EVALUATION OF MACROSCOPIC MODEL BASED ON GODUNOV SCHEME FOR ESTIMATING TRAFFIC FLOW ON A FREEWAY

by Anburuvel Arulanantham*, Yuji Kamide** and Takashi Nakatsuji***

1. Introduction

Accurate freeway traffic models are considered as valuable tools for the design and evaluation of traffic management and monitoring strategies. For example, macroscopic and microscopic traffic models can be used to predict the effects of implementing different strategies on a freeway. To evaluate a model for possible use in a traffic study, it is worth investigating its properties. Like many sectors in science, the way to do this is to simulate the flow of traffic using computer. Simulations will aid the designer in planning more efficient road networks.

A macroscopic model describing the traffic states in an aggregate manner which emphasizes the relationship between speed and density[2)] is one of the tools for real-time applications because of its simplicity of traffic flow description and its computational efficiency. In this paper higher order macroscopic traffic flow model based on Godunov scheme is evaluated for traffic flow estimation in a freeway using computer simulation.

2. Flow of Research

Figure 1 illustrates detailed description of this research initiates with configuring model of the selected freeway and defining its properties followed by the introduction of higher order macroscopic model representing traffic flow. Computer simulation is then performed in order to compute traffic flows at certain locations. Those simulated traffic volumes are compared with measurement data to determine the efficiency of adopted macroscopic model.

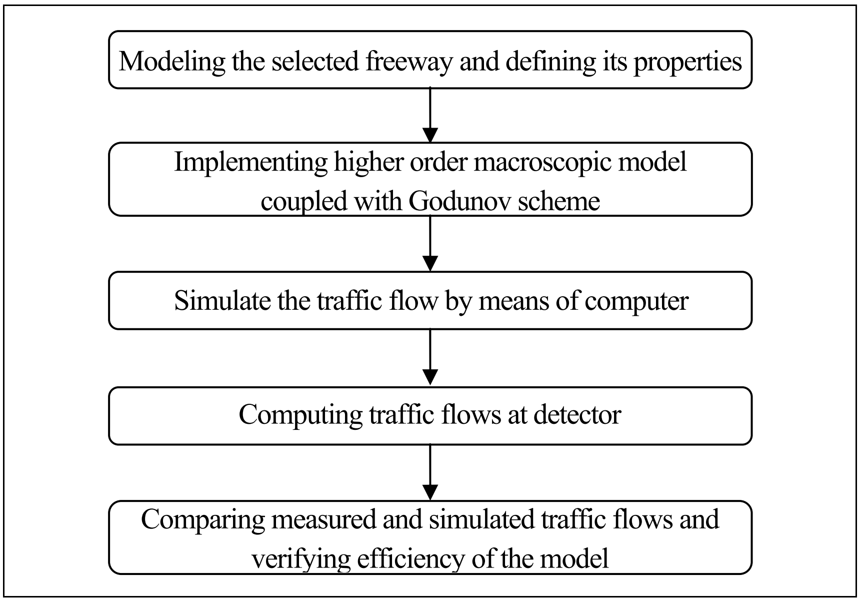

Figure 1: Flow of the research

3. Study Site

This study uses 24-hour traffic data collected on November 1, 1994, from Matsubara line of the Hanshin expressway in Japan. The schematic layout of the road section is depicted in figure 2. The study section is 2 lanes and

* Graduate Student, **, Graduate Student, ***Professor Laboratory of Transportation Intelligence, Graduate School of Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo 060-8628, Japan. Tel: +81- 011-706-6217 Fax: +81- 011-706-6216
E-mail: aanbu007@eng.hokudai.ac.jp
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11.220 km length and was divided into 28 segments for the purpose of traffic simulation. 15 minute inflow and outflow data of the study section was collected. In addition to that 15 minute detector data on traffic volumes are available at the mainstream entrance, exit, and at the end of segments 4, 9, 13, 17, 20, and 25.

