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Prediction of Planning Time in Busan Ports-Connected Expressways

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Abstract : *Expressways mean the primary arterial highways with a high level of efficiency and safety. However, Gyeongbu and Namhae expressways connected with Busan ports are showing travel time delay by increased traffic including the medium/large-sized vehicles of about 20% compared to those of about 13% regardless of the peak periods. This study, thus, intends to analyze lane traffic characteristics in the basic 8-lane segments of the above-mentioned expressways, compute the planning and buffer times based on travel time reliability, find the lane speed showing a higher correlation with planning time between the lane speeds in the basic 8-lane segments, and finally suggest a correlation model for predicting the planning time in expressways.*

Key words : *Expressways, Traffic characteristics, Space mean speed, Travel time reliability, Correlation analysis, Correlation model*

1. Introduction

1.1 Background

Expressways mean the high-speed arterial highways with a high level of efficiency and safety. However, most of expressways don't play their roles by the high rate of the medium/large-sized vehicles of about 13% and increased traffic. In addition it is not easy to continue to build new expressways because of limited budget and time. So, it is absolutely needed to improve the mobility and efficiency of existing expressways instead of constructing new ones.

1.2 Objectives

Study expressways as shown in Fig. 1 are showing travel delay by the higher rate of the medium/large-sized vehicles of about 20%. In the studies of travel time and speed, detector speed was reported to show the higher reliability in travel time estimation/prediction of expressways at a speed of over 70km/h(Oh et al., 2003), and average speed was reported to have the higher correlation with the speed on lane 2 than on lanes 3 and 4 in urban freeway(Kim and Jeong, 2012). So, this study is to investigate the lane traffic characteristics in the 8-lane expressways, identify the lane speed characteristics highly correlated with travel time reliability, and suggest the better correlation models for predicting planning time in the 8-lane expressways.

1.3 Data Collection

Study segments were selected from the basic 8-lane ones, as described in Table 1. So, data collection was repeatedly conducted from Jun. 16, 2014 to Jul. 6, 2014, and a master dataset for analysis was generated every 15 minutes in the basic 8-lane segments(i.e., lane 1 for passing vehicles, lane 2 for small-sized ones, lane 3 for medium-sized ones and lane 4 for large-sized ones for each direction).

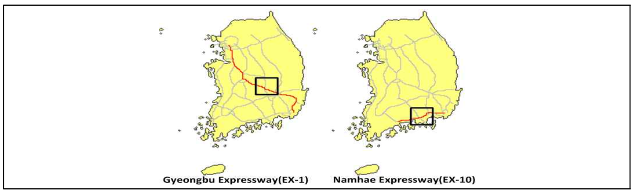

Fig. 1 Expressways under the study

Table 1 Geometry of expressways under the study

Item	Gyeongbu(EX-1)		Namhae(EX-10)	
	Total	Segment	Total	Segment
Length(km)	416.0	4×15	273.1	4×15
No. of lanes	4 to 10	8	4 to 8	8
Rate of Medium/ Large Vehicles(%)	18.7		21.3	

2. Analysis of traffic characteristics

2.1 Flow

Flow was expressed by an hourly flow, as follows(TRB, 1975);

$$Q = \frac{N}{T} \tag{1}$$

Where, Q : Flow(veh/h)

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N : No. of vehicles observed at station(veh)
T : Observed time(1hour)

