Safety Impacts of Converting Two-Way Left-Turn Lanes to Raised Medians and Associated Design Concerns

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Raised medians and two-way left-turn lanes (TWLTLs) are the two most common types of median treatments on arterial streets. This paper aims to conduct a detailed study on the safety impacts of conversion from TWLTLs to raised medians on state roads in Florida. In addition, the study also investigated several potential safety concerns related to raised medians on state roads, including crashes at median openings, vehicles directly hitting the median curb, and median crossover crashes. Based on data availability, 17.51 miles of urban arterial sections in Florida that were converted from TWLTLs to raised medians were analyzed. Police reports of all the crashes before and after median conversion were reviewed to correct miscoded crash types and obtain additional detailed crash information. Overall, a 28.5% reduction in total crash rate was observed after the 10 study locations were converted from TWLTLs to raised medians. The reductions in the proportions of left-turn and right-turn crashes were statistically significant, while the changes in the proportions of other crash types were not statistically significant. Furthermore, the crash data did not show evidence that raised medians are an additional hazard compared with TWLTLs.

INTRODUCTION

A two-way left-turn lane (TWLTL) is a continuous lane between opposing lanes of traffic to allow traffic to make left turns from both directions, and a raised median is a physical barrier that separates opposing lanes of traffic. TWLTLs reduce left turns from through lanes, provide operational flexibility for emergency vehicles, and give unrestricted access to abutting businesses and residences. On the other hand, they do not provide a pedestrian refuge area, increase head-on crashes, and operate poorly on high-traffic arterials. Compared to TWLTLs, raised medians provide a pedestrian refuge area, reduce head-on crashes, and reduce the number of conflicting maneuvers at driveways. However, they might increase crashes at median openings and limit direct access to properties (Koepke and Levinson 1992).

The Florida Department of Transportation (FDOT 2006) has had a policy to install raised medians in most new multilane highway projects since the 1990s. It requires "all multilane projects over 40 mph in design speed to have a restrictive median, and all other multilane facilities with design speeds ≤ 40 mph to include sections of raised median for enhancing vehicular and pedestrian safety, improving traffic efficiency, and attaining the standards of the Access Management Classification of that highway system" (FDOT 2006).

This FDOT policy was based on earlier study results showing the benefits of raised medians, as compared with TWLTLs. Several studies over the past two decades documented a reduction in crash rate after arterials with TWLTLs were converted to raised medians (Maze and Plazak 1997, Gluck et al. 1999, Gattis et al. 2005, Parsonson et al. 2000, Eisele and Frawley 2005). However, results from some more recent studies (for example, Phillips 2004, Schultz et al. 2007) showed an increase in crash rates after conversion from TWLTLs to raised medians. Phillips (2004) observed a higher proportion of fatal crashes at locations with raised medians compared with their TWLTL counterparts (0.55% versus 0.20%). Squires and Parsonson (1989) concluded that TWLTLs could be safer than raised medians on six-lane arterials with few concentrated access points. They also found that the safety performance of raised medians could be overestimated because of shifting of crashes to other surrounding intersections. Hence, the safety impacts of the conversion from TWLTLs to raised medians have not been clear. This paper presents the results from a detailed study to evaluate the safety impacts of median conversion from TWLTLs to raised medians on state roads in Florida (Alluri et al. 2012). In addition, the study also investigated several potential safety concerns related to raised medians, including crashes that occur at median openings involving vehicles turning left and making U-turns, vehicles directly hitting the median curb, and median crossover crashes.

Information on how the crash had occurred is not available in the crash summary records, and could only be determined from a detailed review of police crash reports. As such, a major effort of this study was to review individual police reports of crashes that occurred before and after the median conversion. These police reports are a key to accurately determine the safety benefits of the median conversion and to investigate the safety concerns related to raised medians.

EXISTING STUDIES

In a cross-sectional study based on statewide data from Florida, Long et al. (1993) found that urban four-lane arterials with raised medians experienced a 16.8% lower crash rate compared to those installed with TWLTLs. Papayannoulis et al. (1999) analyzed 264 roadway segments from Delaware, Illinois, Michigan, New Jersey, and Wisconsin and found that, compared with undivided arterials, TWLTLs had a 20% reduction in total crash rate, while raised medians had a 40% reduction. Mauga and Kaseko (2010) used multivariate regression analysis to relate geometric and access management features to traffic safety at midblock sections and found a 23.2% reduction in crash rate for raised medians compared with TWLTLs.

Dixon et al. (1999) concluded that the performance of raised medians is excellent except at locations with significant U-turn activity. However, contradicting statements were found in the literature. Bonneson and McCoy (1998) stated that improved safety and operational performance were a function of U-turn activity at intersections. Carter et al. (2005) concluded that U-turns did not have a large negative safety effect on signalized intersections. Levinson et al. (2005) also observed similar results for unsignalized intersections (i.e., at median openings).

