A Study on the Safety of Left-Side Off-Ramps on Freeways

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ABSTRACT

The safety effects of four left-side off-ramps on freeways in the Tampa Bay area were evaluated. An in-field observation and recording of the traffic flow on these left-side off-ramps was conducted, followed by a cross sectional study on traffic crash between left and right side off-ramps with historic crash records and a conflict study. Data including traffic conflicts, vehicle speed, traffic sign, and crash records of four left-side off-ramps together with crash records of these left-side and some other right-side off-ramps in the Tampa Bay area were collected.

The traffic flow near the left-side off-ramps areas was recorded and analyzed. Four types of traffic conflicts were identified and counted. The average conflict rates near the ramp area were found to be about 10 per 1,000 vehicles. In addition, approximately 5% of vehicles were observed to make lane change maneuvers on three left-side off-ramps, among which nearly 15% were aggressive last minute lane changes. The vehicle speed differences between two movements on the optional lanes were less than 10 mph with the traffic flow still remaining in a stable state. Traffic signs installed before the left-side off-ramps were discussed and some recommendations on other auxiliary traffic signs were made.

The crash records of left-side off-ramps together with their right-side counterparts were analyzed. The right-side off-ramps were selected based on their similarity with the left-side counterpart on geometric characteristics. A cross sectional comparison between them on crash rate was conducted and the critical crash rate for each left-side off-ramp was calculated. A t-test indicated that the crash rate for left-side exiting at three study sites is significantly greater than that for their nearby right-side counterparts. However, the critical crash rate analysis results indicated that the crash occurrences on those left-side off-ramps are not significantly higher than critical crash rate of normal right-side off-ramps. Based on the analysis results, it’s recommended that no special engineering treatments or improvements are needed for the left-side off-ramps on freeways. The study also shows that the two-lane exits with optional lanes have better safety performances than two-lane exits without optional lanes.

KEYWORD

Left-side Off-Ramp, Cross Sectional Study, Conflict Study, Critical Crash Rate

INTRODUCTION

While no conclusions have been drawn on this topic through systematic research activities, the abnormal left exits on freeways were commonly regarded to result in safety issues related to driver expectancy. Recently a major traffic incident on a left-side off-ramp along I-275 raised a great concern on the safety effects of off-ramps on this side of the freeway.

The effects of the four left-side off-ramps on traffic safety in the Tampa bay area, which includes: the new I-4 EB @50th Street, I-275@I-375, I-275@I-175, and I-275@31st Street, were evaluated in this paper. The main findings and suggestions on left-side off-ramps through their research work are summarized in this report.

OBJECTIVES

This study is aimed to achieve the following objectives:

- Examine the operational performance of the selected left-side off-ramps by a conflict study and a speed study;
- Investigate the advanced warning signs for the left-side off-ramps and analyze the necessity for additional traffic signage;
- Compare the crash records of those left-side and right-side off-ramps to see whether there are any significant differences; and
- Compare the actual crash rate with the critical crash rate to see if there is a need for safety improvement measures.

LITERATURE REVIEW

Although some studies have mentioned freeway off-ramps during the past several decades, none of them have focused on the safety impact of left-side off-ramps. To examine the impact of ramp locations on traffic safety, Cirillo, et al. (1) did an innovative investigation of the traffic study on the interstate system in 1969. The study found that a relationship between crash frequency and geometric elements could be established. About thirty years later, Garber and Fontaine (2) developed a guideline to search the operational and safety characteristics for the optimal ramp design. The newest instructions for ramp design are the "Freeway and Interchange Geometric Design Handbook" edited by Leisch (3) and published by the Institute of Transportation Engineers (ITE) in 2006. The handbook focuses on geometric and operational characteristics of freeways and interchanges, including on and off-ramps. It also recognizes that geometric design procedures for freeways and interchanges may vary. It is valued as a supplement of the AASHTO Greenbook (4), the Highway Capacity Manual (HCM) (5), and Traffic engineering Handbook 5th Edition (6).

