"TRAVEL TIME PREDICTION METHOD FROM TOLL COLLECTION SYSTEM DATA BASED ON DETERMINISTIC QUEUEING THEORY"

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ABSTRACT

This study proposes a method for predicting near future travel time of each freeway section between adjacent interchanges from toll collection system data. Since the times a vehicle passes ramps are recorded in the toll collection system data, its travel time between on and off ramps is directly observed. Based on the deterministic queueing theory, the hypothetical cumulative trips for each section are constructed from the travel time without traffic counter data. Near future travel time is then predicted by extrapolating the hypothetical curves. The method has been verified by actual data and reasonable travel time has been predicted.

INTRODUCTION

In recent years, ITS-related research has been studied on a worldwide scale. In the road traffic control system, various methods of producing information to provide to the driver are being studied ([4],[5]). We have utilized data obtained from toll collection systems, and researched a method for obtaining travel-time information using toll collection system data. The following has been shown by past research ([1],[2],[3]).

(1)Removing unusual data makes it possible to use toll collection system data.
(2)Travel time can be predicted by pattern matching using toll collection system data.

However, the precision of the prediction method using pattern matching depends on the accumulated travel time pattern. Therefore, we propose a travel time prediction method applying the cumulative trips (abbreviated to "CTP" hereafter) concept using only the toll collection system on the prediction day. The prediction method applying the CTP-concept needs traffic flow data from several point on an object road. Generally, traffic flow data is obtained from a sensor such as a traffic counter. However, when a sensor is used, measuring mistakes occur, and abnormal values are often obtained. Furthermore, sensors are expensive to install. However, using toll collection system data makes sensor data unnecessary. With this method, we first calculate the hypothetical CTP from several points using the toll collection system data. Next, we predict the travel-time by a method applying the CTP concept. CTP is easy to use for the prediction, because it increases monotonously and it doesn't vibrate. Furthermore, the prediction can consider the traffic conditions on the prediction day. This method can be easily applied to ETC, because it uses only the toll collection system.

OBJECT ROAD AND TOLL COLLECTION SYSTEM DATA

In this research, the object roads are toll roads, such as expressways. In Japan, expressways have toll collection systems, and the toll is usually decided by mileage. We can thus obtain toll collection system data including road entry/exit time data at toll gates, ID data of entered/exited toll gates, and kind-of-vehicle data (travel time can be calculated from toll gate entry/exit times). However, expressways have service areas (hereunder, S.A.) or rest areas (hereunder, R.A.). Thus, when using toll collection system data, we have to overcome the following problems:

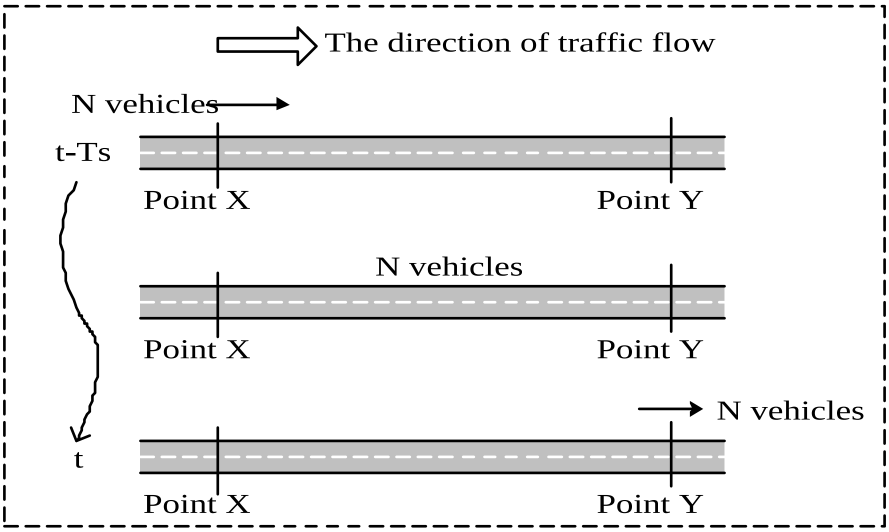
- There are many unusual data such as extremely long travel times and extremely short travel times
- There are some sections that have few data

These problems have been solved by past research ([1],[2],[3]). We can estimate current travel times for roads without sensors by using toll collection system data. Fig.1 shows an example of current travel time calculated from toll collection system data.

Fig.1 Examples of Travel Time calculated from Toll Collection System Data

CUMULATIVE TRIPS AND TRAVEL TIME

CTP is a accumulated traffic flow volume at a point on a road. In this paper, we presuppose first-in-first-out. Fig.1 shows a plot of CTP data from two points. From fig.1, the difference between the CTP data at two points at the same time is the number of vehicles(Nc) between the two points. Moreover, the difference between time of the two points on the same CTP is the travel time(Ts) between the two points. The travel time is calculated from the CTP by using these relations.