Levinson et al. (2005) analyzed 806 unsignalized median openings in seven states and found that the urban arterial corridors experienced an average of 0.41 U-turn-plus-left-turn crashes per median opening per year; and rural arterial corridors experienced an average of 0.20 U-turn-plus-left-turn crashes per median opening per year. Zhou et al. (2003) conducted a four-year before-and-after analysis at a location that was converted from a traditional two-way opening to a directional median opening, and the results showed a 68% reduction in crashes with no additional crashes at the nearby median U-turn opening.

Based on the review of the existing literature on the safety performance of raised medians and TWLTLs, Bonneson and McCoy (1997) found that conversion from a TWLTL to a raised median reduced total crashes by about one-third. Gluck et al. (1999) summarized the findings of 16 studies that compared crash rates at undivided locations, locations with TWLTLs, and locations with raised medians. The authors reported six studies that had a decrease in sideswipe, angle, and head-on crashes averaging to 31%, 40%, and 54%, respectively. They also reported that the percent decrease in rear-end crashes ranged from −15% to 50% with an average of 27%. Lewis (2006) and Schultz et al. (2007) conducted before-and-after analyses to evaluate the safety effectiveness of raised medians over TWLTLs, and reported mixed results. The authors concluded that raised medians did not reduce total crash rates, but reduced angle, fatal, and injury crash rates. Lewis (2006) observed that higher signal density might have contributed to an increase in rear-end crashes after median construction. More recently, Mauga and Kaseko (2010) used multivariate regression models to develop relationships between access management features and crash rates by crash severity, crash type, and total crashes. The authors concluded that the conversion from a TWLTL to a raised median resulted in a reduction in all types of crashes except single-vehicle crashes.

Parsonson et al. (1993) evaluated the safety performance of a 4.34-mile six-lane arterial section on Memorial Drive, Dekalb County, Georgia, which was converted from a TWLTL to a raised median. The improvement was estimated to have prevented about 300 crashes and about 150 injuries in a one-year period. The authors also observed a 37% and 48% reduction in total and injury crash rates, respectively. Maze and Plazak (1997) evaluated the safety effect of conversion from a TWLTL to a raised median in the cities of Ankeny and Clive in Iowa. They found that crash rates reduced by 36.5% and 41.7% in the two cities, respectively. Bonneson and McCoy (1997) criticized that these results were from studies that do not account for the regression-to-the-mean (RTM) effect and, therefore, the actual reduction in crashes could be up to 15% less depending on the analysis period and crash frequency.

Recent studies have accounted for the RTM bias by using advanced Bayesian analyses. Lyon et al. (2008) evaluated the safety effectiveness of TWLTLs based on before-and-after analysis using the empirical Bayes (EB) approach. Based on a 95% significance level, the authors concluded that reductions of at least 29%, 36%, and 19% can be expected in total, rear-end, and injury crashes, respectively, when TWLTLs are installed at rural sections. Schultz et al. (2011) used the hierarchical Bayesian approach to evaluate the safety performance of raised medians. After installing raised medians, crash frequencies of total and severe injury crashes reduced by 39% and 44%, respectively.

In summary, studies have shown different reductions and distributions by crash severities and crash types, and different correlations among the geometric characteristics of roads. These studies have often produced contradictory results, most likely due to one or more of the following reasons: high variability in crash data, variations in crash reporting thresholds, fewer number of crashes, inconsistencies in the target crash types identified for the analysis, and differences in the analytical approaches (e.g., before-and-after analysis versus cross-sectional analysis) (Bonneson and McCoy 1997).

DATA PREPARATION

This section describes the efforts undertaken to identify urban arterials where TWLTLs were converted to raised medians. It also discusses the police report review process. Police reports were reviewed to verify and correct miscoded crash types and to determine how the crash occurred from the illustrative sketches and descriptions.

Identify Study Locations

FDOT's Roadway Characteristics Inventory (RCI) database was used to identify urban arterials with raised medians that were converted from TWLTLs. Study locations were identified by comparing the segments with TWLTLs in the 2005 RCI database with the segments with raised medians in the 2010 RCI database.

A total of 2,675 segments with TWLTLs were extracted from the 2005 RCI database, and 2,597 segments with raised medians were extracted from the 2010 RCI database. The two extracted datasets were then matched based on the median change. Since many smaller segments were generated, they were aggregated into longer segments based on 2010 data. As a result, a total of 225 roadway segments that were converted from a TWLTL to a raised median were identified. Segments shorter than 200 feet and those on non-state roads were excluded. Finally, a total of 78 segments were considered for further analysis. The median construction periods of the 78 roadway segments were requested from the FDOT district offices to determine the before and after periods for analysis. Construction dates were available for 35 locations.

Locations with at least 24 months of crash data before and after the median construction were included in the before-and-after safety analysis. In addition, one month prior to the start of the construction period and three months after the end of the construction period were excluded considering potential pre-construction activities and the fact that some drivers may need time to adjust to the new treatment and resume normal travel patterns. As such, a total of 10 locations were found to have at least two years of before and after analysis periods, and were included in the before-and-after safety analysis. In addition, a total of 18 locations with at least 12 months of data after the construction of raised medians were used to evaluate potential design concerns associated with raised medians.

