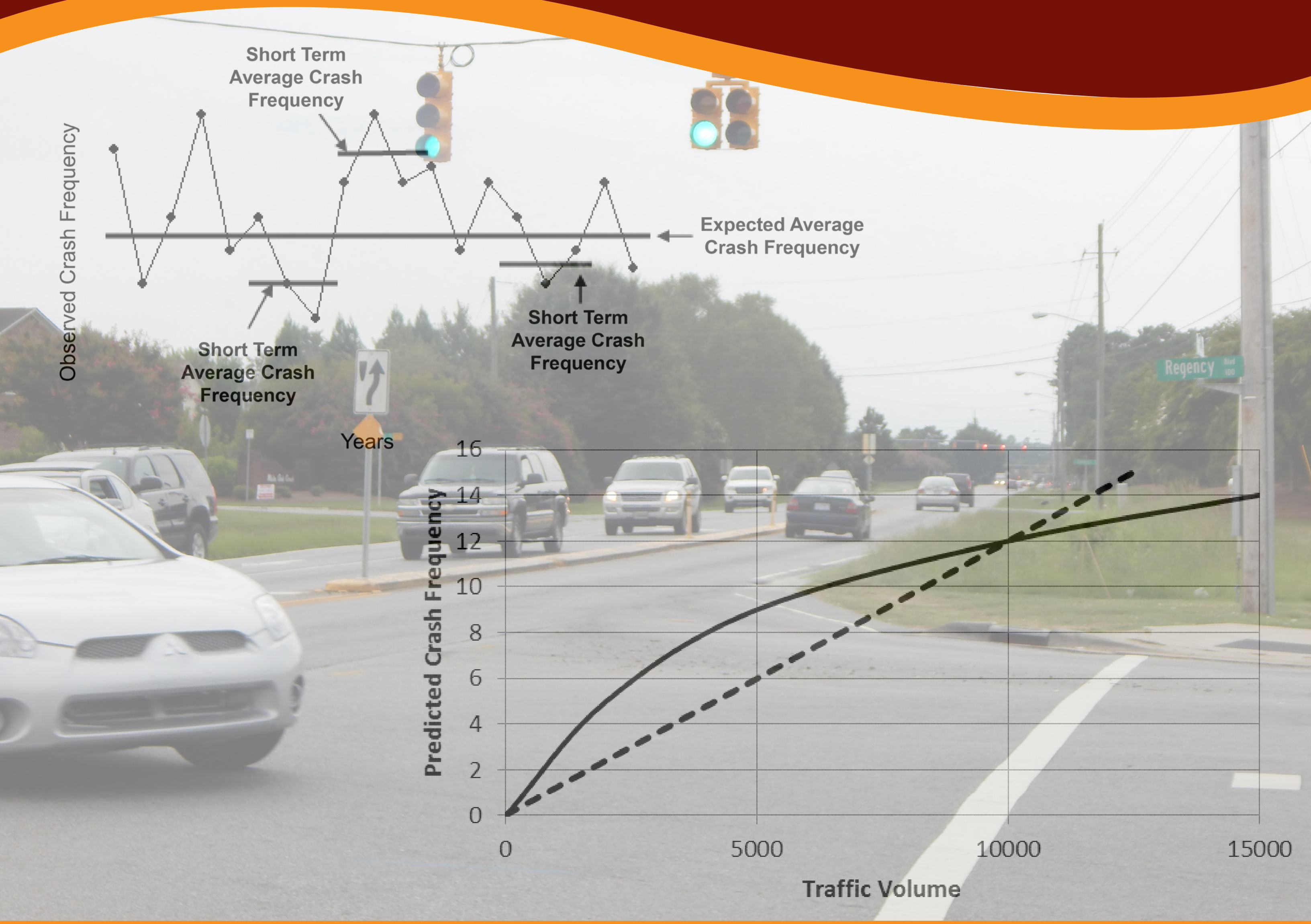
Evaluation of Four Network Screening Performance Measures



FHWA-SA-16-103

October 2016

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

http://safety.fhwa.dot.gov

TECHNICAL DOCUMENTATION PAGE

1. Report No. FHWA-SA-16-103	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Evaluation of Four Network Screening Performance Measures	5. Report Date: October 2016 6. Performing Organization Code
7. Author(s) Frank Gross, Tim Harmon, Matt Albee, Scott Himes, Raghavan Srinivasan, Daniel Carter, and Michael Dugas	8. Performing Organization Report No.
9. Performing Organization Name and Address VHB 8300 Boone Boulevard Suite 700 Vienna, VA 22182	10. Work Unit No. 11. Contract or Grant No. DTFH61-10-D-00022-T-13005
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Safety 1200 New Jersey Ave., SE Washington, DC 20590	13. Type of Report and Period Final Report, August 2015 – October 2016 14. Sponsoring Agency Code FHWA

15. Supplementary Notes
The Contracting Officer's Task Manager (COTM) was Stuart Thompson.

16. Abstract
High quality data and reliable analytical methods are the foundation of data-driven decision-making. The Reliability of Safety Management Methods series includes five information guides that identify opportunities to employ more reliable methods to support decisions throughout the roadway safety management process. Four of the guides focus on specific components of the roadway safety management process: network screening, diagnosis, countermeasure selection, and safety effectiveness evaluation. The fifth guide focuses on the systemic approach to safety management, which describes a complimentary approach to the methods described in the network screening, diagnosis, and countermeasure selection guides. The purpose of the Reliability of Safety Management Methods series is to demonstrate the value of more reliable methods in these activities, and demonstrate limitations of traditional (less reliable) methods.

The Evaluation of Four Network Screening Performance Measures is a supplement to the network screening guide, and also serves as an example of diagnosis and countermeasure selection. The objectives of this guide are to 1) raise awareness of more reliable network screening performance measures, and 2) demonstrate the value of more reliable performance measures using real-world data. The target audience includes data analysts, program managers, and project managers involved in projects that impact highway safety.

The primary question related to network screening is "which performance measure is most likely to produce a list of sites with the greatest potential for improvement and subsequently result in the greatest benefit and most cost-effective safety improvements?" To answer this question, the study follows the safety management process from network screening through economic analysis, using statewide intersection data from New Hampshire. The dataset includes fatal and injury crash data, traffic data, and roadway data for years 2010 through 2014. The research team identified ranked lists of sites based on four network screening performance measures, performed a safety diagnosis on the top 35 intersections, developed potential strategies to target the underlying safety issues, and conducted an economic analysis for each intersection improvement package. This guide compares the overall economic benefit and overall benefit-cost ratio for each of the four measures. The EB excess expected measure and the EB expected measure produced the list of sites with the highest overall economic benefit and the highest return on investment, respectively. The crash rate measure produced the lowest overall economic benefit and the lowest return on investment. Readers will understand the value of and be prepared to select more reliable performance measures in network screening to account for potential bias, obtain more reliable results, and achieve decisions that are more effective.

17. Key Words: Roadway, Safety, Data, Analysis, Network, Screening	18. Distribution Statement No restrictions.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 76	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed pages authorized

ACKNOWLEDGMENTS

The research team acknowledges the New Hampshire Department of Transportation's willingness to provide their statewide safety data to support the development of this guide, as well as their generous attentiveness with feedback and insight throughout the site review process.

The research team would also like to thank the following individuals who served as members on the Technical Working Group for this effort.

Technical Working Group

Stuart Thompson, FHWA Office of Safety

Ray Krammes, FHWA Office of Safety

Yanira Rivera, FHWA Office of Safety

Marc Starnes, FHWA Office of Safety

TABLE OF CONTENTS

1. The Roadway Safety Management Process 1
2. Overview of Study 3
3. Network Screening Performance Measures 4
  Crash Frequency 4
  Crash Rate 4
  Expected Crash Frequency with EB Adjustment 4
  Excess Expected Crash Frequency with EB Adjustment 6
4. Methodology 8
  Data Acquisition 8
  Network Screening 8
  Diagnosis 9
  Countermeasure Selection 12
  Economic Analysis 12
5. Results 16
6. Summary 19
7. Future Research 21
References 22
Appendix A: Safety Performance Functions 23
Appendix B: Network Screening Results 25
Appendix C: Network Screening Process 29
Appendix D: Data Summary of Study Sites 33
Appendix E: Example Intersection Packages 38
Appendix F: Road Safety Audit Results 62
Appendix G: Crash Modification Factors 68
Appendix H: Countermeasure Cost Data 70
Appendix I: Economic Analysis Results 71

LIST OF TABLES

Table 1. Performance measures for network screening. 6
Table 2. Data requirements for network screening performance measures. 7
Table 3. Service life for strategies. 14
Table 4. Number of sites identified by multiple screening performance measures. 16
Table 5. BCR results by network screening performance measure (all sites). 17
Table 6. BCR results by network screening performance measure (all sites). 17
Table 7. BCR results by network screening performance measure (exclusive sites). 18
Table 8. Top 20 intersections by KABC crash frequency. 25
Table 9. Top 20 intersections by KABC rate. 26
Table 10. Top 20 intersections by EB expected KABC. 27
Table 11. Top 20 intersections by EB expected excess KABC. 28
Table 12. Intersection maintenance jurisdiction. 33
Table 13. Intersection class. 33
Table 14. Intersection area type. 33
Table 15. Intersection traffic control type. 34
Table 16. Intersection leg count. 34
Table 17. Crash and traffic volume data summary for 35 study sites. 35
Table 18. Crash summary by year for intersection 4798. 39
Table 19. Crash summary by month for intersection 4798. 40
Table 20. Crash summary by day of week for intersection 4798. 40
Table 21. Crash summary by crash type and severity for intersection 4798. 40
Table 22. Crash summary by time of day for intersection 4798. 41
Table 23. Crash summary by surface condition for intersection 4798. 41
Table 24. Crash summary by light condition for intersection 4798. 41
Table 25. Crash summary by number of vehicles for intersection 4798. 42
Table 26. Crash summary by contributing factor for intersection 4798. 42
Table 27. Crash summary by vision obscurement for intersection 4798. 42
Table 28. Crash summary by vehicle direction for intersection 4798. 42
Table 29. Crash summary by vehicle type for intersection 4798. 43
Table 30. Crash summary by operator age for intersection 4798. 43
Table 31. Crash summary by state of residence for intersection 4798. 43
Table 32. Crash details for intersection 4798. 44
Table 33. Crash summary by year for intersection 8681. 45
Table 34. Crash summary by month for intersection 8681. 46
Table 35. Crash summary by day of week for intersection 8681. 46
Table 36. Crash summary by crash type and severity for intersection 8681. 46
Table 37. Crash summary by time of day for intersection 8681. 47
Table 38. Crash summary by surface condition for intersection 8681. 47
Table 39. Crash summary by light condition for intersection 8681. 47
Table 40. Crash summary by number of vehicles for intersection 8681. 48
Table 41. Crash summary by contributing factor for intersection 8681. 48

Table 42. Crash summary by vision obscurement for intersection 8681. 48
Table 43. Crash summary by vehicle direction for intersection 8681 48
Table 44. Crash summary by vehicle type for intersection 8681. 49
Table 45. Crash summary by operator age for intersection 8681. 49
Table 46. Crash summary by state of residence for intersection 8681. 49
Table 47. Crash details for intersection 8681. 50
Table 48. Crash summary by year for intersection 37259. 51
Table 49. Crash summary by month for intersection 37259. 51
Table 50. Crash summary by day of week for intersection 37259. 52
Table 51. Crash summary by crash type and severity for intersection 37259. 52
Table 52. Crash summary by time of day for intersection 37259. 52
Table 53. Crash summary by surface condition for intersection 37259. 52
Table 54. Crash summary by light condition for intersection 37259. 52
Table 55. Crash summary by number of vehicles for intersection 37259. 52
Table 56. Crash summary by contributing factor for intersection 37259. 53
Table 57. Crash summary by vision obscurement for intersection 37259. 53
Table 58. Crash summary by vehicle direction for intersection 37259. 53
Table 59. Crash summary by vehicle type for intersection 37259. 53
Table 60. Crash summary by operator age for intersection 37259. 53
Table 61. Crash summary by state of residence for intersection 37259. 53
Table 62. Crash details for intersection 37259 54
Table 63. Crash summary by year for intersection 58744. 55
Table 64. Crash summary by month for intersection 58744. 56
Table 65. Crash summary by day of week for intersection 58744. 56
Table 66. Crash summary by crash type and severity for intersection 58744. 56
Table 67. Crash summary by time of day for intersection 58744. 57
Table 68. Crash summary by surface condition for intersection 58744. 57
Table 69. Crash summary by light condition for intersection 58744. 57
Table 70. Crash summary by number of vehicles for intersection 58744. 58
Table 71. Crash summary by contributing factor for intersection 58744. 58
Table 72. Crash summary by vision obscurement for intersection 58744. 58
Table 73. Crash summary by vehicle direction for intersection 58744. 59
Table 74. Crash summary by vehicle type for intersection 58744. 59
Table 75. Crash summary by operator age for intersection 58744. 59
Table 76. Crash summary by state of residence for intersection 58744. 60
Table 77. Crash details for intersection 58744 61

LIST OF FIGURES

Figure 1. Chart. Schematic of roadway safety management process. 1
Figure 2. Equation. Fatal and injury crash rate. 4
Figure 3. Equation. Expected crash frequency with EB adjustment. 5
Figure 4. Equation. Weighting factor for EB method. 5
Figure 5. Equation. Excess expected crash frequency with EB adjustment. 6
Figure 6. Chart. Example collision diagram. 10
Figure 7. Equation. Estimated annual benefit. 13
Figure 8. Equation. Estimated present value benefit. 14
Figure 9. Equation. Benefit-cost ratio. 15
Figure 10. Chart. Map of study sites. 37
Figure 11. Chart. Collision diagram legend. 38
Figure 12. Chart. Collision diagram for intersection 4798. 39
Figure 13. Chart. Collision diagram for intersection 8681 45
Figure 14. Chart. Collision diagram for intersection 37259. 51
Figure 15. Chart. Collision diagram for intersection 58744. 55
Figure 16. Screenshot. Pedestrians in concrete median in absence of crosswalk. 67

LIST OF ACRONYMS

AADT	Annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ANG	Angle collision
BCR	Benefit-cost ratio
BI	Bicyclist collision
CMF	Crash Modification Factor
DOT	Department of Transportation
EB	Empirical Bayes
FHWA	Federal Highway Administration
FO	Fixed object collision
GIS	Geographic information system
GPS	Global positioning system
HO	Head on collision
HSIP	Highway Safety Improvement Program
ICWS	Intersection Conflict Warning Systems
LT	Left turn collision
NHDOT	New Hampshire Department of Transportation
O_M	Other multiple vehicle collision
O_S	Other single vehicle collision
PDO	Property damage only
PV	Parked vehicle collision
PVB	Present value benefit
PVC	Present value cost
RE	Rear-end collision
RLIL	Red Light Indicator Light
RSA	Road Safety Audit
RTM	Regression-to-the-mean
SPF	Safety Performance Function
SS_O	Sideswipe opposite direction collision
SS_S	Sideswipe same direction collision
PED	Pedestrian collision
SP	Spill
U	Unknown collision

PREFACE

High quality data and reliable analytical methods are the foundation of data-driven decision-making. The purpose of the Reliability of Safety Management Methods series is to demonstrate the value of more reliable methods, and demonstrate limitations of traditional (less reliable) methods in the roadway safety management process.

The six-step roadway safety management process provides a structured framework for analysts to identify, plan, program, and evaluate projects, or employ individual steps to solve a specific problem. The following is a brief summary of the six-step roadway safety management process.

Step 1. Network screening is the process of analyzing the network to identify sites for further investigation. It is not possible to conduct a detailed investigation across the entire network, so network screening helps the analyst to pare down the list of sites.

Step 2. Diagnosis is the process of further investigating sites identified in network screening. The objective of diagnosis is to identify existing and potential safety issues.

Step 3. Countermeasure selection is the process of assessing ways to address or mitigate the underlying safety issues identified in step 2 (diagnosis). Countermeasures should directly target the specific issues, and may include engineering, education, enforcement, and EMS-related measures (i.e., the 4E approach).

Step 4. Economic appraisal is the process of comparing the relative costs and benefits of the various alternatives when it is not feasible or practical to implement all potential countermeasures.

Step 5. Project prioritization is the process of developing a portfolio of projects for selection based on available funding in a given fiscal year.

Step 6. Safety effectiveness evaluation is the process of estimating the safety impacts of implemented projects. This is the final step of the roadway safety management process, which provides a critical feedback link for future decisions.

