***A'*** is obtained, we may predict 'arrival-based' travel time T_k by extending two cumulative curves. The procedure of the prediction is described below (Figure 6).

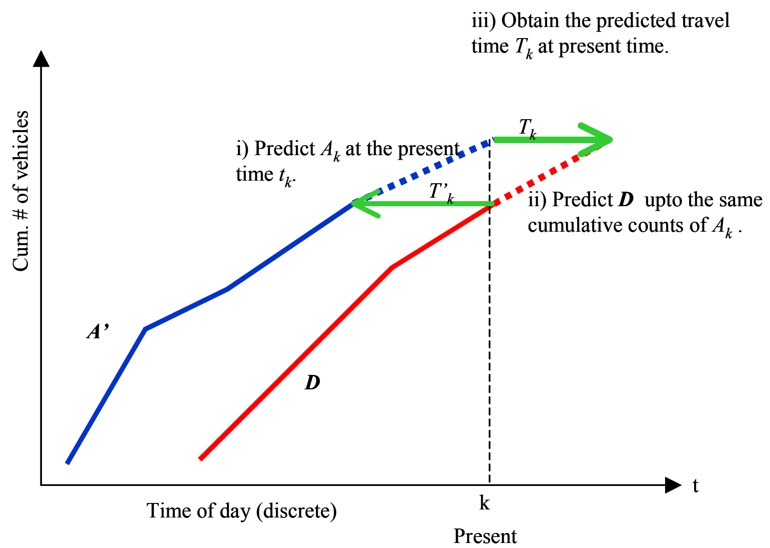

Figure 6: Travel time prediction based on the prediction of two cumulative flow curves.

i) Since ***A'*** was estimated at the past time (t_k - T'_k), extend ***A'*** to the present time t_k with some time-series prediction technique, and obtain the predicted cumulative vehicle count A_k at the upstream end.

ii) Then, extend ***D*** up to the same level of cumulative vehicle count A_k with the same prediction method.

iii) The horizontal distance of two predicted cumulative curve can be regarded as the predicted 'arrival-based' travel time T_k at the present.

METHODOLOGIES TO PREDICT TIME SERIES DATA

There are some available methods to be applied for the prediction of cumulative flow curves. In this research, the following three methods are evaluated of their prediction performance.

AUTO-REGRESSION (AR) MODEL

AR model predicts the future value of traffic flow q_1 from the past time series $\{q_0, q_{-1}, \ldots q_{-m+1}, \}$ with the following linear summation function.

$$q_1 = a_0\, q_0 + a_1\, q_{-1} + \ldots + a_{m-1}\, q_{-m+1} \qquad \text{(eq.1)}$$

Here, $\{a_i \mid i = 0, 1, \ldots, m\text{-}1\}$ are AR-coefficients to be estimated by, for instance, Levinson's algorithm. The number of data m is to be determined so as to well approximate the future value.

HISTORICAL PATTERN MATCHING

This method uses the most "similar" historical traffic flow data in place of today's future traffic flow data. The similarity is evaluated with the distance between the two vectors, today's observed traffic flow data and past flow data, as shown in Figure 7.

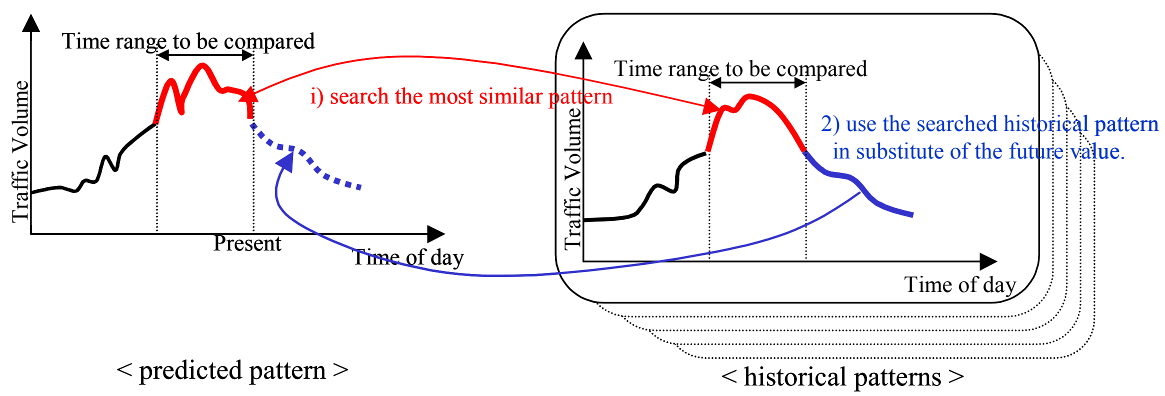

Figure 7: Prediction using historical pattern matching

TEMPLATE PATTERN OF DAILY TRAFFIC FLOW + AR MODEL

This method applies AR-model to the differential data that subtracts "template" traffic flow pattern from today's traffic flow, as shown in Figure 8. The template flow pattern is prepared for each day type, e.g. weekdays and holidays, by calculating the average of historical traffic flow data.

