SUCCESSIVE ENTRANCE RAMP SPACING ANALYSIS

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Abstract: This study is to analyze speed variation at merging section of successive entrance ramp and to suggest design criterion of ramp spacing at successive entrance ramp in urban area. Traffic volume and speeds are collected at 2 sites by detector. The 85 percentile speed(S) at merging lane(lane 1) is modeled as S = 49.5 + 355.7(D/Q) - 0.94(D2/Q) + 6.78 (D/AL2) where, D=distance from gore(m), Q=lane 1 volume(vphpl), and AL2=acceleration length at second entrance ramp(m). Finally the more traffic volume and the shorter acceleration length of the second entrance ramp, longer ramp spacing is needed.

Key Words : Ramp Spacing, Successive Entrance Ramp, Merging Lane Speed, Acceleration Length, Distance from Gore

1. OVERVIEW

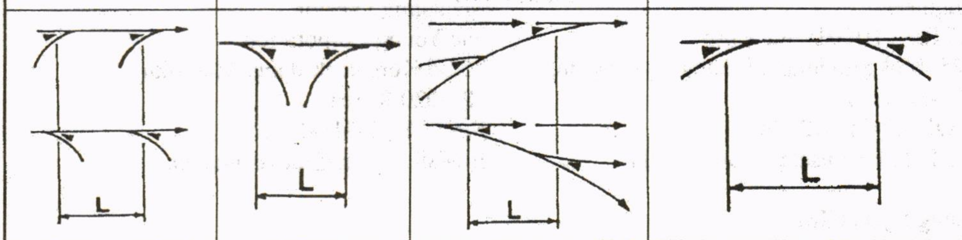
A ramp serves to link arterial traffic to and from freeway. According to the Highway Capacity Manual, a ramp consists of a ramp-freeway junction, a ramp roadway, and a ramp-street junction. In the process of ramp traffic merging onto the fast-moving freeway traffic stream, vehicles involved have to make lane changes, accelerate, or decelerate, as they join or leave freeway traffic stream. Consequently, this is the area with high traffic accident potentials. Ramps and freeway junctions should be carefully planned and designed to ensure smooth traffic flow with high level of safety.

The purpose of this study is to present a design guide for spacing two successive on-ramps. The study used field data collected at 2 sites taking into account of various traffic and geometrical conditions of urban areas.

2. EXISTING DESIGN GUIDES

2.1 AASHTO Design Criteria(USA)

USA design guide is specified in "A Policy on Geometric Design of Highways and Streets (1). The guide as shown on Figure 1 requires the minimum distance of 300m, between two successive on-ramps, for full freeways and 240m for freeway distributor road (FDR) or collector distributor road (CDR), which is determined on the basis of the operating experiences in the past and to allow appropriate distance necessary for traffic signs.



EN-EN OR EX-EX		EX - EN		TURNING ROADWAYS		EN-EX(WEAVING)			
						SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SYSTEM INTERCHANGE	
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTER-CHANGE	SERVICE INTER-CHANGE	FULL FWY	CDR OR	FULL FWY	CDR OR
Minimum Lengths Measured Between Successive Ramp Terminals (m)									
300	240	150	120	240	180	600	480	480	300

Note FDR - FREEWAY DISTRIBUTER ROAD EN - ERTANCE
CDR - COLLECTOR DISTRIBUTER ROAD EX – EXIT

Figure 1. AASHTO Recommended Minimum Ramp Terminal Spacing

2.2 Japanese Design Guide (2)

Japanese design guide for the minimum and standard distance by freeway design/operating speed between two successive ramps is shown in the Table 1. According to the guide, for a freeway design speed of 100km/hr or operating speed of 90km/hr, the minimum required distance between ramps is 150m, with a standard of 275m. The same criteria applies to the ramp combinations of on-and-on, off-and-off, turning roadways, and on-and-off (in case of weaving), whereas half of the value is used for off-and-on ramp situation.