The Reliability of Safety Management Methods series includes five information guides, which identify opportunities to employ more reliable methods to support decisions throughout the roadway safety management process. The first four guides focus on specific components of the roadway safety management process: network screening, diagnosis, countermeasure selection, and safety effectiveness evaluation. The fifth guide focuses on the systemic approach to safety management, which describes a complimentary approach to the methods described in the network screening, diagnosis, and countermeasure selection guides.

- Reliability of Safety Management Methods: Network Screening
- Reliability of Safety Management Methods: Diagnosis
- Reliability of Safety Management Methods: Countermeasure Selection
- Reliability of Safety Management Methods: Safety Effectiveness Evaluation
- Reliability of Safety Management Methods: Systemic Safety Programs

The Evaluation of Four Network Screening Performance Measures is a supplement to the network screening guide. The objectives of this guide are to 1) raise awareness of more reliable network screening performance measures, and 2) demonstrate the value of more reliable network screening performance measures through a comprehensive evaluation using real-world data. The target audience includes data analysts, program managers, and project managers involved in projects that impact highway safety.

The primary question related to network screening is "which performance measure is most likely to produce a list of sites with the greatest potential for improvement and subsequently result in the greatest benefit and most cost-effective safety improvements?" To answer this question, the study follows the safety management process from network screening through economic analysis, using statewide intersection data from New Hampshire. The dataset includes fatal and injury crash data, traffic data, and roadway data for years 2010 through 2014. The research team identified ranked lists of sites based on four network screening performance measures, performed a comprehensive safety diagnosis on the top 35 intersections, developed potential strategies to target the underlying safety issues, and conducted an economic analysis for each intersection improvement package.

This guide compares the overall economic benefit and overall benefit-cost ratio for each of the four network screening performance measures. The Empirical Bayes (EB) excess expected measure produced the list of sites with the highest overall economic benefit. The EB expected measure produced the list of sites with the highest return on investment. The crash rate measure produced the list of sites with the lowest economic benefit and the lowest return on investment. Readers will understand the value of and be prepared to select more reliable performance measures in network screening to account for potential bias, obtain more reliable results, and achieve decisions that are more effective.

1. THE ROADWAY SAFETY MANAGEMENT PROCESS

The roadway safety management process is a six-step process as shown in Figure 1 and outlined in the *Highway Safety Manual*.[1] Following Figure 1 is a brief description of each step. Analysts can apply the roadway safety management process sequentially to identify, plan, program, and evaluate projects, or employ individual steps to solve a specific problem.

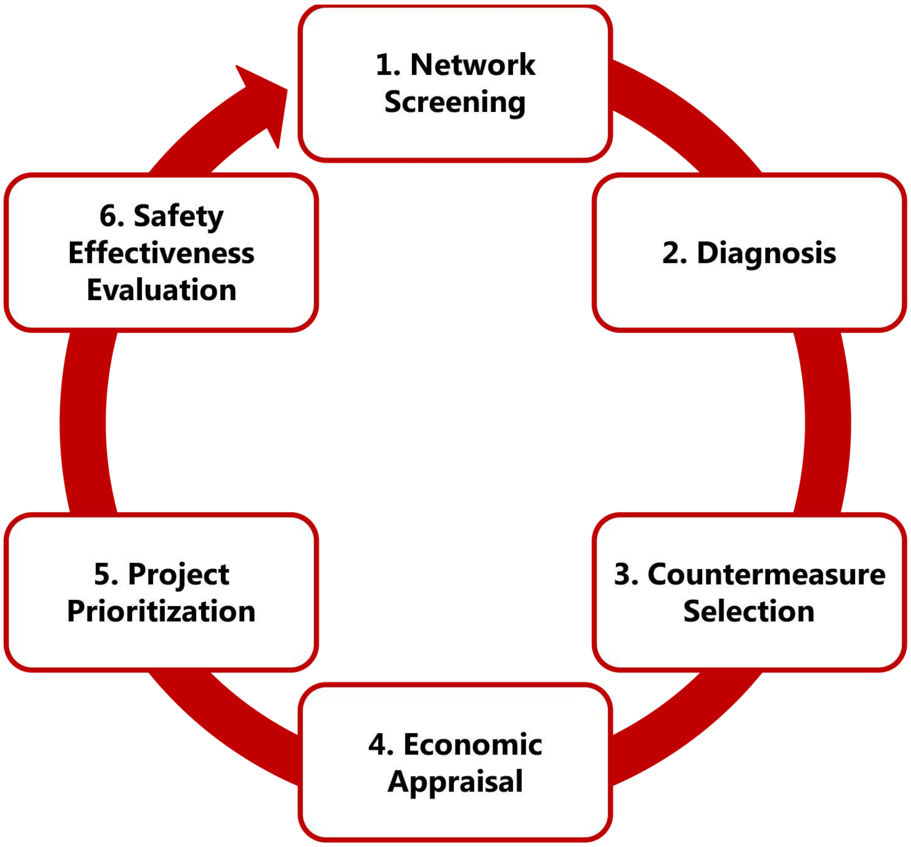


Figure 1. Chart. Schematic of roadway safety management process.

STEP 1: NETWORK SCREENING

Network screening is the process of analyzing the network to identify sites for further investigation. It is not possible to conduct a detailed investigation at each site in the entire network, so network screening pares down the list of sites across the network to a manageable list. Analysts select a performance measure and other criteria for analyzing the safety performance of each site. The performance measure may reflect an entire site or specific windows or peak sections of roadway segments depending on the selected screening method.

There are various performance measures available for network screening. Chapter 4 of the *Highway Safety Manual* provides a discussion of these measures along with associated strengths and limitations. [1] Refer to the *Reliability of Safety Management Methods: Network Screening* guide for a demonstration of the value and example applications of various network screening performance measures.[2]

STEP 2: DIAGNOSIS

Diagnosis is the process of further investigating sites identified in network screening. The objective of diagnosis is to identify existing and potential safety issues at each site. Diagnosis often involves a review of the crash history, traffic operations, geometric characteristics, and general site conditions as well as a field visit to observe road user behaviors. This is achieved through a Road Safety Audit (RSA) or other form of safety review. The result of diagnosis is a list of contributing factors associated with historical and potential future crashes. It is important to understand and diagnose the underlying issues before developing potential countermeasures. Refer to the *Reliability of Safety Management Methods: Diagnosis* guide for a demonstration of the value and example applications of various diagnosis methods.[3]

STEP 3: COUNTERMEASURE SELECTION

Countermeasure selection is the process of assessing ways to address or mitigate the underlying safety issues identified in step 2 (diagnosis). The countermeasures should directly target the specific issues, and may include engineering, education, enforcement, and EMS-related measures (i.e., the 4E approach). This can be achieved as an extension of the RSA process, or may occur as a separate process. Refer to the *Reliability of Safety Management Methods: Countermeasure Selection* guide for a demonstration of the value and example applications of various countermeasure selection methods.[4]

STEP 4: ECONOMIC APPRAISAL

Economic appraisal is the process of comparing the relative costs and benefits of the various alternatives. It is often not feasible or practical to implement all potential countermeasures. As such, it is necessary to estimate the cost and benefits of each potential countermeasure. Estimating the cost of a project is relatively straightforward, and includes the construction cost and annual maintenance costs. For the safety benefit, analysts use crash modification factors (CMFs) to estimate the change in crashes after the implementation of a given countermeasure. The CMF Clearinghouse is the primary resource for identifying applicable CMFs, including those presented in the Highway Safety Manual. Refer to chapter 7 of the *Highway Safety Manual* for further information and considerations related to economic appraisal.[1]

STEP 5: PROJECT PRIORITIZATION

Project prioritization is the process of developing a portfolio of projects for selection based on available funding in a given fiscal year. Agencies select the final list of projects based on available budget as well as other factors. Refer to chapter 8 of the *Highway Safety Manual* for further information and considerations related to project prioritization.[1]

STEP 6: SAFETY EFFECTIVENESS EVALUATION

Safety effectiveness evaluation is the process of estimating the safety impacts of implemented projects. This is the final step of the roadway safety management process, which provides a critical feedback link for future decisions. Agencies conduct evaluation at multiple levels, including project level, countermeasure level, and program level. Refer to the *Reliability of Safety Management Methods: Safety Effectiveness Evaluation* guide for a demonstration of the value and example applications of various safety effectiveness evaluation methods.[5]

2. OVERVIEW OF STUDY

Network screening is the first step in the roadway safety management process, and is critical to the effectiveness of an agency's highway safety program. Agencies can apply various network screening performance measures to identify sites with promise (i.e., those sites expected to benefit the most from targeted, cost-effective treatments). This aligns with the purpose of the federal Highway Safety Improvement Program (HSIP), which is to achieve a significant reduction in fatalities and serious injuries on all public roads.[6] To achieve this goal, the network screening process should maximize the opportunity to improve safety; otherwise, agencies may allocate resources inefficiently to sites with less potential for improvement while locations with a higher potential for cost-effective safety improvement remain untreated.

The primary question related to network screening is "which performance measure is most likely to produce a list of sites with the greatest potential for improvement and subsequently result in the greatest benefit and most cost-effective safety improvements?" This study seeks to answer the second part of this question by replicating the safety management process from network screening through economic analysis. To perform this assessment, the research team used a statewide intersection inventory and conducted a typical network screening exercise using each of four common performance measures (i.e., crash frequency, crash rate, Empirical Bayes (EB) expected crashes, and EB expected excess crashes). This resulted in four ranked lists of sites for further investigation. The research team used the results to simulate the development of a set of projects at the top sites using actual data from New Hampshire. Finally, the team estimated and compared the benefits and costs of projects to determine which network screening performance measure produced the list of sites with the highest overall benefit and the highest return on investment.

The remainder of this guide details the process and results of the study. Chapter 3 provides an overview of the four performance measures included in this study. Chapter 4 provides a detailed discussion of the methodology from network screening through economic appraisal along with a description of the data collection process and a summary of the dataset used for the analysis. Chapter 5 presents the results and Chapter 6 provides a discussion of the results, including a discussion of the performance measures resulting in the highest economic benefits and highest return on investment.

3. NETWORK SCREENING PERFORMANCE MEASURES

The four performance measures evaluated in this guide are as follows.

- Crash frequency.
- Crash rate.
- Expected crash frequency with EB adjustment.
- Excess expected crash frequency with EB adjustment.

The remainder of this section describes the four network screening performance measures in detail, identifying issues related to the specific measures. Refer to Chapter 4 of the *Highway Safety Manual* and the *Reliability of Safety Management Methods: Network Screening* guide for further discussion of these measures and the associated strengths and limitations.

CRASH FREQUENCY

The crash frequency represents the number of crashes per year or during a given study period at a site. This measure does not account for potential regression to the mean (RTM) bias or differences in traffic volume among sites. Using three to five years of crash data, analysts rank sites in descending order by the crash frequency and possibly by crash type and crash severity.

In this study, the team computed and ranked each intersection by the number of fatal and injury crashes (KABC on the KABCO scale) during the five-year period from 2010 to 2014.

CRASH RATE

The crash rate represents the number of crashes per some measure of exposure such as traffic volume. The crash rate does not account for potential bias due to RTM. While the crash rate does account for differences in traffic volume among sites, it does not account for the nonlinear relationship between crashes and traffic volume. Using three to five years of crash data, analysts rank sites in descending order by the crash rate and possibly by crash type and crash severity.

For this study, Figure 2 represents the equation to calculate the crash rate per million entering vehicles:

$$Fatal\ and\ Injury\ Crash\ Rate = \left(\frac{KABC\ crashes}{Total\ entering\ traffic\ volume}\right) \times 1{,}000{,}000$$

Figure 2. Equation. Fatal and injury crash rate.

EXPECTED CRASH FREQUENCY WITH EB ADJUSTMENT

The EB method combines the observed crash frequency with the predicted crash frequency for a given site to produce an estimate of the expected crash frequency in crashes per year. Note the predicted crash frequency is from a safety performance function (SPF). The SPF represents the average crash frequency from a reference group. Similar to the crash frequency measure, analysts rank sites from high to low based on the expected crash frequency. This measure accounts for potential bias due to RTM, differences in traffic volume among sites, and the nonlinear relationship between crash frequency and traffic volume.

The following is a brief overview of the EB method:

Step 1. Identify Reference Group: Identify a group of sites representative of the facility type of interest for network screening. The reference group should reflect the major factors affecting crash risk, including traffic volume and other site characteristics. For example, a reference group may consist of all four-leg signalized intersections.

Step 2. Develop SPFs: Using data from the reference sites, estimate an SPF relating crashes to independent variables such as traffic volume and other site characteristics. As discussed in the following steps, the EB method incorporates information from SPFs (i.e., predicted crashes and the overdispersion parameter) to estimate crashes based on traffic volume and site characteristics. See Appendix A for discussion of the SPFs.

Step 3. Estimate Predicted Crashes: Use the SPFs and traffic volume data for each site included in the network screening to estimate the predicted number of crashes for each year in the study period.

Step 4. Estimate Expected Crashes: Using the EB method, compute the expected crashes for each site for each year in the study period as the weighted sum of the predicted crashes from the SPF and observed crashes. For details on the EB method, refer to the *Highway Safety Manual* or Hauer.[1,7]

The outcome of step 4 is the expected crash frequency with EB adjustment. For this study, the expected crash frequency with EB adjustment is the EB estimate of fatal and injury crashes (KABC on the KABCO scale). Figure 3 and Figure 4 represent the equations used in the process.

$$EB_{FI} = P_{FI} \times w + FI \times (1 - w)$$

Figure 3. Equation. Expected crash frequency with EB adjustment.

$$w = \frac{1}{1 + k \times P_{FI}}$$

Figure 4. Equation. Weighting factor for EB method.

Where,

EB_{FI} = EB expected number of KABC crashes over the five-year study period.

P_{FI} = predicted number of KABC crashes over the five-year period based on an SPF.[1]

FI = observed number of KABC crashes over the five-year period.

w = EB weight as shown in the above equation.

k = overdispersion parameter from the SPF.

[1] The research team estimated SPFs with five years of crash data (2010 through 2014) for four intersection types (i.e., three-legged signalized, four-legged signalized, three-legged stop-controlled, and four-legged stop-controlled).

EXCESS EXPECTED CRASH FREQUENCY WITH EB ADJUSTMENT

The excess expected crash frequency with EB adjustment is the difference between the expected crashes and the predicted crashes. Analysts rank sites from high to low based on the excess expected crash frequency. This measure accounts for potential RTM bias, differences in traffic volume among sites, and the nonlinear relationship between crash frequency and traffic volume. Furthermore, it establishes a threshold using the SPF to provide an indication of when sites are performing relatively well or not with respect to other similar sites.

For this study, the excess expected crash frequency with EB adjustment is the EB estimate of fatal and injury crashes (KABC on the KABCO scale) minus the predicted number of KABC crashes based on the applicable SPF. Figure 5 represents the equation used in the process.

$$EE_{FI} = EB_{FI} - P_{FI}$$

Figure 5. Equation. Excess expected crash frequency with EB adjustment.

Where,

EE_{FI} = expected excess of fatal and injury (KABC) crashes.

All other terms as previously defined.

The key to effective network screening is selecting an appropriate performance measure. More reliable performance measures account for RTM, differences in traffic volume, and crash severity.

Table 1 provides a summary of the four performance measures employed in this study with an indication of the ability to account for potential bias due to RTM and differences in traffic volume.

Table 1. Performance measures for network screening.

Performance Measure	Accounts for RTM Bias	Accounts for Traffic Volume
Crash frequency	No	No
Crash rate	No	Yes
Expected crash frequency with EB adjustment	Yes	Yes
Excess expected crash frequency with EB adjustment	Yes	Yes

Note: This information is based on Table 4-2 and subsequent discussion in the HSM.[1]

Table 2 provides a brief summary of the data requirements for the four network screening performance measures. The following is a description of each data element.

- **Crash Data**: Summary of crashes by site for the study period, crash type, and crash severity of interest.
- **Roadway Data**: Characteristics to define the facility type of interest for network screening. Intersection-level characteristics included area type (rural or urban), number of approaches, and type of traffic control.
- **Traffic Volume Data**: Summary of traffic volume by site for each year in the analysis.
- **SPF**: SPFs are required for specific performance measures to predict average crashes.

Table 2. Data requirements for network screening performance measures.

Performance Measure	Crash	Roadway	Traffic	SPF
Crash Frequency	●			
Crash Rate	●	Optional	●	
Expected Crash Frequency with EB Adjustment	●	●	●	●
Excess Expected Crash Frequency with EB Adjustment	●	●	●	●

4. METHODOLOGY

The research team simulated the development of projects for a safety program using the network screening results based on four different performance measures: crash frequency, crash rate, expected crash frequency with EB adjustment, and excess expected crash frequency with EB adjustment. The intent was to replicate a typical highway safety improvement program, focusing on fatal and severe injury crashes; however, only considering fatal and severe injury crashes would have presented issues in sample size. As such, the research team included fatal and all injury crashes as an approximation. The team then conducted desktop RSAs (i.e., review of all information virtually; no in-field site visits) to identify safety issues and propose countermeasures for each of the sites identified during the network screening. Finally, the team performed an economic analysis to estimate the benefit, cost, and overall benefit-cost ratio (BCR) for each suggested strategy, package of intersection improvements, and the program of projects generated from each network screening measure. The methodology is explained in more detail within the following sections.