Review Police Reports

FDOT's Crash Analysis Reporting (CAR) system was used to identify crashes that occurred at the study locations. Since the police reports were available only from January 2003 to December 2010, only the locations with a construction period between February 2005 and September 2008 were included in the before-and-after analysis. Also, when available, a maximum of 36 months of crash data before and after construction were used. Based on these criteria, 10 locations were selected for before-and-after analysis. Police reports of crashes that occurred at these 10 locations were downloaded from the Hummingbird web system hosted on FDOT's Intranet. Based on the illustrations and descriptions available in the police reports, the correct crash type was recorded and used in the analysis.

Overall, crash type was corrected for 18.7% of the crashes. Table 1 gives the distribution of the coded and corrected crash type for the most common crash types. For example, it shows that police officers identified 676 angle crashes in the reports. However, through review of the illustrative sketches and descriptions in the police reports, only 402 were identified as having been correctly coded as angle crashes, while the remaining 274 crashes should have been coded as head-on (3), left-turn (183), median crossover (4), rear-end (22), right-turn (33), and sideswipe (29). Similarly, police officers had coded 100 head-on crashes. However, only 25 were correctly coded as head-on, while the remaining 75 were actually angle (20), left-turn (15), median crossover (3), rear-end (35), and right-turn (2). After all the crash types were corrected, for example, there were a total of 560 angle crashes (instead of 676), including 402 (or 71.8%) that were correctly coded and 158 (or 28.2%) that were corrected.

Table 1: Distribution of the Coded and Corrected Crash Type

		Crash Type Coded in Police reports							Total Crashes **WITH** Corrected Crash Type	Percent Corrected
		Angle	Head-On	Left-Turn	Median Crossover	Rear End	Right-Turn	Side-swipe		
Corrected Crash Type	Angle	402	20	38	-	37	5	58	560	28.2%
	Head-On	3	25	-	-	-	-	-	28	10.7%
	Left-Turn	183	15	334	-	4	-	21	557	40.0%
	Median Crossover	4	3	1	7	2	-	2	19	63.2%
	Rear-End	22	35	1	-	1,486	1	12	1,557	4.6%
	Right-Turn	33	2	-	-	10	45	17	107	57.9%
	Sideswipe	29	-	6	-	6	2	189	232	18.5%
Total Crashes **WITHOUT** Corrected Crash Type		676	100	380	7	1,545	53	299	3,060	18.7%

Table 1 also shows that 63.2% of the median crossover crashes were coded incorrectly, followed by right-turn and left-turn crashes at 57.9% and 40.0%, respectively. Of the 107 right-turn crashes, 33 were incorrectly coded by police officers as angle crashes. Similarly, 183 of 557 left-turn crashes were incorrectly coded as angle crashes. Likewise, 7 of 19 median crossover crashes were incorrectly coded as either angle or head-on crashes.

BEFORE-AND-AFTER ANALYSIS

This section discusses the results from the before-and-after analysis conducted based on crash type, crash severity, and facility type. Table 2 provides the summary statistics by study location. The table also provides the crash rates for both the before and after periods. Equation (1) gives the formula used to calculate crash rate in crashes per million vehicle miles traveled.

$$(1)\quad Crash\ Rate = \frac{Total\ Crashes \times 10^6}{AADT \times Segment\ Length \times Analysis\ Period\ in\ Years}$$

Table 2: Summary Statistics by Study Location

S No.	Roadway ID	Segment Length (mi)	No. of Lanes	Posted Speed Limit	Before				After				Percent Change in Crash Rate
					Period[a]	No. of Crashes	Mean AADT	Crash Rate[b]	Period[a]	No. of Crashes	Mean AADT	Crash Rate[b]	
1[c,d]	93130000	0.290	4	35	36	15	18,340	2.576	30	15	18,887	3.001	17%
2[d]	58010000	0.260	2	55	19	5	11,560	2.879	35	13	10,454	4.493	56%
3[d]	94010000	0.910	4	40	36	86	38,930	2.217	15	26	34,154	1.834	-17%
4[d]	36004000	0.314	4	35	36	24	36,625	1.906	17	3	23,000	0.803	-58%
5[c,d]	2030000	0.252	6	45	36	21	31,524	2.414	36	1	27,500	0.132	-95%
6[c,d]	10030000	0.295	6	45	36	98	57,020	5.321	32	30	49,850	2.096	-61%
7[c,d]	10030000	0.485	6	45	36	152	56,424	5.073	32	74	51,101	3.068	-40%
8[c,d]	10030000	0.480	6	45	36	103	50,301	3.896	32	55	45,473	2.589	-34%
9[c,d]	17040000	3.584	6	45	36	331	50,239	1.679	36	251	46,992	1.361	-19%
10[c,d]	48070000	0.524	6	35	27	71	35,690	4.623	36	62	39,516	2.734	-41%
11[c,d]	55002000	0.948	6	45	32	204	27,093	8.160	36	85	26,224	3.122	-62%
12[c,d]	55060000	1.019	4	45	26	40	31,725	1.565	36	111	27,234	3.653	134%
13[c,d]	55080000	1.517	4	45	24	144	31,394	4.142	36	158	29,889	3.182	-23%
14[d]	75003000	2.417	6	45	36	832	54,338	5.785	22	351	49,732	4.364	-25%
15[d]	75010000	1.357	6	50	14	95	49,100	3.348	36	160	48,638	2.214	-34%
16[d]	87030000	1.204	4	35	21	145	43,200	4.364	36	135	44,985	2.276	-48%
17[d]	87090000	1.268	6	40	21	115	51,787	2.742	36	181	53,163	2.452	-11%
18[d]	72014000	0.388	4	35	14	37	50,122	4.468	36	93	50,925	4.298	-4%

