PREDICTING OPERATING SPEED ON CURVE SECTIONS OF EIGHT-LANE EXPRESSWAY IN PLAIN AREA

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by

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Abstract

In China, a number of four-lane expressways have been enlarged to eight-lane expressways for coping with the increase of traffic volume since 2000. Taking everything into account, extension projects' alignment designs generally followed the original designs of existing roads. To evaluate driving safety of extension project, it is necessary to check the consistency of operating speed and design speed. Numerous studies took rural two-lane and four-lane highways as research subjects and provide models for predicting operating speeds. However, less attention has been paid to eight-lane expressway. In this study, field operating speed data both of cars and trucks on 30 curve sections of eight-lane expressway was collected. With the data, correlation between V85 (operating speed) and alignment was analyzed. The correlation analysis results showed that, comparing with original data, classified V85 data (V85a: average operating speed of a curve, V85s: operating speed of the start point of a curve, V85m: operating speed of the middle point of a curve, and V85e: operating speed of the ending point of a curve) had better correlations with alignment parameters. It was also found that classified V85 data in one direction (upstream: from terminus to beginning\downstream: from beginning to terminus) was significantly related with alignment parameters. Seeking to provide a better understanding of operating speed distribution on eight-lane expressway, this study proposed four speed predicting models (linear or curve fitting models) respectively of cars and trucks (V85a\V85s\V85m\V85e). Results of modeling showed that angle (deflection angle)\Rb(radius of preceding curve)\Ra(radius of successive curve) were three most important parameters for predicting operating speeds of cars and trucks.

BACKGROUND

With traffic volume growing, LOSs (level of service) of four-lane expressways keep going down. Reconstruction and extension projects of expressways become popular under this circumstance. Considering both traffic volume demand and technique characteristic, it is common to enlarge four-lane section to eight-lane section in expressway extension projects (1). Alignment design of extension project generally follows the original design of existing four-lane expressway. Operating speeds on new eight-lane expressway could change with the changes of road surroundings such as number of lanes, road width, traffic flow form, and so on. It is necessary to give new consideration to the design consistency of new eight-lane expressway since operating speeds change.

In 2004, Ministry of Communications P.R.C. published <Guidelines of Safety Audit of Highway> (JTG/TB05-2004) which provides two methods for predicting operating speed. Method 1 treats the tangent sections of which grades less than 3% and the curve sections of which radiuses larger than 1000m as independent sections. And the maximum car's operating speed of the independent sections is assumed to 120km/h; as to truck, the maximum operating speed is assumed to 75km/h. Method 2 is only able to predict operating speed of passenger cars. In addition, the maximum calculated operating speed using method 2 also equals to 120km/h. (2) Therefore, both of these two methods are not suitable for predicting operating speeds of eight-lane expressway because that predicted results could not meet field data. To serve as authoritative guidelines for important projects in China, these two recommended calculating methods obviously need modifications. According to this problem, this paper puts forward predicting operating speed models for eight-lane expressway in plain area with analysis of obtained field data. Considering the fact that expressway alignment in plain area generally consists of curve sections, this study only chose curve sections as research objects.

PREVIOUS MODELS FOR OPERATING SPEED PREDICTION

Past researches did a lot of work for rural two-lane (3~10). Curve radius was mostly used in early studies as the predictor (11, 12). More predictors of geometric features were used in later studies (13, 14, 15), while in some models, traffic and pavement information were also used (3, 16). A large number of studies used radius as an explanatory variable for operating speed prediction while a few (6 only) used length of curve (17). The variables that have been identified as significantly relating to operating speed include: radius of the curve, length of the curve, length of the preceding and successive tangents, grades, superelevation, average daily traffic volume, pavement condition, approach speed, and speed limit. The most frequently used predictors are: radius, length of curve, length of tangent, grade, superelevation, and lane width. Length of tangent and grade were also used as independent variables in a few studies (18, 19). Study 20 provided models of operating speed for both inside lane and outside lane of rural four-lane highway using predictors including ST(shoulder type index)\ MT(median type index)\PT(pavement type index)\AG (approaching section grade index）\R(curve radius）\LC (length of curve)and FC(front curve index). Research (21) proposed a structural model that relates mean speed and speed deviations by lane and was contemporaneously influenced by environmental, temporal, and traffic flow factors. This research macroscopically addressed endogenous issues related to lane-mean traffic speeds and lane-speed deviations. It provided a better understanding of mean speeds and speed deviations across the lanes of a multilane highway.