A few past studies were found to examine the factors that affect freeway off-ramp safety. In 1998, Bared, et al. (7) found that the crash frequency on freeway ramps increased with freeway Annual Average Daily Traffic (AADT) volume, but decreased with deceleration lane length. A 100 ft increase in deceleration lane length will result in a 4.8% reduction in crash frequency. The results also indicated that off-ramps had more crashes as compared to on-ramps. The statistical model, developed by Bauer and Harwood (8), found that the ramp AADT explained most of the variability in the crash data report at selected sites. Other variables found to be significant were: contained freeway AADT, area type (rural, urban), ramp type (on, off), ramp configurations, ramp lengths, and speed-change lane (deceleration lanes, acceleration lanes). However, no left-side off-ramps were included in these studies.

Makigami et al (9) established a mathematical method to compare the merging probability of the outside on-ramp with inside on-ramp on a Japanese urban expressway. Right-side merging lanes provided more comfortable merging traffic operations to drivers than the left-side ramp. It's suggested that the left-side ramp merging-lane length should be 50% longer than the right-side and that additional attention should be given to operational countermeasures, such as speed regulation and ramp metering in order to maintain large gaps. Only on-ramps were examined in this study and no further conclusions for off-ramps were made.

McCartt, et al. (10) examined 1,150 crashes that occurred on heavily traveled urban interstate ramps in northern Virginia. About half of all these crashes occurred when at-fault drivers were in the process of exiting interstates, and the crash type most frequently associated with exiting ramp was run-off-road. It was also found that the run-off-road crashes frequently occurred when vehicles were exiting interstates at night, in bad weather, or on curved portions of ramps. No information about the location of the off-ramps, that is, left-side or right-side, was provided.

To identify the best design for a guide sign for the two-lane exit with an option lane, Upchurch, et al. (11) examined the effect of different off-ramp designs. Four candidate sign designs were evaluated using 96 test subjects in a driving simulator. The number of missed exits and the number of unnecessary lane changes were adopted as measures of effectiveness; one design was recommended for inclusion in the Manual on Uniform Traffic Control Devices (MUTCD). Only off-ramps on the right sides were considered in this study.

After closely reviewing the literature, there are currently no conclusions on operational and safety performance of left-side off-ramps. The left-side off-ramps are not the norm on most interstate highways, and their impact on freeway operations and safety are not clear.

METHODOLOGY

To evaluate the impact of left-side off-ramps on traffic operations and safety, a traffic conflict study, a cross sectional safety comparison, and a critical crash rate study were conducted for the four selected left-side off-ramps.

Traffic Conflict Study

A traffic conflict was defined as "an event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision" (12). Evasive maneuvers, such as applying brakes, swerving, or noticeably decelerating in order to avoid a collision can be considered as conflicts. The purpose of the conflict study is to determine if any safety and operational problems exist at the four freeway segments with left-side off-ramps. The conflict rate, defined by number of conflicts per 1,000 total vehicles, was used to measure the safety performance of the research objects based on the assumption that the conflict numbers are correlated with the actual crash frequency.

Four basic types of conflicts are often used in traffic conflict studies, including diverging conflict, merging conflict, weaving conflict, and crossing conflict. For this project, a total of four types of traffic conflicts near the left-side off-ramps were defined.

The first type of conflict is lane change conflicts. These occur between the first vehicle changing from the exit lane to the through lane and the following vehicle on the through lane to where the first vehicle is changing. This type of conflict occurs when the vehicle which intended to keep on the highway stayed on the exit lane erroneously. To keep moving on the highway, the vehicle needs to make a lane change maneuver from the exit lane to the through lane. When the distance between the first vehicle and the following vehicle is too short for the lane change maneuver, the following vehicle would have to slow down or swerve to avoid a crash. This lane change conflict is defined as “type 1” conflict in the following paragraphs. The second type of conflict, “type 2”, is also caused by a vehicle on the through lane weaving into left-side exit lane. This type of conflict often happens when drivers assume that the off-ramps are located on the right side of the freeway. The “type 3” conflict is caused by an exit vehicle slowing down on an optional lane. This type of conflict occurs between two vehicles traveling on the same lane. When the first vehicle is diverging from the original direction, it might slow down to make the necessary maneuver. If the following distance was too close, a type 3 traffic conflict would occur. The type 4 conflict is the secondary conflict caused by any of the above three conflict situations. When the second vehicle makes an evasive maneuver, it may place another road user (a third vehicle) in danger of a collision. The secondary conflict will almost always look much like a slow-vehicle, same–direction conflict or a lane-change conflict. The difference is that in a secondary conflict, the third vehicle responds to a second vehicle that is in a conflict situation itself.

