Identifying Crash Distributions and Prone Locations by Lane Groups at Freeway Diverging Areas

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Crash distributions and the locations of all crashes and severe crashes at freeway diverging areas were analyzed and compared. Contributing factors to crashes were identified; these included exit ramp types, geometric design features, traffic conditions, and crash-related attributes. Exit ramp types are defined by the number of lanes exiting freeways and AASHTO's lane-balance theory. Four typical exit ramp types were considered: one-lane exit with lane-balanced design (Type 1), one-lane exit with lane-unbalanced design (Type 2), two-lane exit with lane-balanced design (Type 3), and two-lane exit with lane-unbalanced design (Type 4). Lanes are further classified as exit and drop lane group, impact lane group, and interior lane group. Proportionality tests were used to compare the crash distributions on different lanes. The results indicate that lane-balanced designs (Type 1 and Type 3) have a statistically significant higher percentage of severe crashes on the impact lane group than that for lane-unbalanced designs (Type 2 and Type 4). For the interior lane group, Type 4 ramps have a statistically significant higher percentage of severe crashes than the other design types. In addition, ordered probit models were developed for all crashes and severe crashes by one-lane exits and two-lane exits, respectively. Outcomes from the models suggested that more crashes occurred on the exit and drop lane group for the lane-unbalanced designs and more severe crashes occurred on the interior lane group for the lane-unbalanced designs. The study will help engineers have a better understanding of crash distributions and locations for different exit types and help them to develop effective countermeasures.

Freeway diverging areas are critical freeway mainline segments where traffic exits via an off ramp to an adjacent roadway. Various maneuvers, such as lane changing, passing, taking over, and exiting, all happen in a confined space. To mitigate traffic conflicts and reduce potential crashes, a University of South Florida research team conducted several comprehensive studies (*1–3*) to evaluate the safety performance of different exit ramp types and the combination of crash causal factors.

In previous studies, exit ramp types were defined by the number of lanes exiting freeways and the lane-balance theory. According to the AASHTO Green Book, the lane-balance design requires "the number of approach lanes on a freeway at exits for lane-balanced should be equal to the number of lanes beyond the exit, plus the number of lanes on the exit, minus one" (*4*). However, because of various constraints, lane balance at freeway exits cannot be achieved in some circumstances.

Four typical exit ramp types were considered in this research, as shown in Figure 1: Type 1 and Type 3 are lane-balanced designs with one-lane exit and two-lane exit; Type 2 and Type 4 are lane-unbalanced designs with one-lane exit and two-lane exit. The study areas were defined as segments 2,500 ft long, 1,500 ft upstream of the gore area and 1,000 ft downstream of the gore area (*1, 2, 5, 6*). The study demonstrated that for total crashes, there were safety benefits in use of lane-balanced exit ramps. The research shows that for one-lane exit ramps, lane-unbalanced exit ramps had 68.3% more crashes than did lane-balanced exit ramps. For two-lane exit ramps, lane-unbalanced exit ramps had 32.2% more crashes than did lane-balanced exit ramps (*1*). The results also indicated that the freeway and ramp annual average daily traffic, freeway posted speed limit, deceleration lane length, right shoulder width, and type of exit notably affected both total crash counts and severe crash counts at freeway diverging areas (*1, 3*). These study results raise further questions—for example, how crashes are distributed along freeway diverging areas, where crashes are located, the differences in crash-prone locations among exit types.

To identify the crash distributions, freeway mainlines are further classified into three lane groups, as shown in Figure 1: the exit and drop lane group, the impact lane group, and the interior lane group. These are as follows:

- The exit and drop lane group is the lanes used to exit freeways. For a Type 1 exit, the deceleration lane is on the right side. For a Type 2 exit, the outside lane becomes the drop lane. For a Type 3 exit, only the rightmost lane is considered as the drop lane, whereas both exit lanes are considered as the drop lanes for a Type 4 exit.
- The impact lane group is the lane immediately left of the exit and drop lanes. Since it is the lane closest to the exit and drop lane, it could be affected by exit traffic depending on the traveling direction. The impact lane for each exit type is highlighted in dark gray in the figure.
- The interior lane group is the leftmost lanes at the diverging areas and are highlighted in light gray in the figure. Since the number of lanes on the freeway varies from site to site, all through lanes except the impact lane are grouped as the interior lanes.

The lane groups are determined by the operational performance of lane sequences and locations. At the freeway diverge and its vicinity,

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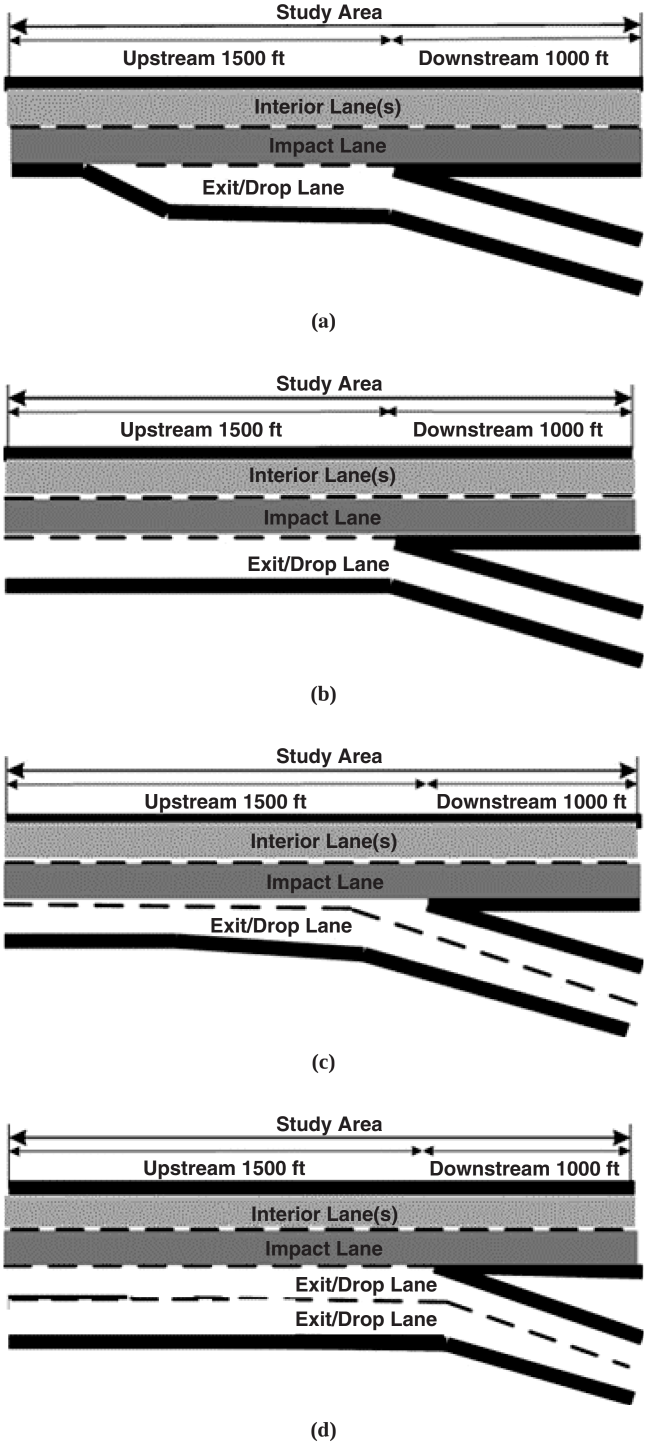