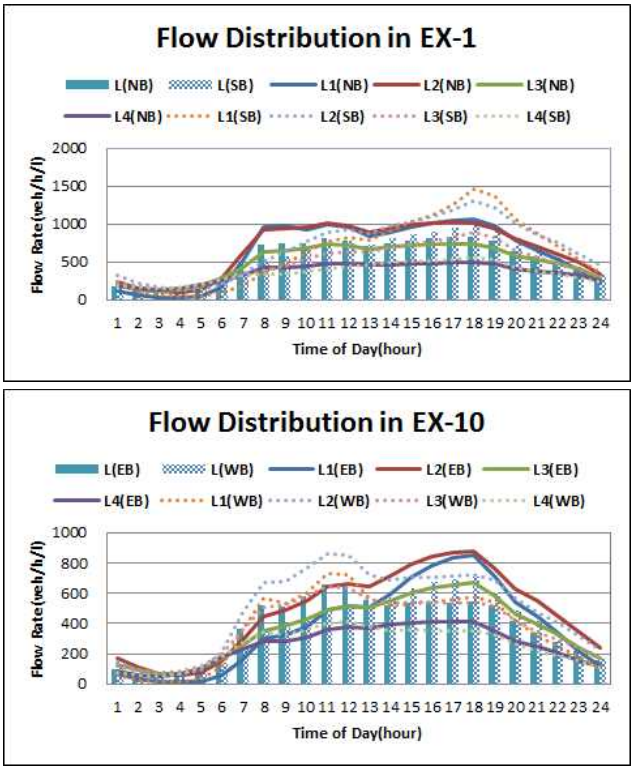


Fig. 2 Flow distribution in expressways under the study

Table 2 Flow statistics in expressways(veh/h/l)

Expressways		L1		L2		L3		L4		L
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
EX-1	NB	630	390	680	350	510	230	370	130	550
	SB	650	430	710	380	530	240	400	150	570
EX-10	EB	380	280	480	280	370	200	260	130	370
	WB	370	240	500	270	380	200	250	120	380

Note: L1 is lane 1, L2 is lane 2, L3 is lane 3, L4 is lane 4, L is lane mean, NB is northbound, SB is southbound, EB is eastbound, WB is westbound, SD is standard deviation

There seemed to be a distinct difference in flow rate between the directions as well as the lanes for each expressway as shown in Fig. 2. Also, average flow rate appeared to increase by about 9% to 27% in lanes 1 and 2 showing a higher deviation, but to decrease by about 4% to 31% in lanes 3 and 4 showing a lower deviation as summarized in Table 2.

2.2 Speed

Speed was converted into the space mean speed, as follows(May, 1990);

$$U_s = \frac{\sum_{i=1}^{n} N_i}{\sum_{i=1}^{n} \frac{N_i}{U_i}} \qquad (2)$$

Where, U_s : Space mean speed in segment(km/h)
n : No. of stations in segment
N_i : No. of vehicles observed at station i(veh)
U_i : Spot mean speed at station i(km/h)

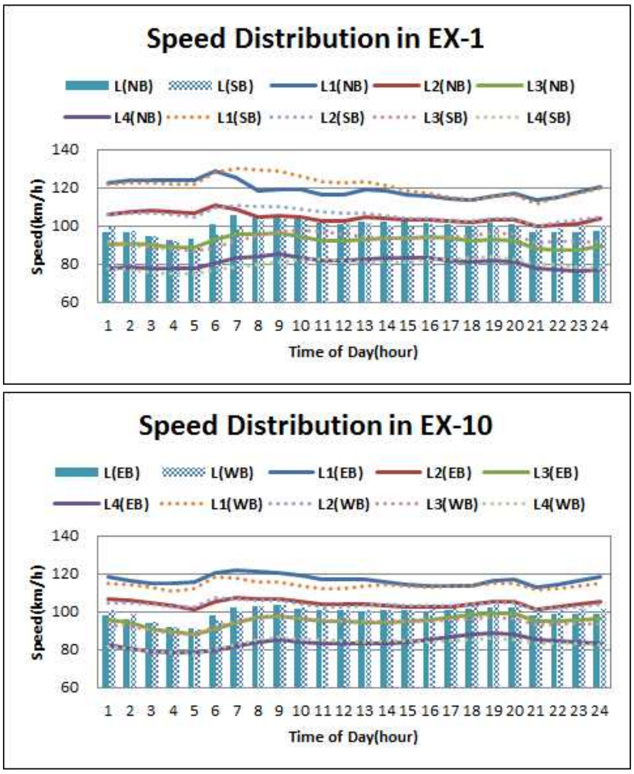


Fig. 3 Speed distribution in expressways under the study

Table 3 Speed statistics in expressways(km/h)