For the selected left-side off-ramps, the above four types of traffic conflicts were counted from video recorded in the field and the traffic conflict rates were calculated correspondingly.

Lane Change Maneuver

In addition to the traffic conflicts, the lane change maneuver was also monitored using video cameras. The number of lane change maneuvers, the total traffic volume, and the percentage of lane changing maneuvers in total traffic volume was calculated. In all types of lane change maneuvers, one specific type called “aggressive lane change” (or “last second lane change”) was listed separately. In the field, researchers observed that some drivers parked their cars at the painted gore area to avoid exiting the freeway from the left-side exit lane, and then waited for a suitable gap to merge back into the freeway. Due to not having an acceleration lane, the reentry speed for the vehicles parking at the gore area is very low and this might cause severe rear-end collisions and conflicts with other vehicles traveling at a high speed.

Cross Sectional Comparison

One of the main objectives of this study is to compare the safety of the left-side off-ramp with the nearby right-side off-ramps. The traditional Before-and-After comparison was found to be unsuitable for this kind of comparison.

The cross sectional comparison is a method used to evaluate the impact of a treatment on an entity when the treatment has not yet been implemented. In this case, the safety performance of the entities in the “before” period when the off-ramps are located on the right sides is not available. The cross sectional study can be implemented by comparing the safety performance of some entities with certain special features to the safety performance of other entities without these special features. In this study, the special feature refers to the off-ramp location. For cross sectional comparison, two sets of sites should be identified with similar control factors aside from the treatment.

For each left-side off-ramp, several right-side off-ramps were selected as pairings for the cross sectional study. As required by the cross sectional study, these right-side off-ramps should have similar characteristics with the left-side off-ramp. In this study, the geometric design type and traffic volume were considered as the criteria to select the similar right-side off-ramps. For each left-side off-ramp, the paired right-side exits had similar geometric designs and traffic volume and were located within 10 miles from the left-side exit.

Crash frequencies or crash rates are two indicators that are generally used in safety studies to compare different treatments or groups. Crash frequency is the actual number of crashes that have happened at a certain location or segment in a particular time or time interval. Crash rate is defined as crashes per million vehicles per mile. In this study, two types of crash rates are used to evaluate the safety of left-exit off-ramps. The first type is the actual crash rate, which is defined as number of crashes per million vehicles per mile traveled. The R, for a particular freeway segment, can be calculated by using the following formula:

$$R = \frac{1{,}000{,}000 \times A}{365 \times T \times V \times L} \tag{1}$$

Where,

R = crash rate at a freeway segment (crashes per million vehicles per mile);
A= number of report crashes (total crashes for the time frame),
T= number of years;
V= average daily traffic volume (vehicles per day);
L= length of the freeway segment (miles).

The second type of crash rate is the critical crash rate which is a statistically derived number, greater than the average rate. It serves as a screening measure to identify locations where crash occurrence is higher than expected for a given facility type and for which safety measures should be considered. For each left-side off-ramp, the following equation can be used to calculate the critical crash rate F_C:

$$F_c = F_a + k\left(\frac{F_a}{M}\right)^{\frac{1}{2}} + \frac{1}{2M} \tag{2}$$

In which, F_C is the crashes per million vehicles per mile. F_a is the calculated value of the statewide crash rate of roadway classes from 1999 to 2003 in Florida. In this study, F_a is selected from the interstate highway roadway class in an urban area of 0.683 crashes per million vehicles per mile. k is a probability constant (1.645 for a 95% confidence level and 3.291 for 99.95% confidence level) and M is the vehicle exposure calculated in 100 million vehicles mileages traveled.

DATA COLLECTION

To evaluate the safety effects of left-exit off-ramp, field data, such as traffic volume, speed, traffic conflicts, and lane change maneuvers were collected by on-site observations. The crash data of the related left and right side off-ramps for the cross sectional safety study were collected from the FDOT crash database.

Existing Left-Side Off-Ramps

I-275/I-375

The first left-side off-ramp is located at the interchange from I-275 to I-375 in Pinellas County, near the intersection of North 5th Street and North 20th Street. There are three through lanes on I-275 and two left-side exit lanes with an optional lane.

