TECHBRIEF

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Developing Crash Modification Factors for Mini-Roundabouts

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This document is a technical summary of the Federal Highway Administration report *Developing Crash Modification Factors for Mini-Roundabouts* (FHWA-HRT-23-019).

INTRODUCTION

The Federal Highway Administration's (FHWA) Development of Crash Modification Factors (DCMF) Program was established in 2012 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. Forty-one State departments of transportation 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 (ELCSI-PFS), which functions under the DCMF Program.

The ELCSI-PFS Technical Advisory Committee selected the evaluation of mini-roundabout (MR) installations as one of the priorities within its purview. MRs are small-diameter roundabouts (50- to 90-ft radii) with traversable islands (central island and splitter islands). As a particular type of roundabout, MRs are expected to improve traffic operations with minimal impact on capacity and reduce the frequency and severity of crashes, most likely by curbing right-angle crashes, which are typical at stop-controlled and signalized intersections. Previous studies indicated the operational benefits of MRs by demonstrating that conversion from intersections controlled by all-way stop-control (AWSC) or two-way stop-control (TWSC) improved intersection operating efficiency and reduced congestion levels (Zhang 2012, 2015). However, a study in South Australia found a 62-percent drop in the 85th percentile speeds through intersections converted to MRs (Zito and Taylor 1996). Only a few studies have assessed the safety effectiveness of MRs based on crash data, most of which were conducted outside of the United States. Some before–after studies on MRs converted from TWSC indicated a crash reduction of roughly 30–79 percent (Green 1977; Lalani 1975; Delbosc et al. 2017).

A before–after safety evaluation study based on actual crash data in the United States was challenging because of the limited number of crashes at MR locations converted from different types of intersection controls (e.g., AWSC, TWSC), a situation that hinders developing reliable crash modification factors (CMFs) for MRs. This TechBrief describes the methods and results from an FHWA-sponsored study that evaluated the safety benefits of MR installations at TWSC and AWSC locations based on crash data obtained from multiple MR locations in the United States.

Study Objective

The objective of this study was to assess the safety effectiveness of MR installations based on crash data and develop statistically valid CMFs. The research team studied CMFs of MR locations converted from both TWSC and AWSC and developed separate CMFs for converted MRs from both for various crash types, including total, fatal and injury (FI), property damage only (PDO), multivehicle total (MV_Total), multivehicle FI (MV_FI), and multivehicle PDO (MV_PDO). In addition, the researcher provided benefit–cost (B/C) ratios for the MR installations. Practitioners can use these CMFs and B/C ratios for decisionmaking in their project development and safety planning processes.

METHODOLOGY

To compensate for the small number of MR locations and insufficient crash data available in the United States, the researchers used a stronger quasi-experimental study design that included comparison sites, namely an interrupted time series design with comparison groups (ITS-CG), and enhanced statistical analysis methods, including fully Bayesian (FB) analysis and generalized linear mixed models (GLMM). The database included three States: Washington, Michigan, and Maryland.

Data

Locations of interest included sites with MR installations with known installation dates, entering volumes in excess of 800 vehicles per hour, and potentially low speed applications. The research team used geographic information systems (GIS) tools to prepare, filter, and combine data from multiple sources and geolocations (typically in shapefile format) (Esri 2019). The research team then located nearby sites with the potential to be used as comparison sites. This potential was judged based on the roadway characteristics (rural or urban), surrounding land use (residential, commercial, or industrial), facility type (major or minor arterial/collector), number of lanes in the main road, and relative proximity to each MR site. After reviewing all candidate sites, the research team selected a set of three comparison sites per MR site, and geometry variables were collected for each study location (both MR and comparison). Table 1 shows the number of MR and comparison sites in each of the three States studied. After data filtering and assembly, the study included 15 MR locations from Washington, 6 from Michigan, and 6 from Maryland. Crash data from 2003 through 2019 were available from Washington, data from 2013 through 2019 from Michigan, and data from 2015 through 2019 from Maryland.

Table 1. Number of MR and comparison sites in three States.

	Treatment (MR) Sites			Comparison Sites	
State	TWSC	AWSC	Unclear	TWSC	AWSC
Washington	9	0	6	35	12
Michigan	0	6	0	0	17
Maryland	3	3	0	9	9

To compile annual average daily traffic (AADT) data for all sites (including those located in lower functional classes) and periods (almost 20 yr at some of the sites due to different dates of MR installation) in the study, the research team performed AADT data extraction using AADT maps and GIS layers available from various sources online (Maryland Department of Transportation (DOT) 2022; King County 2022; Michigan DOT 2022) to obtain the needed AADT figures. The research team imputed the missing AADT values when imputation was feasible from a trend (i.e., for sites with more than 1 yr of AADT available, or for locations where other nearby locations had sufficient AADT data available).