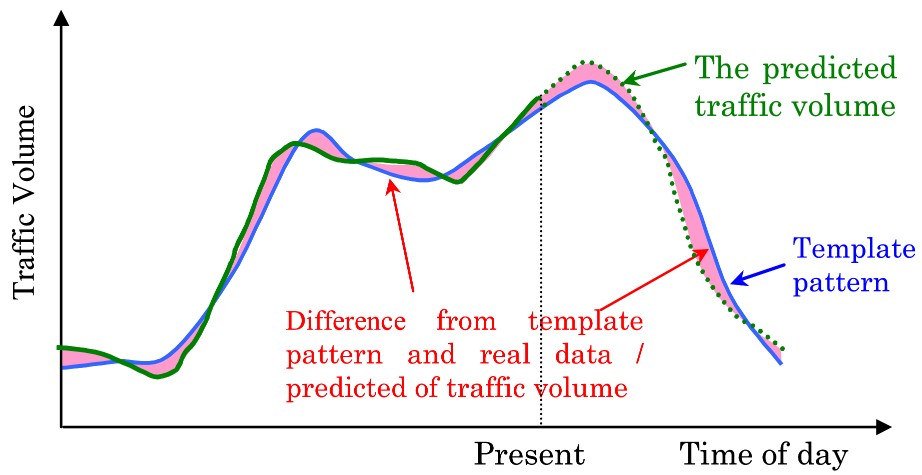

Figure 8: Prediction using template pattern of daily traffic flow + AR model

EXPERIMENT OF PREDICTION WITH OBSERVED DATA

In order to validate the proposed methods, the proposed methods are applied to the observed data collected on Keiyo-Road in Chiba Prefecture. The length of the subjective section where the travel times provided is approximately 13km, from Chiba-nishi toll barrier (TB) to Funabashi TB. The detector data at Funabashi TB and the uplinks of ETC equipped vehicles from Chiba-nishi TB to Funabashi TB are collected for about 1 month. During this period, the portion of the vehicles with on-board ETC equipments was 6% to the total throughput traffic volume.

The result of some questionnaire survey says that the most of drivers with popular trip distance may accept the error of predicted travel time within plus/minus 10minites. Therefore, as shown in Table 1, the performance of each prediction method is evaluated in terms of 'hitting ratio', which means the expectation whether the difference between the predicted travel time and the 'arrival-based' travel time may be less than the allowable time, 5 minutes and 10 minutes here. As a reference, the performances of the detector based travel time are included in the table, which accumulates each travel time of 1km unit sections estimated with detector speed and is currently provided on Keiyo-Road.

Table 1: Comparison of hitting ratio of each prediction method.

	Size of unit section	Light - heavy congestion		Medium - heavy congestion	
		within 5min.	within 10min.	within 5min.	within 10min.
(a) AR Model	13km	83%	94%	72%	91%
(b) Pattern Matching		89%	98%	82%	97%
(c) Template Pattern + AR Model		94%	99%	90%	98%
(Reference) Detector based travel time.	1km	93%	99%	89%	98%

It is found that "(c) Template Pattern + AR Model" method are the best among the other methods. Figure 9 illustrates the predicted traffic flows with the method (c). The prediction performance of traffic flow affects on the preciseness of the predicted travel time. We may confirm the method (c) reasonably predicts the future traffic flows in the range forward 5 - 60 minutes.

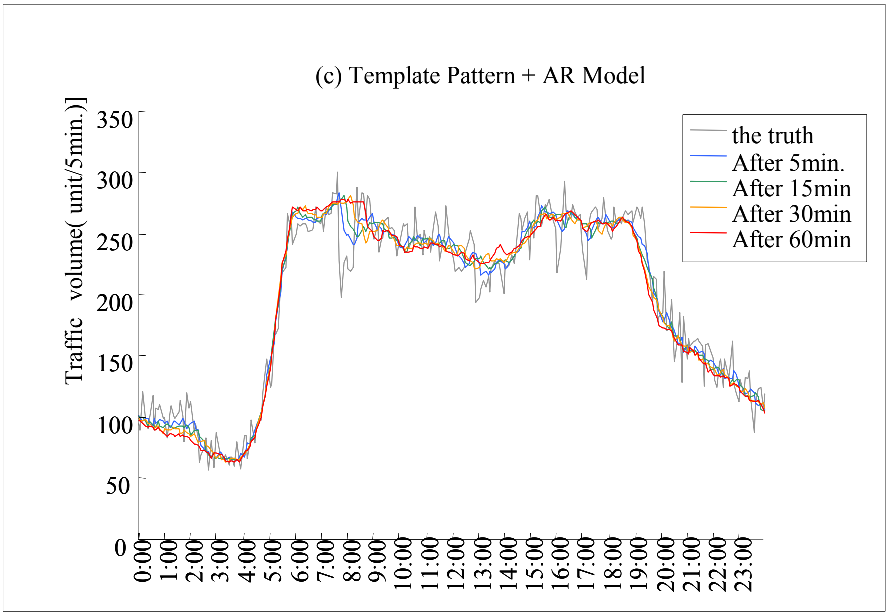

Figure 9: Predicted traffic flows with "template + AR-model" (18/10/2003)

Even though the prediction method use only two sensors at the upstream and the downstream sections, the hitting ratio is better than "Detector-based travel time", which uses 13 detectors. We may expect to reduce the construction and the maintenance cost of ATIS by using uplink information and prediction methodology, while keeping the quality of the provided travel time information.

CONCLUSION

This paper proposed the methodology to predict travel time in short term using uplink information of equipped vehicles and traffic volume collected on Expressways. A couple of methods to predict travel times are proposed in this paper, and we conclude "template pattern + AR-model" shows the satisfactory performance through the experiment with observed data on Keiyo-Road. For the next stage, we will focus on the operational issues of the proposed method, e.g. prediction under incidental situation, model fitting to seasonal fluctuations, etc.

REFERENCES

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[2] R. Horiguchi, H. Otaka, H. Akahane: "Short term travel time prediction using cumulative traffic counts and uplink information collected on expressways", Proceedings of 2nd ITS Symposium in Japan, 2003. (in Japanese)