TECH**BRIEF**

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

www.fhwa.dot.gov/research

Safety Evaluation of Restricted Crossing U-Turn Intersection

FHWA Publication No.: FHWA-HRT-17-083

FHWA Contact: Roya Amjadi, HRDS-20, (202) 493-3383, roya.amjadi@dot.gov

This document is a technical summary of the Federal Highway Administration report *Development of a Crash Modification Factor for Signalized RCUTs* (FHWA-HRT-17-082).

Objective

The Federal Highway Administration (FHWA) established the Development of Crash Modification Factors (DCMF) program to address highway safety research needs for evaluating new and innovative safety strategies (improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. The ultimate goal of the DCMF program is to save lives by identifying new safety strategies that effectively reduce crashes and to promote those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit–cost (B/C) ratios through research. State transportation departments and other transportation agencies need objective measures for safety effectiveness and B/C ratios before investing in new strategies for statewide safety improvements. Forty State transportation departments provided technical feedback on safety improvements to the DCMF program and implemented new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study, which functions under the DCMF program.

This research examined the safety impacts of replacing a traditional signalized intersection with a signalized restricted crossing U-turn intersection (RCUT). An RCUT is defined as a three-approach or four-approach intersection where minor street left-turn and through movements (if any) are rerouted to one-way downstream U-turn crossovers. The objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. The primary measures examined were based on total crashes and fatal and injury crashes. A further objective was to conduct a spatial patterns analysis, assessing notable clusters of crashes, as well as changes to crash types and day/night between the before and after periods.

While there are theoretical reasons that support the relative safety benefits of RCUTs as compared to conventional intersections, it is also possible that certain RCUT elements could diminish or negate these benefits. For example, signalized RCUTs involve a greater number of signals and require that some users travel longer overall distances. There is no known completed research on the safety of signalized RCUTs.

Introduction

RCUTs are also known as superstreets, J-turns, reduced conflict intersections, and synchronized streets. Ten States have installed more than 50 RCUTs since the late 1980s.[1] At least five States have installed signalized RCUTs—those at which the major street crossover(s) and U-turn crossover(s) are under the control of traffic signals. Studies have shown RCUTs to have advantages over traditional intersections in terms of travel time and delay, signal progression, pedestrian crossing, and transit service.

A literature review revealed that few research studies have focused on the safety effectiveness of RCUTs and none have focused on signalized RCUTs. The first of three studies analyzing the safety effects of RCUTs at unsignalized intersections found that at 13 rural sites in North Carolina, stop-controlled RCUTs replacing two-way stop-control intersections led to a reduction in total crashes between 27 and 74 percent, depending on the analysis method employed.[2] The number of fatal and injury, angle, and left-turn crashes decreased substantially with conversion to the RCUT design, while the number of sideswipe, rear end, and other crashes decreased slightly or increased. The second study, using nine sites in Maryland similar to those in North Carolina (with the exception of merge lanes and yield-control), found a 44-percent decrease in total crashes.[3] The third study found that stop-controlled RCUTs reduced total crashes by 35 percent and injury crashes by 54 percent in five rural sites in Missouri.[4]

Methodology

This research examined the safety impacts of replacing traditional signalized intersections with signalized RCUTs. The objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. The primary measures examined were based on total crashes and fatal and injury crashes. A further objective was to conduct a spatial pattern analysis, to assess notable clusters of crashes, as well as to identify changes to crash types and day/night between the before and after periods.

The project team derived a B/C ratio to evaluate the overall effectiveness. The evaluation of overall effectiveness included the consideration of the installation costs as well as benefits, characterized as crash savings (if any) and an estimate of the travel time savings experienced by motorists using the RCUT.

The project team selected the before-after analysis with comparison sites methodology for this evaluation. The method accounts for simultaneous event biases, which the project team thought to be the most threatening potential bias to the evaluation. Simultaneous event biases that could have been important include the recession of the late 2000s and development in the area of the study sites.

To account for simultaneous event biases, the project team used comparison sites as described by Hauer.[5] The team identified four potential comparison sites for each treatment site. Potential comparison sites were large surface street intersections (to ensure adequate sample sizes) near the treatment site (to ensure that the same events occurred at both places). Aerial photographs were reviewed to ensure the sites did not undergo any discernable treatment during the study period.

An empirical Bayes methodology was unnecessary in this case, because regression to the mean was not a serious threat to the validity of the analysis. The treatment sites were not chosen on the basis of any type of hazardous site identification process. Instead, the agencies selected the sites for RCUT installation primarily to relieve congestion. The project team collected data from 11 treatment sites in 4 States: Alabama, North Carolina, Ohio, and Texas. The treatment sites were all in suburban areas, on four-lane or six-lane divided arterials, and characterized by high-speed traffic and minimal crossing pedestrians.

