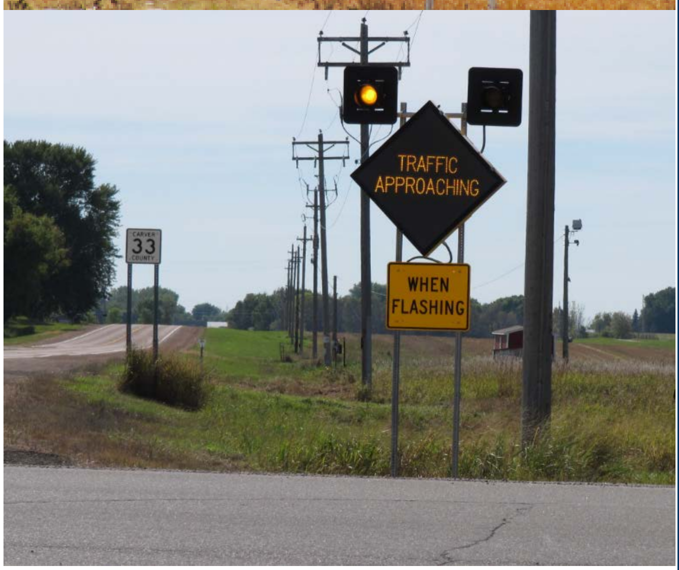


Independent Technical Review of RICWS Evaluation

Minnesota DOT Traffic Safety Evaluation

May 20, 2019

This page intentionally left blank.

Independent Technical Review of RICWS Evaluation

Minnesota DOT Traffic Safety Evaluation

Prepared For:

Minnesota Department of Transportation

Prepared by:

HDR

May 2, 2019

This page intentionally left blank.

Contents

Tables

Figures

Cover Photographs courtesy of Minnesota Department of Transportation

This page intentionally left blank

Introduction

The Minnesota Department of Transportation (MnDOT) has deployed Rural Intersection Control Warning System (RICWS) devices throughout Minnesota for safety improvement. RICWS is designed to reduce conflicts at rural, thru-stop intersections. The system typically consists of signs and flashing lights alerting motorists on the major and minor approaches of “entering” and “approaching” traffic.

MnDOT conducted a before-after safety evaluation to estimate the effectiveness of RICWS at reducing crash frequency using comparison groups. The study unexpectedly revealed that there is no statistically significant evidence that RICWS is effective in mitigating crashes relative to the control groups. An independent technical review of the RICWS evaluation was conducted by HDR to assess the methodological approach applied by MnDOT and to identify if there is need for additional research and improvements.

HDR compiled and reviewed information provided by MnDOT to develop an understanding of the scope and approach to the analysis, analysis methods, and outcomes. The following three areas that may have contributed to the unexpected RICWS study outcomes were investigated:

1. the appropriateness of the statistical approach used for the analysis;
2. the quality and accuracy of the analytical data used for conducting statistical modelling; and,
3. how well the selected control sites corresponded to the RICWS test sites.

The technical report concludes with a summary of the findings and recommendations on how the RICWS evaluation could be improved.

Data Files Reviewed

A summary of all of the files for review provided by MnDOT is presented in Table 1. These files and how they were used will be referenced throughout the report.

Table 1: List of Files Supplied by MnDOT

File	Description
List of RICWS and Control Sites.xlsx	Table that lists information for each RICWS and Control site including the MnDOT district, county, major road, minor road, turn-on date, intersection configuration, etc.
Control_Crashes-Intersection Specific.xlsx	Data file that includes worksheets *2006-15 Crashes* and *2016-18 Crashes* that display all respective control site crash data over 2006 to 2015 and 2016 to 2018.
RICWS_Crashes-Intersection Specific.xlsx	Data file that includes worksheets *2006-15 Crashes* and *2016-18 Crashes* that display all respective RICWS site crash data over 2006 to 2015 and 2016 to 2018.
Sample RICWS & Control Site Data.xlsx	Data file that includes all crash data for five RICWS sites and five control sites over the 2006 to 2018 period
CrashCodes.xlsx	Table that lists the values and names for each crash code displayed in the crash files.

File	Description
Control AADT.xlsx	Data file that provides the given and interpolated AADT for all control sites over the 2006 to 2018 period and the route location information.
RICWS AADT.xlsx	Data file that provides the given and interpolated AADT for all RICWS sites over the 2006 to 2018 period and the route location information.
Data Analysis1.xlsx	The analytical data file used to conduct the statistical analysis of the RICWS evaluation. Includes three worksheets: *Stats Data*, *3 Yrs Before* and *Data Dictionary*.
Data Analysis - Regression1.xlsx	Data file used for multiple regression analysis.
Test-For-Fit_POISSON.xlsx	Workbook that displays the Poisson goodness of fit results in *POISSON – Goodness of Fit* and the data used for the Poisson regression in *YCrash*.
DSP - TEMPLATE_FINAL.xlsx	Tables of the data collection templates for the District Safety Plans for rural sections, rural curves, rural intersections, urban sections, urban intersections, and intersection data.
Copy of Maintenance Log 20160728.xlsx	Table of all recorded RICWS maintenance issues.
Analysis Explanation.docx	Document that explains the statistical methods used and displays the SPSS outcomes of the statistical tests.
Control Location Selection.docx	Document that describes how the control sites were selected and matched to their associated RICWS sites.

Overview of RICWS Evaluation

The MnDOT applied the "before-after analysis using a comparison group and no safety performance function" evaluation method referenced in the *Master Evaluation Plan* to measure the safety effectiveness of RICWS. If RICWS is effective, then the average differences in crash rates and densities before (B_t) and after (A_t) RICWS is expected to be less than the average differences in crash rates and densities at the control sites:

$$(A_t - B_t) < (A_c - B_c).$$

The study consists of 142 intersections, 66 with RICWS devices, and 76 control sites with no RICWS devices. Control intersections were chosen to correspond with each of the provided RICWS sites as seen in Table A-1 of Appendix A. MnDOT's Basemap and District Safety Plan Database were used to help choose control locations. These control locations were selected based on the following criteria:

- Proximity to RICWS site
- Similar AADT volumes for major and minor legs
- Similar risk factors (near a railroad crossing, on/near a curve, in a development, percent skew, previous stop)
- Same route number (i.e. TH 23)
- Same number of legs and intersection configuration (divided/undivided)

The control locations from a previous study done by CH2MHILL were matched up with RICWS sites, with the exception of ten sites. Most of the sites found a good match based on the criteria described above; however, there were ten sites that were not a close match to the RICWS sites. These sites were matched (doubled-up) to RICWS sites based on radial proximity, but were not always a good match of the RICWS site. For this reason, there are 76 control sites when there are only 66 RICWS sites.