Expressways		L1		L2		L3		L4		L
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
EX-1	NB	119	4	104	3	92	3	81	3	100
	SB	119	5	104	2	91	2	80	2	99
EX-10	EB	117	3	104	2	95	3	84	3	100
	WB	114	2	104	1	94	3	83	2	99

There did not seem to be a significant difference in speed between the directions but there was a distinct difference between the lane speeds for each expressway as shown in Fig. 3. Also, average speed appeared to decrease by about 6% to 17% in lanes 3 and 4 showing about 2.5km/h deviation, but to increase by about 5% to 18% in lanes 1 and 2 showing a higher deviation as summarized in Table 3.

2.3 Density

Density was estimated by the reciprocal of the distance headway, as follows(May, 1990);

$$K = \frac{3{,}600 \times n}{\sum_{i=1}^{n} d_{hi}} \qquad (3)$$

Where, d_{hi} : Distance headway of each vehicle i(m)

K : Density(veh/km)

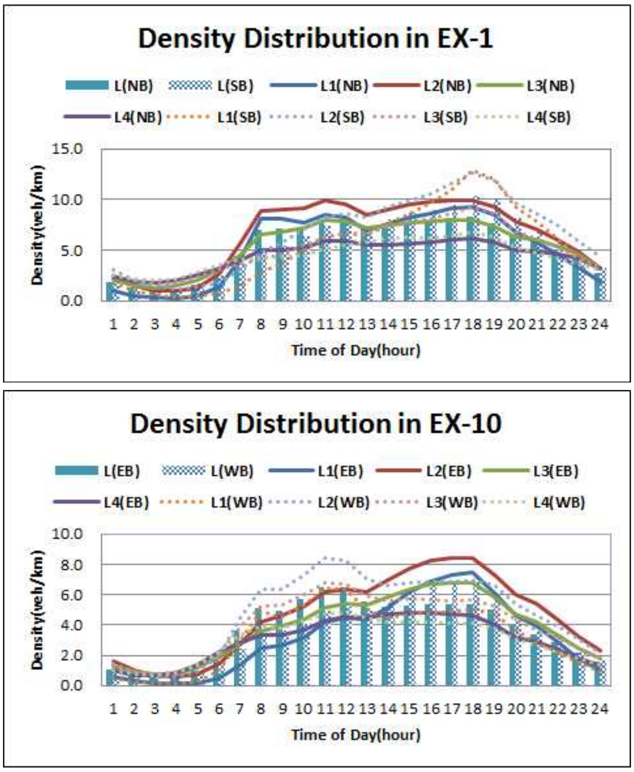


Fig. 4 Density distribution in expressways under the study

Table 4 Density statistics in expressways(veh/km)

Expressways		L1		L2		L3		L4		L
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
EX-1	NB	5	3	7	3	5	2	4	1	6
	SB	6	4	7	4	6	3	5	2	6
EX-10	EB	3	2	5	3	4	2	3	1	4
	WB	3	2	5	3	4	2	3	1	4

There seemed to be a distinct difference in density between the directions as well as the lanes for each expressway as shown in Fig. 4. Also, average density appeared to decrease by about 8% to 18% in lanes 1 and 4 showing about 2.3veh/km deviation, but to increase by about 3% to 23% in lanes 2 and 3 showing about 2.7veh/km deviation as summarized in Table 4.

2.4 Travel Time Reliability

Travel time reliability was estimated by the planning time (T_p) and buffer time(T_b), as follows(SHRP2, 2013);

$$T_p = 36 \times \left(\frac{\frac{l}{U_{95}}}{\frac{l}{U_r}} \right) \times \frac{l}{U_r} \qquad (4)$$

$$T_b = 36 \times \left(\frac{\frac{l}{U_{95}} - \frac{l}{U_s}}{\frac{l}{U_s}} \times 100\% \right) \times \frac{l}{U_s} \quad \text{if } U_s > U_{95} \qquad (5)$$

$$= 0 \qquad \textit{otherwise}$$

Where, T_p : Planning time(sec)

