Research Report

Development of a Travel Time Prediction Method for the TOYOTA G-BOOK Telematics Service

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Abstract

To realize optimal dynamic route guidance and arrival time prediction with the TOYOTA G-BOOK telematics service, we developed a new computational method that we call the "Three-range Composite Prediction Method." With this, we can predict travel times using traffic information provided by the VICS (Vehicle Information and Communication Systems). This method involves three prediction models and a process for combining them. The three models have been developed with the aim of both characterizing the dynamics of traffic flows and the regular patterns of traffic demand, which enable us to predict traffic conditions both in the immediate future and somewhat further in the future. The combining process calculates travel times by combining the outputs of the three models using weight coefficients that are optimized for every area, route, and time range. This combining process makes it possible to predict future travel times with higher accuracy over a longer time range.

Keywords Traffic information, Travel time prediction, Car navigation, Telematics service, VICS

1. Introduction

In Japan, the VICS (Vehicle Information and Communication System) has been providing traffic information since 1996. Nowadays, it covers all highways and most arterial roads in every prefecture. VICS provides current traffic information such as travel times, degree of congestion, and traffic restrictions. Thus, car navigation systems with a VICS receiver can determine the fastest route. The calculated route is not always optimal, however, especially in the case of a faraway destination, because the traffic conditions change with time. To solve this problem, we have to be able to predict future travel times.

In addition to VICS, as of 2001, the provision of predicted traffic information by private companies became legal in Japan. To provide optimal dynamic route guidance and arrival time prediction with the TOYOTA G-BOOK telematics service,[1-4] we have developed a method for predicting traffic conditions. We assumed that this method would be used in a centralized system that is connected to the VICS center and which would be used to generate traffic condition predictions. The prediction results would be provided to users through cellular phone network from the center.

2. Prediction method

2. 1 Concept of travel time prediction

The following system of equations for traffic phenomena is called the Payne model.[5)]

$$Q=KV \quad \cdots\cdots(1)$$

$$\frac{\partial K}{\partial t}+\frac{\partial Q}{\partial x}=g(x,t) \quad \cdots\cdots(2)$$

$$\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}=\frac{V_e(K)-V}{\tau}-\frac{c^2}{K}\frac{\partial K}{\partial x} \quad \cdots\cdots(3)$$

These equations express the relationship between traffic flow Q, density K and velocity V. Function $g(x, t)$ of Eq. (2) expresses the generation and disappearance of vehicles, which reflects a change in the traffic demand. Equation (3) expresses a traffic flow dynamics known as the Kinematic Wave. Through these formulae, the traffic conditions are related to the dynamics of the traffic flow and the regular patterns of traffic demand.

The dynamics of traffic flow is observed, for example, in the propagation of a traffic jam. This reflects a change in the present traffic conditions. On the other hand, similar congestion is observed every day, because traffic demand reflects social activities, which is related to the factors such as day of the week, time, weather, events, etc.

In predicting an event in the very near future, such as 30 minutes from now, the dynamics of the traffic flow is dominant. In contrast, when attempting prediction further into the future, such as a few hours from now, the regular patterns of traffic demand becomes the most important. Between these two cases, such as about 90 minutes from now, we should consider both phenomena. Therefore, we have divided the prediction time range into three ranges (short-, middle-, and long-range) and have developed appropriate models for each range.

Moreover, our final prediction is calculated by computing the weighted sum of the three outputs, as shown in **Fig. 1**. We call this the "Three-range Composite Prediction Method". Each of the three models is described in detail below.

2. 2 Short-range prediction model

According to Eq. (3), the temporal variation in velocity ($\partial V/\partial t$) is closely related to the spatial variations in velocity and density ($\partial V/\partial x$, $\partial K/\partial x$). Travel time is the reciprocal of velocity; that is to say, the variation in the travel time for a particular

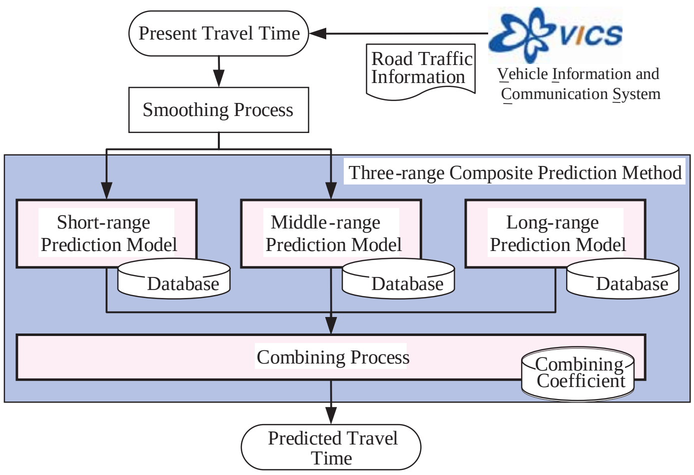

Fig. 1 Structure of the Three-range Composite Prediction Method.

link is affected by any variation in the travel time for the surrounding links. With our method, a future travel time is obtained as a function of the travel time for the related links.