As above, the major portion of completed work was for rural two-lane and little is known about eight-lane expressways. Besides, most of the models mentioned were about predicting operating speed of car and few models were for predicting truck's operating speed. However, it is widely known that excessive speed differences among cars and trucks can also cause driving safety problems (22, 23). A series of regression models were developed to predict 85th percentile truck operating speeds upstream, along, and down stream of a horizontal curve in study (24). These models consider the effect of length and grade of approach tangent, horizontal curve radius, and length and grade of departure. But these models are also used for trucks on two-lane rural highways.

DATA COLLECTION AND TREATMENT

HU-Ning Expressway

Field speed data for analysis was collected on HU-Ning expressway which is the only eight-lane expressway in Jiangsu province at present. With an annual growth rate of 18.3%, old four-lane HU-Ning expressway's AADT (annual average daily traffic volume) finally achieved 41143pcu/d in 2002(6 years after opened to traffic), and its LOS (level of service) declined to C level. The extension project of old four-lane HU-Ning expressway lasted 3 years (2003-2006). New eight-lane HU-Ning expressway is 248.2km in length and 42.5 in width. Design speed of the extension project is 120km/h and the alignment design followed the original. Alignment of HU-Ning expressway chiefly consists of curve sections without transition curves. Curve sections account for a portion of 81.3% of the whole mileage. Radiuses of the 91 curve sections of this road are from 3000 to 10000 meters. Deflection angles in the design are all larger than 10°. The minimum vertical curve radius of convex vertical curve is 13000m while the one of concave vertical curve is 11200m. The biggest longitudinal grade of this road is 2.6% and the shortest grade length is 400m.

Observation Point

30 different curves sections of which radiuses ranged from 3000m to 10000m were selected for collecting data. Operating speeds at five points on each section were recorded. The five observation points are: 200m before starting point of the curve, starting point of the curve, middle point of the curve, end point of the curve, and 200m after end point of the curve. One thing that's worth mentioning here regarding the first and fifth observation points is that speeds of the two points were collected to discuss the impacts on a curve's average operating speed of preceding and successive curves. 300 sets of field speed data were obtained by testing the operating speeds in two directions at 150 observation points. Cars' and trucks' operating speeds were respectively recorded by different

staff at the same time. For convenience, assign numbers (1-4) to the four lanes from median separator to curb line in one direction. Lane 1 which abuts on median separator is the passing lane for cars while lane 3 is the passing lane for trucks. To avoid unexpected influence to the validity of data caused by vehicles' accelerating, we chose to record operating speeds of cars on lane 2 and operating speeds of trucks on lane 4.

FIGURE 1 Scene Photos of Speed Testing

Equipment

Radar Speed Guns, Digital Camera, Video Camera, Stopwatch, Range Finder, Interphone, Record book.

Time

Speed data was collected at AM 9:00-11:00 and PM 14:00-17:00 in good weather conditions.

Treatment of Field Data

Generally, to assure validity of Pearson correlation, there is a demand that each set of selected data should follow normal distribution. Using Kolmogorov-Smirnov test, it was found that the distribution of the data was normal could not be rejected at the 95% confidence level. Operating speed at each observation point was defined as the 85th percentiles of collected speed data (V85). Then the 85th percentiles of collected speed data of each observation point (V85), respectively of cars and trucks, were calculated for further correlation analysis and modeling.

Required Sample Size

Desired sample size, which represents the least number required for determining acceptable 85th percentile operating speed (V85) at each observation point, was calculated with following formula.

$$n = \left(\frac{\sigma K}{E} \right)^2 \tag{1}$$

Where:

n= the least number of sample size.