U_r: Regulatory speed(100km/h)

l : Length of segment(15km)

U_{95} : 95th percentile speed(km/h)

T_b : Buffer time(sec)

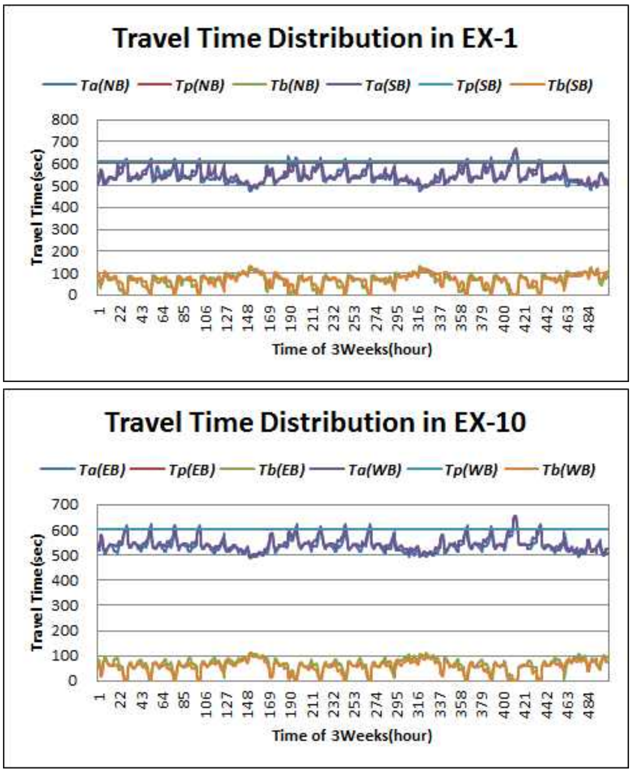


Fig. 5 Travel time distribution in expressways

There did not seem to be a significant difference in travel time reliability(T_p and T_b) between the directions but there was a distinct difference between the actual travel times(T_a) as shown in Fig. 5. Also, average planning and buffer times in EX-1 appeared to increase by about 10sec and about 7sec, respectively when compared to EX-10 as summarized in Table 5. As a result, there was a need to review the correlation analysis between lane speed characteristics and travel time reliability, an inverse proportion to speed in expressways described in the above.

Table 5 Travel time reliability in expressways(sec)

Reliability	EX-1(NB)	EX-1(SB)	EX-10(EB)	EX-10(WB)
T_p	606	613	600	600
T_b	65	69	64	57

3. Correlation Analysis of U_{si} and T_P

3.1 Correlation Analysis of $U_{si} - T_P$ in EX-1

Lane speed(U_{si}) and planning time(T_P) in EX-1 appeared to have the negative linear relationship regardless of the direction as shown in Fig. 6.

