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A New Estimation Method of Traffic Situation on a Freeway Network

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1. INTRODUCTION

It is most desirable to make a traffic flow model by which we can estimate traffic states and relate the data collection system with data presentation system. The aim of this paper is to present a method by which we relate estimated traffic situations with actually observed situations.

Cremer presented a macroscopic simulation model [1] for estimating traffic flow situation: He employed the payne model [2] and combined it with a Kalman filter technique to estimate traffic situation of a single section. The Cremer model is responsive to the change of traffic situations. However, the method has a few points to be improved:

The model work with a single road section but not with a road network. When we apply the model to a network, we have to divide it into several single sections, in which we estimate the traffic states at boundaries extrapolating. The extrapolation lessens the precision of the estimation.

To cope with this deterioration, it is necessary to find a method which treats a road network as a whole system without dividing it into subsections.

In addition, Cremer uses a constant weighting factor to estimate traffic flow rates between adjacent segments. The weighting factor describe the effect of the interaction between both segments. Therefore, it is advisable to change the factor in response to traffic situation.

Furthermore, in the Cremer model, the density-speed curve plays an important role in estimating the average traffic states. He uses invariant parameters in the curve. It is expected to improve estimation precision by adopting variant parameters with space and time. It is the purpose of this paper to describe how we can improve the Cremer model by those operations.

First, in the next section, we introduce the theoretical

background of a macroscopic simulation model and the Kalman filter technique. In addition, we extend the Cremer model for a road network.

We establish a method which treats the network as a whole system. We introduce an exponential function for describing the weighting factor that is responsive to traffic situations. Also, we establish how we change the parameters in a density-speed curve with time and space. In the fourth section, we apply the methods to an actual freeway. We quantify the effectiveness of the methods. Finally, we conclude that the improvements were very effective.

2. THEORETICAL BACKGROUND

2.1 Macroscopic Simulation Model

The most important part of the estimation method is a dynamic model which comprises of the rules and mechanisms by which the process is described. The model which was chosen as the most adequate for the given problem describes traffic flow dynamics by aggregate flow variables of density, average speed and volume . Let us consider a section of a freeway which for convenience is subdivided into several road segments with a length of about 500 m (Figure 2.1) .With respect to this space-discrete configuration the following variables of traffic flow are introduced:

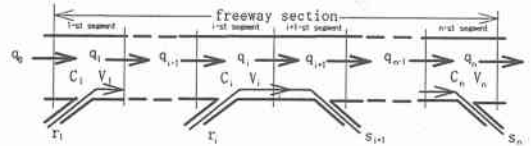


Fig. 2.1 Discretized section of a freeway

- $c_i(k)$  traffic density in segment i [veh/km]
- $v_i(k)$  time mean speed within segment i [km/hr]
- $q_i(k)$  volume from segment i to i+1 [veh/hr]

- $w_i(k)$  space mean speed from segment  $i$  to  $i+1$  [km/hr]
- $r_i(k)$  possible entering ramp volumes [veh/hr]
- $s_i(k)$  possible leaving ramp volumes [veh/hr]

Using these variables, a simple balance for the vehicles within segment  $i$  at time  $k+1$  given the following difference equation.

$$c_i(k+1) = c_i(k) + \frac{\Delta t}{\Delta_i} \left[ \alpha c_{i-1} v_{i-1} + (1-2\alpha) c_i v_i - (1-\alpha) c_{i+1} v_{i+1} + r_i - s_i \right]_{(k)} \quad (2.1)$$

The following difference equation for section average velocity which was formulated according to empirical observation has proved to be quit realistic

$$v_i(k+1) = v_i(k) + \frac{\Delta t}{\tau} \left[ v(c_i) - v_i \right]_{(k)} + \frac{\Delta t}{\Delta_i} \left[ v_i (v_{i-1} - v_i) \right]_{(k)} + \frac{\Delta t}{\Delta_i} \frac{v}{\tau} \left[ \frac{c_i - c_{i+1}}{c_i + k} \right]_{(k)} \quad (2.2)$$