The *Data Analysis1.xlsx* file includes the analytical dataset built for conducting the statistical analysis. The number of crashes and traffic volumes were tracked for each site before and after RICWS was installed. The before period commenced in January 2006 until the turn-on date of the RICWS site. The after period commenced on the turn-on date of the RICWS site until the end of March 2018. The site-specific before and after number of crashes, years, and volumes were used to compute the before and after crash densities and rates given by:

$$Density = \frac{\#\ of\ crashes}{\#\ of\ site\ years},$$

$$Crash\ Rate = \frac{\#\ of\ crashes * 1{,}000{,}000}{Volume}.$$

HDR reviewed the document *Analysis Explanation.docx* from MnDOT. This document provided a description of the dependent variables tested for changing means and medians before and after RICWS turn-on date per site. MnDOT explored analyses using ordinary least squares (OLS) regression where the dependent variable of total crashes was regressed on site characteristics. OLS techniques are applicable when all of the assumptions of the model are met such as no serial correlation, homoscedasticity[1], and normality[2] of the model errors. The document indicated that the OLS approach may not be appropriate because the normality of model errors assumption was violated.

Non-parametric statistical methods, which make no assumptions regarding the underlying distribution of the data, such as the Mann-Whitney and Wilcoxon test statistics were used to indicate whether or not different categories of crash densities or rates changed during the study period. MnDOT applied its statistical approach using all crash data tracked since January 2006 to the RICWS turn-on dates, and then from the turn-on dates until March 2018, and then repeated its approach with crash data only being tracked three years prior to the RICWS turn-on dates, and then until March 2018.

The SPSS[3] outputs from the non-parametric and OLS models are provided in the document *Analysis Explanation.docx.* The MnDOT results summarized in the SPSS output showed that there was no evidence of changing rates or densities before and after RICWS turn-on dates.

Review of Statistical Approach

As a first step to its statistical review, HDR investigated whether parametric tests would be suitable provided the data could be properly transformed. When statistical assumptions are met,

[1] The error terms have the same variance in each observation.
[2] The error terms follow a normal distribution.
[3] IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

parametric tests have more power to detect smaller differences between studied populations with statistical significance.

HDR used SPSS for data investigations, preparation, and analyses. HDR set up the data so that it can be run for analysis in SPSS. The data from the file *Data Analysis1.xlsx,* sheet *Stats Data* is in matrix format with each site belonging to a single row and each before and after response displayed in separate columns. HDR converted the data from the wide matrix format into the long panel format so that each site has a row of data for each before and after period and the response columns are not differentiated by time period. Separate indicators or dummy variables were created to flag whether a site was a test site or not (TX), and whether the crash tracking period was after turn-on date versus before (TIMEPERIOD). The interaction variable (RICWS_POST) between these two indicators would then capture the effect of RICWS before and after turn-on dates relative to before and after turn-on dates from the control sites.

As this was a technical independent review to demonstrate if parametric methods would be more appropriate to detect RICWS impacts over time, HDR only explored total density and crash rates as dependent variables from the file *Data Analysis1.xlsx*. The dependent and independent variables used by HDR are as follows:

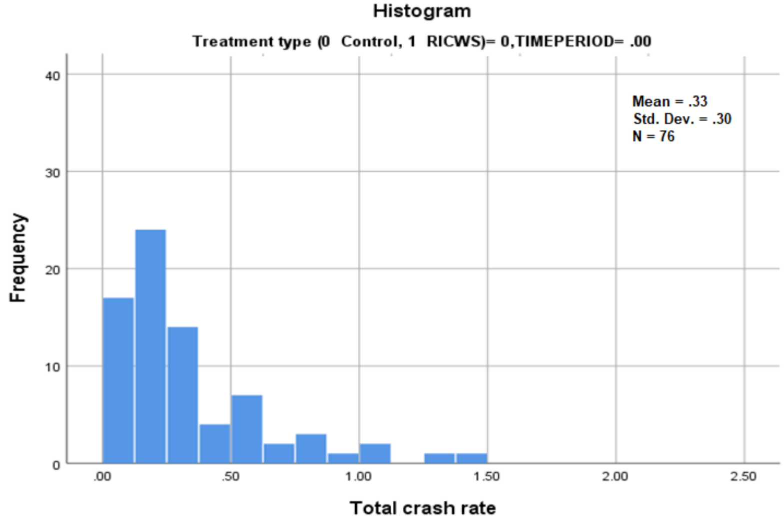
DENS: Density
RATE: Total crash rate
TX: Type of intersection type (0=control, 1=test)
TIMEPERIOD: Study period (0=data tracked from Jan 2006 to day before turn-on day, 1=turn-on day to March 2018)
RICWS_POST=TX*TIMEPERIOD
YRS: Number of years prior/after turn-on (from Jan 2006 to day before turn-on day, turn-on day to March 2018)
VOL: Volume (Jan 2006 to day before turn-on day, turn-on day to March 2018)
NUM_LEGS = Number of legs (3 = T-intersection, 4 = 4-legged intersection)
NUM_LANE = Number of lanes (2 = one lane each way undivided, 4 = two lanes each way divided)
CURVE: Located on or near a curve (0 no, 1 yes)
RR_XING : Located near a railroad crossing (0 no, 1 yes)
SKEW: Is the intersection at a skew? (0 no, 1 yes)
AMT_SKEW: The degree of skew of the intersection
DVLPMNT = Is the intersection located in a development (0 = no, 1 = yes)
SPEED_LIMIT = Speed limit of the major road
LIGHTING = Is there lighting present at the intersection (0 = no, 1 = yes).

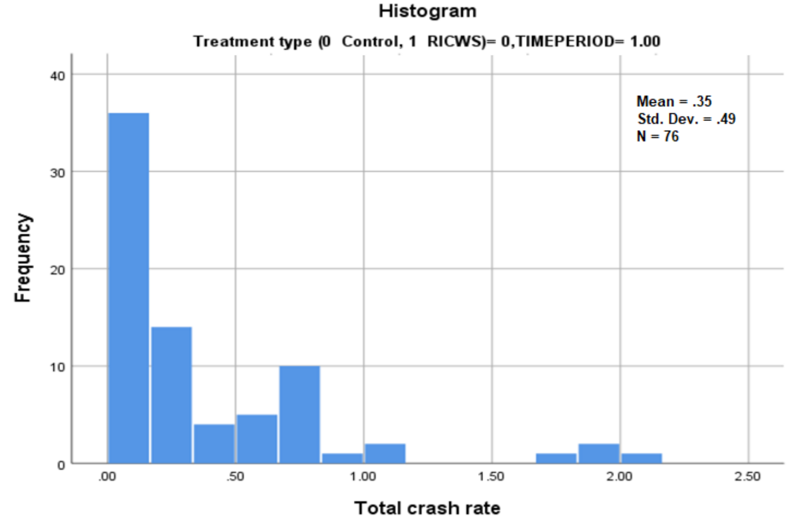
HDR studied the distributions of the crash and density rates by type of site and time period. Both variables exhibit similar trends between the control and test groups and before and after RICWS turn-on dates as shown in Figure 1 and Figure 2.