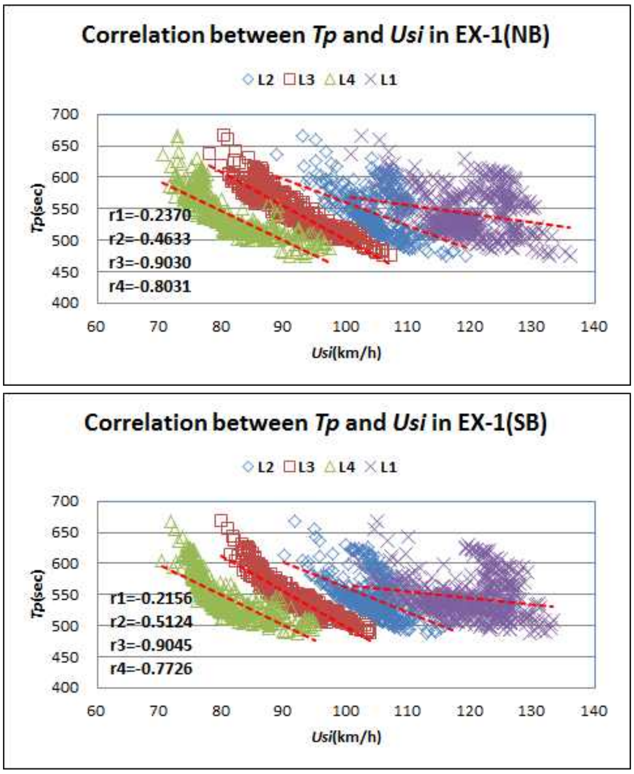


Fig. 6 Correlation of $U_{si} - T_P$ in EX-1

In particular there seemed to have the lowest correlation coefficients(r1) of -0.2370 and -0.2156 in lane 1, but the highest ones(r3) of -0.9030 and -0.9045 in lane 3 for the NB and SB directions in EX-1, respectively as summarized in Table 6.

3.2 Correlation Analysis of $U_{si} - T_P$ in EX-10

Lane speed(U_{si}) and planning time(T_P) in EX-10(EB) also appeared to have the negative linear relationship regardless of the direction as shown in Fig. 7.

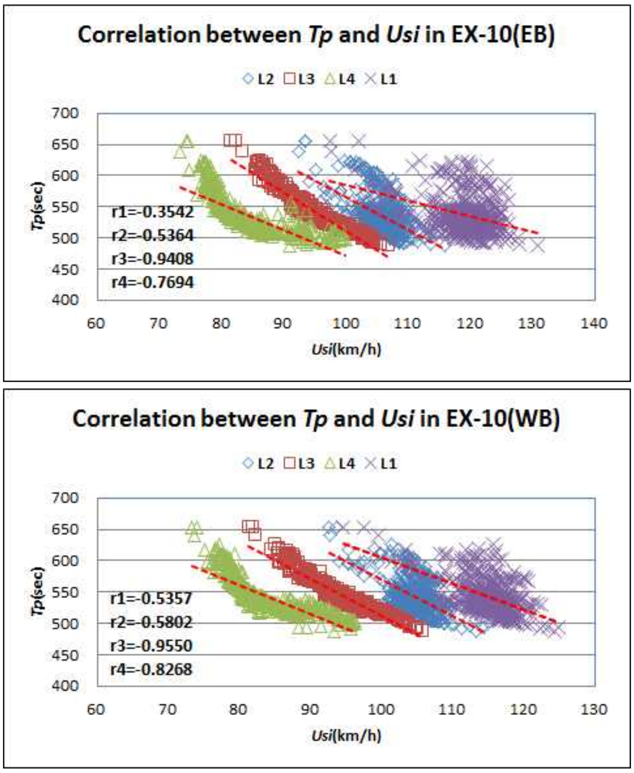


Fig. 7 Correlation of $U_{si} - T_P$ in EX-10

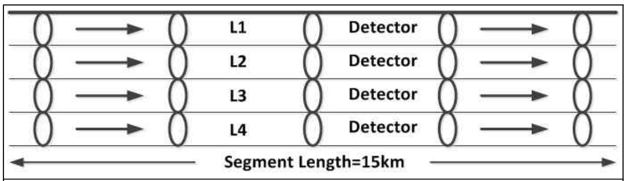
Table 6 Correlation analysis in expressways

Expressways		L1	L2	L3	L4
EX-1	NB	-0.2370	-0.4633	-0.9030	-0.8031
	SB	-0.2156	-0.5124	-0.9045	-0.7726
EX-10	EB	-0.3542	-0.5364	-0.9480	-0.7694
	WB	-0.5357	-0.5802	-0.9550	-0.8268

In particular there seemed to have the lowest correlation coefficients(r1) of -0.3542 and -0.5357 in lane 1, but the highest ones(r3) of -0.9480 and -0.9550 in lane 3 for the EB and WB directions in EX-10, respectively as summarized in Table 6. As a result, there was a need to consider the correlation model between the speed(U_{s3}) in lane 3 and planning time(T_P), because there showed the highest correlation coefficient(r3) regardless of the direction in expressways.