DATA ACQUISITION

The team reached out to New Hampshire Department of Transportation (NHDOT) as the sample data source due to the team's familiarity with the intersection and crash dataset structure from previous projects. NHDOT provided the following datasets in geographic information system (GIS) format.

- Crash location, unit, and injury data from 2002 to 2014.
- Annual road inventory snapshot data from 2007 to 2016, including traffic volumes.
- Intersection inventory snapshots for available years 2010, 2012, 2014, and 2015.
- Intersection leg (approach) inventory snapshots for available years 2014 and 2015.

The research team used the most recent five years of data (2010 through 2014) in this study. This represents a period of consistent crash reporting and reflects relatively current conditions.

NETWORK SCREENING

After receiving the data, the first step in the analysis was conducting the network screenings. The research team decided to limit the number and types of sites in the analysis to yield more consistent results that are easily comparable. The two options included segment-based and intersection-based screening. There are many methods for screening roadway segments, and there is potential for substantial variation in geometrics, operations, and facility types. Further, the potential safety issues and recommended countermeasures may vary widely from site to site in a segment-based study.

Intersections offer a more consistent means for comparing the results across network screening measures. As such, the researchers limited the scope of the network screening to at-grade intersections between two-way major and minor roads. The team excluded intersections with one or more of the following characteristics from the study:

- The intersection was a ramp terminal (functional class of major or minor road coded as 'Principal Arterial - Interstate' or 'Principal Arterial - Other Freeway/Expressway').
- Major or minor road annual average daily traffic (AADT) was not available.
- Intersection type changed during the study period.
- Leg offset was over 20 feet.
- Number of legs was less than three (not an intersection) or greater than four (multi-leg intersection).
- Traffic control was something other than stop control or traffic signal.

The analysis included fatal and injury crashes coded as "At Intersection" or "Intersection Related". The research team used the GIS files to locate intersection crashes along the approaches as well as at the intersection. The research team assigned crashes to an intersection when a crash was within 125 feet of the intersection in urban areas and within 250 feet of the intersection in rural areas. The team did not consider crashes not geolocated to each site at this stage of the analysis.

The team developed an SPF for each facility type for fatal and injury crash severity only. Note FHWA's tool, *The Calibrator*, is useful for assessing the performance of SPFs. For each intersection, the research team calculated average major and minor road AADTs based on roadway inventory data from 2010 to 2014. Appendix A presents the SPFs for the selected intersection types.

The research team calculated the value of each screening performance measure for each intersection and ranked them in decreasing order. The network screening included all intersection types (i.e., urban and rural, three-legged and four-legged, and stop-controlled and signalized). The research team identified the top 20 sites from each screening. Appendix B contains the network screening results. Appendix C details the process used to conduct the network screening.

There was potential for 80 total sites given the top 20 sites from each of the four lists; however, there were only 39 unique sites due to overlap among the lists. Of the 39 unique sites, four sites appeared on all four network screening lists. The research team subsequently decided to remove those sites from the analysis because they would not provide any comparative difference between the screening measures, leaving 35 sites for further consideration. Appendix D provides a data summary of the 35 locations and a map showing the geographic distribution of sites across New Hampshire.

DIAGNOSIS

It is difficult to investigate the safety concerns at a site with raw, unprocessed data. In preparation for conducting RSAs, the research team developed collision diagrams and crash summaries for each of the 35 sites. These materials facilitated the subsequent RSAs and led to more standardized, complete, and efficient procedures.

Prior to summarizing the data, analysts queried the entire crash dataset to locate crashes that were missing standard geolocation information (global positioning system (GPS) coordinates). For these crashes, the research team used street names in the crash database to locate crashes with the respective site. The team added these crashes to the data tables for each site. Copies of the actual crash reports were not available; however, NHDOT's crash dataset provides all data from the crash report except the written description of the crash and crash diagram.

Collision diagrams provide a visualization of the crashes occurring at each intersection. Figure 6 provides an example of a collision diagram. The symbols represent the individual crashes, and different symbols indicate different crash types. The placement of the symbols indicates the general location and direction of the vehicles involved in the crash.

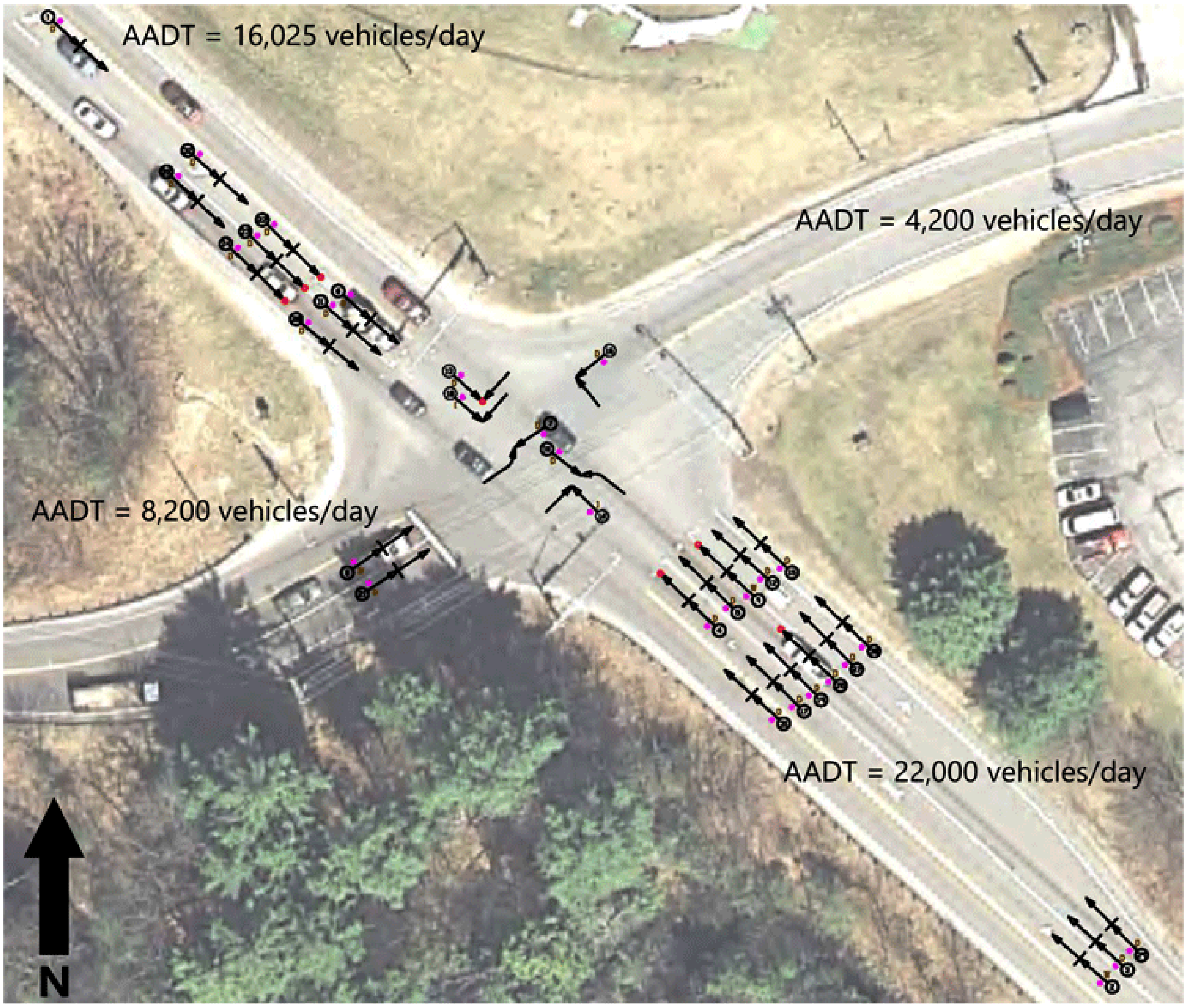


Figure 6. Chart. Example collision diagram. Aerial image source: NH GRANIT[(8)].

The team developed collision diagrams for each intersection, which aided in identifying patterns in crash type and location. The team used North Carolina Department of Transportation's collision diagram tool as a basis for the collision diagrams, and formatted the NHDOT crash data accordingly to work in that system. In these diagrams, symbols denote location, crash type, severity, lighting condition, and road condition. Data analysts manually placed crash symbols over an aerial image of the intersection using the crash data to determine vehicle direction, apparent contributing factors, pre-crash maneuvers, and point of impact. Several crashes had missing data and the analyst could not accurately place the crash on the diagram. Other crash types, such as "spill" or "other multiple-vehicle collision," were too ambiguous for inclusion in the diagrams. Refer to Appendix E for other examples of collision diagrams used in this study.

Analysts compiled crash summaries and other site data into packages for the RSAs. The components of the packages are the collision diagram, intersection leg AADTs, tables with crash summary statistics, and a table with relevant details of the specific crashes in the collision diagram. The team used the packages to characterize the intersection and identify crash patterns during the RSAs. Appendix E provides examples of the intersection packages. The research team selected the examples to represent the different area types (urban and rural) and traffic control types (stop and signal control). The team selected one intersection from each of the four network screening measures to provide diversity in the underlying method as well.

Road Safety Audits

The research team conducted desktop RSAs at each of the 35 intersections. The RSA team consisted of three experienced RSA analysts with backgrounds in highway safety, design, and operations. The RSA team was not involved in the network screening phase of the project, and the site rankings and screening methods for each site were not revealed until after the RSAs were completed to prevent any bias in the results.

The team performed desktop reviews, primarily collecting site observations using Google Earth™, Google Maps™, and Google StreetView™ imagery services. The goal of the RSAs was to relate prevalent crash patterns with observed site conditions to identify crash contributing factors. Subsequently, the RSA team developed a list of appropriate countermeasures to target the crash contributing factors. The team compiled notes for each site using a standard template, which included sections for prevalent crash types, general site characteristics and contributing factors, and suggested strategies. At this stage, the team recorded all potentially feasible countermeasure suggestions for each site given the countermeasure was applicable to the site conditions and targeted the identified safety issues. The team made a conscious effort to limit the recommended strategies to those that NHDOT might consider if they were conducting the review for a real project.

During the RSAs, the research team identified one site that was ranked in the network screening based on a single crash that, upon further review, was located incorrectly at the subject intersection (meaning that the intersection should have had zero crashes). The site was removed from further consideration. It was later determined that the crash rate performance measure selected this site for further investigation, further supporting previous discussions of the limitations of the crash rate measure.

Appendix F contains the results of the RSAs from the four intersections shown in Appendix E. These represent the typical nature of the observations and recommended strategies identified in this phase.

COUNTERMEASURE SELECTION

Following the RSAs, the research team provided the intersection summary packages and RSA results to NHDOT for review and confirmation. NHDOT provided comments for each site and provided additional insight into the field conditions and observations the RSA team may have missed without field visits. They also noted they had already conducted RSAs or were planning improvements at some of the intersections. In most cases, NHDOT confirmed the appropriateness of suggested strategies, and offered additional feedback on those that might not be appropriate. The research team excluded strategies deemed inappropriate by NHDOT from the economic analysis, but kept the strategies in the list of potential countermeasures with a note to document the team's consideration and reason for eliminating.

The research team incorporated NHDOT's comments into the RSA summary documents and refined the lists of potential countermeasures to consider in the economic analysis.

ECONOMIC ANALYSIS

The research team conducted an economic analysis of the potential strategies for each of the intersections. The economic analysis resulted in a BCR for each strategy (given complete information) and a BCR for the intersection as a whole. The economic analysis included identifying the following information for each strategy:

- CMF.
- Estimated benefit (i.e., present value benefit).
- Estimated cost (i.e., present value cost).
- Benefit-cost ratio.

Crash Modification Factors

The research team identified CMFs for approximately 35 strategies from the CMF Clearinghouse, the *Signalized Intersections Informational Guide: Second Edition*, and *Intersection Safety: A Manual for Local Rural Road Owners*.[9,10] Additionally, CMFs for Intersection Conflict Warning Systems (ICWS) and Red Light Indicator Lights (RLILs) came from recently developed reports from the research team.[11,12] Refer to the CMF Clearinghouse for guidance on searching for and selecting an appropriate CMF.

The research team identified CMFs for total crashes, individual crash severities, and individual crash types, and prioritized the CMFs for application in the economic analysis. If CMFs existed for crash types targeted by the strategy, the research team used these specific CMFs in the economic analysis. For example, the research team used the disobeyed signal crash CMF for installation of RLILs and the angle crash CMF for installation of a traffic signal. If CMFs were not available for specific crash types, the research team used a combination of CMFs stratified by crash severity. For example, the research team used the CMF for fatal and injury crashes as well as the CMF for property damage only crashes to estimate the benefit of upgrading signal heads and installing reflective backplates. In other cases, where CMFs were not available by crash type or severity, the research team used the CMF for total crashes in the economic analysis.

When selecting CMFs, the research team used the most applicable CMF, considering the number of intersection legs, area type, and existing traffic control type. For example, the research team identified and applied different CMFs for installing a traffic signal at an urban, four-leg, all-way stop-control intersection and installing a traffic signal at a rural, four-leg, two-way stop-control intersection.

Some strategies were too specific to identify applicable CMFs. For example, a CMF did not exist for removing fixed objects at one intersection. Instead, the research team used the CMF for removing fixed objects in general, which included both segment and intersection locations. In other cases, there were no applicable CMFs for the strategy of interest. In these cases, the research team was not able to estimate the potential benefit, and eliminated these strategies from the remainder of the economic analysis.

Appendix G presents the CMFs used during the economic analysis.

Estimated Benefits

The research team estimated the annual benefit as the annual change in crashes multiplied by the average crash cost as shown in Figure 7:

$$A = C_{without} * (1 - CMF) * CC$$

Figure 7. Equation. Estimated annual benefit.

Where:

> A = estimated annual benefit.
>
> $C_{without}$ = estimated annual crashes without treatment. For this exercise, the research team estimated the annual crashes without treatment as the number of observed crashes before treatment divided by the number of years in the before period.
>
> CMF = applicable crash modification factor.
>
> CC = average crash cost.

In many cases, the research team proposed strategies for specific approaches or intersection quadrants (e.g., trim vegetation in the northwest quadrant to improve intersection sight distance). The economic analysis only included crashes specifically associated with the approach or approaches targeted by the strategy. For example, if an agency improves intersection sight distance in the northwest quadrant, the improvement will likely only affect crashes on the adjacent approaches (i.e., north and west legs of the intersection). For strategies such as installing a roundabout, the improvement is likely to affect crashes on all approaches.

The research team used crash costs by crash type and severity level as appropriate based on the CMF. For costs by injury level (K, A, B, C, and O on the KABCO scale), the research team used the NHDOT 2013 *HSIP Guidelines*.(13) For costs by crash type, the research team used the FHWA *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*. (14) Note the crash costs from the FHWA report reflect 2001 values, resulting in conservative calculated benefits.

The project team estimated the present value benefit (PVB) based on the equation in Figure 8.

$$PVB = A * \frac{(1+i)^n - 1}{i * (1+i)^n}$$

Figure 8. Equation. Estimated present value benefit.

Where:

PVB = present value benefit.

i = discount rate.

n = service life.

Note the research team assumed a discount rate of five percent for this analysis. The research team estimated the service life for each strategy based on information from previous RSAs and input from NHDOT. The service life ranged from 3 years for strategies such as striping and trimming vegetation to 25 years for more permanent strategies (e.g., installing a roundabout or turn lane). Table 3 provides a summary of the service life for strategies included in the economic analysis.

Table 3. Service life for strategies.