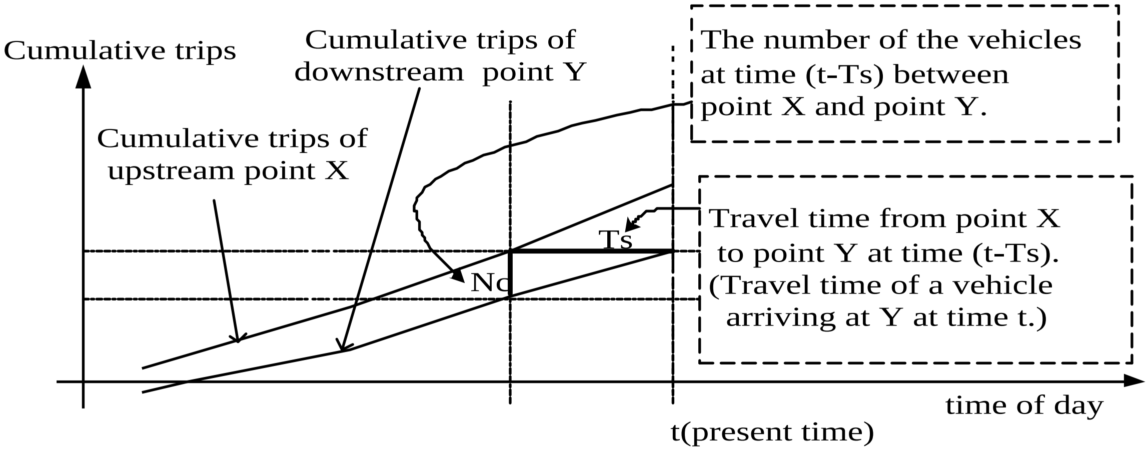


Fig2. Relations between cumulative trips and travel time.

TOLL COLLECTION SYSTEM DATA AND HYPOTHETICAL CUMULATIVE TRIPS

We can obtain the passing time at each tollgate and the number of passing vehicles from the toll collection system. The passing time of each tollgate can then be used to calculate the travel time between each tollgate. The hypothetical CTP data of the object road are made by using these data. As mentioned above, the difference between two points CTP at the same time is the number of vehicles between the two points. Moreover, the difference between two-point hour on the same CTP is the travel time between the two point. From the relations between the number of vehicles and the travel-time, hypothetical-CTP-data is made by using the travel-time between each tollgate and the traffic flow at the most downstream tollgate obtained from the toll collection system. Fig.2 shows the method of calculating the hypothetical CTP data.