Table 1. Japanese Ramp Terminal Spacing (L)

Design Speed (km/h)		Below 48	64～80	96～113	Over 129
Operating Speed (km/h)		37～45	60～70	84～93	103
L(m)	Minimum	60	120	150	275
	Standard	120	215	275	365

2.3 German Design Guide (3)

The German design guide as shown in Table 2 presents varying distances depending on the number of on-ramp lanes: 400m is required where each of two successive on-ramps has one lane, or the first on-ramp has one lane and the second on-ramp has two lanes, whereas 650m is required where the first on-ramp has two lanes and the second on-ramp has one lane.

Table 2. German's Ramp Terminal Spacing

Class	First on Ramp	Second on Ramp	Ramp Spacing (m)
Number of Lanes on Ramp	1	1	400m
	1	2	400m
	2	1	650m

3. DATA COLLECTION AND REDUCTION

3.1 Selecting Survey Section

For the purpose of collecting field data, a section of freeway was selected where: there are consecutive on-ramps located close each other, the acceleration lane ends before the second on-ramp nose, and the acceleration lane for the second on-ramp ends at the point of merging without continuing as an additional lane of the freeway.

Two study sites were selected and has the following characteristics: main roadway had four lane(two lane on each direction), the distance between two consecutive on-ramps was 300m for the upstream direction and 350m for the downstream direction; the acceleration lane was a parallel type for the first on-ramp and direct type for the second on-ramp; the length of acceleration lane on the second on-ramp was 230m for the upstream direction and 80m for the downstream direction.

3.2 Data Collection

As Figure 2 shows, detectors were installed on the outer lane(merge lane of freeway) to collect traffic volume, speed and vehicle's bumper-to-bumper distance. The detector at upstream direction is installed at 0m(gore), 90m, 180m, 270m, and 350m. The detector at downstream direction is installed at 0m(gore), 120m, 180m, and 300m. These data were collected when the freeway traffic is at its stable flow condition. For the data analysis time unit, 15 minutes were used.

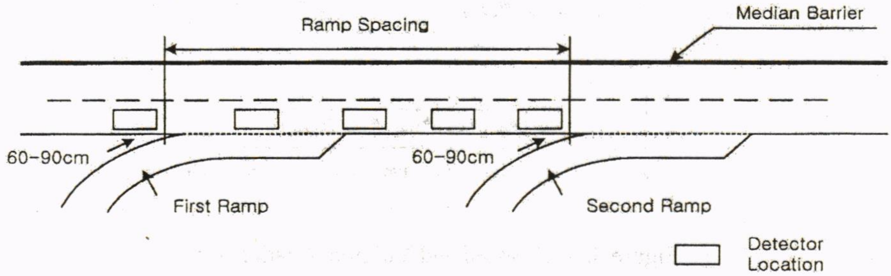


Figure 2. Field Data Collection Scheme

3.3 Data Reduction

Detectors were linked to a computer to provide on-line data that was processed using statistical analysis program to present 15-minute and hourly equivalent traffic volume data, speed distribution for 85%, 50%, and 15% speed, and bumper-to-bumper distance data. In this process, the speed data detected as 40km/h or lower was ignored and excluded in the data analysis because they were considered to be unstable traffic flow.

The data reduction included 85% and 50% speed ratio. The 85% speed ratio was defined to be the ratio of 85% speed at each detection point to the 85% speed at the nose (0 meter distance) of the first on-ramp. Similarly, 50% speed ratio was defined to be the ratio of 50% speed at detection point to the 50% speed at the nose(0 meter distance) of the first on-ramp. This is depicted on Figure 3.