Service Life (years)	Strategies
3	Install Reflective Tape on Backplates, Trim Vegetation and Remove Trees, Install Crosswalk, Install Stop Bars
5	Install Red Light Indicator Light (RLIL), Install Reflective Backplates
7	Resurface to Enhance Pavement Friction, Install High Friction Surface Treatment, Add Curbing with Sidewalk, Install Supplemental STOP AHEAD Pavement Markings
10	Install Intersection Conflict Warning System (ICWS)
12	Upgrade Pedestrian Signals to Countdown Signals, Add Signal Head, Upgrade Signal Heads, Convert Phasing from Permissive to Protected-Permissive, Coordinate Signals, Retime Signals, Implement Split Phasing
15	Install Intersection Lighting, Install Second Stop Sign, Convert to All-Way Stop, Install Advance Intersection Warning Sign with Street Name, Install No Left Turn and No Right Turn Signs, Prohibit RTOR with Signs, Add Lane Designation through Signing at Intersection and in Advance, Prohibit Parking to Improve Sight Distance through Signing and Striping, Upgrade Signing
20	Install Traffic Signal
25	Install Right-Turn Lane, Channelize Right Turn, Install Left-Turn Lane, Extend Turn Lanes, Convert Thru Lane to Exclusive Left Turn Lane, Install Roundabout, Improve Intersection Skew, Install Offset Left Turn Lanes, Convert Median Opening from Full Movement to Leftover, Reduce Embankment, Relocate Fixed Objects further from Intersection

Estimated Costs

The research team estimated construction costs for each of the strategies based on various sources. NHDOT provided cost estimates for some strategies, and the team searched the internet and other State DOT websites to estimate the cost of others. Construction costs include the cost of materials and installation. In some cases, such as for ICWS, the research team was able to identify and include the annual maintenance cost. In other cases, the research team did not include annual maintenance costs. In most cases, the annual maintenance costs are negligible, such as for RLILs or reflective backplates. For these strategies, agencies would typically replace the unit at the end of its useful service life.

Appendix H provides a summary of cost estimates used for the economic analysis.

Benefit-Cost Ratios

The research team calculated the BCR for each strategy as the PVB divided by the present value cost (PVC) (i.e., construction cost plus present value of maintenance costs) as shown in Figure 9.

$$BCR = \frac{PVB}{PVC}$$

Figure 9. Equation. Benefit-cost ratio.

Additionally, the research team combined multiple strategies to develop intersection improvement packages. In some cases, there were multiple potential options to address a specific safety concern. For example, strategies such as ICWS, a roundabout, or a traffic signal are all viable options to address issues related to right-angle crashes at a two-way stop-controlled intersection. In these cases, the team selected the most cost-effective individual strategy as the primary improvement. The research team included other supporting improvements such as enhancing signing and striping, trimming vegetation, and installing intersection lighting as appropriate with the primary strategy. For each intersection improvement package, the research team summed the present value benefits and costs for the individual strategies, and divided the total benefit by the total cost to estimate the overall BCR.

Appendix I provides a summary of the economic analysis for each intersection improvement package, including a list of strategies included in the analysis, the network screening performance measure from which the site was identified, the present value benefit, the present value cost, and the BCR. For example, the research team suggested the following strategies for site 4798: install right-turn lane, resurface to enhance pavement friction, and extend turn lanes to reduce spillover. The estimated PVB for this combination of strategies at this location is $1,214,767 with a PVC of $235,000, resulting in a BCR of 5.17. Again, the research team excluded strategies with no CMF information from the economic analysis.

5. RESULTS

From the economic analysis, the research team aggregated intersection improvement packages with respect to the four performance measures used for network screening. Again, the four performance measures included crash frequency, crash rate, EB expected crashes, and EB excess expected crashes – all for the fatal and non-fatal injury severity level. The economic analysis included 35 intersection improvement packages, and each performance measure includes 16 intersections. Some intersections appeared in multiple performance measure lists, and four intersections appeared in all four screening lists, which the team removed from the analysis. One site included a single crash, and that crash was located incorrectly at the subject intersection (meaning the intersection should have had zero crashes). The team excluded the site from further analysis and later associated the site with the crash rate performance measure, further supporting previous discussions of the limitations of the crash rate measure.

Table 4 provides a summary of the number of sites that overlap among performance measures. For example, there were two sites on the KABC crash frequency list that also appeared on the KABC crash rate list. Appendix B presents more details about the screening results for each intersection. There was generally limited overlap between the crash rate and other measures, and no overlap in sites between the crash rate and EB expected measures. The greatest overlap is between the EB expected and crash frequency measures (14 of 18 sites). There is also substantial overlap among the EB expected excess, EB expected, and crash frequency measures.

Table 4. Number of sites identified by multiple screening performance measures.

Network Screening Performance Measure	Crash Frequency	Crash Rate	EB Expected	EB Expected Excess
Crash Frequency	--	--	--	--
Crash Rate	2	--	--	--
EB Expected	14	0	--	--
EB Expected Excess	10	5	8	--

Table 5 presents the results of the economic analysis by performance measure, including the total estimated benefits, total estimated costs, and overall BCR across all related intersections. The following are key observations from the results:

- **Highest overall benefit:** The **EB expected excess** measure produced the list of sites with the highest overall benefit ($22,014,117 in total estimated benefits).
- **Highest return on investment:** The **EB expected** measure produced the list of sites with the highest return on investment (7.08 BCR).
- **Lowest overall benefit:** The **crash rate** measure produced the list of sites with the lowest (by a large margin) overall benefit ($8,106,398 in total estimated benefits).
- **Lowest return on investment:** The **crash rate** measure produced the list of sites with the lowest (by a large margin) return on investment (2.39 BCR).

While the EB expected excess measure produced the list of sites with the greatest overall benefit and the EB expected measure produced the list of sites with the greatest return on investment, all four measures produced a list of sites that could be improved cost-effectively (i.e., BCR greater than 1.0). Further, the EB measures require appropriate SPFs, which may not be available to some agencies. When the EB-based measures are infeasible, it appears the crash frequency measure provides a reasonable alternative. Specifically, the crash frequency measure resulted in the second greatest overall benefit and the second greatest BCR.

Table 5. BCR results by network screening performance measure (all sites).

Network Screening Performance Measure	Estimated Benefit	Estimated Cost	BCR
Crash Frequency	$17,942,270	$2,699,700	6.65
Crash Rate	$8,106,398	$3,396,450	2.39
EB Expected	$15,671,311	$2,213,950	7.08
EB Expected Excess	$22,014,117	$3,891,250	5.66

Table 6 presents the average, minimum, and maximum values of KABC crashes and traffic volume for the sites identified by each performance measure. The crash frequency and EB expected measures identified sites with the highest average KABC crashes and traffic volume. The EB expected excess measure identified sites with slightly lower average KABC crashes and traffic volumes. The crash rate measure identified sites with the lowest average KABC crashes and traffic volume.

Table 6. BCR results by network screening performance measure (all sites).

Network Screening Performance Measure	Average KABC Crashes (Min, Max)	Average Trasffic Volume (Min, Max)
Crash Frequency	10.9 (6, 16)	22,795 (7,600, 36,630)
Crash Rate	5.4 (1, 10)	5,236 (128, 9,864)
EB Expected	10.9 (6, 16)	26,395 (15,312, 48,210)
EB Expected Excess	10.3 (6, 16)	15,585 (6,290, 36,630)

Table 7 presents similar results by performance measure, but only includes results for the sites exclusive to a single performance measure, or in other words only the sites that were ranked on that network screening list and no others. This analysis helps to examine more cleanly any differences in the types of sites that might be favored by each method and more highly influence the comparison of methods. The crash rate measure includes the most sites (11) exclusive to a single list, followed by EB expected excess (3) and EB expected (2). Note there are no exclusive sites associated with the crash frequency measure. The table presents results on a per site basis (i.e., estimated benefit per site and estimated cost per site) due to the difference in the number of sites.

While the sample size is too small to draw firm conclusions, the following are observations based on the summary of exclusive sites.

- The crash rate measure appears to favor sites that require nearly as much cost to address the safety issues as the potential benefit. This is likely associated with the level of potential benefit at sites associated with the crash rate measure. Specifically, many of these sites experience relatively few crashes per year, but rank high on the crash rate list due to relatively low traffic volumes.
- The EB expected measure appears to favor sites with potential for a higher return on investment (i.e., the highest BCR). While the average estimated benefit per site is the lowest of all measures, the cost to achieve these benefits is also the lowest, resulting in a high BCR.
- The EB expected excess measure appears to favor sites with the highest potential for improvement. While these sites tend to require the highest average cost to address the underlying safety issues, these sites also resulted in the highest estimated benefit per site and the second highest BCR.

Table 7. BCR results by network screening performance measure (exclusive sites).

Network Screening Performance Measure	Estimated Benefit (per site)	Estimated Cost (per site)	BCR	Sites
Crash Frequency	--	--	--	0
Crash Rate	$377,296	$229,827	1.64	11
EB Expected	$94,348	$12,675	7.44	2
EB Expected Excess	$2,461,510	$437,333	5.63	3

6. SUMMARY

The objective of this study was to evaluate the effectiveness of four common network screening performance measures in producing the greatest estimated net benefits of projects and the greatest return on investment. To accomplish this objective, the study simulated the planning of projects at sites identified by the following four network screening performance measures using statewide intersection data from New Hampshire.

- Crash frequency.
- Crash rate.
- EB expected crash frequency.
- EB excess expected crash frequency.

The research team acquired data from NHDOT and refined the datasets to intersections, crashes, and traffic volumes for the 2010 to 2014 time period. The final dataset included only stop-controlled or signalized intersections of two-way roads with three or four legs. The study also included only those intersections with traffic volume data on the major and minor roads. The research team developed SPFs to predict fatal and injury crashes for each of the following facilities types represented in the data.

- 3-leg signalized intersections.
- 4-leg signalized intersections.
- 3-leg stop-controlled intersections.
- 4-leg stop-controlled intersections.

The research team identified the top 20 sites based on each performance measure. Of the 80 sites among the four lists, there was considerable overlap and only 39 unique intersections. The research team identified four sites that appeared on all four lists. The team excluded these sites from the analysis because they are redundant and would add the same magnitude of benefit and cost to each of the four performance measures. In total, the team investigated 35 intersections.

The research team conducted in-office road safety audits to identify crash contributing factors, and then developed targeted strategies to address the underlying safety issues. Based on a review and feedback from NHDOT staff, the team developed intersection improvement packages for 35 sites. The team conducted an economic analysis of the final selection of projects and packages of countermeasures and compared the results by network screening measure. Note the network screening measure remained secret to avoid potential bias in diagnosing and selecting countermeasures during subsequent steps.

The results for the overall sets of projects indicate the EB excess expected and EB expected measures provide the highest overall benefit and overall return on investment, respectively. The crash frequency measure provided the second highest overall benefit and return on investment. The crash rate method produced the list of sites with the lowest overall benefit and lowest overall return on investment.

The research team subsequently compared the economic effectiveness per site among the performance measures for the sites exclusive to each list (i.e. the sites ranked by that measure and no others). The objective of this method was to examine more cleanly any differences in the types of sites that might be favored by each method and more highly influence the comparison of methods. Due to the overlap in sites between the crash frequency and EB methods, there was limited sample size in this analysis.

The results indicate the EB-based measures and the crash frequency measure provide relatively high and comparable benefits and return on investment, particularly when compared to the crash rate measure. The question remains whether it is worthwhile to employ the EB expected measure over crash frequency for network screening. The answer depends on the cost to implement the EB expected measure and the difference in overall benefits given a fixed budget. If an agency can implement EB expected measure for less than the difference in benefits between the EB expected and crash frequency measure, then it is worthwhile to pursue the more reliable EB expected measure.

Based on this dataset, which is limited to intersections in New Hampshire, the results suggest the EB expected measure provides the greatest return on investment (BCR = 7.08) and the crash frequency measure provides the second greatest return on investment (BCR = 6.65). Assuming a $10M safety program budget, and assuming the BCRs hold for the entire program, the difference in annual benefits between the EB expected and crash frequency measure would be $4.3M ($70.8M - $66.5M). An agency could likely implement the EB expected network screening measure for less than $4.3M per year. The associated costs would include a basic roadway inventory of all centreline miles (i.e., the Model Inventory Roadway Elements—Fundamental Data Elements), an intersection inventory, development or calibration of intersection SPFs, and programming to integrate the EB expected measure in the existing network screening process. Any software upgrades to conduct network screening would be the same regardless of the performance measure.

This guide is meant to assist highway safety practitioners and researchers in selecting network screening measures based on their ability to produce effective projects. Although the study only estimates the effectiveness of potential intersection projects in New Hampshire, the results provide some insight into the effectiveness of the various screening measures. In summary, the EB expected measure provided the highest return on investment, the crash frequency measure provided the second highest return on investment, and the crash rate measure fell woefully short of the other three measures included in this study. Based on these results, it is likely that agencies can implement the EB expected measure for less than the difference in benefits between the EB expected and crash frequency measures. Further, the crash frequency measure provides a reasonable alternative in the interim while an agency prepares for more reliable methods.

7. FUTURE RESEARCH

The analysis conducted in this study has a number of potential limitations. First, it only included common types of intersections with known traffic volumes using a simple ranking method. The majority of intersections in New Hampshire do not have traffic volume data for minor roads, and those likely have a lower number of crashes than those with known volume data on all legs. The sample did not include multi-leg (5+) and intersections with traffic control type other than signal or stop control. The overall sample may have characteristics that are favored by one or more of the performance measures in screening. However, the same sites were screened by each measure and most sites ranked highly on more than one screening.

The number of sites meeting the criteria for the screening represented a small proportion of all intersections in New Hampshire. Most sites did not have traffic volume data recorded for the minor roads, which precluded them from analysis with all measures except crash frequency. This is a general limitation of data availability. It seems this may not be a concern, however, because the sites selected by KABC crash frequency were often also ranked highly by the EB methods and still provided a high level of economic benefit. Another potential data limitation for users is the lack of SPFs, which prevents analysis by the EB measures. Again, the KABC crash frequency measure appears to be a reasonable alternative. The crash rate method clearly did not consistently identify sites that are great candidates for spot safety improvements.

The network screening was limited to intersections, which are relatively discrete locations. The analysis did not include segments, which can vary in length depending on the crash density and screening measure. It is unclear how the different segment lengths and screening methods (e.g. peak searching method and sliding window method) would influence the results, if at all. The analysis also focused on data from New Hampshire. There is a need to conduct similar studies with datasets from other States to determine if the results are consistent.

It is possible that a similar evaluation of screening measures following the same methodology, but with total crashes rather than fatal and injury, would yield different results. The evaluation conducted for this study focused on the effectiveness of each measure in achieving goals of safety programs – to reduce fatal and severe injury crashes. Only considering fatal and severe injury crashes would have presented issues in sample size, so the research team included fatal and all injury crashes as an approximation. Further research is needed to determine if the screening measures can produce similar results when based on total crashes.

Finally, gaps in existing CMFs limited the economic analysis of potential strategies. Specifically, the team only included those countermeasures with applicable CMFs in the economic analysis. There is a need to develop additional CMFs to help fill the gaps. The following are strategies for which CMFs were not available for this analysis: enhance signal enforcement, add lane use pavement markings, optimize signal timing, improve access management, realign crosswalk location, install advance street name on intersection warning sign, and install skip lines to continue edge line (edge line extensions).

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), *Highway Safety Manual*, First Edition, Washington, DC, 2010.
2. Srinivasan, R., F. Gross, B. Lan, and G. Bahar. *Reliability of Safety Management Methods: Network Screening*, Report No. FHWA-SA-16-037, Federal Highway Administration, Washington, D.C., November 2016.
3. Srinivasan, R., G. Bahar, and F. Gross. *Reliability of Safety Management Methods: Diagnosis*, Report No. FHWA-SA-16-038, Federal Highway Administration, Washington, D.C., November 2016.
4. Bahar, G., R. Srinivasan, and F. Gross. *Reliability of Safety Management Methods: Countermeasure Selection*, Report No. FHWA-SA-16-039, Federal Highway Administration, Washington, D.C., August 2016.
5. Srinivasan, R., F. Gross, and G. Bahar. *Reliability of Safety Management Methods: Safety Effectiveness Evaluation*, Report No. FHWA-SA-16-040, Federal Highway Administration, Washington, D.C., March 2016.
6. Fixing America's Surface Transportation Act, Highway Safety Improvement Program [23 U.S.C. 148(b)].
7. Hauer, E. (1997), *Observational Before-After Studies in Road Safety*, Pergamon, Elsevier Science Ltd.
8. New Hampshire Geographically Referenced Analysis and Information Transfer System (NH GRANIT). Available for download at: http://www.granit.unh.edu/data/downloadfreedata/category/databycategory.html.
9. Chandler, B., M. Myers, J. Atkinson, T. Bryer, R. Retting, J. Smithline, J. Trim, P. Wojtkieicz, G. Thomas, S. Venglar, S. Sunkari, B. Malone, and P. Izadpanah. *Signalized Intersections Informational Guide*, Second Edition. Report No. FHWA-SA-13-027, Federal Highway Administration, Washington, D.C., July 2013.
10. Golembiewski, G.A. and B. Chandler. *Intersection Safety: A Manual for Local Rural Road Owners*, Report No. FHWA-SA-11-08, Federal Highway Administration, Washington, D.C., 2011.
11. Himes, S., F. Gross, K. Eccles, and B. Persaud. *Safety Evaluation of Intersection Conflict Warning Systems*, Report No. FHWA-HRT-16-035, Federal Highway Administration, McLean, VA, June 2016.
12. Himes, S., F. Gross, B. Persaud, and K. Eccles. Safety Evaluation of Red Light Indicator Lights (RLILs), Final Report, Federal Highway Administration, McLean, VA, May 2016.
13. New Hampshire Department of Transportation (NHDOT). *Highway Safety Improvement Program Guidelines*, 2013.
14. Council, F., Zaloshnja, E., Miller, T., and Persaud, B. *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*. Report No. FHWA-HRT-05- 051, Federal Highway Administration, McLean, VA, 2005. Available online at: http://www.fhwa.dot.gov/publications/ research/safety/05051/.
15. Aerial imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Available online at: http://goto.arcgisonline.com/maps/World_Imagery.
16. Google®, Inc. (2016) *Pedestrians in concrete median from Google Maps/Earth™*. Available at: https://goo.gl/maps/eNVQDJ2gY6H2. Accessed October 31, 2016.