σ=standard deviation of observed values.

E=allowable error of observed values.

K=degree of confidence (commonly choose 95% degree of confidence for calculating, that means K=equals to1.96)

The value of E depends on precision demand of observed speed data and generally equals to 2km/h (25). However, in this study, the value of E was set to 2.5km/ h considering relatively larger divergence of operating speeds on eight-lane expressway. Experience demonstrated that the measurement error would become lager as the angle of declination between the direction of radar speed gun and the traffic direction increases. So the speed data might not be accurately measured. From calculation, desired sample sizes of passenger cars and trucks are 67 and 70 respectively.

METHODOLOGY

Variables

9 key variables which normally are used in alignment design of curve sections were considered in speed prediction model building. These variables are the following: R(curve radius)\ Rb(radius of preceding curve)\Ra(radius of successive curve)LC\(length of curve)\angle(deflection angle)\ Rv(vertical curve radius)\i(longitudinal Grade)\L(length of grade)\Lv(distance from grade change point).

Model Development Procedure

In this paper, to obtain the best model for the prediction, both linear regression method and curve fitting method were used in modeling.

Firstly, the correlation between V85 and the selected 9 variables was analyzed. Then, this study proposed four speed predicting models respectively of cars and trucks (V85a: average operating speed of a curve, V85s: operating speed of the start point of a curve, V85m: operating speed of the middle point of a curve, and V85e: operating speed of the ending point of a curve).These models were built using calculated 85th percentile speeds (V85) which were separated into classes of V85a\V85s\V85m\V85e. The value of V85a is the average of five V85 values at different observation points of each curve.

R^2 is normally used as determination coefficient in linear regression method to explain how much variation of dependent variable is caused by independent variables variation. However, to dispel the influence caused by sample size, R_{adj}^2 was selected to replace R^2 for judging the validation of forecasting model. The equations with high R_{adj}^2 and appropriate C_p were chosen as final models. And variance analysis was used to assure the validity of the linear models. If linear models were not ideal, curve fitting equation would be established to replace it. Dispel outlier by plotting scatter diagram before using curve fitting method. If adjusted R Square was acceptable, variance analysis, partial regression coefficient and constant test were to be used to decide the final curve fitting equation of operating speed model.

CORRELATION BETWEEN V85 AND VARIABLES

Car

The correlations among V85 on curve sections and seven of the nine selected variables including R, RV, i，LV, L, LC and angle were firstly analyzed. As shown in table 1, Pearson correlation coefficient and the value of Sig. were calculated by SPSS.

TABLE 1 Correlations among Cars' V85 and Selected Variables

		V85	R	RV	i	LV	L	LC	angle
V85	PC	1	.402**	-.158	-.007	-.046	-.159	-.282**	-.335**
	Sig.		.000	.080	.475	.343	.082	.006	.001
R	PC	.402**	1	-.448**	.000	-.230*	-.240*	-.182	-.713**
	Sig.	.000		.000	.500	.020	.017	.053	.000
RV	PC	-.158	-.448**	1	.000	.224*	.219*	-.060	.406**
	Sig.	.080	.000		.500	.023	.027	.299	.000
i	PC	-.007	.000	.000	1	.164	.000	.000	.000
	Sig.	.475	.500	.500		.073	.500	.500	.500
LV	PC	-.046	-.230*	.224*	.164	1	.078	.116	.143
	Sig.	.343	.020	.023	.073		.247	.153	.102
L	PC	-.159	-.240*	.219*	.000	.078	1	-.017	.262*
	Sig.	.082	.017	.027	.500	.247		.442	.010
LC	PC	-.282**	-.182	-.060	.000	.116	-.017	1	.286**
	Sig.	.006	.053	.299	.500	.153	.442		.005
angle	PC	-.335**	-.713**	.406**	.000	.143	.262*	.286**	1
	Sig.	.001	.000	.000	.500	.102	.010	.005	