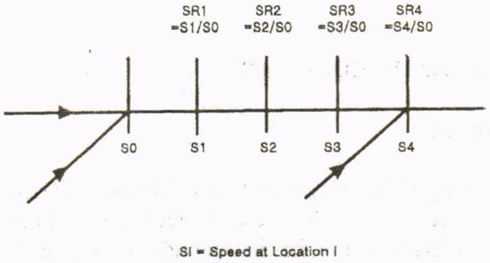


Figure 3. Speed Ratio Illustration

4. DATA ANALYSIS

4.1 Speed and Volume Relation

The analysis of the data shows a common speed and volume relation as shown on Figure 4 where speed drops as volume increases. As shown in Figure, freeway traffic speed at each detection point beyond nose is lower due to merging effect than the point marked 0 meter which is at the nose.

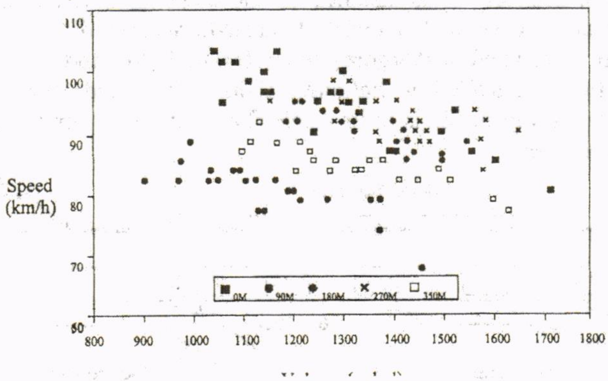


Figure 4. 85% Speed and Volume Relationship

4.2 Speed and Distance Relation

The speed at each distance within the consecutive on-ramp section is shown on Figure 5. In the case of upstream direction, the 85% speed decreased at the first on-ramp, and then increased until traffic approaches to the gore of the second on-ramp where the speed decreased again, which is well represented by a concave quadratic form.

In case of the downstream direction, although the speed increased and then decreased similarly as the upstream direction, the speed drop at the gore of the second on-ramp was not as much as that for upstream direction. This is attributable to the fact that the length of acceleration lane at the second on-ramp of the downstream direction is 230m, whereas that of the upstream direction is 80m. This characteristic reflects the strong justification of the length of acceleration lane at the second on-ramp being a possible independent variable in establishing the speed estimating model, as described in the section that follows.

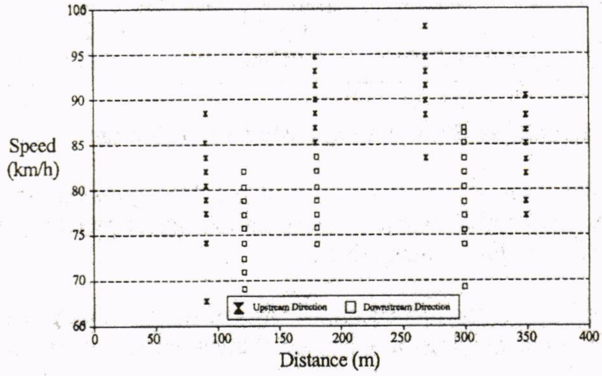


Figure 5. 85% Speed and Distance

4.3 Establishing Speed Relation Model

4.3.1 Dependent Variable and Independent Variable

In order to verify if it was possible to combine and analyze the field data from the two survey locations, i.e., the upstream and downstream direction, an analysis was conducted using F statistics, that is $F_{v1,v2} = s_1^2 / s_2^2$. The result was that all four dependent variables showed p-values greater than 0.05, significance level(α), failing to reject the hypothesis of the same distribution. Consequently, we combined the data from both locations into one, and proceeded with the analysis.

On establishing speed model, we used 85% speed(S85) and 50% speed(S50); and 85% speed ratio(SR85) and 50% speed ratio(SR50). Independent variables considered are freeway merging lane volume(Q, vphpl), distance from the gore of the first on-ramp (D, meter), acceleration lane length of the second on-ramp(AL2, meter), and combinations of these. In summary, the independent variables are D, D^2, 1/Q, D/Q, D^2/Q, and D/AL2.