APPENDIX A: SAFETY PERFORMANCE FUNCTIONS

The research team used SAS to estimate SPFs for intersections with two-way roads on both the major and minor road approaches. The team used generalized linear modeling to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. In specifying a negative binomial error structure, the model estimates the dispersion parameter (k). For a given dataset, smaller values of k indicate relatively better models (i.e., less dispersion).

The following equation represents the functional form of the SPFs, which is consistent with the standard practice for developing these models:

$$Y = \exp(intercept + a_1X_1 + a_2X_2 + \cdots \ldots . a_nX_n)$$

Where,

Y = predicted number of KABC crashes over a 5 year period.

Intercept and a_i = regression model parameters.

X_i = geometric and operational characteristics.

In the models documented below, lg_Total_AADT is the natural logarithm of total AADT, lg_Maj_AADT is the natural logarithm of the major road AADT, and lg_Min_AADT is the natural logarithm of the minor road AADT. Each SPF includes either total entering traffic volume or separate terms for the major and minor road traffic volume. For each SPF, the team determined the appropriate functional form based on cumulative residual (CURE) plots and other goodness-of-fit measures such as the dispersion parameter. In addition to the AADT term(s), the research team included an indicator variable to represent the area type (rural or urban); however, area type was not significant in any of the models.

The remainder of this section presents the model results for the following four SPFs:

1. 3-leg signalized intersections.
2. 4-leg signalized intersections.
3. 3-leg stop-controlled intersections.
4. 4-leg stop-controlled intersections.

SPF FOR 3-LEG SIGNALIZED INTERSECTIONS

250 KABC crashes at 108 intersections (15 in rural area; 93 in urban area)

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-8.6133	2.8701	-14.2386	-2.9880	9.01	0.0027
lg_Total_AADT	1	0.9453	0.2870	0.3828	1.5078	10.85	0.0010
Dispersion	1	0.5463	0.1495	0.3195	0.9342		

SPF FOR 4-LEG SIGNALIZED INTERSECTIONS

777 KABC crashes at 190 intersections (24 in rural area; 166 in urban area)

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-4.1821	1.3370	-6.8025	-1.5616	9.78	0.0018
lg_Total_AADT	1	0.5650	0.1351	0.3001	0.8298	17.48	<.0001
Dispersion	1	0.3922	0.0695	0.2772	0.5550		

SPF FOR 3-LEG STOP-CONTROLLED INTERSECTIONS

402 KABC crashes at 824 intersections (388 in rural area; 436 in urban area)

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-11.6938	0.9518	-13.5593	-9.8283	150.95	<.0001
lg_Total_AADT	1	1.2144	0.1034	1.0117	1.4171	137.87	<.0001
Dispersion	1	0.9271	0.1795	0.6343	1.3550		

SPF FOR 4-LEG STOP-CONTROLLED INTERSECTIONS

444 KABC crashes at 276 intersections (119 in rural area; 157 in urban area)

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-8.6153	1.1452	-10.8599	-6.3707	56.59	<.0001
lg_Maj_AADT	1	0.6485	0.1351	0.3838	0.9133	23.05	<.0001
lg_Min_AADT	1	0.4674	0.0992	0.2730	0.6618	22.21	<.0001
Dispersion	1	0.9143	0.1573	0.6526	1.2811		

APPENDIX B: NETWORK SCREENING RESULTS

Table 8 through Table 11 present the ranked site lists from the network screening analyses along with the count of crashes by severity. For intersections identified by multiple network screening measures, the tables show the intersection identification number (NH ID) in bold. In each table, the final column indicates other screening lists on which the intersection appears, if applicable.

The KABC crash frequency often do not match the crash counts shown in subsequent information such as the intersection packages in Appendix D. The network screening used only crashes that NHDOT had geolocated in their GIS data. Prior to the data processing that led to the RSAs, the research team used additional data, such as street names from the crash attribute data, to identify crashes that occurred at each intersection.

Table 8. Top 20 intersections by KABC crash frequency.

Rank	NH ID	K	A	B	C	Total	Other Top 20 Lists
1	**28289**	0	1	13	9	28	Rate, EB Expected, EB Expected Excess
2	**46353**	0	1	7	8	17	EB Expected, EB Expected Excess
3	**66065**	0	0	4	2	15	EB Expected, EB Expected Excess
4	**43086**	0	0	8	4	13	EB Expected, EB Expected Excess
5	**16729**	0	2	5	5	13	EB Expected, EB Expected Excess
6	**65699**	0	0	10	3	13	Rate, EB Expected, EB Expected Excess
7	**20710**	0	0	7	5	12	EB Expected, EB Expected Excess
8	**64655**	0	1	3	4	12	Rate, EB Expected, EB Expected Excess
9	**58377**	0	0	9	2	12	Rate, EB Expected, EB Expected Excess
10	**58744**	0	1	8	2	11	EB Expected
11	**31393**	0	2	9	3	11	EB Expected, EB Expected Excess
12	**69212**	0	2	5	3	10	EB Expected, EB Expected Excess
13	**47849**	0	1	8	2	10	EB Expected
14	**47078**	0	1	5	4	10	EB Expected
15	**2194**	0	0	8	5	10	EB Expected
16	**4798**	0	1	1	5	10	EB Expected
17	**71726**	0	0	9	6	10	EB Expected, EB Expected Excess
18	**41342**	0	0	7	2	10	Rate, EB Expected Excess
19	**32239**	1	2	5	1	10	Rate, EB Expected Excess
20	**62679**	0	1	4	3	9	EB Expected

Table 9. Top 20 intersections by KABC rate.

Rank	NH ID	K	A	B	C	Total	Other Top 20 Lists
1	37259	0	0	1	0	1	-
2	*14404	0	0	1	0	1	-
3	**58377**	0	0	9	2	12	Frequency, EB Expected, EB Expected Excess
4	**32239**	1	2	5	1	10	Frequency, EB Expected Excess
5	3468	0	1	7	2	8	-
6	**64655**	0	1	3	4	12	Frequency, EB Expected, EB Expected Excess
7	**10677**	0	0	4	4	8	EB Expected Excess
8	57403	0	0	2	1	2	-
9	**62868**	0	0	3	3	8	EB Expected Excess
10	27897	0	0	3	1	5	-
11	75487	0	0	3	1	4	-
12	**65699**	0	0	10	3	13	Frequency, EB Expected, EB Expected Excess
13	65409	0	0	5	1	7	-
14	**8944**	0	0	5	3	8	EB Expected Excess
15	24673	0	0	6	0	8	-
16	67283	0	1	2	2	5	-
17	15305	0	0	1	0	1	-
18	**28289**	0	1	13	9	28	Frequency, EB Expected, EB Expected Excess
19	**41342**	0	0	7	2	10	Frequency, EB Expected Excess
20	52047	0	0	0	1	1	-

*Note: The single crash at intersection 14404 was incorrectly located.

Table 10. Top 20 intersections by EB expected KABC.

Rank	NH ID	K	A	B	C	Total	Other Top 20 Lists
1	**28289**	0	1	13	9	28	Frequency, Rate, EB Expected Excess
2	**46353**	0	1	7	8	17	Frequency, EB Expected Excess
3	**43086**	0	0	8	4	13	Frequency, EB Expected Excess
4	**58744**	0	1	8	2	11	Frequency
5	**16729**	0	2	5	5	13	Frequency, EB Expected Excess
6	**20710**	0	0	7	5	12	Frequency, EB Expected Excess
7	**64655**	0	1	3	4	12	Frequency, Rate, EB Expected Excess
8	**69212**	0	2	5	3	10	Frequency, EB Expected Excess
9	**66065**	0	0	4	2	15	Frequency, EB Expected Excess
10	**62679**	0	1	4	3	9	Frequency
11	**47849**	0	1	8	2	10	Frequency
12	**65699**	0	0	10	3	13	Frequency, Rate, EB Expected Excess
13	19266	0	0	6	3	9	-
14	**47078**	0	1	5	4	10	Frequency
15	**58377**	0	0	9	2	12	Frequency, Rate, EB Expected Excess
16	**2194**	0	0	8	5	10	Frequency
17	**31393**	0	2	9	3	11	Frequency, EB Expected Excess
18	**4798**	0	1	1	5	10	Frequency
19	6421	0	0	4	4	9	-
20	**71726**	0	0	9	6	10	Frequency, EB Expected Excess

Table 11. Top 20 intersections by EB expected excess KABC.

Rank	NH ID	K	A	B	C	Total	Other Top 20 Lists
1	**28289**	0	1	13	9	28	Frequency, Rate, EB Expected
2	**46353**	0	1	7	8	17	Frequency, EB Expected
3	**66065**	0	0	4	2	15	Frequency, EB Expected
4	**64655**	0	1	3	4	12	Frequency, Rate, EB Expected
5	**58377**	0	0	9	2	12	Frequency, Rate, EB Expected
6	**43086**	0	0	8	4	13	Frequency, EB Expected
7	**16729**	0	2	5	5	13	Frequency, EB Expected
8	**65699**	0	0	10	3	13	Frequency, Rate, EB Expected
9	**32239**	1	2	5	1	10	Frequency, Rate
10	**20710**	0	0	7	5	12	Frequency, EB Expected
11	**31393**	0	2	9	3	11	Frequency, EB Expected
12	**69212**	0	2	5	3	10	Frequency, EB Expected
13	23133	1	0	6	1	8	-
14	**62868**	0	0	3	3	8	Rate
15	**8944**	0	0	5	3	8	Rate
16	**41342**	0	0	7	2	10	Frequency, Rate
17	**10677**	0	0	4	4	8	Rate
18	41420	0	0	7	1	8	-
19	8681	0	0	5	7	8	-
20	**71726**	0	0	9	6	10	Frequency, EB Expected

APPENDIX C: NETWORK SCREENING PROCESS

Appendix C provides an overview of the data manipulation, merging, and filtering to facilitate the network screening process. The following sections describe the data files and data fields as well as the thought process to create the network screening file, including linking data elements from different files such as the intersection file, intersection leg file, and crash file. Note the data were manipulated and merged using ArcGIS as NHDOT provided the data in this format.

PROCESS TO CREATE NETWORK SCREENING FILE

1. Start with the 2015 intersections list in GIS.
2. List all unique IDs for the major and minor roads (up to 2 of each).
    a. Use intersection leg file (includes ID to identify associated intersection, a field for major or minor road, and a field relating the leg to the approaching road ID).
3. Merge AADT and number of lanes from road inventory file based on road ID in leg file.
4. Develop intersection level file by aggregating the leg data
    a. Start with NH_INTERSECTIONS_2015 as the basis. Join other data to create the master intersection file.
5. Drop intersections if:
    a. Legs are ramp related – *This was done as part of the leg data assembly*
    b. Changes occur for any of the following characteristics during the 5-year period. If elements are not available in earlier years, assume they didn't change.
        i. Roadway – *dropped 670 intersections for leg/road data consistency issues and ramp presence.*
        ii. Intersection – *dropped 212 intersections for which the number of legs (IntersectionType1) variable changed from 2010 to 2015. Did not drop based on a change in the value for Traffic Control. Changes might be due to updating the database rather than an actual change of traffic control.*
    c. Missing major and/or minor AADT – *dropped 40,493 intersections because they did not have both major and minor AADT.*
    d. Have fewer than 3 or more than 4 legs – *dropped 12 intersections for this reason*
    e. Are not stop-controlled or signalized intersections (Intersection file, Field: TrafficControl1) – *dropped 85 intersections for this reason, but counted flashing beacons as stop controlled.*
    f. Have a leg offset over 20 feet (Intersection file, field: Offset Intersection) – *dropped 16 intersections for this reason.*
6. Assemble intersection characteristics for latest year.
    a. Intersection ID (AgencyID)
    b. Number of legs (Leg Count and IntersectionType1 in 2015)
    c. Traffic control (TrafficControl1 in 2014)
    d. One-way vs two-way (Operation Way in Leg file for 2015)
    e. Number of lanes on major (using Major Rd ID and link to Asset Road file)
    f. Rural vs urban (Area Type)
    g. Major Rd class – state vs non-state (jurisdiction from 2015 intersection file)
    h. Lat/long or x/y (in intersection file)

7. Assemble AADT
    a. Major AADT and Minor AADT – average of what is available
8. Assemble crash counts by year for each intersection in the selected subset
    a. Crashes associated to nearest intersection, 250 ft buffer. Use NEAR function.
    b. Use all intersections for this, not subset for the screening.
    c. Fatal + injury only

LINKING INTERSECTION FILE TO INTERSECTION LEG FILE

"Agency ID" is the intersection ID. This field exists on both the intersection and leg files and can be used to link the two. The following is an overview of the intersections versus legs.

- There are 42,223 intersections in the 2015 file and there are 133,160 intersection legs in the 2015 file. So, this is approximately 3.15 legs per intersection, which would indicate there are legs for every intersection point.
- A spatial join of intersection legs to intersections (50 ft buffer) showed that there were some intersections that only joined to one leg, and some that only joined to two legs. This may indicate that some intersections will not have full leg information.
- Attribute join indicated that some intersections don't have leg data.

LINKING MAJOR AND MINOR AADT TO INTERSECTIONS

The only AADT field is in the roadway file

- ASSET_2015_ROADS only has 2012 volumes
- ASSET_2014_ROADS only has 2012 volumes
- ASSET_2013_ROADS only has 2011 volumes
- ASSET_2012_ROADS only has 2010 volumes
- ASSET_2011_ROADS only has 2009 volumes
- ASSET_2010_ROADS has an AADT field, but no field indicating which year it's from

How to connect these AADTs to the intersections other than spatial join:

- In the Intersection file, there is UNIQUE_ID_MAJOR and UNIQUE_ID_MINOR.
- In the roadway (ASSETS) layer, there is UNIQUE_ID.
- Join on these variables, but roadway segments break at intersections, so each leg is a separate segment with UNIQUE_ID. The intersection file chooses one randomly as the UNIQUE_ID_MAJOR.

The road, intersection, and intersection leg files are joined via two methods:

- On road segment
    - Road file, UNIQUE_ID
    - Intersection file, UNIQUE_ID_MAJOR and UNIQUE_ID_MINOR
    - Leg file, Leg Link
- On intersection point
    - Intersection file, AGENCYID
    - Intersection leg file, AgencyID

There is a potential concern regarding the joining of road data to the intersections using only the UNIQUE_ID MAJOR and UNIQUE_ID_MINOR. Each intersection has only one ID number listed for each of those variables. For a 4-leg intersection, there are two unique major road segments and two unique minor road segments associated with the intersection. If there is only one major segment and one minor segment, it might not join those that have AADT, or it might not join those that show the intersection is at a ramp, etc.

Used the leg file to supplant the UNIQUE_ID_MAJOR and UNIQUE_ID_MINOR fields in the intersection file. In effect, for each intersection, we listed two IDs for the major and two for the minor. Then, we linked the data like AADT, functional class, etc. from the road file.

DATA FILES AND FIELDS

Major and minor AADT	Road file (ASSET) Field: AADT and AADT_CURR_YEAR. Join based on UNIQUE_ID.
At-grade indicator	No way to tell from the data, but examination of the map indicates that the intersection file only contains at-grade intersections.
Ramp relation	Road file (ASSET) Field: FUNCT_SYSTEM_DESCR. The intersection is a ramp terminal if either the major or minor road is = 'Principal Arterial - Interstate' OR 'Principal Arterial - Other Freeway/Expressway'
Traffic control	Intersection file Field: TrafficControl1
Number of legs	Intersection file; Fields: LegCount and IntersectionType1
One-way vs two-way	Road file (ASSET); Field: DIRECTION_WAY Join based on UNIQUE_ID.
Number of lanes on major road	Road file (ASSET); Field: NUM_LANES Join based on UNIQUE_ID.
Rural vs urban	Intersection file; Field: AreaType
Major road classification – state vs non-state	Intersection file; Field: Jurisdiction
Coordinates	Intersection file; Fields: Lat and Long

Potential issue with the Intersection file's determination of which road is the major road (based on UNIQUE_ID_MAJOR).