[a] Analysis period is in months.
[b] Crash rate is in crashes per million vehicle miles traveled (MVM).
[c] Location is included in before-and-after analysis.
[d] Location is included in evaluating the design concerns associated with raised medians.

An observational before-and-after evaluation study discussed in the Highway Safety Manual (HSM) was used to assess whether the construction of raised medians resulted in a shift in the frequency of a specific crash type as a proportion of total crashes. Consistent with the HSM, the Wilcoxon Signed Rank test was used to assess whether or not the conversion from TWLTLs to raised medians resulted in a shift in the frequency of each specific crash type and crash severity level as a proportion of total crashes (American Association of State Highways and Transportation Officials [AASHTO] 2010).

It is noted here that only the simple before-and-after method is needed in this study, as TWLTLs on state roads in Florida have been systematically converted to raised medians based on FDOT policy (FDOT 2006). In other words, the locations used in this study were not subject to the RTM bias as they were not selected for median conversion based on high crash experience.

Crash Type

Table 3 gives the before-and-after study results by crash type. The reductions in the proportions of left-turn and right-turn crashes were statistically significant at 89.4% confidence level. The changes in the proportions of the other crash types, namely, head-on, rear-end, angle, side-swipe, and pedestrian crashes, were not statistically significant. Before-and-after crash statistics on median crossover crashes were not provided as the analysis does not yield meaningful results. Very few crashes in the before period were coded as "median crossovers" because of the absence of a median (i.e., a physical barrier) in the before period.

Overall, the total crash rate across all 10 locations reduced from 3.04 crashes per million vehicle miles traveled to 2.18 crashes per million vehicle miles traveled after median conversion, representing a 28.5% reduction. A reduction in crash rate was observed for all the major crash types, including head-on, rear-end, angle, left-turn, right-turn, sideswipe, and pedestrian crashes. The pedestrian crash rate statistics must be interpreted with caution as pedestrian exposure was not considered while calculating pedestrian crash rate.

Table 3: Summary Statistics by Crash Type

Crash Type	Before Period			After Period			Percent Change in Crash Rate	Is the Change in Proportion of Crashes Statistically Significant?[d]
	Crash Freq.[a]	Crash Rate[b]	Proportion of Crashes[c]	Crash Freq.[a]	Crash Rate[b]	Proportion of Crashes[c]		
Head-On	0.32	0.02	0.007	0.14	0.01	0.005	-49.9%	No (90.6%)
Rear-End	17.80	1.15	0.379	13.22	0.94	0.433	-18.2%	No (90.2%)
Angle	7.25	0.47	0.15	5.00	0.36	0.16	-24.1%	No (89.4%)
Left-Turn	9.68	0.63	0.206	3.58	0.26	0.118	-59.2%	Yes (89.4%)
Right-Turn	1.95	0.13	0.042	0.80	0.06	0.026	-55.0%	Yes (89.4%)
Sideswipe	2.75	0.18	0.059	1.92	0.14	0.063	-23.1%	No (90.2%)
Pedestrian	1.08	0.07[e]	0.023	0.83	0.06[e]	0.027	-14.7%	No (90.2%)
Total[f]	46.95	3.04	1.000	30.49	2.18	1.000	-28.5%	Not Applicable

[a] Crash frequency is in crashes per mile per year.
[b] Crash rate is in crashes per million vehicle miles traveled.
[c] Proportion of observed crashes of a specific target collision type is calculated relative to total crashes across the entire analysis period.
[d] Wilcoxon signed rank test was used to determine whether or not the shifts in proportions for target collision types were statistically significant. The percentage in parentheses gives the confidence level.
[e] Pedestrian exposure was not taken into consideration while calculating pedestrian crash rate.
[f] Total crashes include all crash types.

Crash Severity

Table 4 gives the before-and-after study results by crash severity. A reduction in the proportion of property damage only (PDO) crashes and an increase in the proportion of injury crashes were observed after raised median conversion; however, these results were not statistically significant. In terms of crash rate, a reduction in crash rate after raised median conversion was observed at both PDO and injury crash severity levels. PDO crash rate had the largest reduction (35.1%) while injury crash rate had the smallest reduction (22.1%).