PC: Pearson Correlation Coefficient (similarly hereinafter)

Sig.：Sig. (1-tailed) (similarly hereinafter)

** Correlation is significant at the 0.01 level (1-tailed) (similarly hereinafter)

* Correlation is significant at the 0.05 level (1-tailed) (similarly hereinafter)

A quick look at the table above indicates the variables of horizontal curves have a little dependency with V85 while variables of vertical curve (Rv(vertical curve radius)\ i(longitudinal Grade) \ L(length of grade) \Lv(distance from grade change point)) are almost irrelevant with V85. Therefore, variables of vertical curve were abandoned in further analysis.

It was considered that definitely different distribution forms of V85 respectively at the five measuring points caused the unsatisfactory result of correlation analysis among V85 and variables of horizontal curve. Therefore, this study further analyzed the correlation respectively among V85 and selected variables of horizontal including R(curve radius)\ Rb(curve radius of preceding curve before)\Ra(curve radius of successive curve) LC\(length of curve)\ angle (deflection angle).

TABLE 2 Correlations among Cars' Classified V85 and Selected variables

		V85a	V85s	V85m	V85e	R	angle	Rb	Ra	LC
V85a	PC	1	.749**	.558*	.815**	.676**	-.687**	.619**	.537*	.141
	Sig.		.000	.012	.000	.002	.002	.005	.016	0.301
V85s	PC	.749**	1	.291	.563*	.388	-.581**	.503*	.655**	.250
	Sig.	.000		.137	.012	.069	.009	.024	.003	.175
V85m	PC	.558*	.291	1	.262	.192	-.513*	.595**	.026	-.424
	Sig.	.012	.137		.163	.238	.021	.008	.461	.051
V85e	PC	.815**	.563*	.262	1	.511*	-.341	.428*	.339	.184
	Sig.	.000	.012	.163		.022	.098	.049	.099	.247
R	PC	.676**	.388	.192	.511*	1	-.651**	.589**	.589**	0.073
	Sig.	.002	.069	.238	.022		.003	.008	.008	.394
angle	PC	.619**	.503*	.595**	.428*	.589**	-.716**	1	.308	.539*
	Sig.	.005	.024	.008	.049	.008	.001		.123	.005
Rb	PC	.689**	.193	.501*	.490*	.589**	-.716**	1	.308	-.301
	Sig.	.002	.237	.024	.027	.008	.001		.123	.129
Ra	PC	.537*	.655**	.026	.339	.589**	-.716**	.308	1	.537*
	Sig.	.016	.003	.461	.099	.008	.001	.123		.016
LC	PC	-.141	-.250	-.424	.184	.073	.539*	-.301	-.301	1
	Sig.	.301	.175	.051	.247	.394	.016	.129	.129	

It can be seen from the table 2, there are relatively significant correlations among classified V85 and selected variables of horizontal variables. However, as can be seen in table 3, these correlations are more significant if the data is classified according to direction.

TABLE 3 Correlations among Cars' Classified V85 and Selected variables (Downstream)

		V85a	V85s	V85m	V85e	R	angle	Rb	Ra	LC
V85a	PC	1	.904**	.870**	.883**	.564	-.857**	.743*	.543	-.181
	Sig.		.001	.002	.002	.073	.003	.017	.082	.334
V85s	PC	.904**	1	.930**	.710*	.339	-.842**	.676*	.765*	-.445
	Sig.	.001		.000	.024	.206	.004	.033	.013	.135
V85m	PC	.870**	.930**	1	.779*	.352	-.685*	.641*	.558	-.238
	Sig.	.002	.000		.011	.196	.031	.043	.075	.285
V85e	PC	.883**	.710*	.779*	1	.505	-.560	.702*	.146	.243
	Sig.	.002	.024	.011		.101	.074	.026	.365	.281