LINKING CRASHES TO INTERSECTIONS

The CRASHES_ALL_LOCATIONS file has 441,115 crashes ranging from year 2002 to 2015.

Selected crashes only 2009-2015 (CRASHES_ALL_LOCATIONS only 09-15) has 204,283 crashes.

1. Create layer for only 2009-2015 crashes.
2. Run NEAR operation with input of crash file and near features of intersections, for a distance of 300 ft. This attaches a few columns to the crash file, indicating the FID (Object ID) of the nearest intersection and how far it is to the intersection. If a crash is more than 300 ft from any intersection, there will be a blank in the NEAR FID field and a NEAR_DIST of -1.
3. Join to the INTERSECTIONS 2015 file based on the FID (Object ID) and pick up the AGENCYID variable to get a better ID for the intersection.
4. Output the crash listing with attached AGENCYID and NEAR_DIST to an Excel file (Crashes 2009-2015 asscted to Ints with Near Dist).
5. Keep only those crashes that are within 300 ft of an intersection (i.e., delete crashes with NEAR_DIST of -1). Create new Excel file (Crashes 2009-2015 associated to Ints within 300 ft). This results in 105,960 crashes.

CODING FOR TRAFFIC CONTROL

Dropped intersections that were not stop controlled or signalized (i.e., those with TrafficControl values of 1, 8, 9, 10, and 18).

Symbol	Value	Label	Count
☑ ◆	<all other values>	<all other values>	
	<Heading>	**TrafficControl1**	
◇	7	All-way flasher (red on all)	?
◇	4	All-way stop signs	?
◇	1	No control	?
◇	10	Other non-signalized	?
◇	17	Other signalized	?
◇	18	Roundabout	?
◇	15	Signals fully actuated (2 pha	?
◇	16	Signals fully actuated (multi-p	?

Symbol	Value	Label	Count
◇	11	Signals pre timed (2 phase)	?
◇	12	Signals pre timed (multi-phas	?
◇	13	Signals semi-actuated (2 pha	?
◇	14	Signals semi-actuated (multi-	?
◇	2	Stop signs on cross street or	?
◇	3	Stop signs on mainline only	?
◇	5	Two-way flasher (red on cros	?
◇	6	Two-way flasher (red on mai	?
◇	99	Unknown	?
◇	8	Yield signs on cross street or	?

APPENDIX D: DATA SUMMARY OF STUDY SITES

The network screening produced ranked lists of intersections throughout New Hampshire, which the research team pared down to 35 unique sites for further review. The following tables summarize the characteristics of the 35 intersections reviewed in detail.

Table 12 presents the distribution of intersections by State and local maintenance. The majority of sites (60 percent) are maintained by local agencies.

Table 12. Intersection maintenance jurisdiction.

Jurisdiction	Count	Percent
State maintained	14	40
Local maintained	21	60
Total	35	100

Table 13 presents the distribution of intersections by intersection class. Intersection class is the designation of routes on the major and minor roads signifying the type of systems that intersect. The majority of sites (71.4 percent) involve a State route. Although some routes are designated and numbered as State routes, in New Hampshire there are sections of State routes that are owned and maintained by municipalities that they are located in. This is the reason for the differences in Table 12 and Table 13.

Table 13. Intersection class.

Intersection Class	Count	Percent
State-State	16	45.7
State-Local	9	25.7
Local-Local	10	28.6
Total	35	100

Table 14 presents the distribution of intersections by area type. The majority of sites (80 percent) are located in urban areas.

Table 14. Intersection area type.

Area Type	Count	Percent
Rural	7	20
Urban	28	80
Total	35	100

Table 15 presents the distribution of intersections by traffic control type. The highest proportion of sites (48 percent) are signalized, while the others are stop-controlled (with or without a flasher).

Table 15. Intersection traffic control type.

Traffic Control Type	Count	Percent
Stop on cross street only	14	40
Two-way flasher, red on cross street	3	9
All-way flasher, red on all	1	3
Signal	17	48
Total	35	100

Table 16 presents the distribution of intersections by leg count. The majority of sites (91 percent) have four legs.

Table 16. Intersection leg count.

Number of Legs	Count	Percent
3	4	9
4	31	91
Total	35	100

Table 17 presents a summary of crash and traffic volume data by site. The first column indicates the intersection identification number. Columns 2 through 13 present the number of crashes by crash type. Note columns 2 through 8 (ANG through O_M) represent multiple vehicle (MV) crash types and columns 9 through 13 (O_S through FO) represent single vehicle (SV) crash types. Column 14 presents the total crashes and column 15 presents the traffic volume for each site.

Table 17. Crash and traffic volume data summary for 35 study sites.

Int. ID	ANG	LT	RE	HO	SS_S	SS_O	PV	O_M	FO	PED	SP	BI	O_S	U	TOTAL	AADT
2194	9	7	18	0	0	2	0	1	2	4	0	0	0	0	43	27,715
3468	9	1	0	0	1	3	0	1	0	1	0	0	0	0	16	5,730
4798	4	2	25	0	0	0	0	1	0	0	0	0	0	0	32	25,213
6421	2	0	11	0	2	0	0	8	0	0	0	0	0	1	24	26,850
8681	29	0	1	0	0	0	0	0	1	1	0	0	0	1	33	11,568
8944	29	0	1	0	0	0	0	0	0	0	0	0	0	1	31	7,900
10677	9	1	3	0	0	0	0	2	0	0	0	0	0	0	15	6,290
*14404	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	370
15305	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	760
16729	2	2	33	0	2	0	1	2	4	0	0	2	0	1	49	19,775
19266	4	0	17	0	2	0	0	3	0	0	0	0	0	5	31	48,210
20710	6	4	13	0	0	0	0	4	0	0	0	0	0	1	28	27,963
23133	6	1	3	0	0	0	0	0	1	0	0	0	0	0	11	12,580
24673	9	1	0	0	0	2	0	0	0	0	0	0	0	0	12	8,605
27897	11	1	0	0	0	0	0	0	0	0	0	0	0	0	12	5,050
31393	26	4	8	0	2	0	0	0	1	0	0	0	0	0	41	18,500
32239	15	1	0	0	0	0	0	2	0	0	0	0	0	0	18	7,600
37259	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	128
41342	12	0	4	0	0	0	0	2	2	4	0	2	0	0	26	9,864
41420	15	5	2	1	0	0	0	2	0	0	0	1	0	0	26	6,900
43086	7	4	3	0	0	0	0	1	0	0	0	1	0	0	16	36,630
46353	11	4	23	1	3	0	0	5	2	0	0	0	0	2	51	22,100
47078	4	0	28	0	2	0	0	3	1	0	0	0	1	3	42	24,514

Int. ID	ANG	LT	RE	HO	SS_S	SS_O	PV	O_M	FO	PED	SP	BI	O_S	U	TOTAL	AADT
47849	7	5	15	0	0	2	0	0	0	0	0	0	0	0	29	32,000
52047	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	600
57403	4	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1,710
58744	5	0	9	0	2	0	0	10	3	0	0	0	0	1	30	31,841
62679	7	1	1	0	0	0	0	4	1	0	1	0	0	0	15	27,166
62868	19	1	1	0	1	0	0	2	0	0	0	0	0	1	25	7,855
65409	7	3	0	0	0	0	0	0	0	0	1	0	1	0	12	7,330
66065	2	1	7	0	1	0	0	2	4	0	0	0	1	4	22	15,312
67283	4	0	0	0	0	0	0	0	1	0	0	0	0	0	5	5,101
69212	0	5	6	0	1	0	0	1	1	0	1	0	1	0	16	20,223
71726	15	3	9	0	0	4	0	0	0	5	0	2	0	0	38	18,305
75487	5	0	0	0	0	0	0	3	0	0	0	0	0	0	8	4,026
Average crashes per site	8.5	1.7	6.9	0.1	0.5	0.4	0.0	1.7	0.7	0.4	0.1	0.2	0.1	0.6	21.9	15,208

Note: ANG = angle, LT = left turn, RE = rear-end, HO = head on, SS_S = sideswipe same direction, SS_O = sideswipe opposite direction, PV = parked vehicle, O_M = other multiple vehicle collision, FO = fixed object, PED = pedestrian, SP = spill, BI = bicyclist, O_S = other single vehicle collision, and U = unknown. The AADT is measured as total entering volume.

Figure 10 shows the geographic distribution of the study sites using New Hampshire county and intersection location data in GIS.

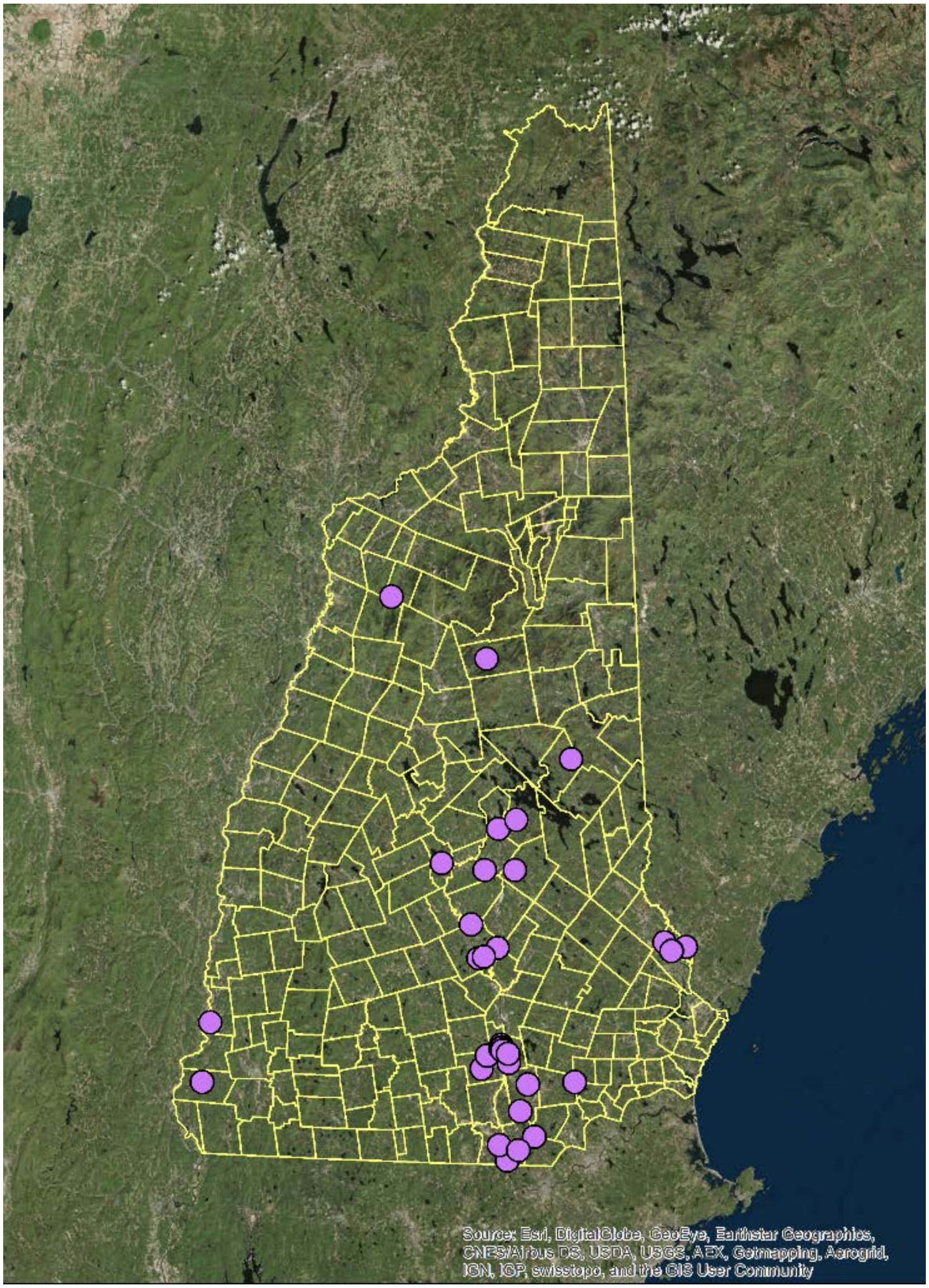


Figure 10. Chart. Map of study sites. Aerial image source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community(15).

APPENDIX E: EXAMPLE INTERSECTION PACKAGES

The following sections present four intersection packages that were prepared prior to the diagnosis. The packages each include a collision diagram, crash summaries, and detailed crash data. The 'CD ID' values in the crash data tables match the crash symbols on the collision diagrams. The collision diagrams also show the two-way AADTs on the respective approaches.

The intersection packages include summaries of the following data attributes.

- Crash Year.
- Month.
- Day of the Week.
- Hour.
- Crash Type by Severity.
- Road Surface Condition.
- Lighting Condition.
- Number of Vehicles.
- Apparent Contributing Factors.
- Vision Obscurement Description.
- Vehicle Direction.
- Vehicle Type.
- Age of Drivers.
- Operator Legal State of Residence.

Figure 11 shows the legend for the collision diagrams.

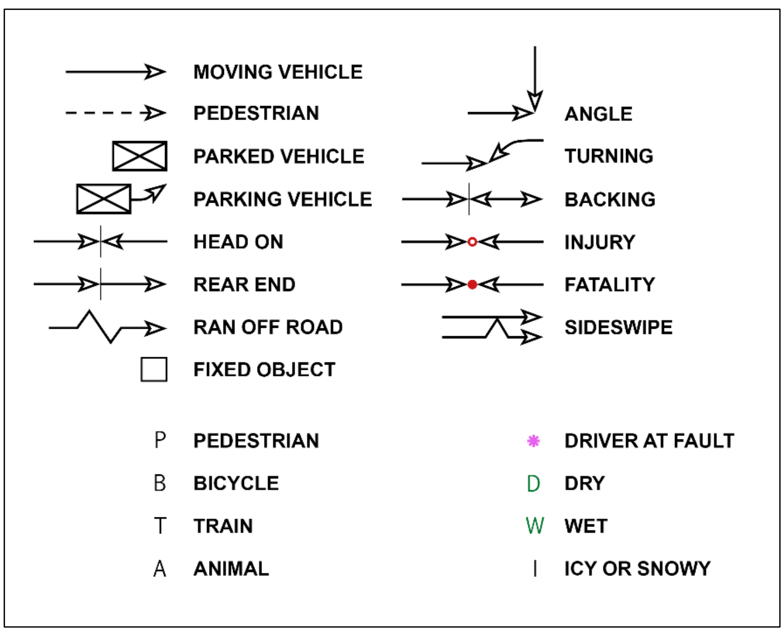


Figure 11. Chart. Collision diagram legend.

INTERSECTION 4798

Figure 12 shows the collision diagram for intersection 4798. Table 18 through Table 32 show the crash summaries.