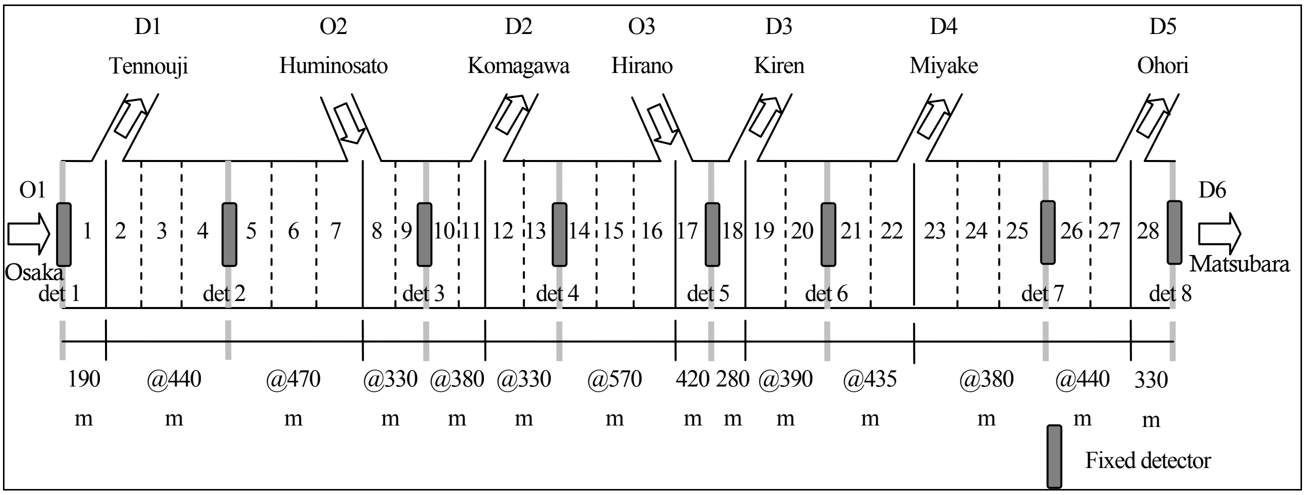

Figure 2: Schematic layout of the road section

4. Traffic Simulation Model

The traffic simulation model used in this research is higher order macroscopic model and discretization of the first-order macroscopic model based on Godunov scheme[1)].

(1) Macroscopic model

Macroscopic models assume that the aggregate behavior of vehicles depends on the traffic conditions in their environment. The underlying theory behind most of these models is the hydrodynamic theory of traffic flow. Simulations based on macroscopic models require much less processing power and time. Thus, macroscopic models are commonly used in the development of new traffic problems where the speed of computation helps to shorten development time.

Figure 3 depicts a space–time discreted freeway section, where length of each segment is Δx_i.

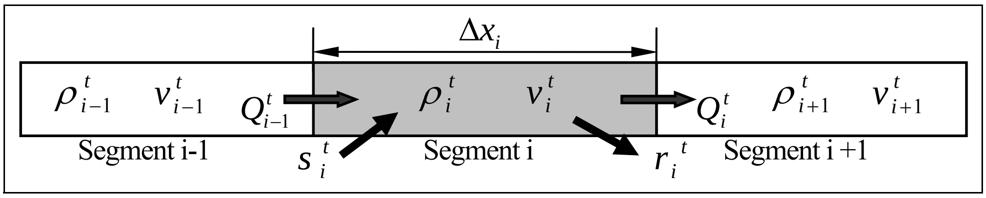

Figure 3 : Discrete model of the freeway section

In general Traffic flow phenomenon is described by three aggregated variables: density (ρ), space mean speed (*v*), and flow rate (*q*). The equations 1, 2, and 3 represent the discrete form of higher order macroscopic model by using the explicit finite difference approximation. The general formulations for ordinary segment are given below.

$$\rho_i^{t+1} = \rho_i^t + \frac{\Delta t}{\Delta x_i}\left(Q_{i-1}^t - Q_i^t - r_i^t + s_i^t\right) \quad \text{……….(1)}$$

$$v_i^{t+1} = v_i^t + \frac{\Delta t}{\tau}\left[V_e(\rho_i^t) - v_i^t\right] + \frac{\Delta t}{\Delta x_i} v_i^t\left(v_{i-1}^t - v_i^t\right) - \frac{\nu \Delta t}{\tau \Delta x_i}\frac{\rho_{i+1}^t - \rho_i^t}{\rho_i^t + \kappa} \quad \text{……….(2)}$$