Figure 1: Histograms of Total Crash Rates by Control and Test Sites and Before and After RICWS Turn-on Dates

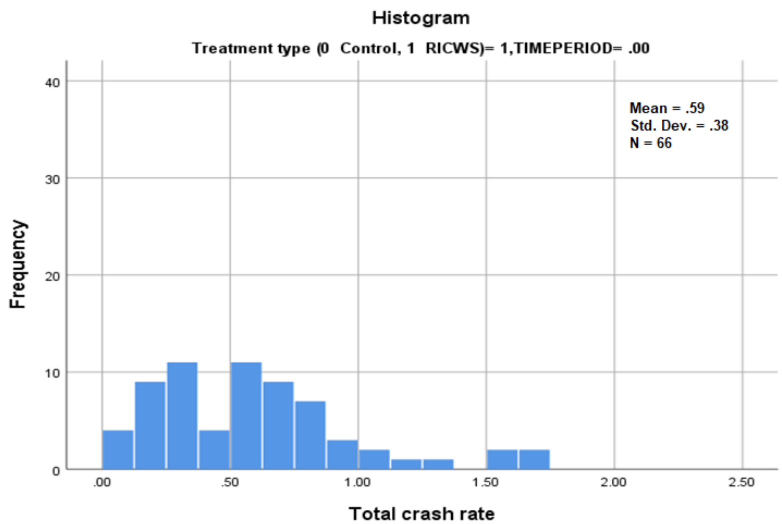
Before RICWS | **After RICWS**

Control





Treatment



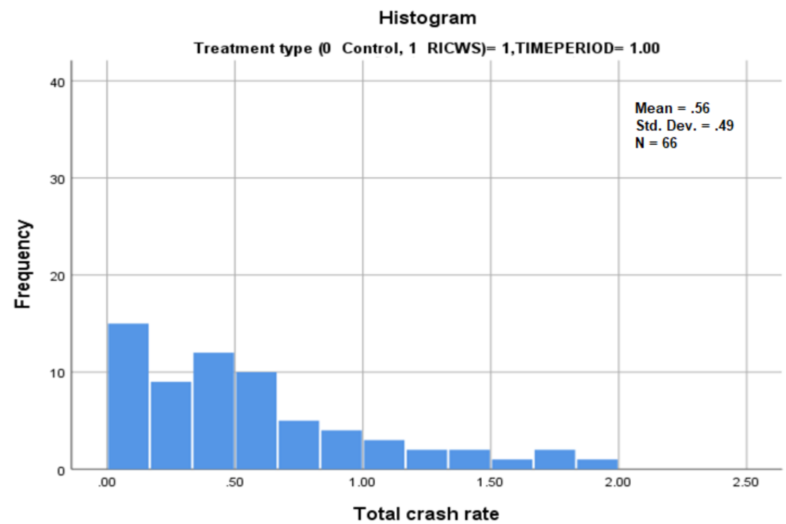
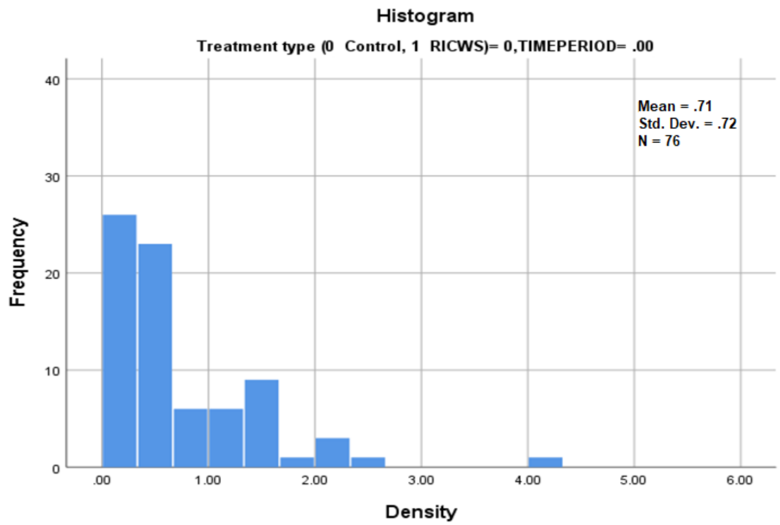
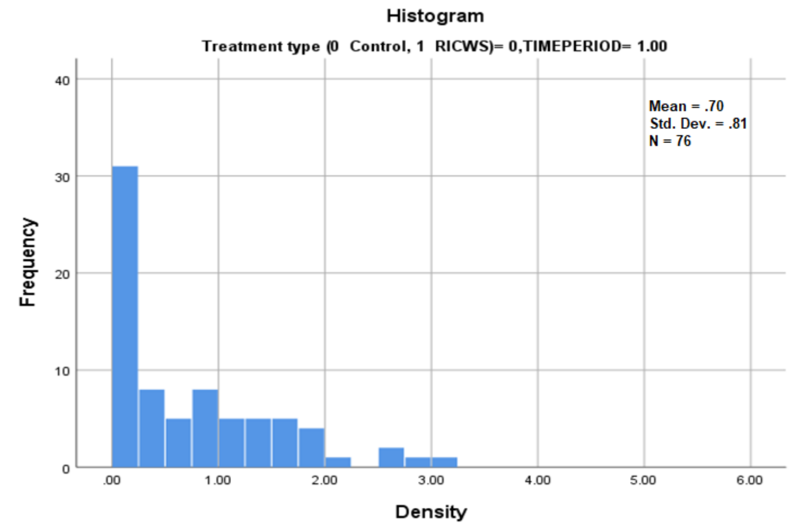


Figure 2: Histograms of Total Crash Densities by Control and Test Sites and Before and After RICWS Turn-on Dates

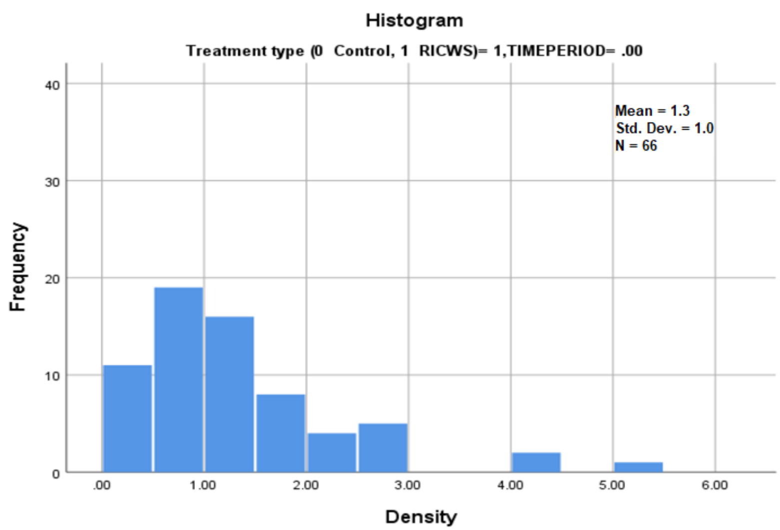
Before RICWS | **After RICWS**

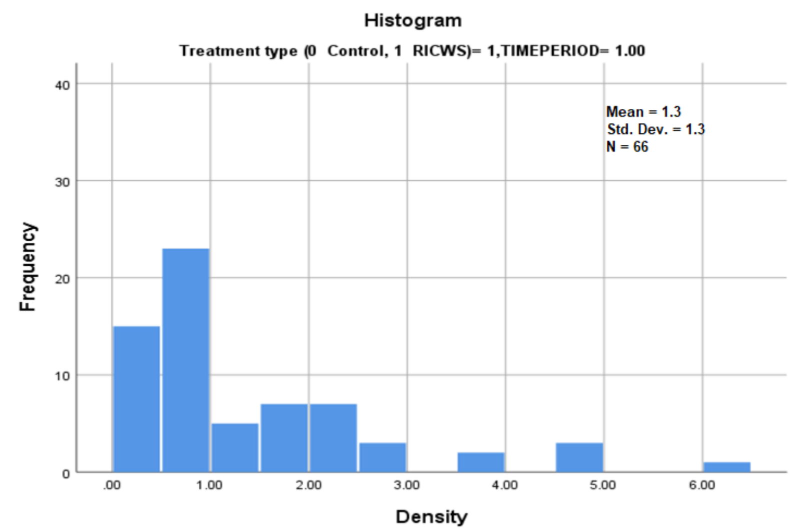
Control





Treatment





Since the frequency distributions of crash rates and densities resemble lognormal distributions, a natural logarithm transformation is suggested to normalize the data prior to analysis. However, there are a high percentage of control sites with zero crashes before and after RICWS turn-on dates. As natural logarithms cannot be applied to zero values, an adjustment is required to the variables prior to taking the logarithms. HDR used the Box-Cox transformation method to find the best fixed value to add to each observation and then the value to determine the best power.