FIGURE 1 Lane groups: (*a*) Type 1 (180 sites), (*b*) Type 2 (68 sites), (*c*) Type 3 (60 sites), and (*d*) Type 4 (18 sites).

the exit and drop lane group is the major section of concern for exiting traffic, whereas the interior lane group could be the least affected. Most through traffic would pass without being interrupted on the interior lane group. The lane between the interior lanes and the exit and drop lanes may be affected by diverging traffic and is categorized as the impact lane group.

Previous research studied overall crashes or severe crashes on specific freeway segments (on ramps, off ramps, deceleration lanes) and identified relevant factors, such as deceleration length, ramp configurations, and ramp curvature (*7–14*). However, few researchers have considered the impact of lane design that follows or does not follow the lane-balanced theory at freeway diverging areas. Thus, no definitive conclusions were drawn for crash distributions on different lanes at the areas.

Little research had been conducted on crash-prone locations at freeway diverge sections. In 2004, Golob et al. conducted a safety analysis for three freeway weaving section types in Southern California: Type A, where every merging or diverging vehicle must execute one lane change; Type B, where either merging or diverging can be done without changing lanes; and Type C, where one maneuver requires at least two lane changes (*15*). Although there was no difference between these types in overall accident rate, the primary crash locations were found to be significantly different between weaving and nonweaving sections. Further analysis is necessary because the study did not specifically consider the difference in the number of lanes at freeway weaving sections. Another study analyzed crashes that occurred on freeway ramps and their vicinity (*16*). Six years of crash data on 98 ramps were used, and crash prediction models were built. The results showed that crash characteristics varied by location with respect to ramps. The study suggested that some important factors (e.g., geometric and traffic features) and hidden relationships be identified for these locations. Because this study was limited to ramp sections, it is unclear how crashes were distributed at the freeway diverging areas. Although some studies were dedicated to identifying crash-prone locations on roadway segments, few specifically considered crash locations at the freeway diverging areas (*17*, *18*).

No conclusion has been reached on the crash distributions and crash-prone locations at freeway diverging areas. Additionally, no clear guidelines are available for either design or operation. Selection of exit ramps with better safety performance is important and requires a good and comprehensive understanding of the impact of exit ramp types on crash distributions and locations. The primary objective for this study is to identify the crash-prone locations for various lane groups by four exit ramp types as well as the crash contributing factors. The study will help engineers have a better understanding of crash distributions and locations for various exit types and aid in development of effective countermeasures.

DATA COLLECTION

The freeway diverging area and the vicinity section defined in this study contain segments 2,500 ft long, 1,500 ft upstream, and 1,000 ft downstream of the ramp, as shown in Figure 1. To achieve the research objective, the study sites were selected from Interstate freeways in Florida. After external impacts, such as large horizontal and vertical curves, were eliminated, a total of 326 segments were identified: 180 Type 1 sites, 68 Type 2 sites, 60 Type 3 sites, and 18 Type 4 sites. Each site had a data set containing geometric features, crash-relevant data, and traffic data. Crash data were extracted from the Florida crash analysis reporting (CAR) system maintained by the Florida Department of Transportation (DOT). Before 2004, the Florida DOT renamed the exit numbers, and previous crash records no longer matched the new exit numbers. Thus, 3 years (2004 to 2006) of crash data were used for 326 sites. A total of 7,872 crashes were reported with an average value of 4.78, 12.82, 10.23, and 15.41 crashes per year per selected site for Type 1, Type 2, Type 3, and Type 4 exit ramps, respectively (*1*). In the Florida CAR system, crash severity is categorized into five levels. A severe crash in this study was identified as any capacitating injury, incapacitating injury, or fatality crash.

The location of each crash was determined by two variables from the CAR system, milepost and lane number. The milepost of the start point (1,500 ft upstream of the exit ramp) was calculated by adding or subtracting 1,500 ft from the milepost at the painted nose. The milepost at the painted nose was obtained from the Florida straight-line diagram. The milepost of the start point was set as the reference point; each crash could be identified by measuring the difference of milepost to reference point. The lane number in the Florida CAR system was used to locate the particular lane at which crashes occurred. It was numbered from the center of the freeway. For example, at a four-lane freeway with a Type 1 exit ramp segment, a crash happening at Lane 1 is located at the interior lane close to the median.