I-275/I-175

The second studied left-side off-ramp is located at the interchange from I-275 to I-175, near the intersection of South 3rd Street and South 19th Street in Pinellas County. There are two through lanes on I-275, and two left-side exit lanes to I-175 with an optional lane (The optional lane is the lane in which drivers can select to stay on the interstate highway or drop to the off-ramp). This is a freeway to freeway connection.

I-275/31st Street

The northbound left-side off-ramp of I-275/31st Street is located near the intersection of South 15th Street and 31st Street in Pinellas County. The difference between the site and the above two sites is that there are two exclusive left side exit lanes with no optional lane.

I-4/50th Street

The left-side off-ramp of I-4/50th Street is located near the intersection of East Columbus Driveway and North 50th Street in Hillsborough County. There are two left-side exit lanes with an optional lane and three through lanes at this location.

Two Types of Left-Side Exit-Lane Configurations

There are two types of geometric designs for left-side exit lanes: two exit lanes with an inside optional lane and two exclusive exit lanes. The two left-side exit-lanes with an optional lane have two exit lanes with the one outside lane becoming exclusively off-ramp and the inside lane being an optional lane where vehicles can make a left exit or continue on the freeway. The off-ramps of I-275/I-375, I-275/I-175 and I-4/50th Street belong to this type of geometric design. Another type of left-side exit lane configurations has two exclusive exit lanes. The off-ramp of I-275/31st Street is this type of design.

Traffic Conflict Data

To obtain the traffic conflict and lane change data for each freeway segment, two hours of traffic flow located just before the off-ramps was recorded on video during peak hours in the morning (7 A.M. to 9 A.M.) or in the afternoon (4 P.M. to 6 P.M.) on weekday. Traffic conflicts and lane changes were identified and manually counted afterward in the lab. Since a safe place from which to observe and record the traffic could be found at the site southbound I-275@I-175, conflict data on the following three left-side off-ramps were collected: southbound I-275@I-375, northbound I-275@31st street, and eastbound I-4@50th street. For all of the three off-ramps, cameras were set up approximately 1000 feet away from the beginning of the gore area.

The volume and speed of different traffic movements on these off-ramps were also collected. The exit and through traffic volumes were counted with electronic traffic counters and saved. The vehicles' speeds were determined from videotape by using a normal method. Two characteristic sections that can be found in both Google Earth and the camcorder's view were selected. The distance between the two sections was measured with Google Earth, and the time each vehicle spent to travel the distance was measured with the videotape. Dividing the distance by the travel time it spent, the vehicle's speed was finally determined.

Traffic Crash Data

Four left-side off-ramps, I-275@I-375, I-275@I-175, I-275@31st Street, and I-4@50th Street, were selected for the cross sectional safety study. For each left-side off-ramp, several right-side off-ramps with similar geometric characteristics were selected as the paired off-ramps and put together as a group for the cross sectional study.

For each off-ramp group except the newly opened I-4@50th St., three year's crash records from 2004 to 2006 were collected for both the left and right-side off-ramps. The segment length was defined as the deceleration length plus 1,000 feet upstream from the off-ramp. Approximately one and a half year's crash data were collected for I-4@50th St. from August, 2006 to December, 2007.

DATA ANALYSIS

Conflict Analysis

Number of Conflicts

Based on the definition of the four conflict types, the numbers of conflicts at the three left-side off-ramps recorded in the videotape were counted, as listed in Table 1. The results indicated that type 1 and type 3 conflicts were the main conflict types on the off-ramp area, while there were relatively small occurrences of type 2 and type 4 conflicts between vehicles.

Table 1 Number of Conflicts at Different Off-Ramps

Off-Ramp	Conflict Type				Total Conflicts	Traffic Volume	Conflict Rate*
	Type 1	Type 2	Type 3	Type 4			
I-275@I-375	40	4	10	5	59	4,945	11.9
I-275@31st Street	16	1	23	3	43	3,494	12.3
I-4@50th Street	22	8	27	4	61	5,781	10.5

* Conflict rate refers to total conflicts per 1,000 vehicles

The conflict rate here is defined as the number of conflicts per 1,000 vehicles. As previously mentioned, the left-side off-ramp of I-275@31st Street was a two-lane off-ramp without an optional lane, while the other two were two-lane off-ramps with an optional lane. A previous cross sectional safety study by Chen, et al. (13) showed that replacing two-lane exit ramps that have an optional lane with two-lane exit ramps without an optional lane will increase crash counts at freeways areas by 11.7%. The conflict study here indicated that the conflict rates at the location with the two exclusive off-ramps are slightly higher than the location with an optional lane, which also coincided with the results of the cross sectional safety study.

