MODELING LANE FLOW DISTRIBUTION ON TWO-LANE INTERCITY EXPRESSWAYS

Nagoya University, Student member, Xi WANG
Nagoya University, Member, Miho ASANO
Nagoya University, Member, Peng CHEN
Nagoya University, Fellow, Hideki NAKAMURA

1. Introduction

On multilane expressways, lane flow distribution (LFD) plays an important role as it influences expressway performance e.g. breakdown probability which has already been confirmed by some existing studies[1), 2)]. However, impacts of traffic conditions and geometry on LFD have not been thoroughly investigated based on empirical data. Especially how traffic conditions such as heavy vehicle percentage, geometry or distance to diverge section impact on LFD still remains unclear.

Therefore, this paper developed a model to estimate shoulder lane flow distribution on two-lane expressways based on uncongested traffic flow data. The influencing factors taken into account for this analysis include traffic flow, heavy vehicle ratio, slope grade and distance to the nearest downstream diverge section.

2. Data description

The 5-min aggregated data at 273 detectors installed on two-lane sections of Tomei (Mikkabi IC to Komaki JCT), Meishin (Komaki JCT to Yokkaichi IC), Shinmeishin (Kameyama-Nishi JCT to Koga-Tsuchiyama IC), Higashimeihan (Nagoya-Nishi IC to Kameyama IC), Chuo (Ihoku IC to Komaki JCT) and Tokaihikuriku (Ichinomiya JCT to Shirakawagou IC) Expressways are chosen from October 1st to 30th in 2009.

As for data processing, the first step in handling the data is to remove missing and error values, traffic accidents, road maintenance and other abnormal conditions from detector data. Then data at uncongested flow conditions are distinguished from those at congested flow conditions by adopting a critical speed threshold based on the Q-V curve constructed at each detector location. Uncongested flow data at each detector are categorized into several groups by cross section traffic flow (i.e. every 20 veh/5min) and heavy vehicle ratio (i.e. every 0.1). Since the selected expressways have two lanes only, shoulder lane flow distribution (SLFD) will be analyzed and the average values of SLFD in each group are used for modeling. This may bring estimation errors to the SLFD modeling. For the analysis, uncongested flow data will be divided into 3 levels by cross-section traffic flow Q, i.e. Q1: 0≦Q≦100, Q2:100<Q≦200, Q3:>200 (veh/5min/2lane).

3. Influencing factors on SLFD

3.1 Influence of cross-section traffic flow

Fig.1 shows the typical relationship between cross-section traffic flow and SLFD based on 5-min aggregated detector data on two-lane expressways at 40.520KP in Chuo Exp. as an example. SLFD increases with the increasing of cross-section traffic flow by following an exponential tendency.

3.2 Influence of distance to diverge section

Fig.2 shows that SLFDs at the positions near to the diverge section have higher values compare to those far from diverge section under different traffic flow levels. As all the diverge sections have diverge lanes at left-hand side, drivers who intend to diverge would prefer to utilize shoulder lane. Therefore, SLFD increases as the distance to the nearest downstream diverge section gets closer.

3.3 Influence of speed limit on SLFD considering different slopes

Slopes at the location where detectors are installed have been collected. Based on the slope data, detector data is divided into three groups: downhill way, flat (slope=0) and uphill way. Fig.3 shows the effect of speed limit in different slope groups. The SLFD on the expressway with the speed limit of 80km/h is found to be significantly higher than on the expressways with the speed limit of 100km/h at the 95% confidence interval for each slope group. Considering speed limit depends