METHODOLOGY

Proportionality Test

Proportionality tests are often used to test the difference between two proportions from two independent samples. Let p_{nm} be the proportion of crashes that occurred in the lane group *n* associated with the exit ramp type *m.* Three lane groups and four exit types are combined in total. For example, p_{e1}, p_{m2}, p_{i3} represent the percentage of crashes that occurred on the exit and drop lane for Type 1 exit ramps, the percentage of crashes that occurred on the impact lane for Type 2 exit ramps, and the percentage of crashes that occurred on interior lanes for Type 3 exit ramps, respectively. The number of lanes on freeways ranges from two to five for all sites. The number of interior lanes is not equal for all the sites. To minimize the influence of different numbers of interior lanes, average crashes for each interior lane were used to calculate the percentage of crashes on the interior lane to the total crashes. Assume that crashes on the exit and drop lane, the impact lane, and the interior lane are C_e, C_m, C_i, respectively, where n_i is the number of interior lanes. The proportions of crashes to total crashes for each lane group by one exit ramp type are calculated as

$$p_e = \frac{C_e}{C_e + C_m + \left(\frac{C_i}{n_i}\right)} \tag{1}$$

$$p_m = \frac{C_m}{C_e + C_m + \left(\frac{C_i}{n_i}\right)} \tag{2}$$

$$p_i = \frac{\left(\frac{C_i}{n_i}\right)}{C_e + C_m + \left(\frac{C_i}{n_i}\right)} \tag{3}$$

The sum of the three proportions, p_e, p_m, and p_i equals 100%. The null hypothesis (H_0) test was used to compare the differences between two specific lane groups by exit types. Typically, two types of tests are used, a one-sided test and a two-sided test. The one-sided test is used to test whether the value of a data set is either less or greater than that of another data set; the two-sided test measures how similar two data sets are, evaluating how the data sets are both greater and less than each other. To determine impacts of exit types on crashes, the two-sided hypothesis test was selected for this study to investigate, whether significant differences exist between different exit types by defined lane groups:

$$H_0 : p_{e1} = p_{e2} \tag{4}$$

versus

$$H_0 : p_{e1} \neq p_{e2} \tag{5}$$

H_0 can be rejected if

$$Z = \frac{\left|p_{e1} - p_{e2}\right|}{\sqrt{\frac{p_{e2}\left(1 - p_{e2}\right)}{M} + \frac{p_{e1}\left(1 - p_{e1}\right)}{N}}} \geq Z_{\alpha/2} \tag{6}$$

where α is the level of significance and $Z_{\alpha/2}$ is the $100(1 - \alpha/2)\%$ value of the standard normal distribution.

Ordered Probit and Logit Model

The ordered probit and logit model is widely used for fitting of data with an ordinal structure such as crash severities (*19–21*). The lane groups could be scaled into three risk levels from low to high: 0, interior lanes; 1, impact lane; and 2, exit and drop lane. Let Y_i denote the lane group for the *i*th observed crashes, the ordered probit model can be written as

$$p\left(Y_i = 0\right) = \Phi\left(u_0 - \beta X_i\right) \tag{7}$$

$$p\left(Y_i = 1\right) = \Phi\left(u_1 - \beta X_i\right) - \Phi\left(u_0 - \beta X_i\right) \tag{8}$$

$$p\left(Y_i = 2\right) = 1 - \Phi\left(u_1 - \beta X_i\right) \tag{9}$$

where

- p = probability of crashes occurring at the specific lane group *i* ($i = 2$ in this case);
- u_i = threshold parameter (cutoff point) to be estimated and that must satisfy the restriction $u_1 < u_2$;
- X_i = vector containing the values of observed crashes *i* on the full set of explanatory variables;
- β = vector of coefficients associated with the explanatory variables; and
- $\Phi(\cdot)$ = standard normal cumulative distribution function.

The cumulative probability equation can be represented as

$$p\left(Y_i > i\right) = \frac{\exp\left(\alpha_i + \beta X_i\right)}{1 + \exp\left(\alpha_i + \beta X_i\right)} \tag{10}$$

where α_i is the *i*th constant coefficient (the negatives of cutoff points). The values of constant coefficients are estimated by the maximum likelihood method. Then, the odds ratio for the cumulative probabilities can be written as follows:

$$\frac{p\left(Y_i > i\right)}{p\left(Y_i \leq i\right)} = \exp\left(\alpha_i + \beta X_i\right) \tag{11}$$

The ordered probit model was estimated with the procedure orprobit in the STATA software package (*22*). A stepwise method was applied to select the significant explanatory variables with the p-value less than .05 (a 95% confidence level). A set of coefficients, β, interpret how the explanatory variables contribute to the ordered variable. A positive sign indicates that crashes are most likely to occur in exiting and drop lanes rather than in impact and interior lanes; a negative sign indicates the opposite. The goodness fit of the models uses two criteria, the pseudo-R^2- and the p-values.

DATA ANALYSIS RESULTS

Crash Location Comparison

Total crashes and severe crashes are plotted in Figures 2 and 3 by locations for one-lane exits and two-lane exits separately. Each crash was identified by the milepost and lane number from the crash database. Overall crash counts are plotted by the dots on the left side of Figure 2 for one-lane exits (Type 1 and Type 2) and Figure 3 for two-lane exits (Type 3 and Type 4); severe crashes are plotted by the dots on the right side of the two figures for the types. Two vertical dashed lines indicate the location of the painted nose (start point of exit ramp). Three lane groups (exit and drop, impact, and interior) are illustrated in the middle of the figures. Since the number of lanes on the freeway ranges from two to five, each crash was mapped by a dot following the original lanes stated in the crash report. The ovals represent the crash-prone locations for each exit ramp type.

As shown in Figure 2, for one-lane exits most crashes occurred on the impact lane group and the interior lane group for a lane-balanced design (Type 1). The differences of crash-prone locations among the lane groups for a lane-unbalanced design (Type 2) are not obvious before the exits. After the painted nose, more severe crashes are likely to occur at the impact lane group and interior lane group. This is mainly because of the one-lane drop for a Type 2 exit ramp, which could increase the likelihood of lane-changing maneuvers for through movements.

As shown in Figure 3, for two-lane exits, high crash propensity occurs near the painted nose of the impact lane for the lane-balanced design (Type 3), whereas the difference for the lane-unbalanced design (Type 4) is not evident. The impact lane for the Type 3 exit ramp is an optional lane, which means traffic can either exit or continue. Although a Type 3 exit has better safety performance than a Type 4 exit ramp (*1*), the drop lane and the area near the painted nose are still the hazardous areas. For severe crashes only, more crashes occurred on the drop and interior lane group after the painted nose for a Type 4 exit ramp. A plausible reason is that the lane-unbalanced design may be more confusing or have greater impact on through-movement vehicles than do the other designs, especially after the lane drop. This characteristic is similar to the lane-unbalanced design for the one-lane exit. In addition, the situation of a two-lane exit is more complicated than that of a one-lane exit because of more lane-changing maneuvers. It is recommended that appropriate safety countermeasures be focused on this specific issue.