Traffic volume and space mean speed which will be measured only at a distances of several kilometers (at the boundaries of the section) can be expressed within the section according to the rules of hydromechanics as a product of density and velocity. Because of the allocation at the end of segment a weighted average seemed to be appropriate.

$$q_i(k) = \alpha c_i(k) v_i(k) + (1-\alpha) c_{i+1}(k) v_{i+1}(k) \quad (2.3)$$

$$w_i(k) = \alpha v_i(k) + (1-\alpha) v_{i+1}(k) \quad (2.4)$$

A dominating function within this dynamic model equation is the steady state speed-density characteristic ( $k$ - $v$ ). The following highly general expression was proposed by May and Keller[3].

$$v\left(\frac{c}{i}\right) = v_f \left[ 1 - \left( \frac{c_i}{c_{\max}} \right)^l \right]^m \quad (2.5)$$

Where  $v_f$  is the free velocity,  $c_{\max}$  denotes jam density and  $l$  and  $m$  are positive real numbers (sensitivity factors).

## 2.2 Kalman Filtering Technique

Since the detection scheme developed in this report is based on the Kalman filtering principles, an extremely brief explanation of the Kalman filtering technique is appropriate [4].

Suppose that the state  $x_k$  of a dynamic evolves according to the vector differential equation

$$\dot{x}_{k+1} = f(x_k, u_k) + w_k$$

The linearized equation can be written as;

$$\dot{x}_{k+1} = A_k X_k + w_k \quad (2.6)$$

$A_k$  is a known  $(n \times n)$ -dimensional dynamic matrix.

$$A_k = \frac{\partial f}{\partial x}$$

Suppose that at each time  $t_k$  is available  $(m)$ -measurement  $y_k$ , that is nonlinearly related to the state which is corrupted by additive noise

$$y_k = g(x_k) + v_k$$

The linearized equation can be written as;

$$y_k = C_k X_k + v_k \quad (2.7)$$

$C_k$  is a known  $(m \times n)$ -dimensional observation matrix

$$C_k = \frac{\partial g}{\partial x}$$

## 2.3 Multiple Section Method

To estimate traffic situation on a freeway, the Cremer method can treat only with a single road section nut not a road network. When we apply the method to a network, we have to divide it into several single sections, in which we estimate the density and time mean speed. We establish a multiple section method which treats the network as a whole system. We contain the single sections on the freeway length. After that, we investigate the Cremer method to estimate traffic situation on a freeway without estimating of the traffic states at boundaries through extrapolations.

To decrease deviations between estimations and observations we use observation points information between two sequel sections (Figure 2.2). Despite the measurement points  $(q_i, w_i)$  when the length increases, the model serves the elements of the dynamic and observation matrices. Also the measurement point is able to improve the

estimation of traffic situation.

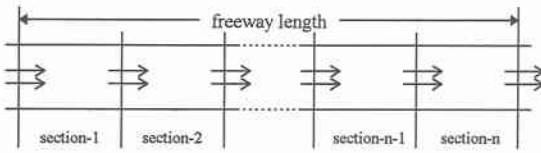


Fig. 2.2 Shows combined sections on a freeway length  
More explanations would be proved in procedures.

### 2.4 Variable Weighting Factor

In order to investigate, we need the Single Section Method in our paper. The estimation of  $q_i(k)$  and  $w_i(k)$  is based on Equations (2.3) and (2.4). The degree of dependency to segment  $i$  in the time  $k$  for  $c_i(k)$  and  $v_i(k)$  is equal to  $\alpha$ , the degree of dependency to segment  $i+1$  in the time  $k$  for  $c_{i+1}(k)$  and  $v_{i+1}(k)$  is equal to  $(1-\alpha)$ . Because of different variations in traffic situations of upstream and downstream in each segment, we introduce  $\alpha_i(k)$  for each segment as a negative exponential functions

$$\alpha_i(k) = e^{-\beta c_i(k)} \quad (2.8)$$

In Function (2.8),  $c_i(k)$  is special density of segment  $i$  and  $\beta$  is curvature function. The value of  $\beta$  is  $(0 < \beta < 0.9)$ , this value estimates by previous experiments from corridor freeway situations. The effects of traffic situation on  $\alpha_i(k)$  for segment  $i$  follow. We substitute the value of  $\alpha_i(k)$  in place of  $\alpha$  in Equations (2.1) to (2.4).