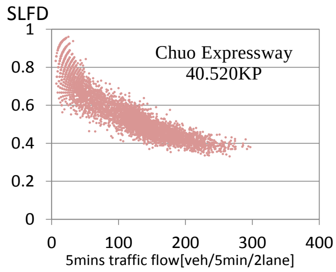

Fig.1 Relationship between SLFD and Q at cross-section

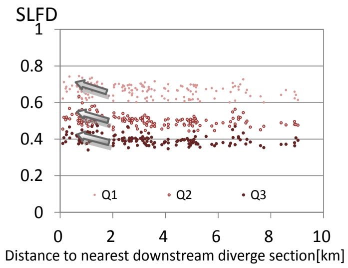

Fig.2 Relationship between SLFD and distance to diverge section

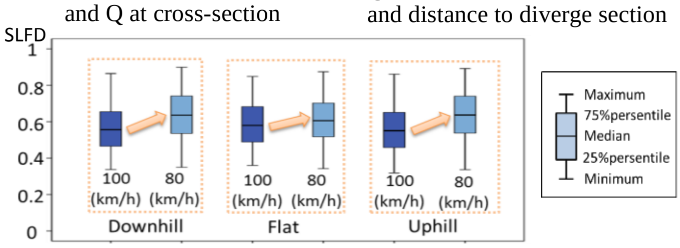

Fig.3 The effect of speed limit in each slope group (Q_{total})

Table 1 t-test results of SLFDs

Q(veh/5min/2lane)		Downhill		Flat		Uphill	
		Speed limit (km/h)		Speed limit (km/h)		Speed limit (km/h)	
		100	80	100	80	100	80
Q_1 (0-100)	Mean	0.700	0.743	0.709	0.686	0.698	0.740
	Std.	0.00427	0.00520	0.00364	0.01199	0.00402	0.00493
	Sample size	1033	2209	173	97	923	1808
	T value	-17.0		1.99		-15.7	
Q_2 (101-200)	Mean	0.513	0.549	0.524	0.522	0.5094	0.5424
	Std.	0.00412	0.00421	0.00368	0.00715	0.00434	0.00434
	Sample size	1551	1926	225	72	1476	1515
	T value	-16.5		0.22		-13.7	
Q_3 (201-)	Mean	0.403	0.412	0.417	0.417	0.389	0.403
	Std.	0.00154	0.00087	0.00138	0.00087	0.00117	0.00090
	Sample size	341	316	44	6	307	224
	T value	-3.48		0.0506		-4.86	
Q_{total}	Mean	0.566	0.636	0.586	0.609	0.560	0.634
	Std.	0.0148	0.0170	0.0142	0.017	0.0151	0.0171
	Sample size	2925	4451	442	175	2706	3547
	T value	-23.4		-2.00		-23.0	

on the geometry condition of expressways, the expressway which has a lower speed limit usually has more complicated geometry condition, e.g. steep slope and tight curve, than that with a higher speed limit. These conditions tend to make drivers travel on the expressway more conservatively with lower speed. As a result, more vehicles prefer to travel on the shoulder lane. This tendency is more significant in both downhill and uphill way groups. The similar tendency can be found under different cross-section traffic flow levels as shown in table 1. Furthermore, for downhill and uphill way groups, the difference between two speed limits data tends to get smaller with the increasing of cross-section traffic flow, which indicates that the influence caused by speed limit on SLFD decrease with increasing cross-section traffic flow.

4. Model development

An exponential function is used to model the shoulder lane flow distribution (SLFD) based on the fundamental relationship between SLFD and cross-section traffic flow. Three parameters are adopted to determine the shape of the curve, as shown in Equation (4.1). α controls the start point, β stands for the curvature and γ represents the asymptotic line. α, β and γ may vary depending on several influencing factors. Herein the influences of heavy vehicle ratio, slope and diverge section are taken into account to develop the model, as represented in Equation (4.2) and (4.3). In this paper, distance to the nearest downstream diverge section is used to present the influence of diverge section on SLFD. The empirical data analysis helps show the SLFD near diverge section has a significant increasing tendency caused by diverge vehicles, but no significant changes have been found far from diverge section. Based on the aforementioned results, Equation (4.4) is presented by assuming exponential relationship.

$$SLFD = (\alpha - \gamma)\,exp(\beta Q) + \gamma \tag{4.1}$$

$$\alpha = \alpha_0 + \alpha_1 hvr + \alpha_2 \delta_2 uphillslope \tag{4.2}$$

$$\beta = \beta_0 + \beta_1 hvr + \beta_2 \delta_2 uphillslope \tag{4.3}$$

$$\gamma = \gamma_0\, exp(\gamma_3 dd) \tag{4.4}$$

where, α, β, γ, α_0, α_1, α_2, β_0, β_1, β_2, γ_0, γ_3 are estimation parameters. δ_2 is a dummy variable (1, if slope>0; 0, if slope≤0). Q is cross-section traffic flow with a range from 0 to 351 (veh/5min/2lane). *hvr* stands for heavy vehicle ratio at cross section. *dd* (km) means the distance to the nearest downstream diverge section hard nose. *Uphill slope* (%) is the slope value where detectors are located on uphill ways. In the process of model development, slopes in the downhill way are found to be not significant in the model. Therefore, only uphill slope are included in the model.