To examine the crash distributions by lane group for each exit ramp type, the percentage of crashes on each lane group was calculated. Figure 4 shows the crash distributions. For the exit and drop lane group, crashes are more likely to occur in lane-unbalanced designs (Type 2 and Type 4). For lane-balanced designs (Type 1 and Type 3), more crashes occurred on the impact lane. The proportion of crashes

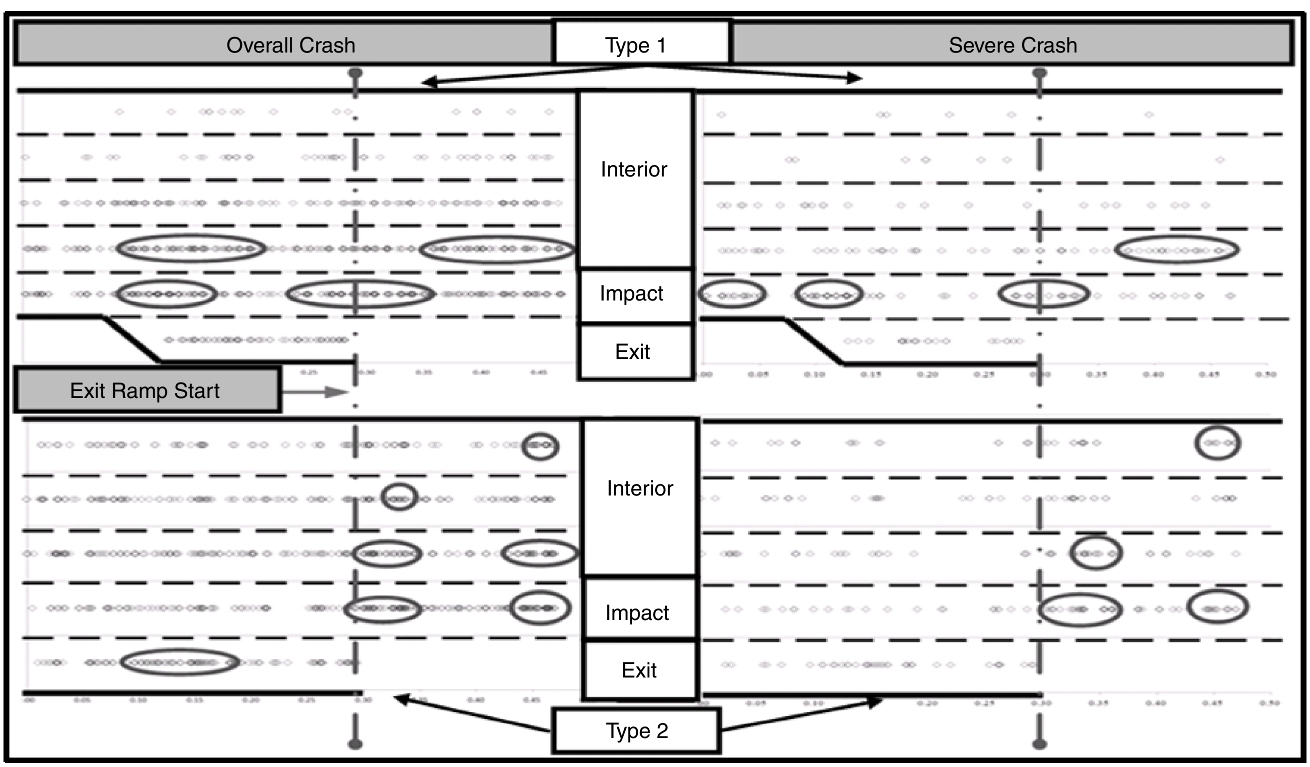

FIGURE 2 Distributions of total crashes and severe crashes for one-lane exits.

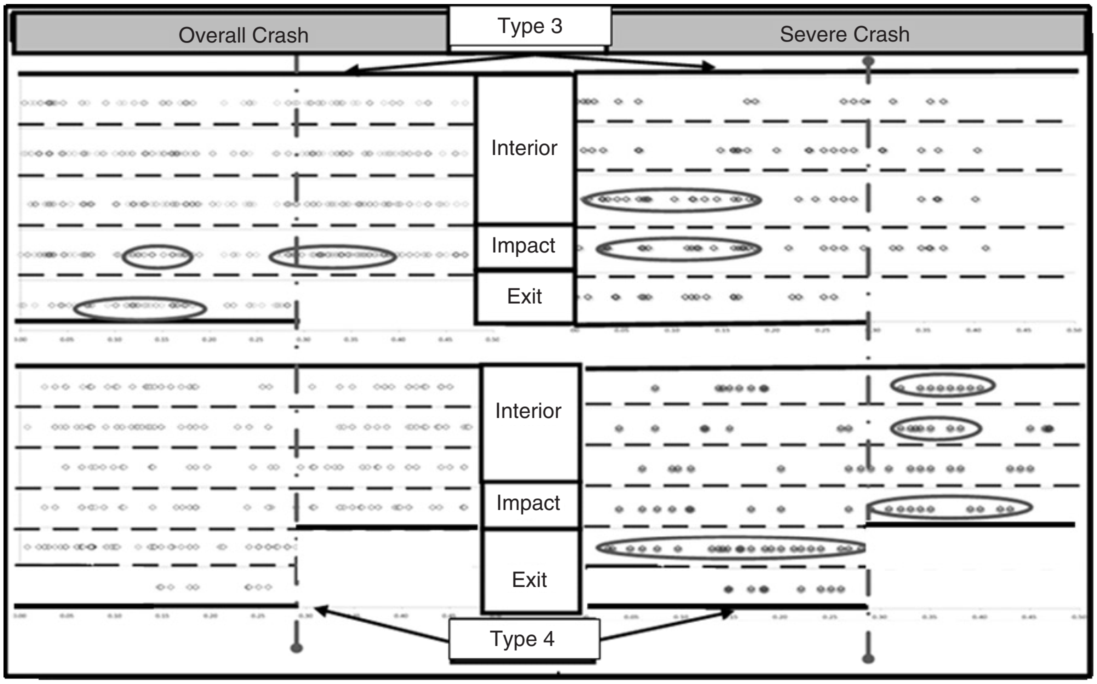

FIGURE 3 Distributions of total crashes and severe crashes for two-lane exits.