Table 4: Summary Statistics by Crash Severity

Crash Severity	Before Period			After Period			Percent Change in Crash Rate	Is the Change in Proportion of Crashes Statistically Significant?[d]
	Crash Freq.[a]	Crash Rate[b]	Proportion of Crashes[c]	Crash Freq.[a]	Crash Rate[b]	Proportion of Crashes[c]		
PDO	23.78	1.54	0.51	13.98	1.00	0.46	-35.1%	No (89.4%)
Injury	22.94	1.49	0.49	16.26	1.16	0.53	-22.1%	No (89.4%)
Fatal	0.24	0.02	0.01	0.25	0.02	0.01	0.0%	No (89.0%)
Fatal and Injury	23.18	1.50	0.49	16.51	1.18	0.54	-21.3%	No (89.4%)
Total[e]	46.95	3.04	1.00	30.49	2.18	1.00	-28.3%	Not Applicable

[a] Crash frequency is in crashes per mile per year.
[b] Crash rate is in crashes per million vehicle miles traveled.
[c] Proportion of observed crashes of a specific target collision type is calculated relative to total crashes across the entire analysis period.
[d] Wilcoxon signed rank test was used to determine whether or not the shifts in proportions for target collision types were statistically significant. The percentage in parentheses gives the confidence level.
[e] Total crashes include all crash types.

Facility Type

A total of 2.826 miles of four-lane urban arterials and 6.568 miles of six-lane urban arterials were converted from TWLTLs to raised medians. Of the 10 study locations, three are four-lane urban arterials, while the remaining seven are six-lane arterials. Table 5 gives crash summary statistics by crash type and crash severity at four-lane and six-lane facilities. Again, the observational before-and-after study considering the shift of proportions was performed to determine if the proportion of crashes after the median construction was significantly different from the proportion of crashes before the median construction for each crash type and severity level for both four-lane and six-lane facilities. Wilcoxon Signed Rank test was conducted to determine whether or not the shifts in proportions for target collision types were statistically significant. Note that this test was not conducted for four-lane facilities since only three four-lane facilities were analyzed, and the sample size is too small to perform the test. None of the shifts in crash proportions on six-lane facilities were found to be statistically significant except left-turn crashes.

After the conversion from TWLTLs to raised medians, six-lane arterials experienced a 39.3% reduction in total crash rate while four-lane arterials experienced an 11% increase in total crash rate. On six-lane sections, a reduction in crash rate was observed in all major crash types, namely, head-on, rear-end, angle, left-turn, right-turn, sideswipe, and pedestrian crashes. On the other hand, four-lane arterials yielded mixed results as a reduction was observed in left-turn, right-turn, and sideswipe crash rates, and an increase was observed in rear-end, angle, and pedestrian crash rates. In terms of crash severity, six-lane arterials experienced reductions in both PDO and injury crash rates, and no change in fatal crash rates, while four-lane sections experienced reductions in PDO and fatal crash rates, and an increase in injury crash rate.

Table 5: Summary Crash Statistics at Four-Lane and Six-Lane Urban Arterials

	Four-Lane Facility								Six-Lane Facility							
	Before Period			After Period			Percent Change in Crash Rate	Is the Change in Prop. of Crashes Stat. Sig.?[d]	Before Period			After Period			Percent Change in Crash Rate	Is the Change in Prop. of Crashes Stat. Sig.?[d]
	Crash Freq.[a]	Crash Rate[b]	Prop. of Crashes[c]	Crash Freq.[a]	Crash Rate[b]	Prop. of Crashes[c]			Crash Freq.[a]	Crash Rate[b]	Prop. of Crashes[c]	Crash Freq.[a]	Crash Rate[b]	Prop. of Crashes[c]		
Crash Type																
Head-On	0.00	0.00	0.00	0.12	0.01	0.00	--	--[e]	0.42	0.02	0.01	0.16	0.01	0.01	-50.0%	No (87.6%)
Rear-End	10.31	0.95	0.32	16.45	1.61	0.48	69.5%	--[e]	20.21	1.20	0.39	11.83	0.76	0.41	-36.7%	No (90.2%)
Angle	4.26	0.39	0.13	5.76	0.56	0.17	43.6%	--[e]	8.21	0.49	0.16	4.67	0.30	0.16	-38.8%	No (89.0%)
Left-Turn	6.06	0.56	0.19	3.60	0.35	0.11	-37.5%	--[e]	10.84	0.64	0.21	3.58	0.23	0.12	-64.1%	Yes (89.0%)
Right-Turn	1.96	0.18	0.06	0.48	0.05	0.01	-72.2%	--[e]	1.95	0.12	0.04	0.93	0.06	0.03	-50.0%	No (89.0%)
Side swipe	1.80	0.17	0.06	0.96	0.09	0.03	-47.1%	--[e]	3.05	0.18	0.06	2.33	0.15	0.08	-16.7%	No (89.0%)
Ped.	0.33	0.03[f]	0.01	0.60	0.06[f]	0.02	100.0%	--[e]	1.32	0.08[f]	0.03	0.93	0.06[f]	0.03	-25.0%	No (90.6%)
Total[g]	32.57	3.01	1.00	34.09	3.34	1.00	11.0%	NA[j]	51.58	3.05	1.00	28.94	1.85	1.00	-39.3%	NA[j]
Crash Severity																
PDO	15.38	1.42	0.47	14.17	1.39	0.42	-2.1%	--[e]	26.47	1.57	0.51	13.90	0.89	0.48	-43.3%	No (89.0%)
Injury	17.02	1.57	0.52	19.81	1.94	0.58	23.6%	--[e]	24.84	1.47	0.48	14.73	0.94	0.51	-36.1%	No (89.0%)
Fatal	0.16	0.02	0.01	0.12	0.01	0.00	-50.0%	--[e]	0.26	0.02	0.01	0.31	0.02	0.01	0.0%	No (87.6%)
F+I[h]	17.18	1.59	0.53	19.93	1.95	0.58	22.6%	--[e]	25.11	1.49	0.49	15.04	0.96	0.52	-35.6%	No (89.0%)
Total[i]	32.57	3.01	1.00	34.09	3.34	1.00	11.0%	NA[j]	51.58	3.05	1.00	28.94	1.85	1.00	-39.3%	NA[j]