HDR used NCSS[4] to find the scalar estimates. Table 2 below provides an example output from NCSS where the variable X=crash rate is based on data tracked since January 2006. Prior to taking the natural logarithm of the crash rate variable, HDR added the value of 0.02 to each observation and then took the resulting value to the power or 0.30.

Table 2: Box-Cox Transformation for the Dependent Variable Total Crash Rate Based on a Timeframe of January 2006 until RICWS Turn-on Date, then from Turn-on Date to March 2018

Optimum (Maximum Likelihood) Estimate of λ for X = RATE
Power Transformation: Y = (X + δ) ^ λ

Item	Power λ	Shift δ	Standard Error of Y = (X + δ) ^ λ	Shapiro-Wilk Normality Test Prob Level	Levene's Equal Variance Test Prob Level
Optimum (MLE)	0.3030	0.02055467	0.2974	0.0108	0.0000
Lower 95% C. L.	0.2136	0.02055467	0.2994	0.0028	0.0000
Upper 95% C. L.	0.3936	0.02055467	0.2994	0.0048	0.0000

OLS regressions were conducted using all available data since January 2006 and then just for the data tracked three years prior to RICWS turn-on dates for two transformed dependent variables, density and crash rates. A summary of the four OLS models that were tested can be seen in Table 3. The SPSS output from the four OLS regressions are provided in Table 4 through Table 7. The Normal Probability-Plot (P-P) is a graphical technique for assessing how well the model errors meet the normality assumptions. The model errors are considered normal if the plotted points form an approximate straight line. The Normal P-P plots for each OLS model can be observed in Figure 3 through Figure 6. All available independent variables were used in the various regression runs; however, only the regressions with statistically significant independent variables are shown for demonstration. The study variables of TX, TIMEPERIOD and RICWS_POST are included as a related set of design variables.

[4] NCSS 12 Statistical Software (2018). NCSS, LLC. Kaysville, Utah, USA, ncss.com/software/ncss.

Table 3: Summary of OLS Regression Models Tested

OLS Regression	Dependent Variable	Timeframe
Model 1	LN(Total Crash Rate)	2006 to RICWS Turn On Date; RICWS Turn-On Date to 2018
Model 2	LN(Total Crash Density)	2006 to RICWS Turn On Date; RICWS Turn-On Date to 2018
Model 3	LN(Total Crash Rate)	Three Years prior to RICWS Turn-on Date; RICWS Turn-on Date to March 2018
Model 4	LN(Total Crash Density)	Three Years prior to RICWS Turn-on Date; RICWS Turn-on Date to March 2018

Table 4: Model 1: OLS Regression Output for Dependent Variable LN(Total Crash Rate) Based on a Timeframe of January 2006 until RICWS Turn-on Date, then from Turn-on Date to March 2018

	Unstandardized Coefficients		Standardized Coefficients		
Variable Names	B	Std. Error	Beta	t	Sig.
(Constant)	-2.389	0.519		-4.600	0.000
LN_VOL	0.127	0.029	0.289	4.353	0.000
SPEED_LIMIT_NUM	-0.007	0.003	-0.121	-2.371	0.018
FOURLEGS	0.308	0.054	0.295	5.736	0.000
TIMEPERIOD	-0.048	0.065	-0.060	-0.735	0.463
Treatment type (0 Control, 1 RICWS)	0.193	0.058	0.242	3.341	0.001
RICWS_POST	0.074	0.082	0.079	0.909	0.364

Dependent Variable: LN_CRASH_RATE
Durbin-Watson Statistic: 1.923

Figure 3: Normal P-P Plot of Regression Standardized Residuals from Model 1

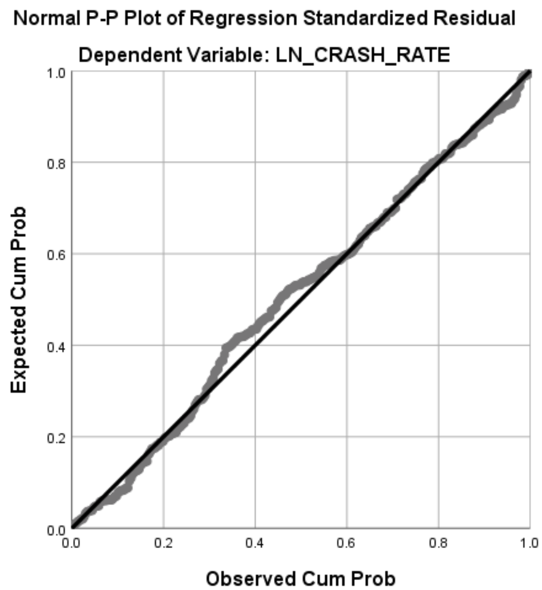


Table 5: Model 2: OLS Regression Output for Dependent Variable LN(Total Crash Density) Based on a Timeframe of January 2006 until RICWS Turn-on Date, then from Turn-on Date to March 2018

	Unstandardized Coefficients		Standardized Coefficients		
Variable Names	B	Std. Error	Beta	t	Sig.
(Constant)	-2.977	0.406		-7.333	0.000
LN_VOL	0.187	0.021	0.546	8.808	0.000
SPEED_LIMIT_NUM	-0.007	0.002	-0.158	-3.100	0.002
Located near a railroad crossing (0 no, 1 yes)	0.090	0.041	0.105	2.200	0.029
TWOLANES	-0.103	0.047	-0.113	-2.194	0.029
FOURLEGS	0.218	0.038	0.267	5.677	0.000
TIMEPERIOD	0.100	0.046	0.161	2.158	0.032
Treatment type (0 Control, 1 RICWS)	0.153	0.041	0.245	3.727	0.000
RICWS_POST	0.046	0.058	0.062	0.788	0.431