R	PC	.564	.339	.352	.505	1	-.651*	.798**	.241	.073
	Sig.	.073	.206	.196	.101		.040	.009	.283	.432
angle	PC	-.857**	-.842**	-.685*	-.560	-.651*	1	-.784*	-.818**	.539
	Sig.	.003	.004	.031	.074	.040		.011	.007	.084
Rb	PC	.743*	.676*	.641*	.702*	.798**	-.784*	1	.489	-.143
	Sig.	.017	.033	.043	.026	.009	.011		.109	.368
Ra	PC	.543	.765*	.558	.146	.241	-.818**	.489	1	-.868**
	Sig.	.082	.013	.075	.365	.283	.007	.109		.003
LC	PC	-.181	-.445	-.238	.243	.073	.539	-.143	-.868**	1
	Sig.	.334	.135	.285	.281	.432	.084	.368	.003	

Downstream: from beginning to terminus (similarly hereinafter).

It can be seen from Table 3, V85a (average V85 of a curve) is significantly related to angle (deflection angle) and Rb (radius of preceding curve). The Pearson correlation coefficients are -0.857 and 0.743, respectively. To a certain extent, V85s (V85 at the starting point of a curve) is significantly related to angle and Ra (radius of successive curve), and the values of the Pearson correlation coefficients are respectively -0.842 and0.765. V85m (V85 at the middle point of a curve) has some relationship with angle and Rb and the Pearson correlation coefficients are -0.685 and 0.641, respectively. V85e (V85 at the ending point of a curve) has the best significant correlation with Rb and their Pearson correlation coefficient is 0.702.

Truck

The same variables as used in cars' analysis, including R\RV\ i\LV\L\ LC \angle, were selected for trucks' analysis. The correlation results of trucks are similar with cars'. There is no correlation between V85 and any parameter of vertical curve and it was also considered that different distribution forms of V85 respectively at different observation points caused the unsatisfactory results of correlation analysis. Then, correlations among classified V85 data and variables of horizontal curve were analyzed and the results are shown in table 4.

TABLE 4 Correlations among Trucks' Classified V85 and Selected Variables

		V85a	V85s	V85m	V85e	R	angle	Rb	Ra	LC
V85a	PC	1	.704**	.493*	.321	.473*	-.743**	.689**	.490*	-.340
	Sig.		.001	.026	.112	.032	.000	.002	.027	.099
V85s	PC	.704**	1	.317	-.345	.058	-.221	.193	.170	-.148
	Sig.	.001		.116	.095	.415	.205	.237	.265	.292
V85m	PC	.493*	.317	1	.193	.456*	-.530*	.501*	.252	.016
	Sig.	.026	.116		.237	.038	.017	.024	.174	.476
V85e	PC	.321	-.345	.193	1	.381	-.454*	.490*	.232	-.002
	Sig.	.112	.095	.237		.073	.039	.027	.193	.496
R	PC	.473*	.058	.456*	.381	1	-.651**	.589**	.589**	.073

	Sig.	.032	.415	.038	.073		.003	.008	.008	.394
angle	PC	-.743**	-.221	-.530*	-.454*	-.651**	1	-.716**	-.716**	.539*
	Sig.	.000	.205	.017	.039	.003		.001	.001	.016
Rb	PC	.689**	.193	.501*	.490*	.589**	-.716**	1	.308	-.301
	Sig.	.002	.237	.024	.027	.008	.001		.123	.129
Ra	PC	.490*	.170	.252	.232	.589**	-.716**	.308	1	-.301
	Sig.	.027	.265	.174	.193	.008	.001	.123		.129
LC	PC	-.340	-.148	.016	-.002	.073	.539*	-.301	-.301	1
	Sig.	.099	.292	.476	.496	.394	.016	.129	.129	

It can be seen from table 4, there are relatively significant correlations among classified V85 and selected variables of horizontal curve. As can be seen in table 5, these correlations become more significant if the data in two directions is separated.