a Crash frequency is in crashes per mile per year; b crash rate is in crashes per million vehicle miles traveled; c proportion of observed crashes of a specific target collision type is calculated relative to total crashes across the entire analysis period; d Wilcoxon signed rank test was used to determine whether or not the shifts in proportions for target collision types were statistically significant. The percentage in parentheses gives the confidence level; e sample size is too small to conduct the Wilcoxon signed rank test; f pedestrian exposure was not taken into consideration while calculating pedestrian crash rate; g total crashes includes all crash types; h fatal and injury; i total crashes is the sum of PDO, injury, and fatal crashes; j not applicable.

EVALUATION OF SAFETY CONCERNS

This section focuses on the following three potential safety concerns related to raised medians: crashes that occur at median openings involving vehicles turning left and making U-turns, vehicles that hit the median curb, and median crossover crashes.

Crashes at Median Openings

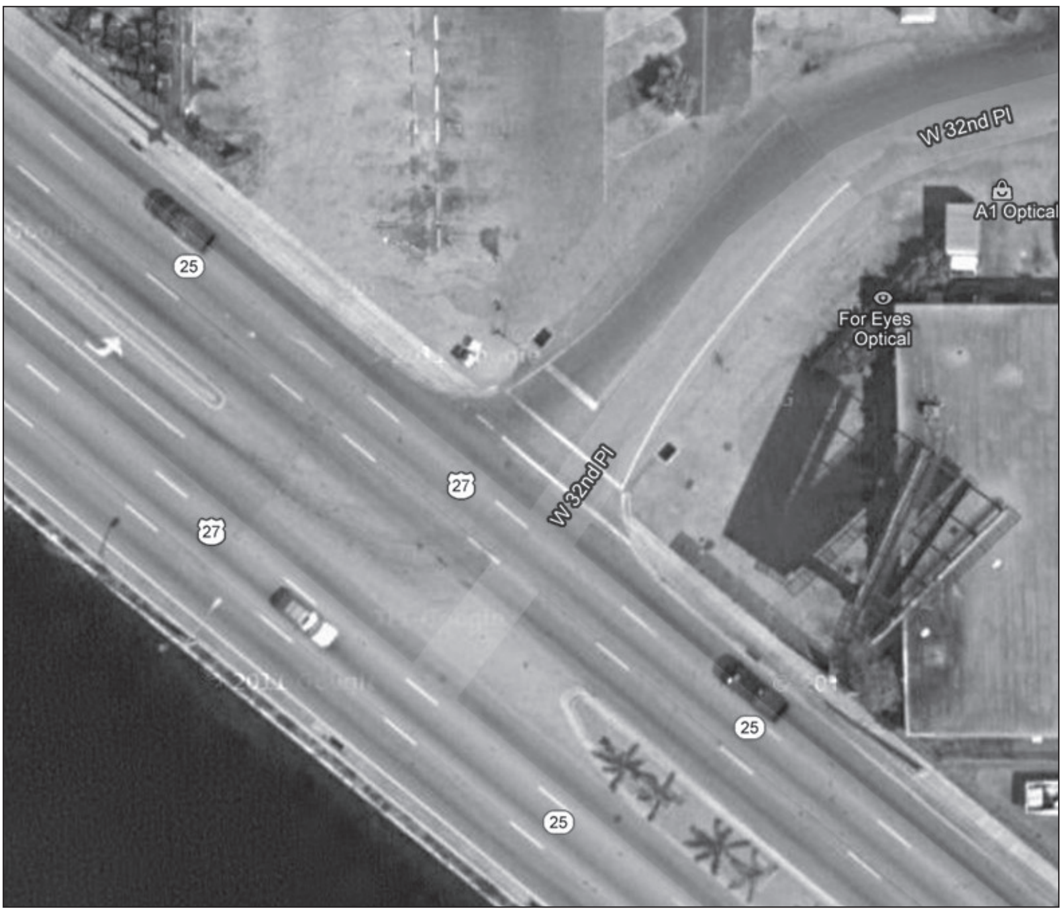
The 18 study locations have the following four types of median openings, as shown in Figures 1 through 4, respectively: uni-directional median opening (Figure 1), bi-directional median opening with center island (Figure 2), full median opening with left-turn bays in both directions (Figure 3), and full median opening with left-turn bay in one direction (Figure 4).