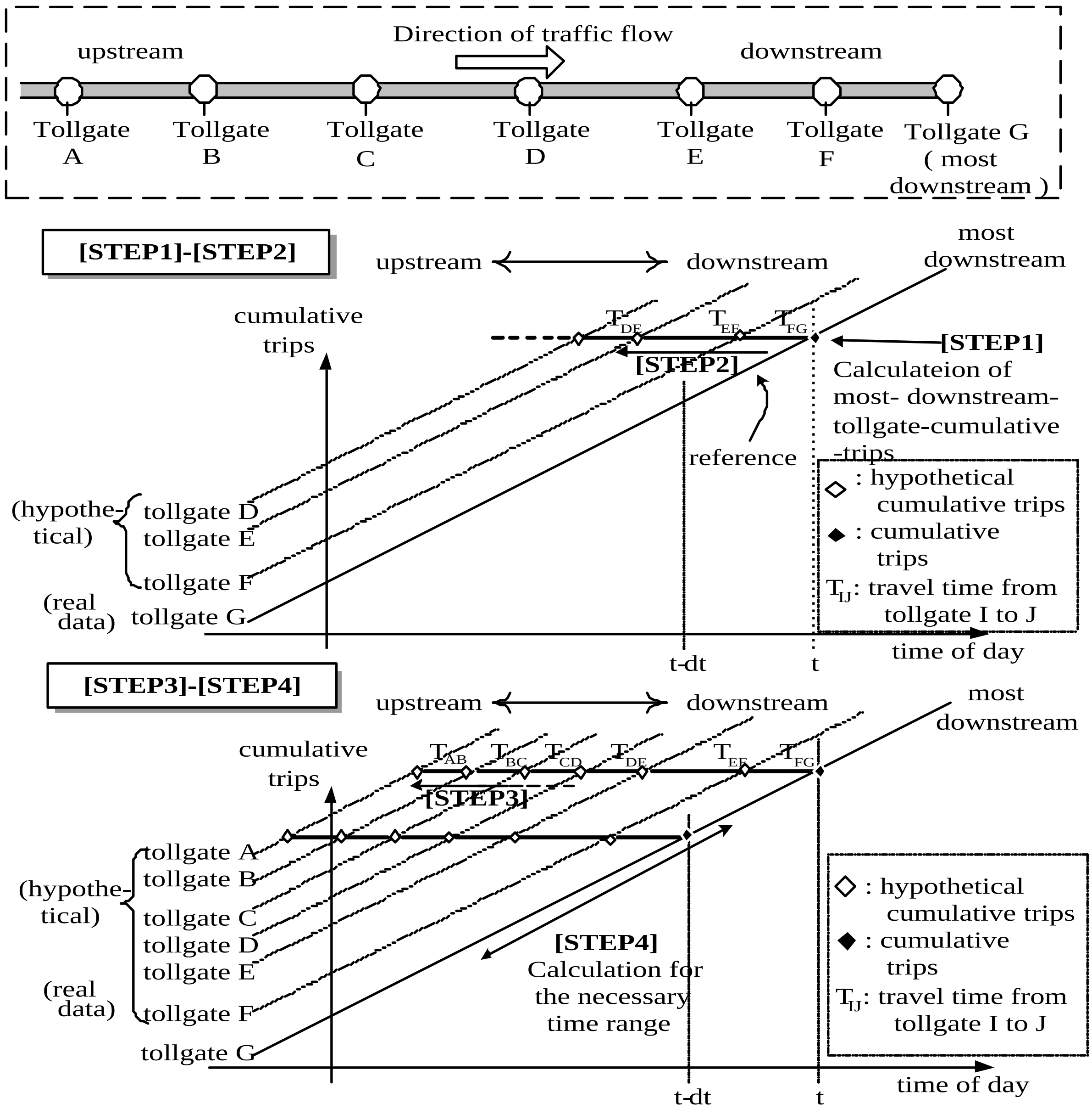

Direction of traffic flow
upstream
downstream
Tollgate A
Tollgate B
Tollgate C
Tollgate D
Tollgate E
Tollgate F
Tollgate G (most downstream)
[STEP1]-[STEP2]
upstream
downstream
most downstream
cumulative trips
T DE
T EF
T FG
[STEP1]
Calculateion of most- downstream-tollgate-cumulative -trips
[STEP2]
reference
(hypothe-tical)
tollgate D
tollgate E
tollgate F
(real data)
tollgate G
: hypothetical cumulative trips
: cumulative trips
T IJ: travel time from tollgate I to J
t-dt
t
time of day
[STEP3]-[STEP4]
upstream
downstream
most downstream
cumulative trips
T AB
T BC
T CD
T DE
T EF
T FG
[STEP3]
tollgate A
tollgate B
(hypothe-tical)
tollgate C
tollgate D
tollgate E
(real data)
tollgate F
tollgate G
[STEP4]
Calculation for the necessary time range
: hypothetical cumulative trips
: cumulative trips
T IJ: travel time from tollgate I to J
t-dt
t
time of day

Fig.3. Calculation method of hypothetical cumulative trips data

The steps in the hypothetical CTP calculation method are as follows.

[STEP1]: The CTP data of the most downstream tollgate is calculated from the most downstream (tollgate) traffic flow of the object road.

[STEP2]: The CTP drawn in [STEP1] is used as the reference. For other toll-gate CTP, we moved the time-coordinate in parallel to the past direction (namely, the left direction in fig.2) for the same CTP value, and we regarded this data as the hypothetical CTP of the upstream point.

[STEP3]: The operation of [STEP2] is carried out for all tollgates on the object road.

[STEP4]:The operations of [STEP2] and [STEP3] are carried out in the necessary time range.

Hypothetical CTP data are calculated by the operations of [STEP1] – [STEP4]. Fig 4. shows an example of the hypothetical CTP calculation.

Fig 4. An example of the hypothetical CTP calculation

TRAVEL TIME PREDICTION METHOD

The travel time is predicted by the hypothetical CTP described in the above paragraph. We first predict the future hypothetical CTP of several points. Next, we calculate the difference in time for the same hypothetical CTP. This difference is the travel time prediction value. In predicting the hypothetical CTP, we can use the prediction method using a differential function. In this paper, we used a prediction method using a differential function in the prediction of the hypothetical CTP. In detail, we predicted the future hypothetical CTP by an extrapolation lengthening CTP by using the inclination of downstream point CTP at time t. Fig.5 outlines of the travel time prediction using a hypothetical CTP.