TABLE 5 Correlations among Trucks' Classified V85 and Selected Variables (Upstream)

		V85a	V85s	V85m	V85e	R	angle	Rb	Ra	LC
V85a	PC	1	.902**	.959**	.450	.569	-.903**	.726*	.559	-.461
	Sig.		.001	.000	.132	.071	.001	.021	.075	.125
V85s	PC	.902**	1	.807**	.194	.397	-.674*	.491	.269	-.207
	Sig.	.001		.008	.323	.165	.034	.108	.260	.311
V85m	PC	.959**	.807**	1	.538	.657*	-.883**	.727*	.657*	-.444
	Sig.	.000	.008		.085	.038	.002	.021	.038	.135
V85e	PC	.450	.194	.538	1	.301	-.518	.542	.577	-.449
	Sig.	.132	.323	.085		.235	.094	.083	.067	.132
R	PC	.569	.397	.657*	.301	1	-.651*	.241	.798**	.073
	Sig.	.071	.165	.038	.235		.040	.283	.009	.432
angle	PC	-.903**	-.674*	-.883**	-.518	-.651*	1	-.818**	-.784*	.539
	Sig.	.001	.034	.002	.094	.040		.007	.011	.084
Rb	PC	.726*	.491	.727*	.542	.241	-.818**	1	.489	-.868**
	Sig.	.021	.108	.021	.083	.283	.007		.109	.003
Ra	PC	.559	.269	.657*	.577	.798**	-.784*	.489	1	-.143
	Sig.	.075	.260	.038	.067	.009	.011	.109		.368
LC	PC	-.461	-.207	-.444	-.449	.073	.539	-.868**	-.461	1
	Sig.	.125	.311	.135	.132	.432	.084	.003	.125	

Upstream: from terminus to beginning. (similarly hereinafter)

It can be seen from Table 5, V85a (Average V85 of a curve) is significantly related to angle (deflection angle) and Rb (radius of preceding curve) with respective Pearson correlation coefficients of -0.903 and 0.726. There is some correlation between V85s and angle, and the Pearson correlation coefficient value is -.647. V85m (V85 at the middle point of a curve) is significantly related to angle and Rb and the values of the Pearson correlation coefficients are -0.883 and 0.727, respectively. V85e (V85 at the ending point of a curve) has some relationship with Ra and Rb and the respective Pearson correlation coefficients are respectively 0.577 and 0.542.

MODEL AND DISCUSSION

Car

As above, there are significant correlations among cars' classified V85 in downstream direction and variables of horizontal alignments. Using the procedure described in the preceding part of methodology, models were firstly developed and then validated. The independent parameter in each equation was selected based on the correlation analysis. These models are presented below.

TABLE 6 Operating Speed Models of Car on Curve Sections

Operating Speed Models		R^2_{adj}	Model type	ANOVA F test Sig.	Coefficients T test	
V85a	$V85a = 129.7 - 0.203 angle$	0.689	linear	0.007	C	0.000
					angle	0.007
V85s	$V85s = 110.7 + 0.002Ra$	0.725	linear	0.020	C	0.02
					Ra	<0.001
V85m	$V85m = 105.9 + 0.004Rb$	0.919	linear	0.006	C	<0.001
					Rb	0.006
V85e	$V85e = 59.9(Rb^{0.088})$	0.649	Power	0.033	C	0.033
					Rb	0.013

Linear equations and curve fitting equations were established followed with variance analysis, partial regression coefficient and constant test. The value of each model's R^2_{adj} exceeds 0.60. Especially, the value of R^2_{adj} of the V85m model equals to 0.919, so it means that operating speed can be well fitted with selected variable. The values of Sig. obtained using F test are all less than 0.05, which means the modes passed the variance analysis.

It is beyond expectation that Ra(radius of successive curve) finally becomes the key parameter of the predicting model of V85s (operating speed of the start point of a curve). It is considered that the drivers control their operating speeds taking the successive alignment beforehand when riving in to a curve. However, Rb is both the key parameter of V85m and V85e. The authors think that drivers are confident in properly controlling their speeds to ensure safety when their vehicles have moved to the second half of a curve. It follows that they do not tend to control their speeds with consideration of successive alignment, be different from V85s, V85m and V85e are more affected by the radius of proceeding curve. Overall the operating speed of a curve is most affected by the deflection angle of a curve since deflection angle finally becomes the key parameter of the predicting model of V85a. And it is reasonable that R(radius of a curve) was not chose as the key parameter of V85a because the range of the curves studied in this project is very great in extent.