The full report includes a detailed explanation of the methodology, including a description of how the estimate of safety effects for target crashes was calculated.

Results

The results for all crashes using comparison sites to adjust for potential simultaneous event biases are shown in table 1. Eight sites had crash modification factor (CMF) values less than 1.0, and three sites had CMF values greater than 1.0. For nine sites, the CMF estimate was more than one standard deviation away from 1.0. The group results showed CMF values less than 1.0. The CMF for all sites was 0.85 with a standard deviation of 0.16, so the CMF was less than one standard deviation away from 1.0 (i.e., the CMF is not statistically significant at the 95-percent confidence level).

Table 2 shows the results from the analysis of injury crashes using comparison sites. Note that some of the crash counts for groups of comparison sites do not match the sums of the component individual sites because comparison site data were not double counted. The CMF values were much like those in the previous table of results, with eight sites having CMF values less than 1.0 and three sites having CMF values greater than 1.0. The CMF for all sites, 0.78, was lower than that for all crashes. This result suggests signalized RCUTs may have a larger positive effect on injury crashes than on property damage only crashes. The CMF for injury crashes at all sites was greater than one standard deviation from a value of 1.0.

Table 1. Results from comparison site analysis of each site and groups of sites.

Site	Before-Period Treatment Crashes	Before-Period Comp. Crashes	After-Period Treatment Crashes	After-Period Comp. Crashes	Var{w}	CMF	Std. Dev. of CMF
AL-Plum	168	228	40	104	0.0055	0.51	0.11
AL-Retail	44	253	3	97	0.0055	0.17	0.10
NC	200	232	159	264	0.075	0.64	0.18
OH-Symmes	113	194	70	78	0.0055	1.49	0.31
OH-Tylersville	104	129	24	50	0.0055	0.57	0.16
OH-Hamilton-Mason	80	79	9	17	0.02	0.47	0.20
TX-Evans	103	69	325	175	0.0055	1.20	0.23
TX-Stone Oak	42	53	169	168	0.0055	1.20	0.28
TX- New Guibeau	103	158	62	185	0.0055	0.50	0.10
TX- Shaenfield	81	37	82	49	0.0055	0.72	0.19
TX-71	156	93	16	23	0.0055	0.39	0.13
All AL	212	481	43	201	0.029	0.44	0.11
All OH	297	396	103	199	0.0055	0.98	0.16
All TX	485	410	654	600	0.022	0.88	0.15
AL, NC, and OH	709	1,109	305	664	0.011	0.71	0.09
All	1,194	1,519	959	1,264	0.036	0.85	0.16

Std. Dev. = standard deviation; AL = Alabama; NC = North Carolina; OH = Ohio; TX = Texas.

Table 2. Results from comparison site analysis of sites and groups of sites for injury crashes.

Site	Before-Period Treatment Crashes	Before-Period Comp. Crashes	After-Period Treatment Crashes	After-Period Comp. Crashes	Var{w}	CMF	Std. Dev. of CMF
AL-Plum	25	28	6	13	0.0055	0.45	0.22
AL-Retail	8	15	1	6	0.0055	0.23	0.20
NC	91	39	33	32	0.0055	0.41	0.12
OH-Symmes	48	28	31	8	0.0055	1.90	0.75
OH-Tylersville	35	83	9	32	0.0055	0.62	0.25
OH-Hamilton-Mason	22	58	3	32	0.0055	0.22	0.13
TX-Evans	29	21	116	60	0.0055	1.27	0.39
TX-Stone Oak	17	20	61	56	0.0055	1.13	0.39
TX- New Guibeau	40	31	17	32	0.0055	0.38	0.13
TX- Shaenfield	27	16	27	28	0.0055	0.50	0.19
TX-71	71	18	11	7	0.0055	0.33	0.15
All AL	33	28	7	13	0.0055	0.41	0.19
All OH	105	169	43	72	0.0055	1.06	0.25
All TX	184	106	232	183	0.0055	0.88	0.15
AL, NC, and OH	229	236	83	117	0.0055	0.63	0.11
All	413	357	315	306	0.068	0.78	0.20

Std. Dev. = standard deviation; AL = Alabama; NC = North Carolina; OH = Ohio; TX = Texas.