Number of Lane Change Maneuvers

The number of lane changing maneuvers was used as additional indicators to measure the operational and safety effects of left-side off-ramps. The number of lane change maneuvers on the three left-side off-ramps was counted from the video recorded in the field, as listed in Table 2. Results showed that in that area there were approximately 200 lane changes in one hour, which is about 3% to 5% of total directional traffic volumes on the freeway near the left-side off-ramp areas. Approximately 15% of the total traffic conflicts were aggressive last minute lane changes.

Table 2 Number of Lane Change Maneuvers at Different Off-Ramps

Off-Ramp	Lane Change	Aggressive Lane Change	Traffic Volume	%[1]	%[2]
I-275@I-375	210	30	4,945	4.2	14.3
I-275@31st Street	205	24	3,494	5.8	11.7
I-4@50th Street	194	29	5,781	3.3	14.9

Note: 1 refers to the percentage value of number of lane change to total traffic volume, and 2 refers to the percentage value of number of aggressive lane change to number of lane change.

Speed Differential on the Optional Lane

Another index used to measure safety and operations near the left-side off-ramp area is the speed differential on the optional lane, which has mixed through and exiting traffic. When the speed differential is too high, the traffic flow will become unstable. Larger differences in speed between vehicles are related to a higher crash rate (14). In this study the speed differentials between through and exiting vehicles on optional lanes were examined.

Two different movements existed on the optional lane, the exit movement and the through movement. In comparison with vehicles on other lanes, the vehicle speed differences on optional lanes are larger. Both left-side off-ramps of I-275@I-375 and I-4@50th Street have optional lanes. The speeds of the exit and through movement on these lanes were measured and calculated.

For each movement based on the individual vehicle speed, the average value and standard deviation of the exit and through movement was calculated, as shown in Table 3. Results indicated that the average speed of exit movement is slower than that of through movement, and the speed difference between them on both optional lanes was less than 10 mph. Past studies indicated that the 10 mph speed differential wouldn't cause major safety problems (15). This means that the vehicle speed differences were not very large and the traffic flow still remained in a stable state. The standard deviations of speed for the vehicles on the optional lanes of I-275@I-375 and I-4@50th Street were 15.4 mph and 12.2 mph, respectively.

Table 3 Distribution of Vehicle Speed on Optional Lanes

Off-Ramp	I-275@I-375		I-4@50th Street	
	Exit Movement	Through Movement	Exit Movement	Through Movement
Average Speed (MPH)	63.1	72.3	64.6	74.4
Speed Standard Deviation (MPH)	8.4	15.2	6.9	7.6
Total Speed Standard Deviation (MPH)	15.4		12.2	

Cross Sectional Crash Comparison

Crash Data

Crash data were obtained from Florida Crash Analysis Reporting (CAR) System which was maintained by the State of Florida. In 2003, the FDOT renamed all the freeways' exit ramps for the whole state. Accordingly, the crash database updated the exit ramp numbers for the entire database. Due to this reason, crash data for freeway exit ramps before 2004 include a lot of missing information and, as a result, cannot be used in this study. A three-year time frame, from 2004 through 2006, was selected to obtain crash data. Eighty-six variables are enclosed in the FDOT crash database including: site identification, time of crashes, traffic conditions, geometric conditions, crash detailed information as location, direction, crash type, severity and relevant information. Cross sectional comparisons were applied in the study and the results for the four sites are shown below. Since the different exclusive factors, such as numbers of lanes, deceleration length and the impacts by nearby on-ramps and off-ramps, would have some impacts on the study sites as well, four sites were categorized separately as four groups by comparing similar right off-ramps that have the same exclusive factors.

Southbound left exit of I-275@I-375 The left-side off-ramp of I-275@I-375 is a two-lane off-ramp with an optional lane. Four right-side off-ramps with similar geometric design and nearby location were selected. The relevant site information and crash records are listed in Table 4. These sites are defined as group 1 in the report.