$$q_i^t = \rho_i^t v_i^t \quad \text{……….(3)}$$

(2) Godunov scheme

Godunov discretization scheme is explained by equations 4, 5 and 6 along with the description of boundary flow between segments in table 1 based on demand-supply concept. The simulation starts by computing local demand and local supply of each segment. Traffic demand function holds the maximum possible outflow of the upstream half-line when the downstream half-line was empty and of great capacity. Similarly traffic supply function holds the value of the maximum possible inflow into the downstream half-line when upstream half-line was oversaturated and endowed with the same equilibrium flow-density relationship as the downstream half-line. The boundary flow is then computed by selecting the minimum between the local demand of the upstream segment and the local supply of the downstream segment[1)].

Local Demand: $D_i^t = \Delta(\rho_l, l)$ ……… (4)

Local Supply: $S_{i+1}^t = \Sigma(\rho_r, r)$ ……… (5)

$Q_i^t = \mathrm{Min}\,[\Delta(\rho_l, l), \Sigma(\rho_r, r)]$ ……… (6)

Table 1: Description of boundary flows between segments

	$Q_{\max}(l) \le Q_{\max}(r)$		$Q_{\max}(l) \ge Q_{\max}(r)$	
$\Delta(\rho_l, l) \backslash \Sigma(\rho_r, r)$	Under critical	Over critical	Under critical	Over critical
Under critical	Q_l	$\mathrm{Min}[Q_l, Q_r]$	$\mathrm{Min}[Q_l, Q_{\max}(r)]$	$\mathrm{Min}[Q_l, Q_r]$
Over critical	$Q_{\max}(l)$	$\mathrm{Min}[Q_{\max}(l), Q_r]$	$Q_{\max}(r)$	Q_r

τ, ν, κ : model parameters

Δt : simulation time interval

Q_i^t : flow at the downstream boundary of segment *i*

$Q_{\max}(.)$: capacity of the segment

$V_e(\rho_i^t)$: equilibrium ρ-*v* relationship

ρ_i^t : density of segment *i*

q_i^t : flow of segment *i*

v_i^t : space mean speed in segment *i*

l, *r* denotes upstream and downstream respectively.

5. Results

(1) Graphical interpretation

Figure 4 illustrates both measured and simulated traffic volumes at detector stations 1 and 2. The x-axis represents real time from 9:00 a.m. to 5:00 a.m. of the following day in between simulation performed.

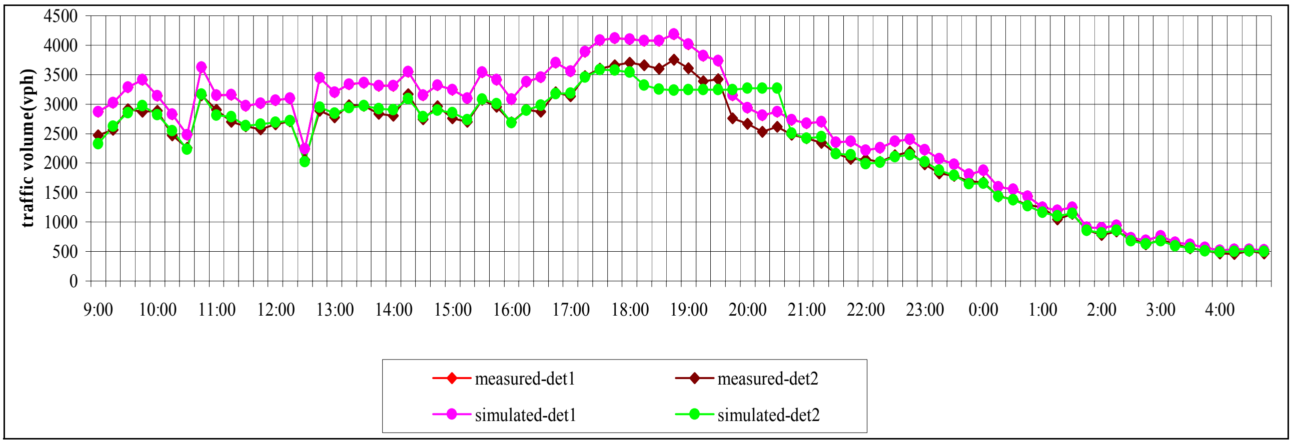

Figure 4: Observed and simulated traffic volumes at detector 1 and 2

(2) Evaluation of performance

Performance of the estimation was evaluated by means of two indices, a root-mean-square (*RMSE*), and mean-absolute-relative error (*MARE*), represented by the following forms.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(z_i - \hat{z}_i\right)^2} \quad \ldots\ldots\ldots (7) \qquad MARE = \frac{1}{N}\sum_{i=1}^{N}\frac{\left|z_i - \hat{z}_i\right|}{z_i} \quad \ldots\ldots\ldots (8)$$