5. Results and discussions

Model parameters of the sections with speed limit 80km/h and 100km/h are separately estimated. Table 2 shows the results of model parameter estimation. All the parameters are significant at the 95% confidence interval. The influences by heavy vehicle ratio and slope are stronger at the expressways with higher speed limit.

Fig.4 shows the comparison of estimated values vs. observed values under different heavy vehicle ratios given a speed limit of 80km/h. At lower *hvr* levels, observed values have obviously higher dispersion, for which the proposed model still have certain shortcoming with limited explainable variables. The model can perform better at higher *hvr* levels where the observed values have milder dispersion. The similar tendency can be found for the model with a speed limit of 100km/h. In addition, the data from the detectors near to diverge sections with high diverge rate (diverging Q/mainline Q, annual average daily value) cannot be well represented, as shown in Fig.5.

Table 2 Model parameters

Parameters		Speed limit (km/h) 80 Coef.	80 t value	100 Coef.	100 t value	Unit of variables
α	α0	0.878	255.48	0.872	155.69	-
	α1	0.0959	17.47	0.180	19.8	-
	α2	0.00489	5.02	0.0149	5.22	%
β	β0	-0.00557	-42.04	-0.00783	-48.91	-
	β1	-0.000912	-9.01	-0.00149	-8.98	-
	β2	-0.000110	-6.29	-0.000460	-9.62	%
γ	γ0	0.258	39.62	0.331	100.9	-
	γ3	-0.0241	-14.44	-0.0143	-17.7	km
R^2		0.9972		0.9976		
n		8173		6073		

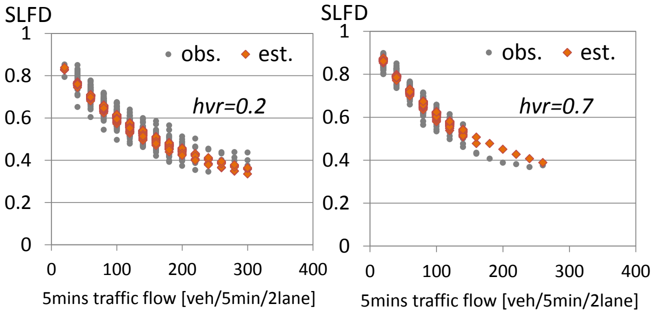

Fig.4 Estimated values vs. observed value (speed limit=80km/h)

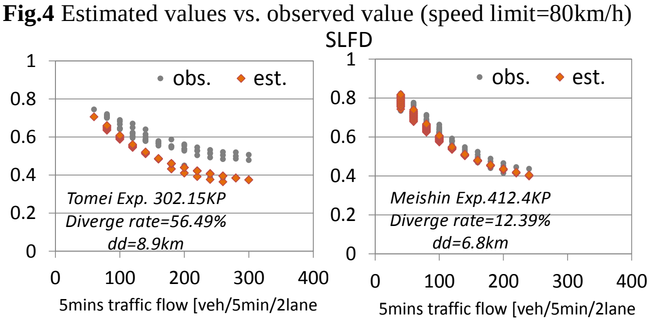

Fig.5 Estimated values vs. observed value

6. Conclusion and future works

SLFDs on the expressways with higher speed limit are significantly lower than those under lower speed limit within each slope group. The developed SLFD model shows that the influences by heavy vehicle ratio and uphill slope are more significant at the expressways with higher speed limit. The model can fit well the observed values under higher heavy vehicle ratios. Since the proposed model cannot well represent the SLFD where the detectors are located near to diverge sections, diverge rate needs to be further added into the model. Upstream slope of the position where detectors are located should also be properly considered.

Acknowledgment

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