Table 4 Site Information of Group 1 Off-Ramps

Exit Location	Right Exit				Left Exit
No.	1	2	3	4	1
Exit No.	1 (I-375)	22	26	28	23A
Section No.	15-002-000	15-190-000	15-190-000	15-190-000	15-190-000
Direction	N	N	S	S	S
Crash Frequency	4	3	3	0	15
AADT	122,000	93,000	135,333	123,333	84,000
Crash Rate	0.113	0.156	0.107	0	0.681
Rear-end Crash	0	2	2	0	3
Angle Crash	0	1	1	0	2
Sideswipe Crash	0	0	1	0	1
PDO Crash	1	2	3	0	10
Injury Crash	3	1	0	0	5
Fatal Crash	0	0	0	0	0

Southbound left exit of I-275@I-175 This off-ramp is also a two-lane off-ramp with an optional lane. Three right-side off-ramps with the same geometric types in adjacent areas were selected. The site information and crash records for the left and right-side off-ramps are listed in Table 5. These sites are defined as group 2 in the report.

Table 5 Site Information of Group 2 Off-Ramps

Exit Location	Right Exit			Left Exit
No.	1	2	3	1
Exit No.	22	26	28	22
Section No.	15-190-000	15-190-000	15-190-000	15-190-000
Direction	N	S	S	S
Crash Frequency	3	3	0	26
AADT	93,000	135,333	123,333	112,750
Crash Rate	0.156	0.107	0	0.639
Rear-end Crash	2	2	0	4
Angle Crash	1	1	0	3
Sideswipe Crash	0	1	0	7
PDO Crash	2	3	0	16
Injury Crash	1	0	0	10
Fatal Crash	0	0	0	0

Southbound Left Exit on Southbound I-275 at 31st Street The geometric design of the left-side off-ramp at I-275/31st St. is different from the previous two in that it has two exclusive off-ramp lanes. Five right-side off-ramps with the same geometric type were selected. The site information and crash records are listed below in Table 6. These sites are defined as group 3 in the following text.

Table 6 Site Information of Group 3 Off-Ramps

Exit Location	Right Exit					Left Exit
No.	1	2	3	4	5	1
Exit No.	39	52	1 (I-175)	30	31B	21
Section No.	10-190-0	10-320-0	15-003-0	15-190-0	15-190-0	15-190-0
Direction	S	N	NE	N	S	N
Crash Frequency	8	0	0	2	9	7
AADT	134,500	80,293	28,500	143,000	130,833	84,000
Crash Rate	0.21	0	0	0.07	0.26	0.32
Rear-end Crash	3	0	0	0	0	0
Angle Crash	2	0	0	0	2	2
Sideswipe Crash	1	0	0	1	1	1
PDO Crash	5	0	0	1	3	2
Injury Crash	3	0	0	1	6	5
Fatal Crash	0	0	0	0	0	0

Eastbound Left-side Exit on I-4 at 50th Street This left-side off-ramp is the same as the first two in that it is a two lane off-ramp with an optional lane. Three right-side off-ramps with the same geometric type were selected. The site information and crash records are listed in Table 7. These sites are defined as group 4 in the following text. Since this exit was opened on August 18th, 2006, crash data was only available for about one year and four months from that day to December 31st, 2007.

Table 7 Site Information of Group 4 Off-Ramps

Exit Location	Right Exit			Left Exit
No.	1	2	3	1
Exit No.	9	10	19	5
Section No.	10-190-000	10-190-000	10-190-000	10-190-000
Direction	W	E	E	E
Crash Frequency	3	9	9	19
AADT	124,333	124,333	104,000	10,700
Crash Rate	0.092	0.159	0.193	0.512
Rear-end Crash	1	4	4	3
Angle Crash	1	0	0	2
Sideswipe Crash	0	0	0	6
PDO Crash	2	8	6	8
Injury Crash	1	1	3	11
Fatal Crash	0	0	0	0

Crash Rate Comparison with t-Test

Figure 1 shows the average crash rates of the left and right off-ramps for all four of the site groups. As can be seen from the figure, all left-side off-ramps have much higher crashes per million vehicles miles traveled (MVMT) than the comparable right-side off-ramps.