Truck

Models of operating speed for truck are presented in table 7. The independent parameter in each equation was selected based on the correlation analysis.

TABLE 7 Operating Speed Models of Truck on Curve Sections

Operating Speed Models		R^2_{adj}	Model type	ANOVA F test Sig.	Coefficients T test	
V85a	$V85_a = 74.654 + (107.7 / angle)$	0.861	Inverse	0.001	C	<0.001
					Angle	0.001
V85s	$V85_s = 72.995 + (161.5 / angle)$	0.516	Inverse	0.027	C	<0.001
					Angle	0.027
V85m	$V85m = 90.509(angle^{-0.034})$	0.792	Power	0.002	C	0.002
					Angle	<0.01
V85e	$V85e = 63.128 + 0.003Rb$	0.539	Linear	0.059	C	<0.01
					Rb	0.059

As can be seen in table 7, established models of V85a and V85m are better than those of V85s and V85e. Note angle was finally chosen as the key parameter of three models: V85a, V85s and V85m. The values of Sig. obtained using F test are all less than 0.05 except the one of V85e, so the three models pass the variance analysis.

Different from past studies, not any parameter of vertical curve but deflection angle finally becomes the most significant fact which obviously affects the operating speeds of trucks. This is possibly because that the variations of the grade and radius\length of vertical curve in this project are relatively small since it is an expressway in plain area.

CONCLUSIONS

In this study, 30 different curve sections with radiuses ranged from 3000 to 10000 were selected as objects for collecting data. With field data, correlation among V85 and selected variables was analyzed and predicting models both for cars and trucks were established.

To sum up, the main conclusions are as following:

(1) For both cars and trucks, there is significant correlation among variables of horizontal curve and V85 in one direction. It is considered that difference between traffic flow forms of two directions caused the different distribution of operating speed.

(2) In the case of expressways in plain area, it turns out that deflection angle and radius of preceding or successive curve play more important roles than R in the predicting operating speed models of car.

(3) In the case of expressways in plain area, indexes of vertical curve do not significantly affect to the trucks' operating speeds. From the modeling results, deflection angle of horizontal curve is the main factor effecting on trucks' V85.

In further study, more speed data will be obtained to improve the precision of the models. Speed models considering different lanes and tangent sections of eight-lane will be also studied.

REFERENCES

(1)Xianyu Chen. Analysis of Current Situation of Traffic and Management Countermeasure of Eight-lane Expressway. *Public Security Science Journal-Journal of Zhejiang Police College*, No. 94, 2006, PP :78-80

(2)Ministry of Communications P.R.C. *Recommended industry standard, <Guidelines of Safety Audit of Highway> (JTG/ TB05 -2004)*. 2004

(3)Daniel R. Jessen, Karen S. Schurr, Patrick T. McCoy, Geza Pesti, Ryan R. Huff. Operating Speed Prediction on Crest Vertical Curves of Rural Two-Lane Highways in Nebraska. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1751, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C.,2001,pp. 67-75.

(4) Islam. M. and Seneviratne P.N. Evaluation of Design Consistency on Two-lane Highways. *ITE Journal*, Institute of Transportation Engineers, No. 64, 1994, PP. 28–31.

(5)Lamm, R., Choueiri, E.M., and Mailaender, T. Comparison of Operating Speed on Dry and Wet Pavements of Two-lane Rural Highways. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1280, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C.,1990,pp. 199-207.

(6) Fitzpatrick, K., J. D. Bloaschke, C. B. Shanburger, R. A. Krammes. *Compatibility of Design Speed, Operating Speed and Posted Speed*. Texas Transportation Institute, College Station, Texas,1995.