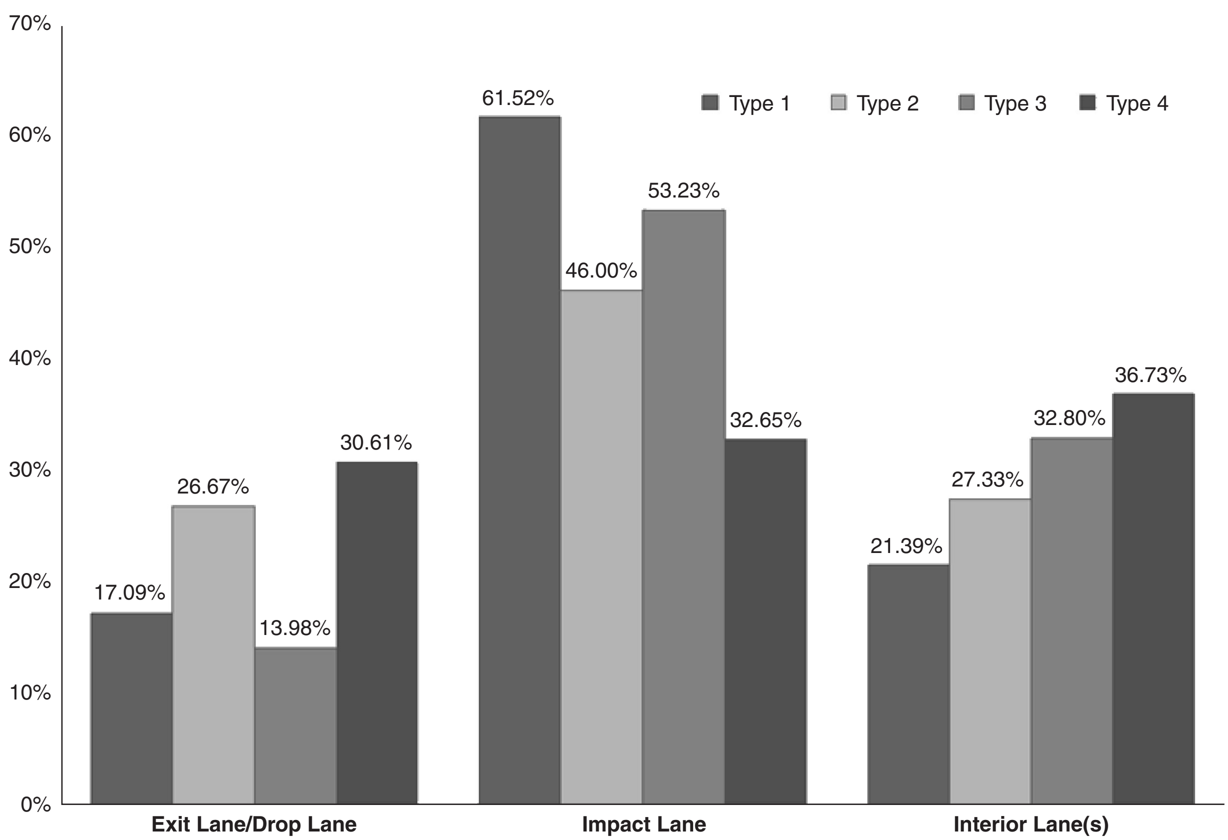

FIGURE 4 Total crash distributions by lane groups for exit ramp types.

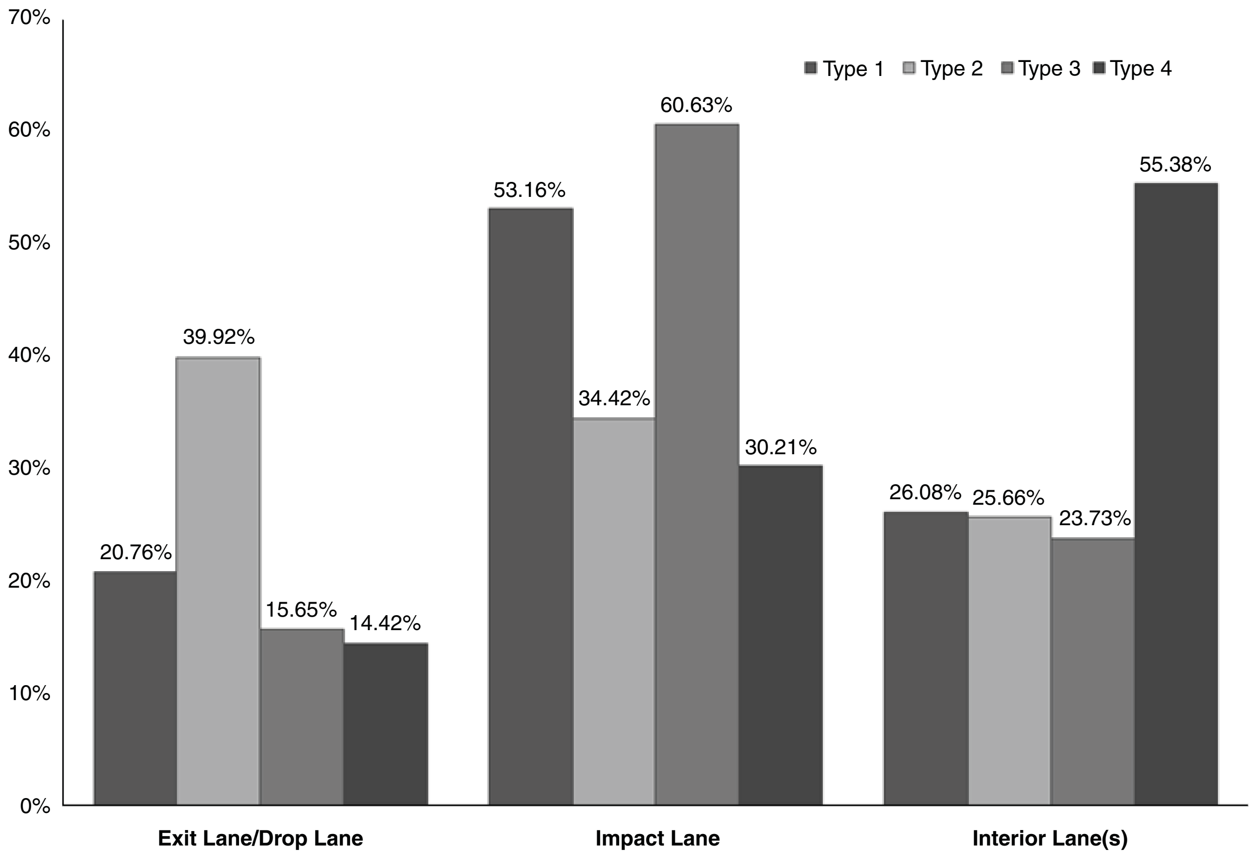

FIGURE 5 Severe crash distributions by lane groups for exit ramp types.