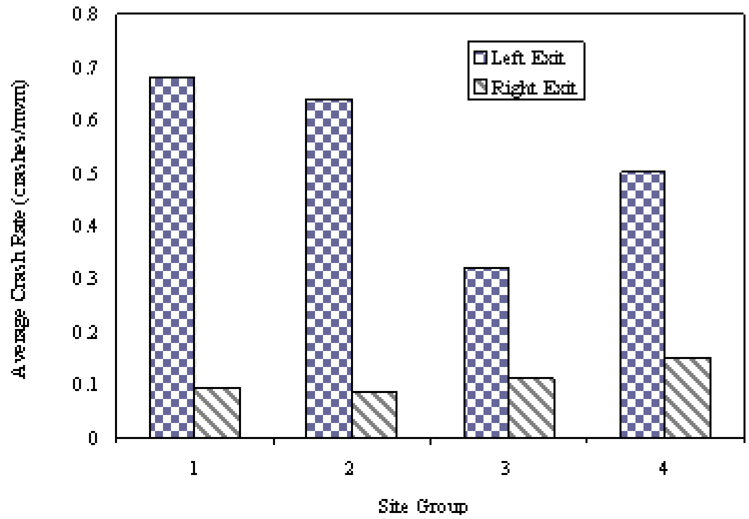


Figure 1 Average Crash Rate in Three Site Groups

A t-test was conducted to examine whether the crash rate of the left-side off-ramps is significantly different with that of the right-side off-ramps. The t-test is applied because the sample sizes are so small that using an assumption of normality and the associated z-test would lead to incorrect inferences.

The null hypothesis for the t-test is that the crash rates of the left-side and right-side off- ramps are equal. The goal of the t-test is to compare the calculated t value with the critical t value. If the calculated t value is greater than the critical t value, the null hypothesis will be rejected, and it can be concluded that the crash rates of the left-side and right-side off-ramps are unequal. The following equation can be used to calculate the t value.

$$t_{\frac{\alpha}{2}} = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{S_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{3}$$

Where $S_p = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$ is the standard deviation of the sample; n_1 and n_2 are the sample sizes of the two populations, and $\overline{X}_1$ and $\overline{X}_2$ are the population means. The degree of freedom used in this test is determined with the following equation:

$$df = \frac{(S_1^2 / n_1 + S_2^2 / n_2)^2}{\frac{(S_1^2 / n_1)^2}{n_1 - 1} + \frac{(S_2^2 / n_2)^2}{n_2 - 1}} \tag{4}$$

Table 8 lists the results of the t-test at a 95% confidence level in which crash rate represents the average crash rate per million vehicles miles traveled. The results indicate that for site groups 1, 2 and 4 the calculated t values are larger than the critical values; however, for the third site group, the calculated t value is smaller than the critical value. The results indicated that the average crash rates of left-side off-ramps at the three study sites out of the total four sites are significantly different with those of the right-side off-ramps at a 95% confidence level. In this case, it means that for left-side off-ramps their crash rates are higher than the right-side off-ramps.

Table 8 Crash Rate and t-Test Comparison

Site Group	1		2		3		4	
	Crash Rate	Sample Size	Crash Rate	Sample Size	Crash Rate	Sample Size	Crash Rate	Sample Size
Right	0.094	4	0.087	3	0.11	5	0.148	3
Left	0.681	2	0.639	2	0.32	2	0.512	2
$t_{\frac{\alpha}{2}}$	7.51		8.34		2.29		7.84	
t_C †	3.18		4.30		2.78		4.30	

† t_C refers to critical t value.

Critical Crash Rate

In order to examine whether the crash occurrence on the left-side exits is higher than the normal conditions, the critical crash rates for the left and right off-ramps in the four groups at 99.95% confidence level are computed by equation 2. Results are listed in Table 9.

Table 9 CCCR and ACR

Off-Ramp	Left-Side		Right-Side	
	CCCR*	ACR†	CCCR*	ACR†
Group 1 (I-275@I-375)	1.03	0.681	0.61	0.094
Group 2 (I-275@I175)	0.95	0.639	0.65	0.087
Group 3 (I-275@31th street)	0.89	0.320	0.74	0.110
Group 4(I-4@50th street)	1.16	0.512	1.07	0.148

* CCCR refers to Calculated Critical Crash Rate;
†ACR refers to Actual Crash Rate.