### 2.5 Variable Characteristic Parameters

In the Cremer method, the density-speed characteristic function ( $k$ - $v$ ) is needed. This function includes some parameters such as jam density, free velocity and sensitive factor from the car-following theory. These parameters depend on the relationship density flow and speed as such time and space[3].

The Box's Complex algorithm can be an optimization of parameters. This algorithm has general function. We suppose a traffic flow model to the general function in this algorithm. Then, we selected the Cremer method for general function in the algorithm. Finally, we can be estimated of the parameters in density-speed characteristics function ( $k$ -

$v$ ). A detailed discussion of this algorithm can be found in the references[5].

## 3. PROCEDURES

To investigate the original Cremer method, we need two kinds of information for the analysis of data.

The first group consist of the past data from one month prior to final estimation. These data serve as initial conditions for estimation of the parameters.

The second group consists of the real time data. These data are obtained during the period of the final estimation. The latter data are utilized in the dynamic equation, the dynamic matrix, the observation matrix and the check point. The observed data used have come from the Metropolitan Expressway in Tokyo.

The Cremer method is separated in to a simulation process and filtering process. Also, the Cremer method analysis by the simulation process and the filtering process.

To analysis the simulation process, we need to use simulation macroscopic model (Section (2.1)). To make initial condition see Table (3.1). In this process,  $q_0(k)$ ,  $r_1(k)$  and  $s_1(k)$  are measurements data. We have to divide the section into the  $n$  segment, then the amount of  $c_i(k)$ ,  $v_i(k)$ ,  $q_i(k)$  and  $w_i(k)$  in each segment in a given time must be estimated. These amounts after comparing to real data, show difference between real condition and estimation.

To analyze the filtering process, it is necessary to know simulation results in each step as it is expressed in equations (2.6) and (2.7). Calculating Dynamic matrix, observation matrix and noise matrix acceding to any observation condition. A detailed discussion of this algorithm can be found in the references[4].

We made improvements on the Cremer method such as weighting factor, estimation of promoters and multiple section method to minimize errors.

The first improvement on the Cremer method is related to the dependence of  $\alpha$  on the density (Eq. 2.8), determined during the whole system. Then, we analyze

Table 3.1 The characteristics of freeway sections.

section	consideration method	station number between	length of section (km)	total segment	total off ramps	total on ramps	check point condition	number of link
S-I	Single	63-54	1.970	4	1	1	3-4	2
S-II	"	54-48	1.230	3	-	1	6-7	"
S-III	"	48-40	1.980	4	1	1	9-10	"
M-I/1	Multiple	63-40	5.130	11	2	3	3-4	"
M-I/2	"	"	"	"	"	"	6-7	"
M-I/3	"	"	"	"	"	"	9-10	"

the Cremer method with new value of the weighting factor by the simulation process and the filtering process again.

The second improvement on the Cremer method is the estimation of parameters of density-speed characteristics function (k-v). We used Box's Complex algorithm and past data to estimate parameters in the three different separated section (S-I, S-II, S-III, shown in Table (3.1)).

Then, we analyze the Cremer method with new variant parameters in the three different separated section (S-I, S-II, S-III) by simulation process and filtering process again.

The third improvement on the Cremer method was to combine sections by multiple section method.

To analysis the multiple section method, we need to used simulation process and filtering process.

In simulation process the basic principles are the same in the Cremer method. In the filtering process the basic principles are the same as in the Cremer method. Therefore, we can use the information from the sensor to dynamic, observation matrix, noise matrix affected measurement data. We discussed, the measurement points in which the couple of variables in different location are considered. Then, we analyzed using the multiple section method in a long length (M-1, show in Table (3.1)) with three different check points (M-I/1, M-I/2, M-I/3 shown in Table (3.1)) by new condition of simulation process and filtering process again.