Figure 1: Uni-directional Median Opening

Figure 2: Bi-directional Median Opening with Center Island

Figure 3: Full Median Opening with Left-turn Bays in Both Directions

Figure 4: Full Median Opening with Left-turn Bay in One Direction



For each location, crashes that occurred at median openings after the location was converted from a TWLTL to a raised median were identified by reviewing police reports, and only those that could be attributed directly to the median opening were included in this analysis. For example, crashes involving vehicles making a U-turn or left-turn at median openings and crashes involving vehicles making a left turn from a side street were identified as median opening related crashes. Table 6 gives the crash rates at four-lane and six-lane facilities by median opening types. In this table, for each facility type, crash rate was calculated as the number of crashes related to median openings per exposure [as shown in Equation (2)], where exposure is the total number of median openings multiplied by the number of years from conversion date to December 2010.

$$(2)\quad Crash\ Rate = \frac{(Total\ \#\, of\ median - opening - related\ crashes)}{(Total\ \#\ of\ median\ openings \times Analysis\ period\ in\ years)}$$

Table 6: Crash Rates at Median Openings by Opening Type and Roadway Facility

Median Opening Type	Four-Lane Facility			Six-Lane Facility		
	No. of Crashes	No. of Median Openings	Crash Rate[a]	No. of Crashes	No. of Median Openings	Crash Rate[a]
Uni-directional median opening	3	8	**0.114**	13	14	**0.273**
Bi-directional median opening with center island	3	5	**0.182**	30	14	**0.630**
Full median opening with left-turn bay in one direction	7	5	**0.424**	14	3	**1.373**
Full median opening with left-turn bays in both directions	14	5	**0.848**	43	5	**2.529**

[a] Crash rate is in median opening related crashes/median opening/year.

In total, 5.54 miles of four-lane urban arterials have 23 median openings, and 11.72 miles of six-lane urban arterials have 36 median openings. A uni-directional median opening on a four-lane facility was found to be the safest alternative for left-turning movements with a crash rate of 0.114 median opening related crashes/median opening/year. Not surprisingly, among the four median opening types, a full median opening with left-turn bays in both directions was the least safe alternative for left-turning movements. For a four-lane facility, the crash rate at this median opening type (0.848 median opening related crashes/median opening/year) is over seven times the crash rate at a uni-directional median opening (0.114 median opening related crashes/median opening/year). Among the three other types of median openings, a bi-directional median opening with center island was found to be the safest alternative for left-turning movements. Crash rates at median openings on four-lane and six-lane facilities were found to have a similar pattern.

In summary, the crash data show evidence that at both four-lane and six-lane facilities, uni-directional median openings provide a relatively safe alternative for left-turning movements. At locations where bi-directional/full median opening is warranted, a bi-directional median opening with center island has fewer median opening related crashes.

Vehicles Hitting the Median Curb

On roadways with TWLTLs, errant vehicles have the opportunity to regain control before hitting an obstacle or an oncoming vehicle. However, raised medians often do not provide enough lateral clearance for errant vehicles. Therefore, one of the safety concerns of constructing raised medians is the frequency of vehicles that directly hit the median curb before stopping or resulting in secondary crashes primarily involving vehicles in opposite travel lanes.

Of the 2,436 crashes that occurred at the 18 locations from median construction December 2010, 48 (2.0%) involved vehicles directly hitting a median curb. Of these 48, 26 (54.2%) were PDOs while the remaining 22 (45.8%) resulted in an injury; there were no fatal crashes. When drug/alcohol involvement was examined, 39 (81.2%) did not involve alcohol/drugs while nine (18.8%) involved driving under influence (DUI). Table 7 gives summary statistics by crash location and crash severity at four-lane and six-lane facilities. About one-third of these crashes (31.3%) occurred near signalized intersections and the rest occurred at midblock locations. Compared with four-lane facilities, a slightly lower percentage of these crashes occurred at mid-block locations on six-lane facilities. In terms of crash severity, four-lane urban arterials experienced a higher percentage of injury crashes compared with six-lane facilities (67% vs. 41%). From these crash statistics, it is evident that those involving vehicles hitting a raised median were more severe on four-lane facilities.