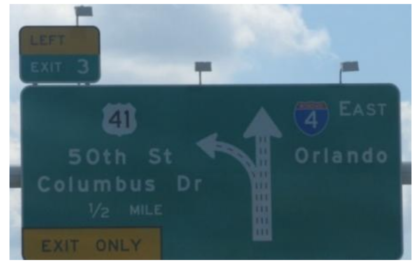
As shown in Table 9, the actual crash rates of all left and right-side off-ramps are lower than the critical crash rates. This implies that based on the critical crash rate, the crash occurrence on those left-side off- ramps are under normal conditions and no special engineering treatments or improvements are needed at this point.

Traffic Sign for Left-Side Off-Ramps

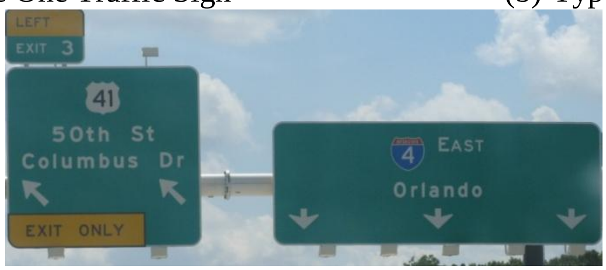
Altogether three advanced warning traffic signs were observed to direct the drivers at each of the four study left-side off-ramps. Of all these traffic signs the first two could be classified into the first type and the third could be classified into the second type. Differences between them are that the first type traffic sign illustrates the lane configuration while the second type allocates lane use on it directly.

The first type of advanced warning signs provides the information on both lane configurations and the distance to the off-ramp, as shown in Figure 2 (a) and (b). It is indicated with figures that 50th street is located on the left side of I-4; the inside two lanes are for the off-ramp movements and the outside three lanes are for through movements with the second left lane being optional lane. The distances from the traffic signs to the left-side exit, which were 1 mile and ½ mile respectively in this case, were shown in the traffic signs as well. The second type of traffic signs were installed about ¼ mile before the left-side off-ramps, as shown in Figure 2(c). It indicated with arrows that outside two lanes are for off-ramp movements and inside three lanes are for through movements with no information about optional lanes. The Yellow color was used to highlight the "EXIT ONLY".

(a) Type One Traffic Sign



(b) Type One Traffic Sign



(c) Type Two Traffic Sign

Figure 2 Traffic Sign Before Left-side Off-Ramps

For all the four left-side off-ramps the three traffic signs were observed to appear in the same sequence, and the sequence and format of the traffic signs before the left-side off-ramps complied with the requirements of Manual on Uniform Traffic Control Device (MUTCD). However, the first type of traffic sign is proposed to be replaced in new edition MUTCD where the lane configuration is to be removed. No additional pavement markings were found to be used around these four left-side off-ramp.

(a)

(b)

Figure 3 New Traffic Sign Proposed in MUTCD

CONCLUSIONS AND RECOMMENDATIONS

To evaluate the effects of off-ramp location on traffic operations and safety, the following data were collected and analyzed: traffic conflict data, speed, and crash records at the four left-side off-ramps. Both a traffic conflict study and a speed study were conducted based on the field data collected at the three study sites. A cross sectional crash comparison and safety study was also conducted for the left-side off-ramps.

Conflict study results showed that approximately 5% of vehicles were observed making lane change maneuvers on all three left-side off-ramps, among which nearly 15% were aggressive lane changes where the drivers made their last-minute lane change through the gore areas. Four types of traffic conflicts were observed. The average conflict rate near the ramp area is about 10 per 1,000 vehicles.

A t-test indicated that the crash rate for left-side exiting at three study sites is significantly greater than that for their nearby right-side off-ramps. The results of critical crash rate analysis indicated that the crash occurrences on those left-side off-ramps are under normal conditions and no special engineering treatments or improvements are recommended by this study. The study also shows that the two-lane exits with optional lanes have better safety performances than two-lane exits without optional lanes.

To reduce the number of traffic conflicts and lane change maneuvers in the left-side off-ramp area, the researchers recommend some special pavement markings and traffic signs. One suggestion is to paint some markings on the pavement with certain text such as “left exit ahead”, “left exit to XXX”, and left turn arrows. A final recommendation is to add some special characters on the existing traffic sign such as “left exit” or “left side exit”. To investigate the effectiveness of the above traffic signs and pavement markings for left-side off-ramps, further study is needed by methods such as driving simulators and driver surveying, etc. As the limited number of left-side off-ramps, the study only considered two-lane off-ramps, further study might need to consider the impact of one-lane left-side off-ramps.

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