As shown in Eq. (4), the forecast change in the travel time $\Delta_{\ell}\tilde{T}^{n}_{t+\ell}$ after time step ℓ on link n is described as a linear combination of the changes in the travel time $\Delta\Theta^{n,c}_{t}$ at time t on link c which has a correlation with link n, where r is the time index for retrospective summation and $a^{n,\ell}_{c,r}$ is the coefficient.

$$\Delta_{\ell}\tilde{T}^{n}_{t+\ell} = \sum_{r=1}^{R}\sum_{c=1}^{C} a^{n,\ell}_{c,r}\Delta\Theta^{n,c}_{t-r-1} \quad \cdots\cdots\cdots\cdots\cdots (4)$$

$$n = 1,\ldots,N; \quad \ell = 1,\ldots,L; \quad c = 1,\ldots,C; \quad r = 1,\ldots,R$$

The value of $a^{n,\ell}_{c,r}$ is determined in advance by applying the least square method using a historical traffic database.

2. 3 Middle-range prediction model

This method focuses on the fact that the traffic congestion profile usually exhibits some typical patterns, especially in the mornings and evenings. Based on this fact, we expected that a past day that is very similar to the current state could be found in the historical database of traffic congestion and then introduced to the model. This simple method makes it possible to predict future changes in traffic congestion based both on typical changes in traffic demand and on the current conditions. Similarities between the present and past conditions are defined by the Euclidean distance of travel time.

By searching through the historical traffic conditions in the database, a day on which the Euclidean distance is the smallest, that is, the day that is most similar to today, is found and the future travel time today is calculated based on the travel time of the day in the database.

2. 4 Long-range prediction model

Since the current traffic conditions at a specific link are thought to have little influence on congestion that may occur several hours later in the same location, the traffic conditions during that time period can be predicted using only the historical traffic database, on the assumption of regularity in the traffic demand. With this method, the future travel time is computed statistically as the median of the set of past travel times past travel times that have similar factors to the present, where the factors that characterize the day are the day of the week, the time of day, the season, and any coincidence with national holidays, especially consecutive holidays such as summer vacation and the "Golden Week" holiday in Japan.

2. 5 Combining process with the three outputs

Finally, the three outputs from the models described above are combined so as to make the prediction more accurate and seamless. The final value for the travel time T_F is given by Eqs. (5) and (6), where w_S, w_M, w_L are the combining coefficients that were determined in advance and T_S, T_M, T_L are the travel times obtained by the short-range, middle-range, and long-range prediction models, respectively.

$$T_F = w_S * T_S + w_M * T_M + w_L * T_L \quad \cdots\cdots\cdots\cdots (5)$$

$$w_S + w_M + w_L = 1.0 \quad \cdots\cdots\cdots\cdots (6)$$

The combining coefficients are determined so as to optimize the evaluation index value, including factors such as errors between the predicted and actual travel times. To take differences in the region, route, and time range into account, the combining coefficients are determined separately for different regions, routes, and time ranges.

Figure 2 shows an example of the predicted and actual travel times on a section of the Tomei

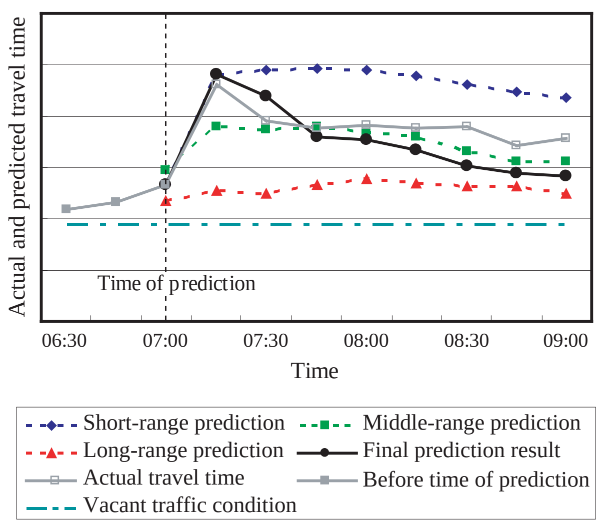

Fig. 2 An example of prediction results and actual travel times.