4. Model Development and Verification

4.1 Model Development



Independent variable
U_{si}: space mean speed by lane (i=1, 2, 3, 4)
Dependent variable
T_P: planning time in the basic 8-lane segment

Fig. 8 Sketch of segment and variables used

With the speed(U_{s3}) on lane 3 in the basic 8-lane segments selected as an independent variable and the planning time(T_P) selected as the dependent one as shown in Fig. 8, the correlation models($T_P = f(U_{s3})$) were suggested as follows;

LIN: $T_P = \beta_0 + \beta_1 \times U_{s3}$ (6)

POW: $T_P = \beta_0 \times U_{s3}^{\beta_1}$ (7)

Where, T_P: Planning time(sec)

U_{s3}: Space mean speed on lane 3(km/h)

β_j: Coefficients of function(j=0, 1)

Table 7 Results of regression analysis

Expressways		Models			
EX-1	LIN	$T_P = 1{,}051.0 - 5.5229 \times U_{s3}$			
		R^2	0.8100	F-sig.	0.000
	POW	$T_P = 31{,}715 \times U_{s3}^{-0.900}$			
		R^2	0.8333	F-sig.	0.000
EX-10	LIN	$T_P = 1{,}082.2 - 5.6939 \times U_{s3}$			
		R^2	0.8724	F-sig.	0.000
	POW	$T_P = 46{,}156 \times U_{s3}^{-0.977}$			
		R^2	0.8845	F-sig.	0.000

Note: LIN is linear model, POW is power model

A regression analysis was used to build the correlation models for predicting the planning time with the high explained variation of R^2>0.81 as summarized in Table 7 and shown in Fig. 9. So, the most appropriate correlation models appeared to be the linear and power models in explanatory powers(R^2) greater than 81% by the speed on lane 3 as summarized in Table 7.

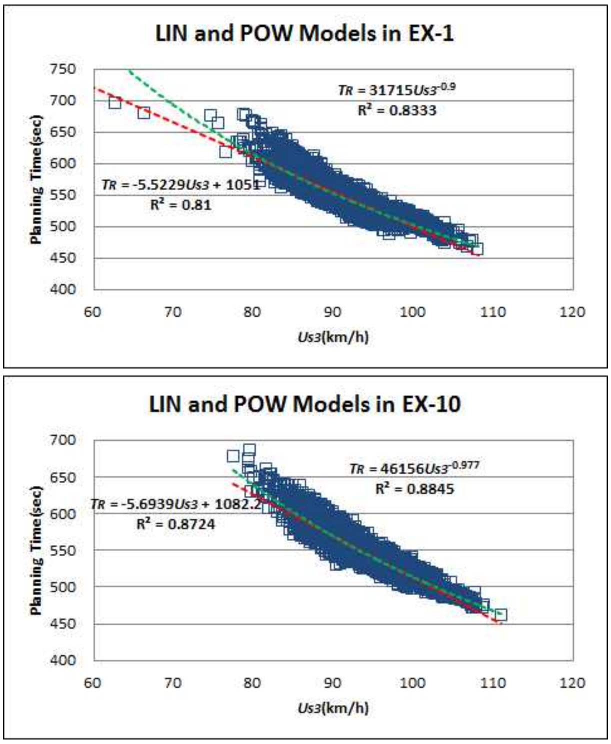


Fig. 9 Development of correlation models

4.2 Model Verification

There were two approaches applied to ensure the validity of the models constructed. One approach was to conduct the paired t-tests between the observed and expected planning times, whether the p-values were greater than the significance level (α/2=0.025) or not at the 95% confidence level.

Table 8 Results of t-Test and correlation analysis

Expressways/ Model		Correlation Coefficient(r)	t-value	p-value	Result
EX-1	LIN	0.9201	1.094	0.409	Accept
	POW	0.9355	-1.569	0.117	Accept
EX-10	LIN	0.9470	-1.405	0.160	Accept
	POW	0.9581	-2.015	0.274	Accept

In the paired t-tests, the computed values of t statistic appeared to fall inside the acceptance regions with the probabilities of 0.409 in the LIN and 0.117 in the POW of EX-1, and those of 0.160 in the LIN and 0.274 in the POW of EX-10, as summarized in Table 8.