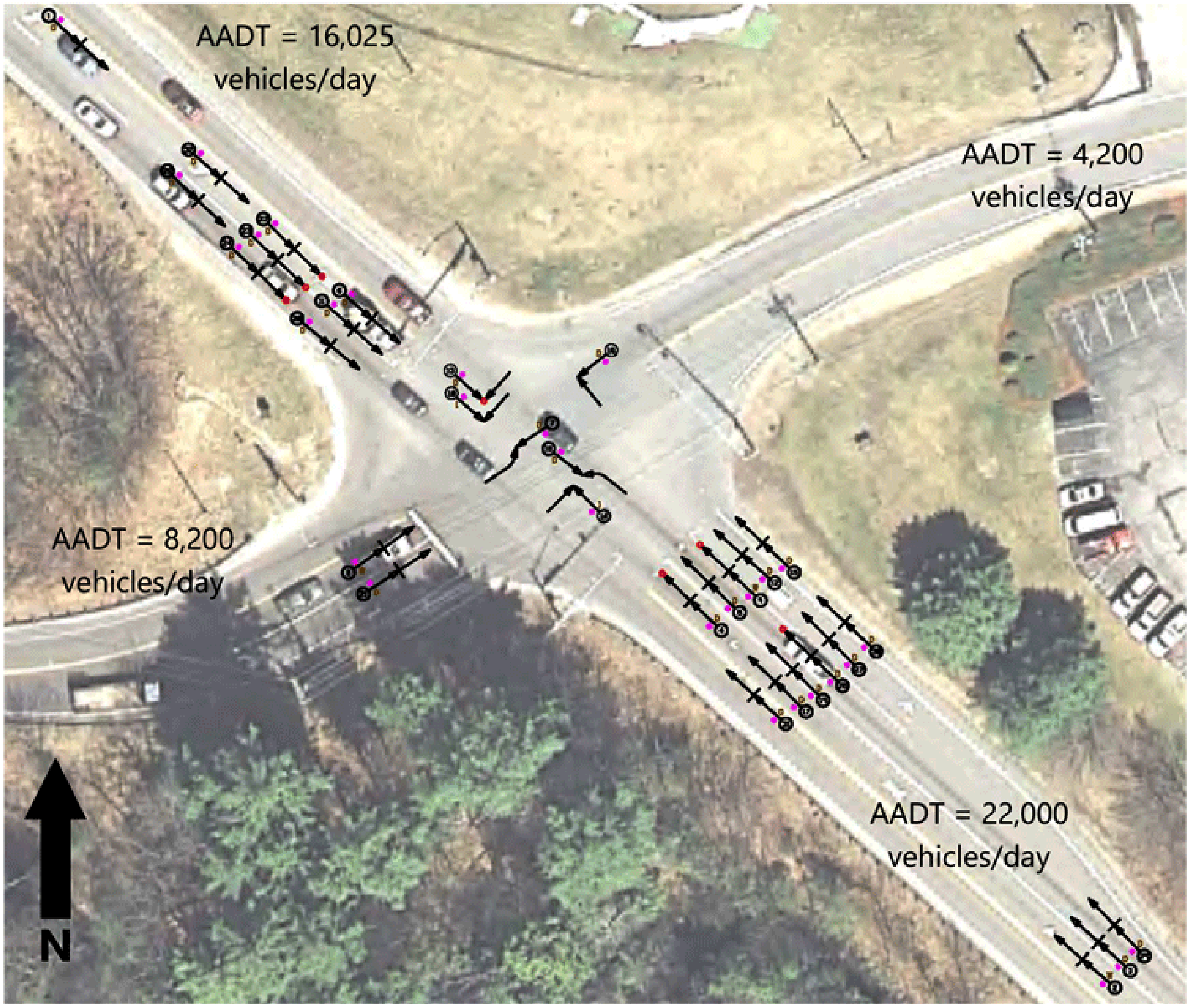


Figure 12. Chart. Collision diagram for intersection 4798. Aerial image source: NH GRANIT[(8)].

Table 18. Crash summary by year for intersection 4798.

Crash Year	Count	Percent
10	9	27%
11	4	12%
12	5	15%
13	9	27%
14	6	18%
Grand Total	**33**	**100%**

Table 19. Crash summary by month for intersection 4798.

Month	Count	Percent
January	5	15%
February	4	12%
March	2	6%
April	1	3%
May	8	24%
June	3	9%
August	5	15%
September	1	3%
October	1	3%
November	3	9%
Grand Total	**33**	**100%**

Table 20. Crash summary by day of week for intersection 4798.

Day of Week	Count	Percent
Sunday	3	9%
Monday	5	15%
Tuesday	6	18%
Wednesday	2	6%
Thursday	10	30%
Friday	6	18%
Saturday	1	3%
Grand Total	**33**	**100%**

Table 21. Crash summary by crash type and severity for intersection 4798.

Crash Type	A	B	C	U	O	Total
Angle	1			1	2	4
Left-Turn				1	1	2
Other Multiple-Vehicle Collision				1		1
Rear-End		1	5		19	25
Unknown					1	1
Total	**1**	**1**	**5**	**3**	**23**	**33**

Note: K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, U = unknown injury, O = no apparent injury (i.e., property damage only—PDO).

Table 22. Crash summary by time of day for intersection 4798.

Hour	Count	Percent
5 AM	1	3%
6 AM	1	3%
7 AM	3	9%
8 AM	3	9%
9 AM	1	3%
10 AM	2	6%
11 AM	1	3%
12 PM	2	6%
1 PM	4	12%
2 PM	3	9%
3 PM	1	3%
4 PM	3	9%
5 PM	3	9%
6 PM	2	6%
7 PM	1	3%
9 PM	2	6%
Grand Total	**33**	**100%**

Table 23. Crash summary by surface condition for intersection 4798.

Surface Description	Count	Percent
Dry	28	85%
Snow/Slush	2	6%
Wet	3	9%
Grand Total	**33**	**100%**

Table 24. Crash summary by light condition for intersection 4798.

Lighting Description	Count	Percent
Dark-No Street Light	2	6%
Dark-Street Light On	4	12%
Daylight	26	79%
Dusk	1	3%
Grand Total	**33**	**100%**

Table 25. Crash summary by number of vehicles for intersection 4798.

Number of Vehicles	Count	Percent
2	30	91%
3	3	9%
Grand Total	**33**	**100%**

Table 26. Crash summary by contributing factor for intersection 4798.

Apparent Contributing Factors	Count	Percent
Disregard Traffic Control Device	2	3%
Driver Inattention/Distraction	21	29%
Failure to Yield R-O-W	2	3%
Following too Close	3	4%
Illegal/Unsafe Speed	2	3%
Improper Turn	1	1%
No Improper Driving	41	56%
Physical Impairment	1	1%
Grand Total	**73**	**100%**

Table 27. Crash summary by vision obscurement for intersection 4798.

Vision Obscurement Description	Count	Percent
No Apparent Obscurement	73	100%
Grand Total	**73**	**100%**

Table 28. Crash summary by vehicle direction for intersection 4798.

Vehicle Direction	Count	Percent
East	7	10%
North	38	52%
South	25	34%
West	3	4%
Grand Total	**73**	**100%**

Table 29. Crash summary by vehicle type for intersection 4798.

Vehicle Type	Count	Percent
Automobile	38	68%
Pick Up/Light Truck	6	11%
Panel/Van	1	2%
Motorcycle	1	2%
Passenger Light Van	1	2%
Utility Vehicle (4x4)	9	16%
Grand Total	**56**	**100%**

Table 30. Crash summary by operator age for intersection 4798.

Age	Count	Percent
16-20	3	4%
21-25	7	10%
26-30	7	10%
31-35	6	9%
36-40	5	7%
41-45	9	13%
46-50	13	18%
51-55	4	6%
56-60	8	11%
61-65	2	3%
66-70	5	7%
71-75	2	3%
Grand Total	**71**	**100%**

Table 31. Crash summary by state of residence for intersection 4798.

Operator Legal State Residence	Count	Percent
Massachusetts	1	1%
Maine	1	1%
New Hampshire	71	98%
Grand Total	**73**	**100%**

Table 32. Crash details for intersection 4798.

CD ID	Crash ID	Date	Day	Time	Severity	Surface Condition	Lighting	Crash Type
1	10014194	6/29/2010	TUE	1010	No Apparent Injury	Dry	Daylight	REAR-END
2	10026004	11/8/2010	MON	755	No Apparent Injury	Wet	Daylight	REAR-END
3	10011476	5/27/2010	THU	808	No Apparent Injury	Dry	Daylight	REAR-END
4	10018566	8/13/2010	FRI	1330	Possible	Dry	Daylight	REAR-END
5	10007782	4/4/2010	SUN	1300	No Apparent Injury	Dry	Daylight	REAR-END
6	10009641	5/3/2010	MON	1659	No Apparent Injury	Dry	Daylight	REAR-END
7	10001799	1/15/2010	FRI	1839	No Apparent Injury	Dry	Dark-Street Light On	LEFT-TURN
8	10022900	9/28/2010	TUE	1649	No Apparent Injury	Wet	Daylight	REAR-END
9	11002582	1/13/2011	THU	1717	Possible	Wet	Dark-Street Light On	REAR-END
10	11006427	2/25/2011	FRI	946	Unknown	Snow/Slush	Daylight	ANGLE
11	11012694	5/7/2011	SAT	1217	No Apparent Injury	Dry	Daylight	REAR-END
12	12001616	1/4/2012	WED	725	No Apparent Injury	Dry	Daylight	REAR-END
13	11022649	11/21/2011	MON	1653	Incapacitating	Dry	Dusk	ANGLE
14	12005468	3/1/2012	THU	713	No Apparent Injury	Snow/Slush	Daylight	ANGLE
15	13007513	1/18/2013	FRI	806	No Apparent Injury	Dry	Daylight	REAR-END
16	12002244	1/16/2012	MON	1802	No Apparent Injury	Dry	Dark-Street Light On	ANGLE
17	12003884	2/2/2012	THU	1304	No Apparent Injury	Dry	Daylight	REAR-END
18	12010006	2/13/2012	MON	1229	Unknown	Dry	Daylight	LEFT-TURN
19	13015522	5/7/2013	TUE	1530	No Apparent Injury	Dry	Daylight	REAR-END
20	13015635	5/31/2013	FRI	1044	No Apparent Injury	Dry	Daylight	REAR-END
21	13007753	2/1/2013	FRI	811	No Apparent Injury	Dry	Daylight	REAR-END
22	13017852	6/13/2013	THU	539	Non_Incapacitating	Dry	Daylight	REAR-END
23	10009659	5/9/2010	SUN	1431	Possible	Dry	Daylight	REAR-END
24	14012517	5/27/2014	TUE	1309	Possible	Dry	Daylight	REAR-END
25	14024719	10/5/2014	SUN	1917	Possible	Dry	Dark-No Street Light	REAR-END
26	14027324	41954	TUE	1143	Unknown	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
27	13015454	41396	THU	1420	No Apparent Injury	Dry	Daylight	REAR-END
28	13022301	41494	THU	1738	No Apparent Injury	Dry	Daylight	REAR-END
29	13022306	41494	THU	2111	No Apparent Injury	Dry	Dark-No Street Light	REAR-END
30	13022359	41507	WED	2116	No Apparent Injury	Dry	Dark-Street Light On	REAR-END
31	14008230	41716	TUE	1751	No Apparent Injury	Dry	Daylight	REAR-END
32	14014340	41795	THU	652	No Apparent Injury	Dry	Daylight	REAR-END
33	14018663	41858	THU	1418	No Apparent Injury	Dry	Daylight	UNKNOWN

INTERSECTION 8681

Figure 13 shows the collision diagram for intersection 8681. Table 33 through Table 47 show the crash summaries.

Figure 13. Chart. Collision diagram for intersection 8681. Aerial image source: NH GRANIT[(8)].

Table 33. Crash summary by year for intersection 8681.

Year	Count	Percent
10	5	15%
11	5	15%
12	8	24%
13	6	18%
14	9	27%
Grand Total	**33**	**100%**

Table 34. Crash summary by month for intersection 8681.

Month	Count	Percent
January	2	6%
February	2	6%
April	4	12%
May	4	12%
June	2	6%
July	4	12%
August	1	3%
September	2	6%
October	3	9%
November	3	9%
December	6	18%
Grand Total	**33**	**100%**

Table 35. Crash summary by day of week for intersection 8681.

Day of Week	Count	Percent
Sunday	3	9%
Monday	6	18%
Tuesday	4	12%
Wednesday	2	6%
Thursday	7	21%
Friday	5	15%
Saturday	6	18%
Grand Total	**33**	**100%**

Table 36. Crash summary by crash type and severity for intersection 8681.

Crash Type	B	C	U	O	Total
Angle	3	7	3	17	30
Fixed Object				1	1
Pedestrian	1				1
Rear-End	1				1
Total	**5**	**7**	**3**	**18**	**33**

Note: K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, U = unknown injury, O = no apparent injury (i.e., property damage only—PDO).

Table 37. Crash summary by time of day for intersection 8681.

Hour	Count	Percent
12 AM	1	3%
6 AM	1	3%
7 AM	1	3%
8 AM	2	6%
9 AM	3	9%
12 PM	2	6%
1 PM	2	6%
2 PM	2	6%
3 PM	3	9%
4 PM	2	6%
5 PM	5	15%
6 PM	4	12%
7 PM	2	6%
8 PM	1	3%
9 PM	1	3%
11 PM	1	3%
Grand Total	**33**	**100%**

Table 38. Crash summary by surface condition for intersection 8681.

Surface Condition	Count	Percent
Dry	22	67%
Snow/Slush	1	3%
Wet	10	30%
Grand Total	**33**	**100%**

Table 39. Crash summary by light condition for intersection 8681.

Lighting Description	Count	Percent
Dark-Street Light On	9	29%
Daylight	20	65%
Dusk	2	6%
Grand Total	**31**	**100%**

Table 40. Crash summary by number of vehicles for intersection 8681.

Number of Vehicles	Count	Percent
0	1	3%
1	2	6%
2	28	85%
3	2	6%
Grand Total	**33**	**100%**

Table 41. Crash summary by contributing factor for intersection 8681.

Apparent Contributing Factors	Count	Percent
Defective Equipment	1	2%
Disregard Traffic Control Device	3	5%
Driver Inattention/Distraction	5	8%
Failure to Yield R-O-W	16	25%
Improper Park/Start/Stop	3	5%
No Improper Driving	27	42%
Unknown	9	14%
Vision Obscurement	1	2%
Grand Total	**65**	**100%**

Table 42. Crash summary by vision obscurement for intersection 8681.

Vision Obscurement	Count	Percent
Glare: Sunlight/Lights/Snow	2	3%
No Apparent Obscurement	62	97%
Grand Total	**64**	**100%**

Table 43. Crash summary by vehicle direction for intersection 8681.

Vehicle Direction	Count	Percent
East	12	17%
North	14	20%
South	21	30%
West	23	32%
Grand Total	**70**	**100%**

Table 44. Crash summary by vehicle type for intersection 8681.

Vehicle Type	Count	Percent
Automobile	42	88%
Utility Vehicle (4x4)	5	10%
Other	1	2%
Grand Total	**48**	**100%**

Table 45. Crash summary by operator age for intersection 8681.

Age	Count	Percent
16-20	8	12%
21-25	7	11%
26-30	8	12%
31-35	8	12%
36-40	3	5%
41-45	2	3%
46-50	5	8%
51-55	8	12%
56-60	1	2%
61-65	3	5%
66-70	6	9%
71-75	2	3%
76-80	1	2%
81+	2	4%
Grand Total	**64**	**100%**

Table 46. Crash summary by state of residence for intersection 8681.

Operator Legal State Residence	Count	Percent
Massachusetts	1	1%
New Hampshire	69	98%
Texas	1	1%
Grand Total	**71**	**100%**

Table 47. Crash details for intersection 8681.

CD ID	Crash ID	Date	Day	Time	Severity	Surface Condition	Lighting	Crash Type
1	10021260	9/27/2010	MON	1402	Non_Incapacitating	Wet	Daylight	ANGLE
2	10001370	1/7/2010	THU	1418	No Apparent Injury	Dry	Daylight	ANGLE
3	10022287	10/1/2010	FRI	1541	No Apparent Injury	Wet	Daylight	ANGLE
4	10026550	11/18/2010	THU	1756	Non_Incapacitating	Dry	Dark-Street Light On	ANGLE
5	10024297	10/30/2010	SAT	1911	No Apparent Injury	Dry	Dark-Street Light On	ANGLE
6	12011849	4/22/2012	SUN	58	Non_Incapacitating	Dry	Dark-Street Light On	PEDESTRIAN
7	14011256	4/15/2014	TUE	2315	Unknown	Wet	Dark-Street Light On	ANGLE
8	14000787	1/4/2014	SAT	1831	Possible	Snow/Slush	Dark-Street Light On	ANGLE
9	14012663	5/31/2014	SAT	1503	No Apparent Injury	Dry	Daylight	ANGLE
10	14024305	12/1/2014	MON	610	No Apparent Injury	Dry	Unknown	ANGLE
11	14024411	11/17/2014	MON	953	No Apparent Injury	Wet	Daylight	ANGLE
12	14028045	12/15/2014	MON	1511	Non_Incapacitating	Dry	Daylight	ANGLE
13	14028152	12/6/2014	SAT	925	No Apparent Injury	Wet	Daylight	ANGLE
14	14007928	4/24/2014	THU	1839	No Apparent Injury	Dry	Daylight	ANGLE
15	11013463	5/19/2011	THU	853	Non_Incapacitating	Wet	Daylight	REAR-END
16	14028198	12/12/2014	FRI	724	Possible	Wet	Daylight	ANGLE
17	11020169	7/31/2011	SUN	1316	No Apparent Injury	Dry	Daylight	ANGLE
18	11029782	12/2/2011	FRI	2055	No Apparent Injury	Dry	Dark-Street Light On	ANGLE
19	11020976	8/3/2011	WED	911	No Apparent Injury	Dry	Daylight	ANGLE
20	11031228	12/30/2011	FRI	1210	Possible	Dry	Daylight	ANGLE
21	12004563	2/16/2012	THU	1823	Possible	Wet	Dark-Street Light On	ANGLE
22	12007635	4/4/2012	WED	1601	No Apparent Injury	Dry	Daylight	FIXED OBJECT
23	12018318	7/31/2012	TUE	1720	No Apparent Injury	Dry	Daylight	ANGLE
24	12014828	6/25/2012	MON	805	No Apparent Injury	Dry	Daylight	ANGLE
25	12012752	7/12/2012	THU	1845	No Apparent Injury	Dry	Unknown	ANGLE
26	12028460	11/17/2012	SAT	1653	Possible	Dry	Dark-Street Light On	ANGLE
27	12026154	10/26/2012	FRI	1732	Unknown	Dry	Dusk	ANGLE
28	13011790	5/12/2013	SUN	1738	Possible	Dry	Daylight	ANGLE
29	13012987	5/20/2013	MON	2140	No Apparent Injury	Dry	Dark-Street Light On	ANGLE
30	13014565	6/11/2013	TUE	1208	Unknown	Dry	Daylight	ANGLE
31	13005307	2/12/2013	TUE	1912	Possible	Wet	Dusk	ANGLE
32	13021126	9/12/2013	THU	1731	No Apparent Injury	Wet	Daylight	ANGLE
33	13016530	7/13/2013	SAT	1304	No Apparent Injury	Dry	Daylight	ANGLE

INTERSECTION 37259

Figure 14 shows the collision diagram for intersection 37259. Table 48 through Table 62 show the crash summaries.