Spatial Patterns

The crash data obtained for this evaluation specified location well enough to allow for a spatial patterns analysis. Notable clusters of crashes included the following:

- AL-Plum: Clusters of rear-end crashes southbound on the major street.
- NC: Large clusters of rear-end crashes in both directions of the major street.
- OH-Symmes: A cluster of rear-end crashes northbound on the major street and a cluster of rear-end crashes eastbound on the minor street.
- OH-Tylersville: Smaller clusters of rear-end and sideswipe crashes in both directions on the major street.
- TX-Evans: Large clusters of rear-end crashes in both directions of the major street; a cluster of sideswipe crashes northbound on the major street; and a cluster of crashes involving northbound left-turn vehicles.
- TX-Stone Oak: Large clusters of rear-end crashes on the major street southbound.
- TX-New Guibeau: Clusters of rear-end crashes northbound on the major street, on the side with the stem of the T-intersection.
- TX-Shaenfield site: Clusters of rear-end crashes in both directions on the major street; notable clusters of sideswipe and fixed object crashes southbound

on the major street on the side with the stem of the T-intersection.

Thus, with a few exceptions, the crash data mostly showed clusters of rear-end crashes occurring at the RCUT sites. These patterns are somewhat different from those seen at typical conventional intersections, which would tend to feature more prominent clusters of turning and angle crashes.

Other Variables

The collected data allowed for examination of other variables besides severity and location. Several important changes occurred at sites between the before and after periods, including the following:

- AL-Plum: The crash type changed drastically, from 68.5 percent "right rear angle" crashes in the before period to 52.5 percent "rear-end center" in the after period.
- AL-Plum: The percentage of daylight crashes decreased from 74.4 to 60.
- AL-Plum: The percentage of crashes in the rain decreased from 20.2 to 7.5.
- NC: The percentage of "left-turn, same roadway" crashes decreased from 29 to 10.7.
- OH-Symmes: The percentage of fixed-object crashes increased from 0 to 10.
- OH-Symmes: The percentage of wet crashes increased from 32.7 to 45.7.
- OH-Tylersville: The percentage of angle crashes decreased from 15.4 to 4.2.
- OH-Tylersville: The percentage of wet crashes decreased from 26 to 12.5.
- TX-Evans: The percentage of "same direction, both going straight, rear-end" crashes increased from 11.7 to 22.8.
- TX-Evans: The percentage of "dark, no light" crashes decreased from 15.5 to 4.9.
- TX-New Guibeau: The percentage of "same direction, both going straight, sideswipe" crashes increased from 2.9 to 16.1, while the percentage of "same direction, one straight, one stopped" crashes decreased from 57.3 to 38.7.
- TX-Shaenfield: The percentage of "same direction, both going straight, sideswipe" crashes increased from 2.5 to 19.5, while the percentage of "same direction, one straight, one stopped" crashes decreased from 60.5 to 24.4.
- TX-Shaenfield: The percentage of "dark, lighted" crashes increased from 13.6 to 29.3.

The most prominent changes with RCUT installation appear to be decreases in angle crashes and increases in sideswipe crashes.

Economic Analysis

For the purposes of the economic analysis, the assumed treatment is the installation of a signalized RCUT. The property damage only crash CMF was 0.85, equivalent to the total crash CMF in table 1. The injury and fatal crash CMF was 0.78, per table 2. The costs included construction of the RCUT and maintenance of the extra traffic signals required by the RCUT. The project team obtained installation costs for 9 of the 11 installation sites, which resulted in an average $354,000 annualized construction cost. When added to the annual maintenance cost for three extra signals at $15,000, this yielded a total annualized RCUT cost of $369,000. The service life is 20 years for RCUTs, like other intersection improvements.[6]

Benefits included fewer crashes and shorter travel times. The project team assumed the following for computing operational benefits:

- On average, the RCUT major street carries 52,000 vehicles per day.
- On average, the RCUT minor street carries 10,000 vehicles per day.
- There is no traffic growth during the analysis period.
- Thirty percent of daily traffic occurs during the four peak hours of the day.
- The RCUT saves 20 seconds per vehicle during the 4 peak hours of the day and has no net operational effect at other times of the day, in line with previous estimates of the effects of signalized RCUTs.[1]
- Time savings are valued at $15 per hour, in line with typical economic analyses.
- There are 250 working days per year that experience time savings.

The project team assumed the following costs for computing the safety-based benefits:

- The property damage only crash cost in 2014 was $18,000.[7,8]
- The injury and fatal crash cost in 2014 was $384,000.[7,8]

For benefits, using several of the assumptions above, the project team estimated the operations to save 103 hours of motorist time per work day, which equates to $388,000 per year. The safety benefit was a savings of 3.0 property-damage-only crashes per year and 2.3 injury and fatal crashes per year, which results in an annual monetary savings of $948,000.