#### 4. RESULTS

After this theoretical analysis the combined estimation problem was tested by numerous simulation studies with different configurations. We investigate the results of procedures in two separated stages.

##### 4.1 Results of Single Section Method

We consider Table (3.1) for initial conditions and implement the simulation process and the filtering process to calculated the estimated traffic situation on the single sections (S-I, S-II, S-III) by the original Cremer method . Then, we improved on the Cremer method (weighting factor and estimation of parameters). Then, we obtain r.m.s. errors flow and r.m.s. space mean speed between above mention estimation and each check points for as each single section. The effects are as follows;

The filtering technique process applied to the simulation model in the original Cremer method, brought about reduction of errors.

The effects of improving the Cremer method by weighting factor reduced errors in the simulation process and filtering process as compared with the original Cremer method.

The effects of improving the Cremer method by weighting factors and estimate parameters reduced errors in the simulation process and filtering process as compared with the original Cremer method.

For example, Figure (4.1) shows the reduction of errors in the simulation process and filtering process, if compared step by step with the original Cremer method.

Figure (4.2) shows related variant parameters with space and time before final estimate traffic situation by Box's Complex algorithm.

##### 4.2 Results of Multiple Section Method

We consider Table (3.1) for initial condition and implement the simulation process and the filtering process to calculated the estimated traffic situation on the combined single sections (M-I/1, M-I-2, M-I/3)). Also, we applied multiple section method as explained in section (2.3),using

results obtained by the Ceremer method. Then, we applied these analysis to the combination of the sections. Then, we obtain r.m.s. errors flow and r.m.s. space mean speed between above mentioned estimation and each check points for combine single sections.

The effects of improving the Ceremer method by the multiple section method reduced errors in the simulation process and filtering process as compared with the original Ceremer method. Figure (4.1) shows effects of the multiple section method on the reduction of error in the simulation process and filtering process as compared with the original Ceremer method.

Finally, we evaluate the Ceremer method and multiple section method to estimate traffic states, and compare the errors of these two methods. The results are shown in Figure (4.3).

These figures shows that multiple section method has better results than the Ceremer method. The effects of estimation of multiple section method as compared with observation are shown Figures (4.4).

Table (5.1) shows the reduction decrease of error percentage from the original Ceremer method and improving the Ceremer method filtering, process.

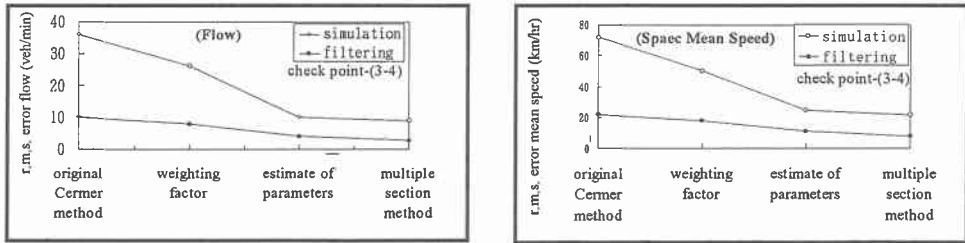


Fig. 4.1 The reduction of estimation error by improvements in the Ceremer method.

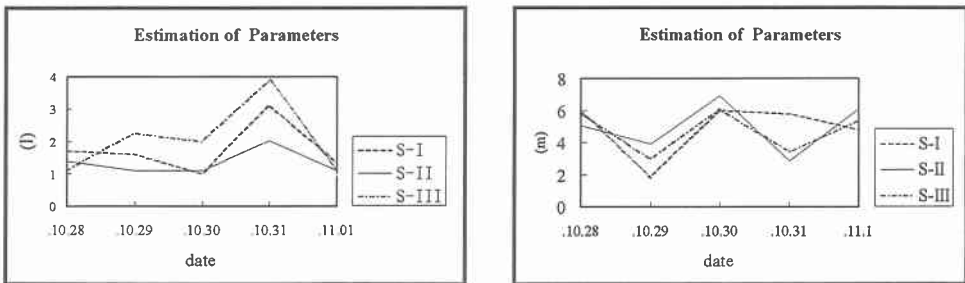


Fig. 4.2 The effects of sensitive factors on parameters by Box's Complex algorithm method.