We analyzed the correlation among dependent variables using "Correlation Matrix".
As shown in Table 4, the analysis indicated that the variables, D and Q/D have the correlation of as high as 0.87, which may cause a problem when they are used together in the same model.

For this reason, when establishing regression equation, their use in the model was excluded. The range of values for Q, D, AL2, selected as dependent variables were as follows:
Q = 750 ~ 1,700 vphpl,   D = 0, 90, 120, 180, 270, 300, 350m,   AL2 = 80m, 230m

Table 4. Correlation Coefficient Matrix

Independent Variable	D	1/Q	D/Q	D/AL2
D	-	0. 01496 P=0.043	0. 87647 P=0.0001	0. 47617 P=0.0001
1/Q	0. 01496 P=0.043	-	0. 40622 P=0.0001	-0. 37379 P=0.0001
D/Q	0. 87647 P=0.0001	0. 40622 P=0.0001	-	0. 42800 P=0.0001
D/AL2	0. 47617 P=0.0001	-0.37379 P=0.0001	0. 4280 P=0.0001	-

4.3.2 Establishing Regression Equations and Model Verification

Based on the result so far obtained, we worked out 11 regression equations, each for 4 dependent variables, or a total of 44 equations. Then we used stepwise regression to eliminate those variables that did not justify themselves.

We verified the suitability of the models on the basis of statistical judgement. There are three criteria that we used in determining the adequacy of the models, and they are as follows.

Is the speed and speed ratio by distance represents a concave quadratic equation?
Is the independent variable sign(+ or -) logical ?
Is the value of independent variable meaningful(In terms of t-value)?

After eliminating those models that were not adequate, 26 final regression equations were established, including eight 85% speed models, six 85% speed ratio models, seven 50% speed models, and five 50% speed ratio models.

4.3.3 Selecting Merging Lane Speed Model

We evaluated models based on both 85% speed and 50% speed for their average F-value that would represent the adequacy of models to determine which model offers better justification.

The evaluation revealed, after comparing the two models for their average F-value, that the model based on 85% speed model offered its justification 1.7 times better than 50% speed model.
Further evaluation was conducted on the 85% speed model and 85% speed ratio model, using F-value and Adj R-sq to make final selection for use in the study.

Table 5. 85% Speed Model

$S85 = 49.5 + 355.7(D/Q) - 0.94(D^2/Q) + 6.78(D/AL2)$

Independent Variable	Constant	D/Q	D^2/Q	D/AL2
t-value P > |t|	23.537 0.0001	13.894 0.0001	-14.203 0.0001	19.808 0.0001
	F-value = 142.03 Adj R-sq = 0.7050 Durbin-Watson value = 1.709			

Table 6. 85% Speed Ratio Model

$SR85 = 0.64 + 0.0023D - 0.0000053D^2 + 0.018(D/AL2)$

Independent Variable	Constant	D	D^2	D/AL2
t-value P > |t|	31.764 0.0001	11.538 0.0001	-11.056 0.0001	5.825 0.0001
	F-value = 62.23 Adj R-sq = 0.5093 Durbin-Watson value = 1.645			

Both models gave low p-value, indicating that the estimated coefficient was meaningful. The Adj R-sq represents the level of justification that the model can be selected. The 85% speed model showed Adj R-sq of 0.70, which is higher than 0.51 of 85% speed ratio model. It also showed Durbin Watson value of 1.709, as compared to base value of two. This indicates that their residuals are normally distributed.

4.4 Consecutive Ramp Spacing Analysis

This section is intended to present design criteria on the basis of the 85% speed model. Figure 6 shows the relation of 85% speed with distance and volume indicating the concave quadratic form. Consequently, the best traffic operation takes place where the speed is at its highest.