Dependent Variable: LN_DENSITY

Durbin-Watson Statistic: 1.944

Figure 4: Normal P-P Plot of Regression Standardized Residuals from Model 2

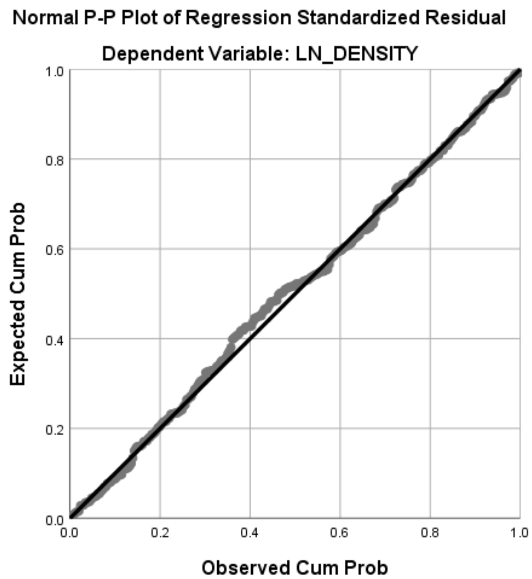


Table 6: Model 3: OLS Regression Output for Dependent Variable LN (Total Crash Rate) Based on a Timeframe of Three Years prior to RICWS Turn-on Date, then from Turn-on Date to March 2018

	Unstandardized Coefficients		Standardized Coefficients		
Variable Names	B	Std. Error	Beta	t	Sig.
(Constant)	-2.099	0.485		-4.327	0.000
LN_VOL	0.121	0.029	0.224	4.168	0.000
SPEED_LIMIT_NUM	-0.008	0.003	-0.144	-2.699	0.007
FOURLEGS	0.239	0.051	0.250	4.660	0.000
TIMEPERIOD	-0.029	0.053	-0.040	-0.544	0.587
Treatment type (0 Control, 1 RICWS)	0.185	0.055	0.254	3.351	0.001
RICWS_POST	0.028	0.078	0.032	0.358	0.721

Dependent Variable: LN_CRASH_RATE

Durbin-Watson Statistic: 1.681

Figure 5: Normal P-P Plot of Regression Standardized Residuals from Model 3

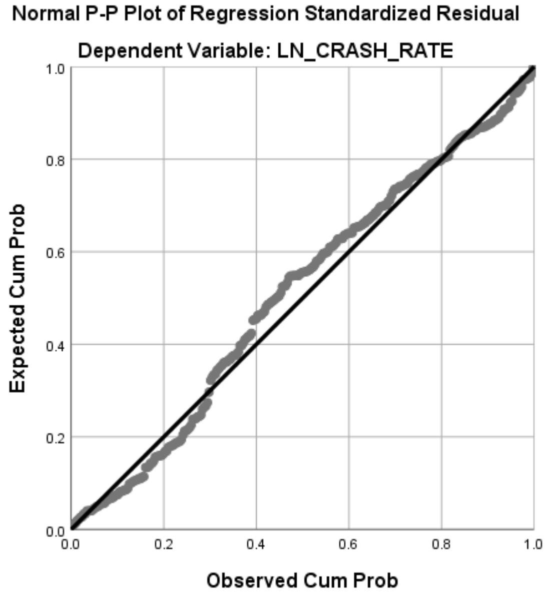
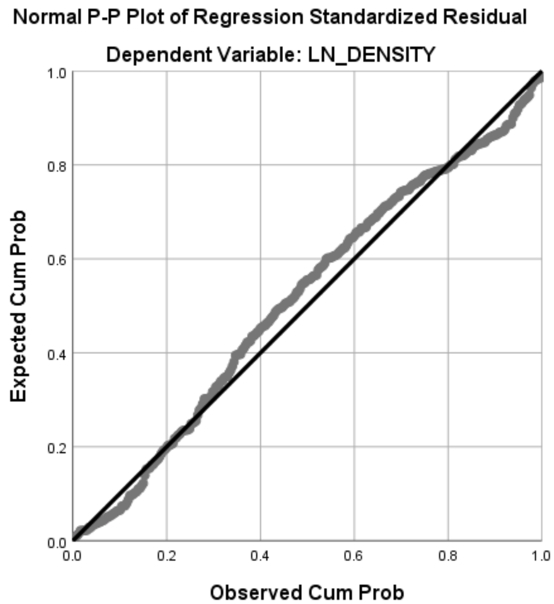


Table 7: Model 4: OLS Regression Output for Dependent Variable LN (Total Crash Rate) Based on a Timeframe of Three Years prior to RICWS Turn-on Date, then from Turn-on Date to March 2018

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-2.998	0.385		-7.791	0.000
LN_VOL	0.188	0.023	0.408	8.153	0.000
SPEED_LIMIT_NUM	-0.005	0.002	-0.109	-2.183	0.030
The degree of skew of the intersection	-0.002	0.001	-0.098	-1.957	0.051
FOURLEGS	0.205	0.041	0.252	5.038	0.000
TIMEPERIOD	-0.014	0.042	-0.023	-0.344	0.731
Treatment type (0 Control, 1 RICWS)	0.148	0.044	0.238	3.379	0.001
RICWS_POST	0.029	0.062	0.039	0.469	0.639

Dependent Variable: LN_DENSITY
Durbin-Watson Statistic: 1.720

Figure 6: Normal P-P Plot of Regression Standardized Residuals from Model 4



Based on the model results, the OLS approach is a reasonable method to use for Models 1 and 2. The key assumption of independence of errors (i.e., model residuals) and normality of errors are met. The two models' Durbin-Watson (DW) statistics of approximately 1.9 indicate serial correlation of errors is not a serious issues. As a rule of thumb, values near 2 reflect randomness in the trends of adjacent regression residuals. The patterns in Figure 3 and Figure 4 support the assumption that the errors are normally distributed as the standardized residuals follow closely along the 45 degree line on the graph. Whenever these plots show trend deviations from the line, then deviations from normality assumptions are present of varying extents.

The OLS results for Models 3 and 4, while similar to Models 1 and 2, do show a movement away from key assumptions of independence of errors and that the errors should follow a normal distribution. The two models' DW statistics of approximately 1.7 are slightly less than 2 suggesting some serial correlation of errors. The normal P-P plot points in Figure 5 and Figure 6 show some departure from a straight line indicating a departure from normality. The shorter duration applied to collect crash data prior to the RICWS turn-on date may have impacted the quality of the data. With additional modelling efforts such as corrections for correlated observations and other transformations to the independent variables, and possibly including new independent variables, the model fit and adherence to testing assumptions could be improved.

Even though parametric test methods are valid or at least acceptable for the collected data using Models 1 to 4, the coefficient for the RICWS impact as represented by the variable RICWS_POST is statistically not significant in any of the models. If the crash data supported the hypothesis that the sites with RICWS traffic control devices reduced crashes since implementation compared to comparable control sites over the same before and after time periods, then the coefficient for the interaction term RICWS_POST should be negative and have a significance value of 0.05 or less. But in fact, the results show that the estimates are essentially not any different from zero with significance levels of 0.364 and 0.431 for Models 1 and 2, respectively and then of 0.721 and 0.639 for Models 3 and 4, respectively. **The use of parametric methods on the available data while appropriate, did not find evidence of crash reductions.**

The next sections explore other areas which may have contributed to the unexpected RICWS study outcomes such as issues related to data quality or criteria used to match control sites to test sites.