The research team collected other site characteristics that could be used as additional covariates in the analysis. These characteristics included land use, proximity to school zones, the presence of a bus stop, bike lanes, crosswalks, median type, and signs and markings, among others. Most of the MRs and comparison sites were located in urban and residential areas; some were located in commercial and mixed land use areas.

Safety Analysis

The empirical analyses in this study were conducted using the statistical methods appropriate to the characteristics of the assembled datasets. Two different analyses were performed: FB analysis of crash frequencies using before–after designs with comparison groups and GLMM for panel data using the multistate dataset developed in this research. The FB analysis was applied to the Washington data for developing CMFs for MRs converted from TWSC, and GLMM analysis was applied to a larger dataset consisting of three States (Washington, Michigan, and Maryland) for MR conversions from both AWSC and TWSC.

FB Analysis of Before–After Data with Comparison Groups Based on Washington Data

A safety evaluation due to limited study locations could benefit from the incorporation of existing knowledge about safety performance of roundabout and stop-controlled intersections into the evaluation. This strategy was considered for the FB analyses to obtain more precise CMF estimates. The FB analyses for the Washington data were conducted based on the crash data for 2003–2019 obtained from nine MR locations (with TWSC as the intersection type before conversion) for the following crash types: total, FI, PDO, MV_Total, MV_FI, and MV_PDO. The treatment group for MR with TWSC as the before condition in Washington consisted of yearly crashes from intersections where MRs were installed during 2012, 2013, 2014, 2016, 2017, and 2019. The team fitted a Poisson-gamma mixture model that included appropriate indicator functions for site type (specifying whether a segment is a treatment site or a comparison site) and period (specifying whether the site belongs to the before- or the after-installation period), as well as the time trend for each site type and other covariates to yearly crash data. Exposure was accounted for by a log of major approach AADT and a log of minor approach AADT. Additionally, the researchers included the following variables as model covariates:

- Number of approaches.
- PedCross01—Whether there is a pedestrian crossing sign: 1 = yes; 0 = no.
- SchoolZone01—Whether there is a school zone within 250 ft: 1 = yes; 0 = no.
- diag1—Length of the first diagonal in feet.
- diag2—Length of the second diagonal in feet.
- Speed limit on the major approaches.

To address the issue of the small sample size, the research team used an informative prior distribution derived based on the CMFs for roundabouts provided on the CMF Clearinghouse website (FHWA 2022) and on previous studies (Kennedy, Hall, and Barnard 1998; Green 1977; Walker and Pitnam 1989; Lalani 1975; Ibrahim and Metcalfe 1993) on MRs in the FB analysis. For the prior distributions of the other regression coefficients, however, proper but diffuse priors were used to reflect the lack of precise knowledge on the parameters a priori. The inferences on the parameters of interest were made based on the samples from the posterior distribution obtained by the Markov chain Monte Carlo algorithm.

GLMM Analysis for MR Conversions Based on Washington, Michigan, and Maryland Data

The research team conducted safety evaluations of MR in the multistate panel data. An explicit account for the longitudinal structure and comparison groups was used to assess the change in crash frequency at MR installations, given the prior traffic control types at those locations.

The research team performed a panel analysis that included all data from TWSC and AWSC conversions and the corresponding comparison sites. The response variables in these analyses were the same as presented in the FB analysis. The research team developed overlap propensity score weights so the analysis results would be indicative of the overlap population between the treated and comparison sites.

RESULTS

Safety Effectiveness

Table 2 contains the summary of the results from the FB analysis for the MRs converted from TWSC for six types of crashes based on the Washington data. The table shows the estimated CMFs and the associated uncertainty estimates (standard deviation (Std Dev)), 95-percent

Table 2. CMFs for MRs converted from TWSC for different crash types.

CMFs	Total	FI	PDO	MV_Total	MV_FI	MV_PDO
TWSC CMF	**0.6330****	**0.5773***	**0.5977****	**0.6802***	0.5980	**0.6389***
Std Dev	0.1512	0.2114	0.1462	0.1621	0.2328	0.1610
95% credible interval	(0.3807, 0.9713)	(0.2616, 1.0672)	(0.3540, 0.9341)	(0.4073, 1.0458)	(0.2556, 1.1408)	(0.3648, 1.0109)
90% credible interval	(0.4157, 0.8956)	(0.3019, 0.9577)	(0.3884, 0.8623)	(0.4422, 0.9698)	(0.2966, 1.0174)	(0.4091, 0.921)
Crash reduction (percent)	**36.70****	**42.27***	**40.23****	**31.98***	40.20	**36.11***

**Statistically significant results at 90-percent level.*
***Statistically significant results at 95-percent level.*
Note: Std Dev represents the posterior Std Dev (uncertainty estimate) for CMF.

credible intervals, and 90-percent credible intervals, as well as the percent crash reduction estimates. The results indicate that there were statistically significant reductions in total, FI, PDO, MV_Total, and MV_PDO crashes after conversion to MRs from TWSC intersections. Reductions for total and PDO crashes were statistically significant with 95-percent probability, and reductions for FI, MV_Total, and MV_PDO crashes were significant with 90-percent probability.