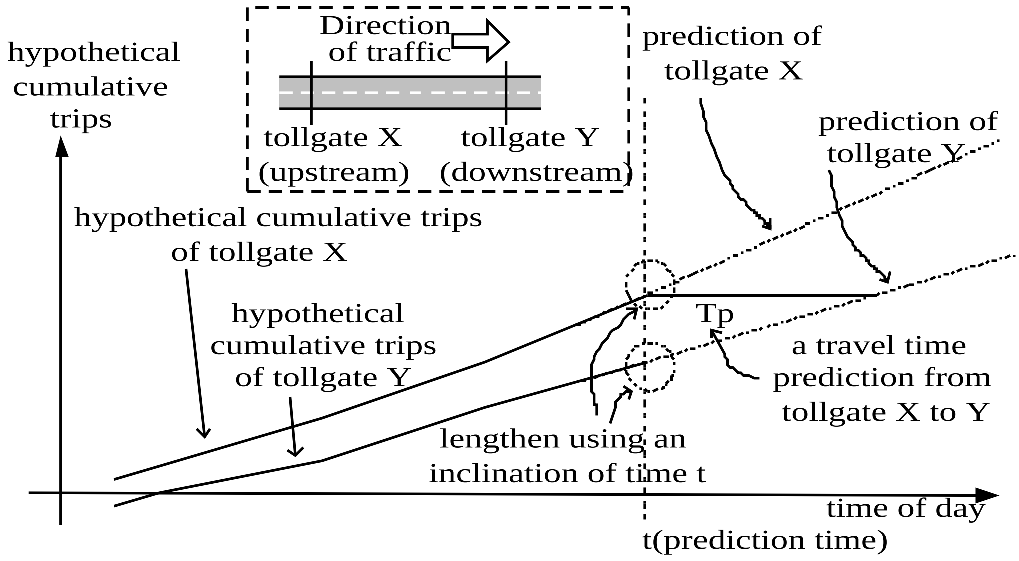


Fig.5. Outline of travel time prediction using hypothetical cumulative trips

In this research, we verified the proposed method by using actual field data from the Kan-Etsu Expressway. The Kan-Etsu Expressway spec from Hanazono to Nerima is shown in table 1.

Fig.6 shows travel time prediction results of a section using this method.

section	distance[km]	Rest area and so on
from Hanazono to Higashi-matsuyama	16.7	Rest area
from Higashi-matsuyama to Tsurugashima	9.8	Service area
from Tsurugashima to Kawagoe	8.4	-
from Kawagoe to Tokorozawa	11.8	Rest area
from Tokorozawa to Nerima	9.4	-
from Hanazono to Tokorozawa	56.1	

Table1. Kan-Etsu expressway spec

(a) A prediction example of travel time from Hanazono to Higashi-matsuyama

(b) A prediction example of travel time from Tokorozawa to Nerima

(c) A prediction example of travel time from Hanazono to Tokorozawa

Fig.6. Prediction example of proposed method using field data

As fig.6(a)(b) indicates, the prediction result is good for a short distance such as 10-20[km]. The prediction result is particularly good at the start and end of traffic congestion as fig.6(b) indicates, where prediction has been difficult up to now. However, as fig.6(c) indicates, the prediction result is good at the start of the traffic congestion. But the prediction result is not good at the peak and end of the traffic congestion. This is because the precision of cumulative trips deteriorates because the distance of the object road is long (over 50 km). From these results, we obtained following.

(1) When the length of the object section is about 20 km, it is more effective to predict cumulative trips by using a differential coefficient.

(2) When the object section is long, we must predict cumulative trips from time of prediction to distant future (about two hours). Therefore, the difference between actual-value and prediction for cumulative trips becomes large. This is because when we predict cumulative trips we predict them with a straight line by using a differential coefficient. Therefore, when we predict cumulative trips from time of prediction to distant future, the difference between actual-value and prediction for cumulative trips becomes large. This causes the precision of the travel time prediction to deteriorate.

Thus, when an object section is about 50 km long, we should use another more accurate method for the cumulative trips prediction.

CONCLUSION

This paper has proposed a travel time prediction method applying a cumulative trips concept using toll collection system data. Moreover, field data has been used to verify that a prediction example using the proposed method yielded good results at the start and end of traffic congestion when the object road is about 10 [km] long. On the other hand, when the object road is about 50 [km] long, there were some time zone where the prediction of travel time was not good. This was because the prediction of cumulative trips deteriorated. Therefore, for a long object road, we should use the accurate method to predict cumulative trips. However, with the proposed method, we can use the cumulative trips applied travel time prediction method without using a sensor such as a traffic counter. In the future, we will advance the verification of this method further, and develop an application to ETC.

ACKNOWLEDGEMENTS

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