that occurred on the interior lane for the four types are 21.39%, 27.33%, 32.80% and 36.73%, respectively. The results suggest that Type 4 exit ramps have more influence on the interior lane group than do the other three types. Comparisons among different lane groups are illustrated in Figure 5 for severe crashes. The results are consistent with the previous observations. For one-lane exits, more than half the crashes (53.16%) occurred on the impact lane for Type 1, whereas about 40% of the total severe crashes occurred on the exit and drop lane for Type 2. For two-lane exits, Type 3 has a higher percentage of severe crashes (60.63%) on the impact lane, whereas about 55.38% of severe crashes occurred on the interior lane for Type 4 exit ramps. The lane-balanced design (Type 1 or Type 3) has more crashes on the impact lane group. The Type 2 exit type has a higher percentage of severe crashes on the drop lane than does Type 1, as expected. More than half the severe crashes occurred on the interior lane group of Type 4, compared with 26.08%, 25.66%, and 23.73% for Type 1, Type 2, and Type 3, respectively.

Reflecting a 90% confidence level, Table 1 lists the proportionality test results by lane groups for each exit ramp type. For total crash counts, only Type 1 has a significantly higher percentage of crashes at the impact lane group than does Type 2. For severe crashes, lane-balanced designs show different performance for the impact lane group. Both Type 1 and Type 3 have a significantly higher percentage of severe crashes on the impact lane than do Type 2 and Type 4 accordingly. In addition, for a one-lane exit, Type 2 has a significant higher percentage of severe crashes on the exit and drop lane group; for a two-lane exit, Type 4 has significantly higher percentage of severe crashes on the interior lane group. The results suggest that severe crashes are more likely to occur on the impact lane for the lane-balanced design (Type 3) and on the interior lane group for the lane-unbalanced design (Type 4).

Ordered probit models were developed for identifying the influence of various exit ramp types and other explanatory variables. The response variable of crash location in relation to the lane group is defined as the ordinal variable: 0, interior lane; 1, impact lane group; and 2, exit and drop lane group. Models were developed for the one-lane exit and the two-lane exit, respectively. Table 2 describes 16 variables initially selected for the model, including geometric data, traffic data, and related crash data.

TABLE 1 Proportionality Test Results

	Proportionality Test (Critical $Z_{\alpha/2} = 1.645$)			
	Total Crashes		Severe Crashes	
Exit Type	Type 1 vs. 2	Type 3 vs. 4	Type 1 vs. 2	Type 3 vs. 4
Exit and drop lane	1.583	1.416	2.875	0.129
Impact lane	2.202	1.608	2.733	2.428
Interior lane	0.957	0.306	0.067	2.446

TABLE 2 Descriptive Statistics of Variables

Variable	Type	Codes and Range	Frequency: Total Crashes	Frequency: Severe Crashes
Lane Group				
Interior lane	Ordinal	0	2,517 (61.02%)	526 (57.42%)
Impact lane		1	856 (20.75%)	162 (17.69%)
Exit and drop lane		2	752 (18.23%)	228 (24.89%)
Number of total lanes on freeway mainline	Count	2~5	4,125	916
Number of lanes on exit ramp		1, 2	4,125	916
Deceleration length (mi)	Continuous	0.05~0.17	4,125	916
Freeway ADT		18,800~291,000	4,125	916
Exit ramp ADT		2,300~76,000	4,125	916
Ramp length		0.10~1.19	4,125	916
Freeway speed limit (mph)		55~70	4,125	916
Ramp speed limit (mph)		25~55	4,125	916
Right shoulder width (ft)		8~15	4,125	916
One-lane exit	Dummy	1 (unbalanced)	68	68
		0 (balanced)	180	180
Two-lane exit		1 (unbalanced)	18	18
		0 (balanced)	60	60
Rear-end crash		1 (rear-end)	1,766	354
		0 (others)	(42.81%)	(38.65%)
Angle crash		1 (angle crash)	342	92
		0 (others)	(8.29%)	(10.04%)
Other crashes		1 (other crashes)	1,395	395
		0 (others)	(33.82%)	(43.12%)
Land type		1 (business)	2,398	554
		0 (residential)	(58.13%)	(60.48%)
Surface type		1 (blacktop)	3,537	820
		0 (others)	(85.75%)	(89.62%)
Right shoulder type		1 (paved)	1,496	355
		0 (others)	(36.27%)	(38.76%)

All explanatory variables were grouped into three types: discrete, continuous, and dummy. The number of lanes on a freeway and the number of lanes on exit ramps are discrete data. Deceleration length, freeway average daily traffic (ADT), ramp ADT, ramp length, freeway speed limit, ramp speed limit, and right shoulder width are continuous variables. Exit ramp type is a dummy variable, and the sideswipe crash was defined as the reference group for rear-end crashes, angle crashes, and other crash types. Correlations between variables were tested to examine the relationship between selected variables. Stepwise methods were applied to select the variables with a 5% significance level. Tables 3 and 4 list the regression results of the final ordered probit models.

For one-lane exits, the *p*-value equals zero, which implies that the model is adequate. Six variables—freeway speed limit, ramp speed limit, ramp length, surface type, land type, and right shoulder width—are not statistically significant to the total crash counts. Five variables—Type 2 exit ramp, deceleration length, other type of crashes, freeway ADT, and ramp ADT—have positive signs, that is, increasing the value of these variables may lead to an increase in crashes on the exit and drop lanes or impact lanes compared with the interior lane-group. Intuitively, with the increase of freeway ADT and ramp ADT, the potential conflicts will increase as well on the exit sections. For the deceleration lane, the model indicates that longer deceleration lane length means more potential crashes. The results of previous studies regarding the safety impact of the deceleration lane length are not consistent. For example, some recent studies found that a long deceleration lane creates more weaving maneuvers at freeway diverging areas (*1, 2, 11*). Another possible explanation is that drivers may accelerate before they exit the main road if the distance is too long. This has the potential to increase crash risks at freeway diverging areas. Crashes are more likely to occur on the interior lane group for a Type 2 exit ramp than for a Type 1 ramp; however, the differences are not significant between the two lane groups from the proportionality tests for overall crashes.