GLMM Analysis for MR Conversions Based on Washington, Michigan, and Maryland Data

Table 3 contains the summary of the results from the FB analysis for the MRs converted from AWSC for six types of crashes based on the multistate data. Only one estimated CMF was found to be statistically significant (MV_Total). The CMFs for other crash types and severities, however, would all suggest crash reductions, but the uncertainties of the CMFs do not provide statistical significance.

Economic Effectiveness

The research team estimated MR installation costs based on various sources. A Transportation Research Board webinar showed a range of MR installations in Michigan for 2017 between $840,000 and $900,000 (Gillum 2017). According to another source, the installation cost for the MRs ranges between $250,000 and $465,000 in Texas (Melton and Shumard 2019). Finally, according to a 2010 FHWA technical summary, MR construction costs are widely dependent on the extent of modification to the location necessary for the conversion, as well as the materials used in the construction (Rodegerdts, Scarbrough, and Bansen 2010). The cost estimates offered in 2010 by the FHWA technical summary ranged from $50,000 up to $250,000. For the economic evaluation, the research team adopted the value of $300,000 in 2020 to represent a national average.

Economic Effectiveness of MR Installation at TWSC

The safety benefit of MR installation is derived from the estimated reductions in total crash frequency for TWSC conversions (table 2). A statistical life value of $11.6 million is the most current value used by the U.S. Department of Transportation (Putnam and Coes 2021). The total yearly benefit (safety only) for MR installation at TWSC locations was estimated as $86,290 in 2020 dollars. In contrast, the 2020 conservative cost of construction was estimated as $300,000. For a useful life of 10 yr and no salvage value at the end of that period, the B/C ratio for the MR installation is estimated as 2.88.

Economic Effectiveness of MR Installation at AWSC

The safety benefit of AWSC conversion was estimated as the monetary value of reduction in MV_Total crash frequencies for AWSC conversions (table 3). The total yearly benefits (safety and operational combined) for MR installation at AWSC locations was estimated as $402,423 in 2020 dollars, whereas the safety-only benefit was $86,074, similar to the benefit of TWSC intersections. Using the same 2020 cost of construction estimate ($300,000) and a useful life of 10 yr with no salvage value at the end of that period, the B/C ratio for the MR installation at AWSC locations was estimated as 13.41 when both safety and operations benefits are considered. The B/C ratio was 2.87 when only safety benefits were considered.

CONCLUSIONS

The focus of this study was to perform rigorous safety-effectiveness evaluations of MR installations at TWSC and AWSC locations and to develop statistically valid CMFs along with uncertainty estimates. The safety data for these evaluations were compiled for locations of

Table 3. CMFs for MRs converted from AWSC based on the multistate data.

Crash Type	Estimate	Standard Error	*z* Value	*p* Value	Significance
Total	0.8813	−0.1263	0.1852	0.4952	—
FI	0.5746	−0.5541	0.4157	0.1825	—
PDO	0.8393	−0.1751	0.1990	0.3788	—
MV_Total	0.6080	−0.4976	0.2455	0.0427	*
MV_FI	0.5422	−0.6122	0.4072	0.1327	—
MV_PDO	0.7710	−0.2600	0.2105	0.2168	—

—Not applicable.
**Significant at the 95.0-percent confidence level.*

known MR installations around the United States where the month of installation and prior intersection condition were known. A set of suitable comparison locations corresponding to the MR locations was also identified to allow the analyses to control for extraneous variables. Additionally, geometric features were collected for analysis, as well as AADT where available. Model-based AADT imputation was performed at locations where AADT was partially available and enough for that task. The study database included three States (Washington, Michigan, and Maryland) and had a longitudinal design, including comparison sites, which allowed ITS-CG evaluations and a general panel data evaluation.

The analyses were performed using FB analysis of before–after (ITS) crash frequency data with comparison groups (CG) and binomial GLMMs for the panel multistate data. The FB analyses for ITS-CG evaluations were carried out based on the Washington crash data for MR conversions from TWSC. Crash reductions ranging from 31 up to 42 percent were estimated for total, FI, PDO, MV_Total, MV_FI, and MV_PDO crash types from these analyses. The CMFs for MR converted from TWSC intersections were statistically significant for total, FI, PDO, MV_Total, and MV_PDO crashes. ITS-CG evaluations were also performed on a multistate dataset, but this effort produced only one statistically significant CMF for MV_Total crashes for AWSC conversions (0.61 CMF, or a 39-percent crash reduction).

Finally, the research team performed an economic analysis of MR conversions from either AWSC or TWSC. Considering both the safety and operational benefits of MR installations from AWSC, this analysis produced a B/C ratio of 13.41, whereas the B/C ratios were 2.88 and 2.87 for AWSC and TWSC conversions, respectively, when only safety benefits were considered. These results indicate the economic feasibility of MR installations.

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