Review of Database

Data quality is important for achieving consistent and reliable statistical results. The analytical data in the *data_analysis1.xlsx* file created by MnDOT was reviewed for quality and accuracy. This required reviewing the crash and AADT files used to aggregate the analytical file. Some discrepancies were observed among the crash files, bringing into question what qualifies as an eligible crash. It is important to specify the unit of analysis for a statistical study, in this case qualified crashes, to ensure that the correct data is being included or omitted from the analysis; otherwise, the wrong data may skew the results of the analysis.

Analytical File

The following variables in the analytical file were evaluated:

- B_ACC/A_ACC : Before and after number of crashes;
- B_YRS/A_YRS: Before and after number of years;
- B_VOL/A_VOL: Before and after volumes; and,
- NUM_LEGS: Number of legs.

Each variable was re-created by compiling and aggregating the appropriate data files listed in Table 1. The before period commenced in January 2006 until the turn-on date of the RICWS site. The after period commenced on the turn-on date of the RICWS site until the end of March 2018. All computations were done using SPSS statistical software. The values of the re-computed variables were compared to the original values in the analytical file to verify whether they matched for each site.

The *RICWS_Crashes-Intersection Specific.xlsx* and *Control_Crashes-Intersection Specific*.xlsx crash data files were aggregated by site to determine the number of crashes before and after the RICWS turn-on date. After matching the results to the analytical file, of the 142 sites three sites with mismatched before crash data and two sites with mismatched after crash data were identified. The sites with discrepancies in number of crashes are provided in Table 8 and Table 9 for before and after crashes, respectively. The tables indicate the treatment type (0 if control, 1 if RICWS), site name, the RICWS turn-on date, the values of the original variables, and the values of the reproduced variables denoted by the *_qc* suffix.

The discrepancies for sites SL 1.053.950, 3.055.035, and 3.055.027 are due to the misspecification of before or after years. For instance, the number of before years for site 3.055.035 is specified as 1.88, when it should be 8.88, as there are 8 years of data prior to the turn-on date year. As a result, six crashes were omitted from the analysis. The discrepancy for site 4.009.065 is because one of the crash cases was assigned to the after period when it should have been in the before period. The crash with ID 325005 in *Control_Crashes-Intersection Specific*.xlsx occurred on February 1, 2016, which is prior to the RICWS turn-on date.

Table 8: Sites with Mismatched Before Crashes

TX	Site	Turn-On Date	B_ACC	B_ACC_qc	B_YRS	B_YRS_qc
0	4.009.065	09-Jun-16	1	2	10.44	10.44
0	SL 1.053.950	23-Oct-17	0	6	0.10	11.82
0	3.055.035	17-Nov-14	3	9	1.88	8.88

Table 9: Sites with Mismatched After Crashes

TX	Site	Turn-On Date	A_ACC	A_ACC_qc	A_YRS	A_YRS_qc
0	4.009.065	09-Jun-16	1	0	1.81	1.81
0	3.055.027	18-Jun-14	0	1	2.32	3.79

The thirteen years (2006 to 2018) of AADT data in the *Control AADT.xlsx* and *RICWS AADT.xlsx* files was used to compute the total before and after volumes of vehicle traffic at each site. The volume calculations are based on the number of legs, lanes, and observed rows for each site in the AADT data files. All possible combinations for reproducing the volumes are provided in Table 10 along with their match rates. Overall, 94 (i.e. 66 percent) before volumes and 106 (i.e. 75 percent) after volumes could be reproduced out of 142 sites.

Table 10: Matching of Volumes by Site Configuration

Combination Case	Number of			No. of Matches		Total	% Matches		Reason for Mismatch
	Legs	Lanes	Obs. Rows	Before	After		Before	After	
1	3	2	1	0	0	2	0%	0%	MI
2	3	2	2	9	9	9	100%	100%	--
3	3	2	3	9	9	9	100%	100%	--
4	3	4	2	2	2	3	67%	67%	AI
5	3	4	3	2	1	2	100%	50%	AI
6	4	2	1	0	0	1	0%	0%	MI
7	4	NULL	2	0	0	1	0%	0%	MI
8	4	2	2	3	3	11	27%	27%	MI
9	4	2	3	29	31	44	66%	70%	AI
10	4	2	4	34	42	47	72%	89%	AI
11	4	4	2	2	3	7	29%	43%	MI
12	4	4	3	1	1	1	100%	100%	--
13	4	4	4	3	5	5	60%	100%	AI
			TOTAL	**94**	**106**	**142**	**66%**	**75%**	

MI: Missing Information and assumptions
AI: Aggregation issues

There are two main reasons for not consistently reproducing the volumes. First, HDR was missing some key assumptions required for computing the volumes. For instance, the assumed AADT value for legs that were not recorded in the AADT data files was not made available to HDR. This was prevalent for about 40 percent of all mismatched volumes. Second, the volumes may not have been well aggregated due to the misspecification of the category of intersection and the number of years in the before or after period. These cases are represented by 60 percent of all volume mismatches. Table 11 displays the number of mismatched volumes categorized by reason.

Table 11: Reasons for Volume Mismatches

Period	Reason for Mismatch		Total
	MI	AI	
Before	17 (35%)	31 (65%)	**48**
After	16 (44%)	20 (56%)	**36**
Total	**33**	**51**	**84**

MI: Missing Information and assumptions
AI: Aggregation issues

The number of legs assigned to each site in the analytical file was also reviewed as it pertains to the volumes. The major and minor Leg 1 and Leg 2 approach lanes in the *List of RICWS and*

Control Sites.xlsx file were used to determine the number of legs for all 142 sites. The NUM_LEGS_qc variable matched to the original NUM_LEGS variable for 96 percent of the sites.

A general summary of the database review results is displayed in Table 12. **The results indicate that the crash and volume data was generally well aggregated. The minor discrepancies found were within an acceptable range that should not affect the overall outcome of the study.**

Table 12: Summary of Database Review

Variables	Matching Sites
Before/After Number of Crashes	98%
Number of Legs	96%
Before/After Volumes	70% (with missing information, potentially 82% if information not missing)

Crash Data

Upon reviewing the aggregation of the crash data, it was determined that further clarification on the definition of a crash is required for this study. This was brought about when HDR found inconsistencies when matching the sums of the aggregated data from the sample crash file *Sample RICWS & Control Site Data.xlsx* to the number of crash values in the analytical file.

The sample crash file was originally assumed to be a subset of the two full crash files *Control_Crashes-Intersection Specific.xlsx* and *RICWS_Crashes-Intersection Specific.xlsx* that were used for analysis. However, HDR found that 26 percent of cases in the sample crash file were not observed in the full crash files used for analysis. After further exploration of the data, HDR realized that for most cases a crash was removed if it was not at the intersection, it was in an alley or driveway access, or its relation to the intersection was unknown. However, there were some cases, listed in Table 13, where it was unclear as to why the crashes were removed from the study.

Table 13: Unexplained Crash IDs that were removed from the Study

CRASHID	Site	TX
80630306	6.060.006	0
82840121	6.060.006	0
80140212	8.015.029	1
123480085	8.015.029	1

The sample file only includes 125 observations from ten RICWS and Control sites compared to 1,683 observations from 142 RICWS and Control site from the combined full crash files. The sample file, therefore, only provides a glimpse as to which crash data was filtered from the analysis. This brings into question what other crashes were removed prior to conducting the analysis that HDR was not made aware of. **The criteria for an eligible crash should be explicitly stated so that no data is omitted that can affect the outcome of the study**.