The one-lane model also indicates that more rear-end crashes and angle crashes are likely to occur on the impact lane and the interior lanes than on the exit and drop lane. Increasing the number of lanes on freeways and ramps would consequently increase the potential crashes on the impact and interior lanes. Increasing the number of mainlines will increase the number of interior lanes and thus increase the chance of crash occurrences at the interior lanes with the other situations unchanged. Some one-lane exits were widened to two lanes on the ramp section. The addition of one lane on the ramp would likely decrease the influence of exiting vehicles on the freeways compared with the nonwidened exits. For example, this would likely reduce the speed differential, which is the primary cause of crashes on the exit lane.

TABLE 3 Ordered Probit Model for Total Crashes by One-Lane Exits

Variable	Coeff.	SE	Z	$P > Z$	95% Confidence Interval	
Rear-end crash	–0.167	0.057	–2.91	.004	–0.028	–0.054
Angle crash	–0.300	0.107	–2.79	.005	–0.051	–0.089
Other crashes	0.157	0.055	2.82	.005	0.047	0.265
Number of lanes on freeway	–0.183	0.035	–5.21	.000	–0.252	–0.114
Lane-unbalanced exit ramp/Type 2	0.358	0.069	5.18	.000	0.223	0.494
Number of lanes on exit ramp	–0.345	0.096	–3.57	.000	–0.535	–0.156
Deceleration length (mi)	2.198	0.942	2.33	.020	0.350	4.045
Lane of freeway ADT in thousands	0.228	0.066	3.42	.001	0.036	0.097
Lane of exit ramp ADT in thousands	0.139	0.037	3.69	.000	0.065	0.213
Right shoulder type	–0.213	0.053	–4.01	.000	–0.317	–0.109
/cut1	–1.455	0.269			–1.983	–0.929
/cut2	–0.968	0.268			–1.495	–0.442

NOTE: Iteration 0: log likelihood = –2,899.694; number of observations = 3,049. Iteration 1: log likelihood = –2,821.545; LR chi-square (10) = 156.84. Iteration 2: log likelihood = –2,821.274; prob > chi-square = 0. Iteration 3: log likelihood = –2,821.273; pseudo-R^2 = .027; coeff. = coefficient; SE = standard error.

For the two-lane exit, only five variables—rear-end crash, angle crash, number of lanes on the freeway, ramp ADT, and Type 4 exit ramp—are found to be statistically significant at the 95% confidence level. Similar to the one-lane model, the two-lane model indicates that more rear-end crashes and angle crashes are likely to occur on the impact lane and the interior lanes than on the exit and drop lane. Increasing the number of lanes on freeways and ramps would increase the potential crashes on the impact lane and interior lanes as well. It is intuitive that increasing ramp ADT would increase the number of crashes on the exit and drop lane. The positive sign of the Type 4 variable indicates that the lane-unbalanced design (Type 4) has a higher likelihood of crashes on the exit lane than does the lane balanced design (Type 3). The conclusion is consistent with the results from statistical tests.

Model Result for Severe Crashes

Two models for severe crashes only were developed for one-lane exits and two-lane exits separately. Table 5 lists the model results. For the one-lane exit, six variables were found to be statistically significant at the 95% confidence level. An increase in freeway ADT or exit ramp ADT would increase the potential crashes on the exit and drop lane group. As the freeway speed limit and the number of lanes on exit ramps increase, crashes are less likely to occur in the interior lanes. These sites with higher speed limits are usually located in suburban or rural areas. Because sites in suburban and rural areas have lower volumes of exiting traffic, disturbances to through vehicles are less than at sites found in urban areas.

In contrast with the total crash model, severe crashes are more likely to occur on the interior lane group and the impact lane group than on the exit and drop lane group for Type 2 exit ramps. This result confirms the conclusion from the proportionality tests. The lane-unbalanced design with one-lane drop would potentially force more vehicles to change lanes. For the two-lane model, the same conclusion was drawn for the lane-unbalanced design. The lane-unbalanced design had a higher percentage of severe crashes than did the lane-balanced design on the interior lanes. For safety, further efforts should focus on selecting practical countermeasures that can reduce

TABLE 4 Ordered Probit Model for Total Crashes by Two-Lane Exits

Variable	Coeff.	SE	Z	$P > Z$	95% Confidence Interval	
Rear-end crash	–0.275	0.106	–2.59	.010	–0.483	–0.066
Angle crash	–0.281	0.149	–1.89	.059	–0.573	0.011
Number of lanes on freeway	–0.387	0.051	–7.53	.000	–0.488	–0.286
Lane-unbalanced exit ramp/Type 4	0.206	0.088	2.33	.020	0.033	0.380
Exit ramp ADT in thousands	0.013	0.004	3.16	.002	0.005	0.021
/cut1	–1.320	0.236			–1.782	–0.858
/cut2	–0.676	0.234			–1.135	–0.217

NOTE: Iteration 0: log likelihood = 979.29515; number of observations = 1,076. Iteration 1: log likelihood = 930.66924; LR chi-square (10) = 97.48. Iteration 2: log likelihood = 930.55393; prob > chi-square = 0. Iteration 3: log likelihood = 930.55393; pseudo-R^2 = .0498.