Where N denotes the total number of entities used for comparison. Here N is equal to the number of time steps. z_i and $\hat{z}_i$ denote respectively the actual value of the reference variable and the corresponding estimation outputs. The *RMSE* and *MARE* of the estimated traffic volume at each detector station are illustrated in figures 5 and 6.

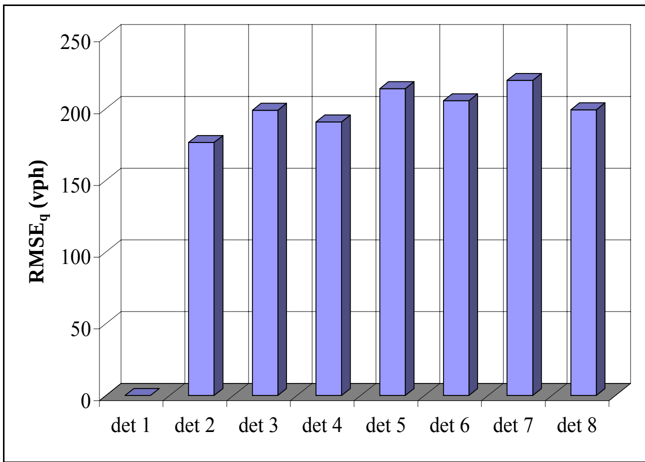

Figure 5: *RMSE* of the estimated traffic volume

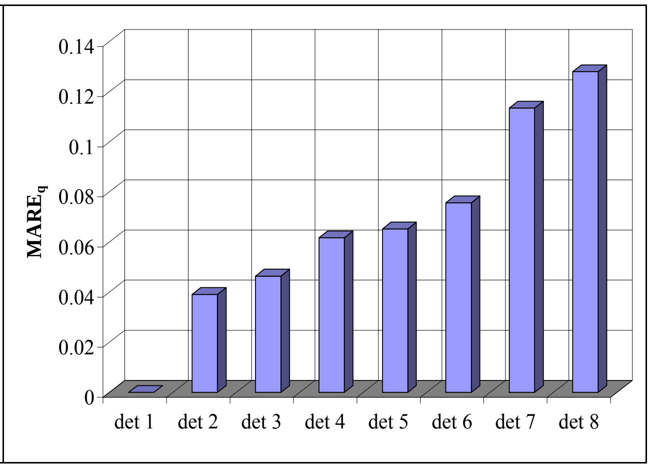

Figure 6: *MARE* of the estimated traffic volume

6. Conclusions and Future Works

We formulated simulation environment in this research based on higher order macroscopic model and the discretization of the first-order macroscopic model incorporated with Godunov scheme for computer simulation. The performance of the simulation model was verified with real traffic data collected from Matsubara line of the Hanshin expressway in Japan. The traffic flows at detector points were estimated by means of the model found to have small deviation from that of measured. It obviously shows that the model can capture the actual traffic phenomenon more precisely. The estimation can further be improved by adopting precise model parameters.

The study presented in this paper concerns only traffic volume estimation at certain locations, which has a possibility to be extended to compute traffic states and OD flows. It requires information on proportion of traffic distribution among OD pairs.

In addition to that the nature of the traffic can be configured more realistically by introducing the ability to model multi-lane traffic flow, which includes the effect of overtaking when lane switching occurs. An accurate grasp of driver's behavior is necessary for this task.

The significant improvement that can be made to the model is enhancing the estimation and prediction by embedding Unscented Kalman filter into the present model. The Unscented Kalman filter is a set of mathematical equations that implement predictor-corrector type estimation that is optimal in the sense that it minimizes the estimated error covariance when some presumed conditions are met.

References

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