Review of Control Groups

The manner in which the control sites were assigned to the RICWS sites was assessed to determine if the comparison groups were a suitable match to the treatment groups. The criteria for matching the control locations to the locations with RICWS traffic control devices are listed in the document provided by MnDOT, *Control Location Selection.docx*. Using the criteria from this document, a similarity index was developed to rate the matching accuracy. The following criteria were used in the development of the similarity index:

- Total volume
- Speed limit of major road
- Number of intersection legs
- Number of lanes
- Near a curve
- Railroad crossing
- Intersection skew
- Development nearby
- Lighting at intersection

For each criterion, HDR created an indicator to flag whether the control and test sites per matched set ID had the same criteria. For example, if both were near a railroad crossing, then the railroad crossing match indicator would be a one; otherwise, it was zero. With respect to continuous variables of total volume and speed, HDR created a ratio of the minimum value divided by the maximum value per matched set ID. If the ratio was in the range of 0.85 to 1, then the agreement between the control and test sites' values was considered a good match or a one; otherwise, it was a zero.

The matching indicators were then weighted to give preference to volume and speed as these variables were consistently statistically significant across multiple model iterations based on the HDR's OLS regression analyses. The weighting is subjective and different weights will produce different similarity indices. Finally the sum of the weighted match indicators was produced per matched set ID and each set was given a score from 0 to 1, where 1 meant that the control and test sites matched on all criteria.

Table 14 captures the frequencies of the "grades" over the 66 matched sets before RICWS turn-on. It shows that 50 percent of the matched sets has an index of 0.65 or higher. In fact, approximately 40 percent has a grade of 0.84 or higher. If total volume is dropped from the similarity index calculations, accuracy improves to 50 percent of matched set IDs has a score of 0.95 or higher.

Table 14: Frequency Table of Similarity Index Scores for the Matched Sets of Control and Test Groups prior to the RICWS Turn-on Dates

Score	Count of Matched Sets	Percentage	Cumulative Percentage
.13	1	1.5	1.5
.16	3	4.5	6.1
.19	1	1.5	7.6
.26	1	1.5	9.1
.29	1	1.5	10.6
.32	2	3.0	13.6
.52	2	3.0	16.7
.55	4	6.1	22.7
.58	7	10.6	33.3
.61	7	10.6	43.9
.65	3	4.5	48.5
.68	7	10.6	59.1
.84	2	3.0	62.1
.87	1	1.5	63.6
.90	2	3.0	66.7
.94	6	9.1	75.8
.97	13	19.7	95.5
1.00	3	4.5	100.0
Total	66	100.0	

HDR observed that ten matched sets had two control sites linked to the test site based on proximity (M2, M6, M16, M17, M23, M24, M33, M40, M48, and M49). Table 15 below provides an example of such a matched set. The range of volumes between the minimum and maximum total volume of vehicles entering the intersection in the matched sets with two control sites was higher on average than for the matched sets with just one control site. For example, the median percent difference between the minimum and maximum volumes for the matched sets with the two control site sets is 40 percent while for the matched sets with one control site, 17 percent.

On the whole, control sites were well matched to test sites, though volume differences do contribute to those occasions where the similarity index is not ideal. Due to the differences in volumes, some of the controls site may not be the best match for nearby treatment sites. It is not necessary to use a particular RICWS site in the study if a comparable control site is not available.

Table 15: Example of Before RICWS Turn-on Dates Volume Variation in Matched Set 24

Site ID	Matched Set	SITES	Before Total Volume
1.169.015	M24	Control	26,569,935
1.135.004	M24	Control	20,877,873
1.169.048	M24	Test	19,833,820

Crash Analysis of Control Groups

HDR observed a great many control sites which had zero crash incidents during the after RICWS turn-on period (refer to Figure 1 and Figure 2). In fact 31 out of 76 control sites had zero crashes. As this was an interesting phenomenon and possibly a source for the unexpected test outcomes of no incremental crash reduction for the RICWS installed intersections, HDR studied the crash rates between the control and test sites which are linked to the 31 control sites of interest and the remaining 45 that had at least one crash after the RICWS turn-on dates. The average crash rates are in Table 16.

Table 16: Comparison of Average Total Crash Rates* before RICWS Turn-On between Control Groups with Zero Crashes and at Least One Crash after RICWS Turn-on

Control Sites	Control sites' Average Before-RICWS Crash Rate	Treatment sites' Average Before RICWS Crash Rate
With no after-RICWS crashes (31)	0.20	0.57
With at least one after- RICWS crash (45)	0.45	0.60

**Crashes prior to RICWS turn-On dates tracked from January 2006 to RICWS turn-on dates*

The fact that the control group's average total crash rate before RICWS turn-on dates was less by over a factor of two for the 31 sites that had zero crashes after RICWS turn-on dates compared to the remaining 45 which had at least one crash in the after RICWS turn-on time period (compare 0.20 to 0.45) suggests that crash trends for these 31 control sites were not in step with the trends of other control and tests sites. Referring back to *MnDOT's Master Evaluation Plan, March 2019*, when estimating the effectiveness of a countermeasure before-after using a comparison group and no SPF, it is important to check that trends in crash counts in the treatment and comparison groups are similar. The treatment sites linked to the two sets of control groups had similar total crash rates prior to the RICWS turn-on dates (compare 0.57 to 0.60).

As a what-if scenario test, HDR dropped the matched set IDs of control and test sites linked to the control sites that had zero crashes after RICWS turn-on dates, and re-ran the OLS regression analyses with the remaining control and test sites linked to 37 matched set IDs. With respect to the dependent variable LN (Total Crash Rate) from *Model 1*, HDR observed a change in the significance level for the interaction term RICWS_POST from 0.364 (i.e., not statistically significant) to 0.166 (marginally statistically significant). As the significance level approaches zero, the more likely the observed regression coefficient is not zero. The coefficient which was positive in *Model 1* (0.074) now is negative (-0.064).

If the study assertion is that the drop between before and after crash rates for the test sites is greater than the drop for the comparable control sites, then the coefficient for the RICWS_POST interaction term should be negative and statistically significant. HDR observed a similar outcome when it repeated the regression analysis for the dependent variable LN (density) in *Model 2*. The significance levels changed from 0.431 to 0.197 while the coefficient changed from 0.046 to 0.047.

While the what-if scenario results only show marginally significant results to support the study's assertion, the fact that there is some evidence to indicate that the RICWS sites have a greater reduction in crashes relative to their matched control sites does open the door to question the suitability of some of the control sites to be part of the study. It is worth a second look to see which control sites did not match particularly well in terms of volume of vehicles entering the intersection *and* trends in crashes during the before and after study time periods.

Summary of Findings and Recommendations

The independent technical review of the RICWS evaluation assessed the validity of the statistical approach used, the veracity of the data, and how well the control sites were selected for the RICWS sites. The review showed that OLS regression can be applied when properly transforming the data to fit the assumptions of the linear model. The outcome of both the review and the evaluation study, however, remained the same. The use of parametric methods on the available data while appropriate, did not find evidence of crash reductions. The manner in which the data was aggregated to create the analytical file was sound as the majority of the number of crashes and volumes were able to be reproduced. As well, the control sites were consistently matched to the RICWS sites in terms of proximity, risk factors, route numbers, and intersection configurations.