highway between Nagoya and Toyota City. In this case, the travel time was predicted for 07:00. Although there were no traffic jams at 07:00, the short-range model forecast a rapid increase in the travel time with the approach of 07:15. The middle-range model, on the other hand, predicted the tendency for the travel time to increase after 07:00 more moderately than the short-range model. The final prediction result indicates that future travel times from the present to a point two hours in the future can be calculated with good accuracy by combining the outputs of the three models.

3. Results of travel time prediction experiments

In 2004, an actual evaluation was performed during the Japanese "Obon" holidays, when the most severe traffic congestion occur. **Figure 3** shows those parts of the Tomei and Meishin highway that were used for the evaluations. The actual travel times for each section were measured using a test car. The travel times predicted using our method were calculated using VICS data obtained when the test car entered the evaluation section. And also, predicted travel times calculated by other company's models were seen in the predicted arrival times displayed on those navigation systems when the test car entered a section.

Figure 4 shows actual and predicted travel times for each section. We set a target error rate of 20 %, because the travel time varies depending on the manner of driving within the section. The results show that the travel times predicted using this method were almost all within the target range. Especially, when congestion occurred as a result of concentrated traffic demand or accidents, the results obtained with this method exhibited a high level of accuracy while other models were less accurate. These results confirmed that our three-range composite prediction model is capable of highly accurate prediction.

4. Conclusion

We have developed a highly accurate method of predicting travel time. This method consists of three prediction models and a process to combine them. The three models were developed to characterize both the dynamics of the traffic flow and the regular patterns of traffic demand, which enable us to predict the traffic conditions both in the immediate future and somewhat further future. The combining process calculates future travel times by combining the three outputs using weight coefficients that are determined to minimize the error between the predicted and actual travel time, taking into account differences in region, route, and time range.

To confirm the accuracy of our traffic prediction, actual driving evaluations was performed during the "Obon" holidays. The results obtained confirm that our three-range composite prediction model is capable of highly accurate prediction, especially under conditions of heavy congestion.

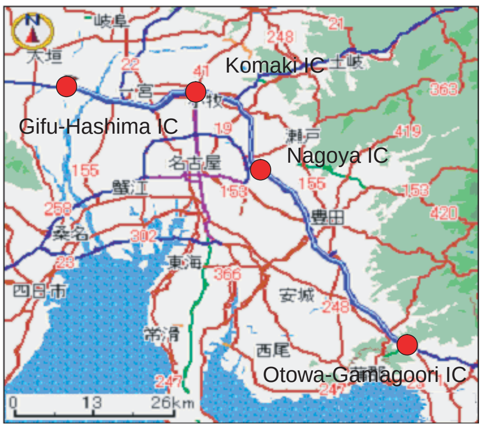

Fig. 3 Evaluated sections.
(The Tomei and Meishin highway)

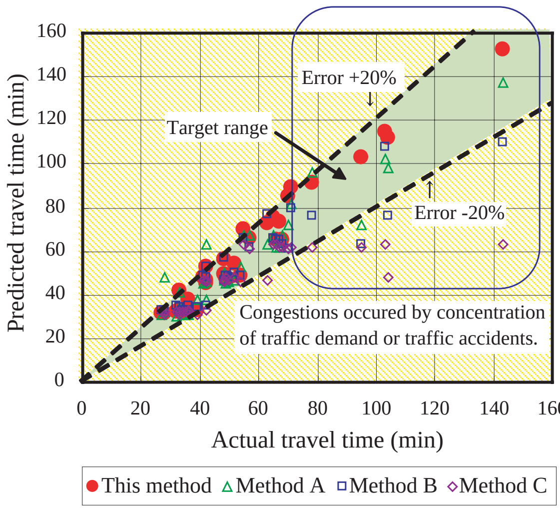

Fig. 4 Actual and predicted travel times.

Figure 5 shows service examples by predicting future travel times. Traffic prediction services using this method will help eliminate driver frustration, in addition to promoting safer and more comfortable travel.

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(a) Area check service

(b) Driving time check service

Fig. 5 Service examples by predicting future travel time.

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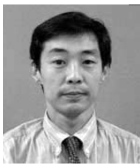

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