Table 7: Crash Statistics of Vehicles Hitting the Raised Median Curb

	Four-lane Facilities		Six-lane Facilities		Total	
	No. of Crashes	**Percent of Crashes**	**No. of Crashes**	**Percent of Crashes**	**No. of Crashes**	**Percent of Crashes**
Crash Location						
Signalized Intersection	2	22%	13	33%	15	31%
Midblock Location	7	78%	26	67%	33	69%
All Locations	**9**	**100%**	**39**	**100%**	**48**	**100%**
Crash Severity						
PDO	3	33%	23	59%	26	54%
Injury	6	67%	16	41%	22	46%
Fatal	0	0%	0	0%	0	0%
Total	**9**	**100%**	**39**	**100%**	**48**	**100%**

Median Crossover Crashes

A median crossover crash occurs if an errant vehicle crosses a raised median and reaches an opposite travel lane at any point during a crash. Although crash reports have a code for "median crossovers" based on the first harmful event, not all crashes where the vehicle crossed over a median are identified as "median crossovers." For example, a crash involving a vehicle hitting a pedestrian and then crossing over a median is categorized as a pedestrian crash. Although it is a pedestrian crash, it also resulted in the vehicle crossing over the median. Such crashes were identified by reviewing the illustrative sketches and descriptions in the police reports. This approach is considered to be conservative as it includes analyzing all the crashes where an errant vehicle crossed a raised median at any point during a crash.

Of the 2,436 crashes that occurred at the 18 locations after median conversion through December 2010, 38 (1.6%) resulted in median crossovers. Of these 38, none were fatal crashes, 20 (52.6%) were PDOs and the rest (47.4%) resulted in injury crashes. Table 8 summarizes the statistics about median crossover crashes by crash location and crash severity at four-lane and six-lane facilities. It can be inferred from Table 8 that median crossover crashes at four-lane facilities are slightly more severe compared with similar crashes at six-lane facilities.

Table 8: Crash Statistics of Median Crossover Crashes

	Four-lane Facilities		Six-lane Facilities		Total	
	No. of Crashes	Percent of Crashes	No. of Crashes	Percent of Crashes	No. of Crashes	Percent of Crashes
Crash Location						
Signalized Intersection	5	36%	7	29%	12	32%
Midblock Location	9	64%	17	71%	26	68%
Total	**14**	**100%**	**24**	**100%**	**38**	**100%**
Crash Severity						
PDO	6	43%	14	58%	20	53%
Injury	8	57%	10	42%	18	47%
Fatal	0	0%	0	0%	0	0%
Total	**14**	**100%**	**24**	**100%**	**38**	**100%**

CONCLUSIONS AND RECOMMENDATIONS

A before-and-after safety evaluation was conducted at 10 urban arterial sections on Florida's state roads that were converted from TWLTLs to raised medians. Illustrative sketches in police reports were reviewed to flag sites where significant changes were made to roadway characteristics besides constructing raised medians. From these reports, no location was found to have significant changes besides constructing raised medians. However, additional resurfacing, restoration, and rehabilitation improvements that possibly were made at these locations could not be identified from the police reports. As such, the results presented in this study do not take into consideration other cross sectional attributes that might have been improved while the locations were converted from TWLTLs to raised medians.

The before-and-after analysis focused on the shift in crash proportions and changes in crash rates before and after conversion by crash type and crash severity. The Wilcoxon Signed Rank test was performed on the proportion of crashes before and after the construction of raised medians for different crash types and crash severity levels. Overall, a 28.5% reduction in total crash rate was observed after the 10 study locations were converted from TWLTLs to raised medians. The reductions in the proportions of left-turn and right-turn crashes were statistically significant at 89.4% confidence level, while the changes in the proportions of other crash types were not statistically significant. No statistically significant reduction was observed after median construction in the shifts in the proportion of any crash severity type (i.e., PDO crashes, injury crashes, fatal crashes, and fatal and injury crashes). On six-lane arterials, the shifts in proportions of all the crash types and crash severity levels, except left-turn crashes, were found to be statistically insignificant.

The safety performance of four types of median openings was evaluated at four-lane and six-lane facilities. Among the four types of median openings, a uni-directional median opening was found to be the safest alternative for left-turning movements, and a full median opening with left-turn bays in both directions was the least safe alternative for left-turning movements. Among the bi-directional/full median openings, a bi-directional median opening with center island was considered to be the safest alternative for left-turning movements.

In regard to vehicles hitting the curb, of the 2,436 crashes that occurred at the 18 locations after median conversion, only about 2.0% involved vehicles directly hitting the median curb. A majority of these crashes were not severe, therefore, it could be concluded that vehicles hitting the curb is not a serious safety concern. Also, of the 2,436 crashes that occurred after median conversion, 1.6% involved vehicles crossing over the median. Again, a majority of these crashes were not severe. Compared with six-lane facilities, a higher percentage of crashes involving vehicles hitting a raised median on four-lane facilities resulted in injuries (67% on four-lane facilities vs. 41% on six-lane facilities). In summary, it is concluded that crashes involving vehicles hitting a curb and median crossovers are not a serious safety concern. The crash data did not show evidence that raised medians are an additional hazard compared with TWLTLs.

Although before-and-after safety studies evaluate the safety performance of roadway enhancements by comparing the crash experience before and after the implementation, they are often limited by sample size. Fewer locations often limit the extent of stratification of the study locations. This limitation could be overcome by conducting cross-sectional safety studies with larger sample sizes. In the future, cross-sectional safety studies should be conducted to evaluate the safety benefits of TWLTLs and raised medians. These studies should also analyze locations based on several roadway and geometric features such as land use, number of lanes, and speed limit.

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