Other approach was to test the utility of the correlation models with traffic data unused. The test results(r) were shown to be 0.9201(LIN) and 0.9355(POW) in EX-1, and 0.9470(LIN) and 0.9581 (POW) in EX-10, as shown in Fig. 10. So, the power model proved to be more effective in predicting planning time in the 8-lane expressways.

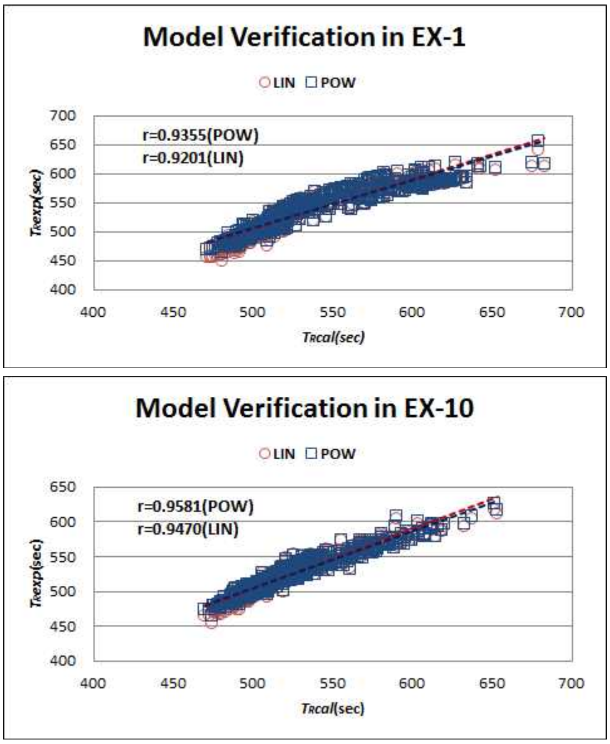


Fig. 10 Verification of correlation models

4.3 Model Evaluation

Root mean square error(RMSE) statistics were applied to evaluate the measures of effectiveness(MOE) between the linear and power models by comparing the planning times. Particularly, there was a little less difference in the RMSE values of the power model than in those of the linear one, as summarized in Table 9.

Table 9 Results of RMSE analysis(sec)

Expressway \ Model	LIN	POW
EX-1	16	14
EX-10	10	9

So, the power model proved to have a little higher predictability than the linear one in the 8-lane expressways.

5. Conclusions

From the analyses and model development of the lane traffic characteristics in the Busan Ports-connected expressways, the following conclusions were drawn;

1) Planning time showed the highest correlation with the speed of lane 3, medium-sized vehicle lane in the 8-lane expressways.
2) Power model proved a higher explanatory power and validity in predicting the planning time in the 8-lane expressways.

It was concluded that this study needed to be continued concerning the various geometric characteristics of expressways for the purpose of proving the reliability of the correlation model.

References

[1] Kim, T. G. and Jeong, Y. W.(2012), “Prediction of Speed in Urban Freeway Having More Freight Vehicles”, Journal of Navigation and Port Research, Vol. 36, No. 7, pp. 591-597.

[2] May, A. D.(1990), “Traffic Flow Theory”, Prentice Hall, Englewood Cliffs, New Jersey 07632.

[3] Oh, S. C., Kim, M. H. and Baek, Y. H.(2003), “Development of a Freeway Travel Time Estimating and Forecasting Model using Traffic Volume”, Journal of Korean Society of Transportation, Vol. 21, No. 5, pp. 83-95.

[4] SHRP2(2013), Evaluating Alternative Operations Strategies to Improve Travel Time Reliability, Strategic Highway Research Program, Report S2-L11-RR-1, Transportation Research Board.

[5] Transportation Research Board(1975), Traffic Flow Theory, A Monograph, Special Report 165, Revised Edition, Transportation Research Board, National Research Council, Washington, D. C.

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