HDR recommends documenting the crash selection criteria to determine what crash types are eligible for the study. All of the crash data that was omitted from the study should be reviewed to confirm that it is in agreement with the crash definitions. It is important to ensure that all crash data was properly included or omitted from the analysis so that the results of the RICWS evaluation are not skewed due to the use of incomplete data.

HDR also recommends re-evaluating some the control sites that were selected for the study. The review found that some control sites may not be the best match for nearby test sites based on volume. It was also noted that for a great many control sites, crash incidents were zero during the after RICWS turn-on period. The initial study design did not include number of crashes as a criterion for matching RICWS sites with nearby control sites. The *"before-after analysis using a comparison group and no SPF"* evaluation method referenced in the *Master Evaluation Plan* was used to establish a design framework from which to measure the safety effectiveness of RICWS. *The Master Evaluation* Plan states "*this approach assumes that the trends in the crash counts in the treatment and comparison groups are similar"*. Therefore, crash trends should also be considered when matching the control and RICWS sites.

This type of analysis is recommended where a suitable comparison group is available. It is not necessary to use a particular RICWS site in the study if a comparable control site is not available. With a total of 66 RICWS sites in the study, there is room for removing particular RICWS sites if suitable control sites cannot be matched to them. Another possibility is to double-up similar RICWS sites to one suitable control site as part of a matched set. If there is one control site with similar characteristics to two nearby RICWS sites, that would be a better solution then dropping a RICWS site altogether because its closest control site was not an ideal match. This matching should only be done for a handful of sites because maintaining a balanced study design is preferred.

The RICWS evaluation was well carried out concerning the statistical and data analysis. The study design, however, should be re-evaluated to ensure that the necessary crash data is being used in the analysis and the appropriate control groups are matched to the RIWCS sites. Careful study design is essential to carrying out high quality research that yields valid results.

References

Master Evaluation Plan - Minnesota DOT Traffic Safety Evaluation. Prepared by HDR and HSRC for Minnesota Department of Transportation (2019).

Appendix A

Table A-1: Matched Set IDs to each Site

Number of Control Sites	Matched Set ID	Site	Treatment (0=control, 1=test)
1	M1	3.023.056	0
1	M1	3.023.090	1
1	M3	3.055.027	0
1	M3	3.055.028	1
1	M4	1.001.014	1
1	M4	1.001.022	0
1	M5	8.007.050	0
1	M5	8.007.051	1
1	M7	7.015.063	1
1	M7	8.212.036	0
1	M8	8.023.065	1
1	M8	8.023.066	0
1	M9	1.169.001	0
1	M9	3.210.051	1
1	M10	3.023.091	1
1	M10	3.023.094	0
1	M11	3.055.030	0
1	M11	3.055.031	1
1	M12	6.003.009	0
1	M12	6.003.013	1
1	M13	8.019.012	0
1	M13	8.023.031	1
1	M14	8.071.015	0
1	M14	8.212.050	1
1	M15	6.042.003	1
1	M15	6.042.004	0
1	M18	6.060.003	1
1	M18	6.063.011	0
1	M19	4.029.020	0
1	M19	4.029.052	1
1	M20	4.210.001	0
1	M20	4.210.019	1
1	M21	4.075.089	1
1	M21	4.075.091	0
1	M22	2.200.049	0
1	M22	4.200.007	1
1	M25	3.023.084	1
1	M25	3.065.023	0

Number of Control Sites	Matched Set ID	Site	Treatment (0=control, 1=test)
1	M26	8.007.013	0
1	M26	8.007.021	1
1	M27	2.006.008	1
1	M27	2.071.069	0
1	M28	8.071.026	0
1	M28	8.071.030	1
1	M29	7.014.040	0
1	M29	N 7.014.561	1
1	M30	1.053.018	0
1	M30	1.053.034	1
1	M31	8.023.012	1
1	M31	8.023.013	0
1	M32	8.023.035	1
1	M32	8.023.037	0
1	M34	6.014.041	0
1	M34	6.043.016	1
1	M35	6.056.066	1
1	M35	M.056.086	0
1	M36	4.010.071	1
1	M36	4.029.075	0
1	M37	4.029.049	1
1	M37	4.029.054	0
1	M38	6.052.031	1
1	M38	6.052.032	0
1	M39	3.006.009	1
1	M39	3.006.010	0
1	M41	3.169.050	0
1	M41	3.169.051	1
1	M42	3.047.002	1
1	M42	3.047.005	0
1	M43	4.075.098	0
1	M43	4.075.109	1
1	M44	7.004.049	0
1	M44	8.007.008	1
1	M45	7.060.040	0
1	M45	7.060.041	1
1	M46	8.015.028	0
1	M46	8.015.029	1
1	M47	8.007.048	0
1	M47	8.007.049	1
1	M50	6.060.032	1
1	M50	7.013.037	0

Number of Control Sites	Matched Set ID	Site	Treatment (0=control, 1=test)
1	M51	8.067.021	0
1	M51	8.067.024	1
1	M52	3.010.049	0
1	M52	3.010.065	1
1	M53	3.023.009	1
1	M53	3.023.016	0
1	M54	3.210.046	0
1	M54	CW 3.004.003	1
1	M55	3.210.034	0
1	M55	3.210.035	1
1	M56	SL 1.053.950	0
1	M56	SL 1.053.Land	1
1	M57	3.055.035	0
1	M57	S 3.002.Minn	1
1	M58	1.002.028	1
1	M58	1.002.032	0
1	M59	1.002.019	0
1	M59	SL 1.002.223	1
1	M60	1.053.047	1
1	M60	1.053.060	0
1	M61	1.037.015	1
1	M61	1.194.001	0
1	M62	1.037.010	0
1	M62	1.037.011	1
1	M63	1.210.010	0
1	M63	SL 1.004.043	1
1	M64	SL 1.037.002	1
1	M64	SL 1.037.280	0
1	M65	M.017.057	0
1	M65	M.017.069	1
1	M66	SL 1.013.045	1
1	M66	SL 1.013.104	0
2	M2	6.060.004	1
2	M2	6.060.006	0
2	M2	6.218.030	0
2	M6	6.042.010	0
2	M6	6.061.053	0
2	M6	6.063.025	1
2	M16	6.060.002	1
2	M16	7.013.048	0
2	M16	7.060.091	0
2	M17	1.002.013	0

Number of Control Sites	Matched Set ID	Site	Treatment (0=control, 1=test)
2	M17	1.002.018	0
2	M17	1.002.030	1
2	M23	2.059.029	0
2	M23	2.059.053	0
2	M23	2.075.046	1
2	M24	1.135.004	0
2	M24	1.169.015	0
2	M24	1.169.048	1
2	M33	3.169.026	1
2	M33	3.169.034	0
2	M33	ML 3.169.009	0
2	M40	6.014.056	1
2	M40	6.014.058	0
2	M40	6.063.026	0
2	M48	6.019.021	1
2	M48	6.019.022	0
2	M48	6.019.023	0
2	M49	4.009.054	0
2	M49	4.009.065	0
2	M49	4.075.049	1