TABLE 5 Ordered Probit Models for Severe Crashes

Variable	Coeff.	SE	*Z*	*P* > *Z*	95% Confidence Interval	
One-Lane Exit						
Lane-unbalanced exit ramp/Type 2	–0.019	0.111	–5.18	.000	–0.023	–0.494
Number of lanes on exit ramp	–0.547	0.252	–2.17	.030	–1.041	–0.053
Freeway ADT in thousands	0.005	0.001	4.97	.000	0.006	0.003
Exit ramp ADT in thousands	0.032	0.009	3.54	.000	0.014	0.050
Freeway speed limit	–0.017	0.008	–2.01	.044	–0.034	–0.004
Right shoulder type	–0.102	0.044	2.31	.021	–0.016	–0.189
/cut1	–0.076	0.706			–2.144	0.622
/cut2	–0.238	0.705			–1.620	1.145
Two-Lane Exit						
Lane-unbalanced exit ramp/Type 4	–0.035	0.212	–2.16	.022	–0.045	–0.038
Number of lanes on freeway	–0.330	0.116	–2.85	.004	–0.557	–0.103
Rear-end crash	–0.302	0.289	–2.04	.035	–0.368	–0.066
Angle crash	–0.557	0.357	–1.56	.12	–1.257	0.144
Exit ramp ADT in thousands	0.0127	0.010	2.25	.12	0.007	0.032
/cut1	–1.078	0.567			–2.189	0.334
/cut2	–0.608	0.565			–1.719	0.499

NOTE: One-lane exit: Iteration 0: log likelihood = –687.81921; number of observations = 697. Iteration 1: log likelihood = –670.93669; LR chi-square(10) = 33.92. Iteration 2: log likelihood = –670.85831; prob > chi-square = 0. Iteration 3: log likelihood = –670.85818; pseudo-R^2 = .024. Two-lane exit: Iteration 0: log likelihood = –201.09974; number of obs. = 219. Iteration 1: log likelihood = –191.07214; LR chi-square (10) = 20.11. Iteration 2: log likelihood = –191.04473; prob > chi-square = 0.0026. Iteration 3: log likelihood = –191.04472; pseudo-R^2 = .005.

the potential severe crashes on the interior lanes, if the designs are lane-unbalanced.

SUMMARY AND CONCLUSIONS

Crash distributions and the locations of all crashes and severe crashes at freeway diverging areas were analyzed and compared. Crash contributing factors were identified, including exit ramp types, geometric design features, traffic conditions, and crash attributes. Exit ramp types were defined by the number of lanes exiting freeways and the lane-balance theory. Lanes were grouped into three categories: the exit and drop lane group, the impact lane group, and the interior lane group. Three years of crash data (2004 to 2006) were retrieved from the Florida CAR system. Both total crash counts and severe crash counts were located on the study segments for each exit ramp type. Proportionality tests were used to compare the crash distributions on different lanes. In addition, ordered probit models were developed for total crash counts and severe crash counts. A summary of major research findings is provided in Table 6 by overall crashes and severe crashes, respectively.

As shown in Table 6, the overall crash-prone location for Type 1 and Type 3 exits is the impact lane, compared with the other two lane groups. For Type 2 exits, the crash-prone locations are the exit lane, the impact lane, and interior lanes after the exit. For Type 4 exits, there is no obvious difference among the three lane groups. The proportionality test indicates that Type 1 ramps have a statistically significant higher percentage of crashes on the impact lane group than that of Type 2; however, there is no statistical difference between Type 3 and Type 4 exits. The ordered models suggest that crashes are more likely to occur on the exit and drop lane for lane-unbalanced designs (Type 2 and Type 4) than for lane-balanced designs (Type 1 and Type 3).

For severe crashes only, both the proportionality tests and the ordered models suggest that more severe crashes are likely to occur on the interior lanes for lane-unbalanced designs (Type 2 and Type 4). A possible reason is that confusion arises for through movement traffic when drivers face the one-lane drop in the lane-unbalanced designs. Lane drops at freeway diverging areas reduce the capacity of the freeway after the exits. This could lead to more weaving maneuvers on the impact and interior lanes, thus increasing injury severity. Potential improvements should be developed for the interior lane groups with lane-unbalanced designs (Type 2 and Type 4), especially after the exits.

A limitation of this study is the small sample size of Type 4 exits. Another limitation is the assumption that all crashes that occurred in the study areas were caused by the presence of exits. The authors tried to minimize impact factors other than the factors of interest; however, thousands of crashes lacked information related to the causes of the crashes. Further efforts to examine each crash report are recommended.

This study can help engineers design practical and optimal exit ramp types and select appropriate countermeasures for crash-prone freeway diverging areas. Potential countermeasures should include two aspects: advanced sign implementation and improvements, and geometric design improvements. Advanced warning signage by location and design may be most applicable when traffic approaches the freeway diverging areas. The results of this study suggest that geometric improvements, such as length of the deceleration lane, number of lanes on a freeway or exit ramps, ramp length or right-shoulder width, and optimal design guidelines, could improve safety performance in the freeway diverging area.

TABLE 6 Summary of Total and Severe Crashes Locations for Exit Ramp Types

Comparison Method	Type 1 Exit	Type 2 Exit	Type 3 Exit	Type 4 Exit
Overall Crash Location Comparison Result				
Prone crash locations	Impact lane	Exit lane Impact lane after the exit Interior lane after the exit	Impact lane near the exit	No obvious difference
Proportionality test	Type 1 versus Type 2. Type 1 has significantly higher percentage of crashes on the impact lane.		Type 3 versus Type 4. No statistically significant differences.	
Ordered model	Type 2 exit ramps have the potential trend of having more crashes on the exit and drop lane group than the interior lane group.		Type 4 exits have higher likelihood crashes on the exit lane than Type 3 exits.	
	Increasing freeway ADT would increase the potential crashes on the exit and drop lane while the increasing of number of lanes on freeways or on the exit ramp would increase crashes on the impact lane or interior lane(s).			
Severe Crash Location Comparison Result				
Prone crash locations	Impact lane	Impact lane after the exit Interior lane after the exit	Impact lane before exit	Impact lanes before the exit Interior lanes after the exit
Proportionality test	Type 1 versus Type 2. Type 1 has significant higher severe crashes than on the exit and drop lane.		Type 3 versus Type 4. Type 4 has significant higher severe crashes on the interior lane(s).	
	Both lane-balanced designs (Type 1, Type 3) have the trend that severe crashes would occur on the impact lanes than the interior lanes compared to lane-unbalanced designs (Type 2, Type 4).			
Ordered model	Both lane-unbalanced designs (Type 2, Type 4) have more severe crashes on the interior lane(s) and impact lanes than the exit and drop lane comparing to the lane-unbalanced designs (Type 1, Type 3).			

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