The study determined the minimum distance between on ramps by finding a location where a linear differential equation, dS over dD yields "0". The minimum distance thus obtained was determined as a design basis. However, the minimum required distance between the two consecutive on-ramps may vary with freeway merging lane volume(Q) as well as acceleration lane length of the second on-ramp. The final guideline is shown in Table 7 and on Figure 7.

The minimum distance between two consecutive on-ramps increases as traffic volume increases; it increases as acceleration lane length of the second on-ramp decreases. It was also found that, as acceleration lane length of the second on-ramp increases, the vehicles on the second ramp would have better maneuver and more opportunity to merge.

Table 7. Minimum Successive Entrance Ramp Spacing

Class		Acceleration Length of Second Ramp(m)			
		50	100	150	200
Merging Lane Traffic Volume (vphpl)	500	230	210	200	200
	1000	260	230	220	210
	1500	300	250	230	220

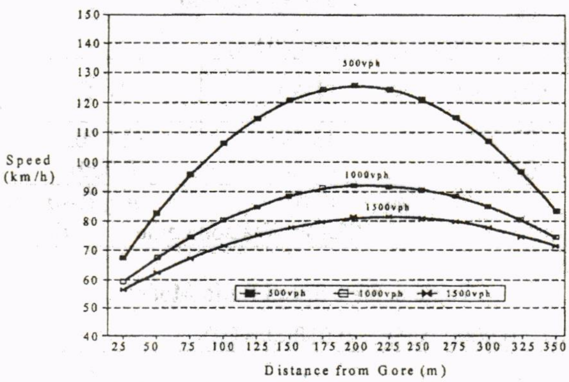


Figure 6. Relation of 85% Speed, Distance, and Freeway Volume
(Case of the Acceleration Length at Second Ramp = 150m)

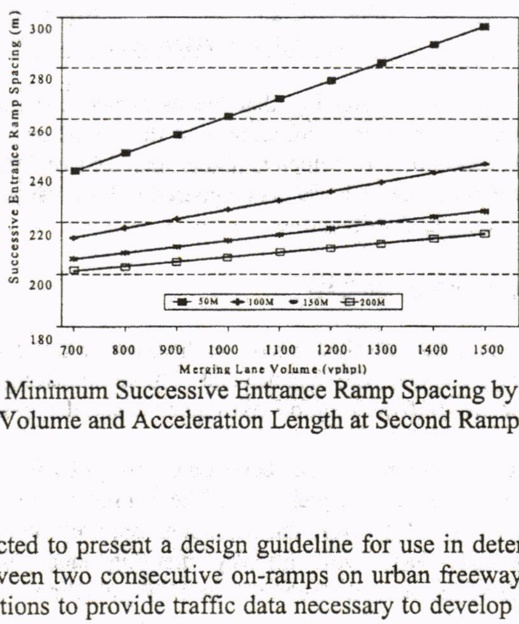


Figure 7. Minimum Successive Entrance Ramp Spacing by Freeway Volume and Acceleration Length at Second Ramp

5. CONCLUSION

The study was conducted to present a design guideline for use in determining the minimum required distance between two consecutive on-ramps on urban freeways. Field surveys were conducted at two locations to provide traffic data necessary to develop speed model. Based on stable flow data, we developed a speed model for freeway merging lane in a section comprising two consecutive on-ramps, and presented a new design guide in determining the distance between the two consecutive on-ramps, and they are summarized as follows:

The traffic speed of freeway merging lane within a section of two consecutive on-ramps is represented by a concave quadratic equation. The relation among 85% speed, distance between two ramps(D in meter), freeway merging lane volume(Q in vphpl), acceleration lane length of the second on-ramp(AL2 in meter) are expressed as:

$$85\% \text{ speed on merging lane} = 49.5+355.7(D/Q) - 0.94(D^2/Q) + 6.78(D/AL2)$$

The distance required between two consecutive on-ramps increases as traffic volume on merging lane increases, and as the length of acceleration lane on the second on-ramp decreases.

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