(7)Ottesen, J. L. and R. A. Krammes. Speed-Profile Model for a Design-Consistency Evaluation Procedure in the United States. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1701, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2000, pp.76-85.

(8)Polus, A., K. Fitzpatrick, D. B. Fambro. Predicting Operating Speed on Tangent Sections of Two-Lane Rural Highways .In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1737, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2000, pp:50-57.

(9)Schurr, K., P. T. McCoy, D. Jessen, G. Pesti, R. Huff. *Relationship between Design, Operating and Posted Speeds under High-Posted Speed Conditions*. Nebraska Department of Roads, Lincoln, Nebraska, 2000.

(10)McFadden, J., and Elefteriadou, L. Formulation and Validation of Operating Speed-based Design Consistency Models by Bootstrapping. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1579, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C.,1997,pp. 97–103.

(11)McLean, J. *Speeds on Curves: Regression Analysis*. Internal Report No. 2003 to the Australian Road Research Board, Australia, 1978.

(12)Lamm, R., E.M. Choueiri, and T. Mailaender. Comparison of Operating Speeds on Dry and Wet

Pavements of Two-Lane Rural Highways. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1280, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 1990.pp:199-207.
(13) Ottesen, J. L. and R. A. Krammes. Speed-Profile Model for a Design-Consistency Evaluation Procedure in the United States. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1701, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2000.pp:76-85.
(14)Medina, A. M. and P. A. Tarko. *Reconciling Speed Limits with Design Speeds*. FHWA/IN/JTRP-2004/26, Joint Transportation Research Program, Indiana Department of Transportation, Federal Highway Administration, Washington, D. C. 2004.
(15)Misaghi, P. and Y. Hassan. Modeling Operating Speed and Speed Differential on Two-lane Rural Roads. *Journal of Transportation Engineering*, Vol. 131, No. 6, 2005, pp: 408-418.
(16)Schurr, K. S., P. T. McCoy, G. Pesti, and R. Huff. Relationship between Design, Operating, and Posted Speeds on Horizontal Curves on Rural Two-Lane Highways in Nebraska， In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1796, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2002，pp.60-71.
(17) Gong, H. Ph. D Dissertation: Operating Speed Prediction Models for Horizontal Curves on Rural Four-Way Non-Freeway Highways, University of Kentucky, Lexington, KY, 2007.
(18) Donnell, E. T., Y. Ni, M. Adolini, and L. Elefteriadou. Speed Prediction Models for Trucks on Two-Lane Rural Highways. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1751, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2001.pp:44-55.
(19)Gibreel, G. M., S. M. Easa, I. A. El-Dimeery. Prediction of Operating Speed on Three-Dimensional Highway Alignments. *Journal of Transportation Engineering*, Vol.127, No. 1, 2001, pp. 21-30.
(20)Huafeng Gong, Nikiforos Stamatiadis. Operating Speed Prediction Models for Horizontal Curves on Rural Four-Lane Highways. In *Transportation Research Record: Journal of the Transportation Research Board*, No.2075, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C.,2008, pp:1-7.
(21) V. Shankar. Modeling the endogeneity of lane-mean speeds and lane-speed deviations: A structural equations approach .*Transportation Research Part A: Policy and Practice*. Volume 32, Issue 5, 1998, pp. 311-322.
(22) Yaping Lin. *Master Degree Paper of Southeast University: Analysis of Operating Speed Influence on Accident and Research on Accident Forecast Model*. 2007.
(23)*Safety Audit of Jingao Expressway (Hebei part)*. CCCCC Second Highway Consultants Co.Ltd, 2006.
(24)Eric T. Donnell1, Yingwei Ni2, Michelle Adolini1, Lily Elefteriadou1. Speed Prediction Models for Trucks on Two-Lane Rural Highways. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1751, Transportation Research Board, Washington D. C. Transportation Research Board of the National Academies, Washington, D.C., 2001. PP: 44-55

(25) Jianliang Liang. *Master Degree Paper of Hebei University of Technology: Study on the Evaluation Method of Expressway Alignment Based on Operating Speed.* 2006.