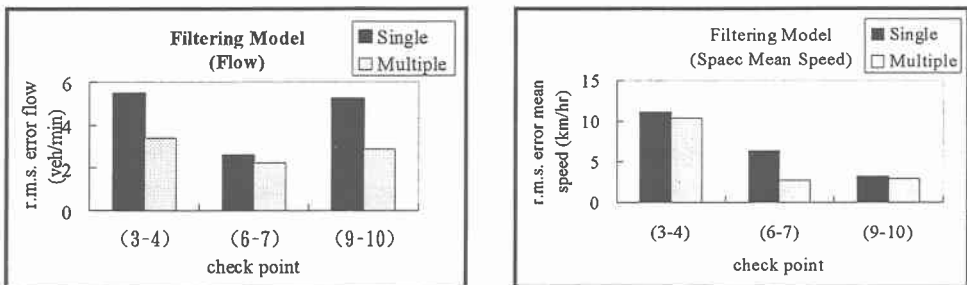


Fig. 4.3 The evaluation of the Ceremer method and the multiple method

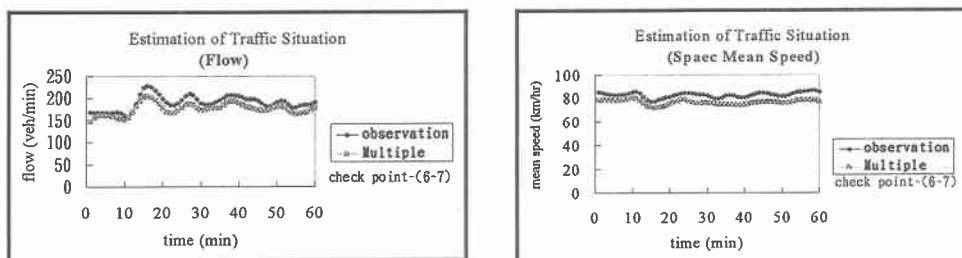


Fig. 4.4 The comparison of the traffic situation and estimation by multiple section method

Table 5.1 Reduction of error percentage between of the original Cremer method and improve the Cremer Method

check point	Single Section Method (D-I,II,III)				Multiple Section Method (N-I/1,2,3)	
	weighting factor		estimation of parameters		combined section	
	r.m.s. error % flow	r.m.s. error % mean speed	r.m.s. error % flow	r.m.s. error % mean speed	r.m.s. error % flow	r.m.s. error % mean speed
3-4	22.2	16.6	48.2	49.0	68.0	57.5
6-7	8.5	5.7	53.3	55.5	60.0	81.2
9-10	0.0	0.6	3.2	88.7	7.7	90.7

## 5. CONCLUSIONS

Major finding are summarized as follows:

- 1- By the introduction of the exponential function, the estimation precision improved 0.0% ~ 22.2% on r.m.s. error flow and 0.6% ~ 16.6% on r.m.s. error space mean speed compared with the results by constant.
- 2- By the estimation of parameters of density-speed curve, the estimation precision improved 3.2% ~ 48.2% on r.m.s. error flow and 49.0% ~ 88.7% on r.m.s. error space mean speed compared with the results by constant.
- 3- By establish a method which treats the network as a whole system without dividing it into subsection and extrapolation manner, precision improved 7.7% ~ 68.0% on r.m.s. error flow and 57.5% ~ 90.4% on r.m.s. error space mean speed compared with the results by the original Cremer method on several single section.

In the future work we shall study the stability and instability of the Cremer method and the multiple section method against change in the various parameters and expand the multiple section method to a wide network.

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