The B/C ratio was 2.6:1 considering the safety benefits only and 3.6:1 considering the safety and operational benefits. With the U.S. Department of Transportation recommended sensitivity analysis, this value could range from 1.5:1 to 3.6:1 considering the safety benefits only and 2.5:1 to 4.7:1 considering safety and operational benefits.[8]

Summary and Conclusions

The objective of this study was to undertake a rigorous before–after evaluation of the safety effectiveness, as measured by crash frequency, of signalized RCUTs. For most individual sites and groups of sites examined, odds ratio tests showed there were high-quality comparison sites available, which enhanced the strength of the analyses. Therefore, this evaluation determined the following as the best general estimates of CMFs (and their corresponding crash reduction factors (CRFs)) for conversion of a conventional intersection to an RCUT intersection:

- Overall crashes: CMF = 0.85 (CRF = 15 percent).
- Injury crashes: CMF = 0.78 (CRF = 22 percent).

The standard deviations of the CMFs were 0.16 and 0.20, respectively. This indicates that the CMF for overall crashes was not significantly different from a neutral value of 1.0.

At the individual site level of analysis, 8 of the 11 sites showed decreases in overall and injury crashes after RCUT installation. The three sites with increases (OH-Symmes, TX-Evans, and TX-Stone Oak) were the only treatment sites with three lanes on both minor street approaches. The only other treatment sites with three lanes on minor street approaches were TX-Shaenfield, a T-intersection, and the other two Ohio sites with three lanes on one minor street approach and two lanes on the other minor street approach. Therefore, it is likely that signalized RCUTs may be relatively safer when the minor streets are narrower and/or carry lower traffic volumes.

There were clusters of rear-end crashes on the major streets of the RCUTs. An examination of crash types before and after RCUT installation showed there was generally a conversion from angle crashes to sideswipe crashes.

The evaluation also produced an estimated B/C ratio for installing an RCUT at the set of test intersections of 3.6 to 1.0 when considering safety and operations, or 2.6 to 1.0 considering safety only. When examining the sensitivity of this result to changes in crash costs, the B/C ratio always exceeded 1.0. Installing signalized RCUT intersections at locations similar to those studied should generally lead to positive results in terms of expected crash reductions.

References

1. Hummer, J.E., Ray, B., Daleiden, A., Jenior, P., and Knudsen, J. (2014). *Restricted Crossing U-Turn Intersection Informational Guide*, Report No. FHWA-SA-14-070, Federal Highway Administration, Washington, DC.
2. Hummer, J., Haley, R., Ott, S., Foyle, R., and Cunningham, C. (2010). *Superstreet Benefits and Capacities*, Report No. FHWA/NC/2009-06, North Carolina Department of Transportation, Raleigh, NC.
3. Inman, V. and Haas, R. (2012). *Field Evaluation of a Restricted Crossing U-turn Intersection, Final Report*, Report No. FHWA-HRT-11-067, Federal Highway Administration, Washington, DC.
4. Edara, P., Sun, C., and Breslow, S. (2013). *Evaluation of J-turn Intersection Design Performance in Missouri*, Report No. 25-1121-0003-179, Research and Innovative Technology Administration, Washington, DC.
5. Hauer, E. (1997). *Observational Before-After Studies in Road Safety*, Pergamon Press Oxford, England, UK.
6. Donnell, E. (2014). *Development of a CMF for Continuous Green T Intersections*, Report No. FHWA-HRT-16-036, Federal Highway Administration, Washington, DC.
7. Council, F., Zaloshnja, E., Miller, T., and Persaud, B. (2005). *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries*, Report No. FHWA-HRT05-051, Federal Highway Administration, Washington, DC.
8. USDOT. (2014). *Guidance on Treatment of the Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses–2014 adjustment*, Memorandum, U.S. Department of Transportation, Washington, DC. Available online: http://www.dot.gov/ sites/dot.gov/ files/docs/VSL_Guidance_2014. pdf, last accessed July 24, 2017.

Researchers—Joseph E. Hummer and Sathish Rao.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Divisions and Resource Center.

Availability—This TechBrief may be obtained from the FHWA Product Distribution Center by email to report.center@dot.gov, fax to (814) 239-2156, phone to (814) 239-1160, or online at http://www.fhwa.dot.gov/research.

Key Words—RCUT, Restricted-Crossing U-Turn, Superstreet, J-Turn, Synchronized Street, Signalized, Safety, CMF.

NOVEMBER 2017 FHWA-HRT-17-083
HRDS-20/11-17(200)E