Figure 14. Chart. Collision diagram for intersection 37259. Aerial image source: NH GRANIT[(8)].

Table 48. Crash summary by year for intersection 37259.

Year	Count	Percent
13	1	100%
Grand Total	**1**	**100%**

Table 49. Crash summary by month for intersection 37259.

Month	Count	Percent
April	1	100%
Grand Total	**1**	**100%**

Table 50. Crash summary by day of week for intersection 37259.

Day of Week	Count	Percent
Saturday	1	100%
Grand Total	**1**	**100%**

Table 51. Crash summary by crash type and severity for intersection 37259.

Crash Type	B	C	U	O	Total
Angle	1				1
Total	**1**				**1**

Note: K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, U = unknown injury, O = no apparent injury (i.e., property damage only—PDO).

Table 52. Crash summary by time of day for intersection 37259.

Hour	Count	Percent
7 AM	1	100%
Grand Total	**1**	**100%**

Table 53. Crash summary by surface condition for intersection 37259.

Surface Condition	Count	Percent
Wet	1	100%
Grand Total	**1**	**100%**

Table 54. Crash summary by light condition for intersection 37259.

Lighting Condition	Count	Percent
Daylight	1	100%
Grand Total	**1**	**100%**

Table 55. Crash summary by number of vehicles for intersection 37259.

Number of Vehicles	Count	Percent
2	1	100%
Grand Total	**1**	**100%**

Table 56. Crash summary by contributing factor for intersection 37259.

Apparent Contributing Factors	Count	Percent
Driver Inattention/Distraction	1	50%
Skidding	1	50%
Grand Total	**2**	**100%**

Table 57. Crash summary by vision obscurement for intersection 37259.

Vision Obscurement	Count	Percent
No Apparent Obscurement	2	100%
Grand Total	**2**	**100%**

Table 58. Crash summary by vehicle direction for intersection 37259.

Vehicle Direction	Count	Percent
North	1	50%
West	1	50%
Grand Total	**2**	**100.00%**

Table 59. Crash summary by vehicle type for intersection 37259.

Vehicle Type	Count	Percent
Automobile	2	100%
Grand Total	**2**	**100%**

Table 60. Crash summary by operator age for intersection 37259.

Driver Age	Count	Percent
28	1	50%
55	1	50%
Grand Total	**2**	**100%**

Table 61. Crash summary by state of residence for intersection 37259.

Operator Legal State Residence	Count	Percent
New Hampshire	2	100%
Grand Total	**2**	**100%**

Table 62. Crash details for intersection 37259.

CD ID	Crash ID	Date	Day	Time	Severity	Surface Condition	Lighting	Crash Type
1	13013354	4/13/2013	SAT	748	Non_Incapacitating	Wet	Daylight	ANGLE

INTERSECTION 58744

Figure 15 shows the collision diagram for intersection 58744. Table 63 through Table 77 show the crash summaries.

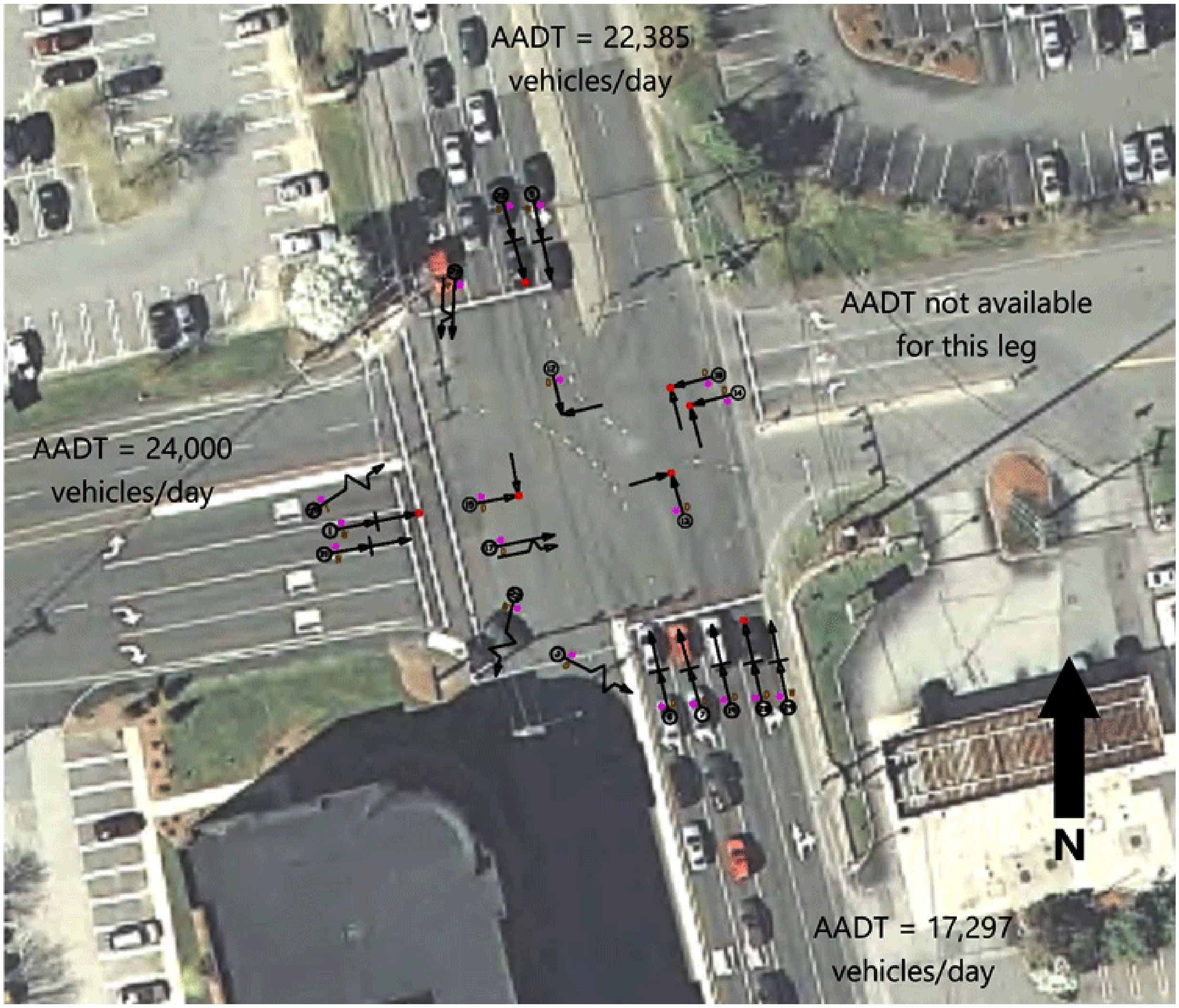


Figure 15. Chart. Collision diagram for intersection 58744. Aerial image source: NH GRANIT(8).

Table 63. Crash summary by year for intersection 58744.

Year	Count	Percent
10	12	40%
11	6	20%
12	4	13%
13	1	4%
14	7	23%
Grand Total	**30**	**100%**

Table 64. Crash summary by month for intersection 58744.

Month	Count	Percent
January	3	10%
February	3	10%
March	2	7%
April	1	3%
May	4	13%
June	2	7%
August	1	3%
September	3	10%
October	4	13%
November	4	13%
December	3	10%
Grand Total	**30**	**100%**

Table 65. Crash summary by day of week for intersection 58744.

Day	Count	Percent
Sunday	2	7%
Monday	7	23%
Tuesday	5	17%
Wednesday	4	13%
Thursday	1	4%
Friday	7	23%
Saturday	4	13%
Grand Total	**30**	**100%**

Table 66. Crash summary by crash type and severity for intersection 58744.

Crash Type	A	B	C	U	O	Total
Angle	1	3		1		5
Fixed Object				3		3
Other Multiple-Vehicle Collision		4		6		10
Rear-End		1	2	4	2	9
Sideswipe, Same Direction				1	1	2
Unknown				1		1
Total	**1**	**8**	**2**	**16**	**3**	**30**

Note: K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, U = unknown injury, O = no apparent injury (i.e., property damage only—PDO).

Table 67. Crash summary by time of day for intersection 58744.

Hour	Count	Percent
1 AM	2	7%
7 AM	1	3%
8 AM	1	3%
9 AM	2	7%
10 AM	1	3%
12 PM	1	3%
1 PM	5	17%
2 PM	2	7%
3 PM	4	13%
4 PM	3	10%
5 PM	2	7%
6 PM	3	10%
8 PM	1	3%
9 PM	2	7%
Grand Total	**30**	**100%**

Table 68. Crash summary by surface condition for intersection 58744.

Surface Condition	Count	Percent
Dry	21	70%
Snow/Slush	1	3%
Wet	8	27%
Grand Total	**30**	**100%**

Table 69. Crash summary by light condition for intersection 58744.

Lighting Description	Count	Percent
<Null>	4	13%
Dark-Street Light On	6	20%
Daylight	18	60%
Dusk	2	7%
Grand Total	**30**	**100%**

Table 70. Crash summary by number of vehicles for intersection 58744.

Number of Vehicles	Count	Percent
1	3	10%
2	21	70%
3	4	13%
4	2	7%
Grand Total	**30**	**100%**

Table 71. Crash summary by contributing factor for intersection 58744.

Apparent Contributing Factors	Count	Percent
<Null>	10	15%
Defective Equipment	1	1%
Disregard Traffic Control Device	4	7%
Driver Inattention/Distraction	7	10%
Failure to Yield R-O-W	2	3%
Following too Close	2	3%
Illegal/Unsafe Speed	1	1%
Improper Park/Start/Stop	1	1%
Improper Turn	2	3%
Improper/Unsafe Lane Use	1	1%
No Improper Driving	29	42%
Other	2	3%
Physical Impairment	2	3%
Unknown	5	6%
Unsafe Backing	1	1%
Grand Total	**70**	**100%**

Table 72. Crash summary by vision obscurement for intersection 58744.

Vision Obscurement	Count	Percent
<Null>	13	19%
No Apparent Obscurement	57	81%
Grand Total	**70**	**100%**

Table 73. Crash summary by vehicle direction for intersection 58744.

Vehicle Direction	Count	Percent
East	15	21%
North	35	50%
South	13	19%
Unknown	2	2%
West	5	7%
Grand Total	**70**	**100%**

Table 74. Crash summary by vehicle type for intersection 58744.

Vehicle Type	Count	Percent
<Null>	24	34%
Automobile	37	53%
Other	2	3%
Pick Up/Light truck	1	1%
Utility Vehicle (4X4)	6	9%
Grand Total	**70**	**100%**

Table 75. Crash summary by operator age for intersection 58744.

Driver Age	Count	Percent
16-20	8	14%
21-25	9	16%
26-30	8	14%
31-35	6	11%
36-40	4	7%
41-45	2	4%
46-50	2	4%
51-55	4	7%
56-60	2	4%
61-65	2	4%
66-70	2	4%
76-80	4	7%
81-85	2	4%
Grand Total	**55**	**100%**

Table 76. Crash summary by state of residence for intersection 58744.

Operator Legal State Residence	Count	Percent
Unknown	2	3%
Massachusetts	15	21%
New Hampshire	53	76%
Grand Total	**70**	**100%**

Table 77. Crash details for intersection 58744.

CD ID	Crash ID	Date	Day	Time	Severity	Surface Condition	Lighting	Crash Type
1	10005598	2/27/2010	SAT	1358	Non_Incapacitating	Wet	Daylight	REAR-END
2	10023747	10/15/2010	FRI	1844	No Apparent Injury	Wet	Dusk	OTHER MULTIPLE-VEHICLE COLLISION
3	10021990	10/5/2010	TUE	803	No Apparent Injury	Dry	Daylight	FIXED OBJECT
4	10022005	10/4/2010	MON	1459	No Apparent Injury	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
5	10019291	8/25/2010	WED	1502	No Apparent Injury	Wet	Daylight	REAR-END
6	10014111	6/25/2010	FRI	155	No Apparent Injury	Dry	Dark-Street Light On	REAR-END
7	10021850	9/24/2010	FRI	1655	No Apparent Injury	Dry	Daylight	REAR-END
8	10024730	9/13/2010	MON	1544	No Apparent Injury	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
9	10003156	1/24/2010	SUN	1642	Non_Incapacitating	Dry	Dusk	OTHER MULTIPLE-VEHICLE COLLISION
10	11014460	5/21/2011	SAT	921	Incapacitating	Dry	Daylight	ANGLE
11	11009059	3/25/2011	FRI	1524	Non_Incapacitating	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
12	12014507	6/23/2012	SAT	1344	No Apparent Injury	Dry	Daylight	ANGLE
13	12011560	5/24/2012	THU	2051	Non_Incapacitating	Dry	Dark-Street Light On	ANGLE
14	12005154	2/21/2012	TUE	110	Non_Incapacitating	Dry	Dark-Street Light On	ANGLE
15	14006230	3/25/2014	TUE	1701	Non_Incapacitating	Dry	Daylight	ANGLE
16	14008826	5/7/2014	WED	1654	Non_Incapacitating	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
17	14010640	4/25/2014	FRI	1820	Unknown	Dry	<Null>	SIDESWIPE, SAME DIRECTION
18	14023580	11/21/2014	FRI	1317	Non_Incapacitating	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
19	14019310	10/13/2014	MON	1430	<Null>	Dry	<Null>	REAR-END
20	14020892	12/15/2014	MON	1035	Possible	Dry	<Null>	REAR-END
21	14024115	12/24/2014	WED	1345	Unknown	Wet	<Null>	REAR-END
22	10028351	12/5/2010	SUN	1200	Possible	Dry	Daylight	REAR-END
23	10025568	11/8/2010	MON	1312	No Apparent Injury	Wet	Daylight	FIXED OBJECT
24	10025572	11/8/2010	MON	1720	No Apparent Injury	Wet	Dark-Street Light On	OTHER MULTIPLE-VEHICLE COLLISION
25	11001203	1/25/2011	TUE	710	No Apparent Injury	Snow/Slush	Daylight	FIXED OBJECT
26	11019003	9/14/2011	WED	1802	No Apparent Injury	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION
27	11003225	1/15/2011	SAT	2136	No Apparent Injury	Wet	Dark-Street Light On	SIDESWIPE, SAME DIRECTION
28	11013909	5/20/2011	FRI	2148	No Apparent Injury	Dry	Dark-Street Light On	UNKNOWN
29	12026262	11/13/2012	TUE	1504	No Apparent Injury	Wet	Daylight	REAR-END
30	13004830	2/18/2013	MON	905	No Apparent Injury	Dry	Daylight	OTHER MULTIPLE-VEHICLE COLLISION

APPENDIX F: ROAD SAFETY AUDIT RESULTS

This section presents the RSA results for the four intersections shown in Appendix D.

INTERSECTION 4798

Prevalent Crash Types

- 78% rear-end (statewide average: 44%)
- 78% daylight
- Very few turning crashes
- Many crashes during weekdays

Observations/Issues

1. Rural, signalized intersection posted 40 mph on mainline
2. Permitted on EB and WB
3. Protected on NB and SB
4. Single thru lane on all approaches
5. Exclusive left on NB and SB approaches
6. Exclusive right turn lanes on NB and EB approaches
7. Supermarket with lots of local traffic on minor road
8. NB approach has red light indicator light
9. Street lights present
10. Overhead street name signs and guide signs
11. One signal head per lane with backplates (no reflective tape)
12. Advance signing of lane designations on NB and SB approaches
13. Advance intersection warning sign with street names on NB and SB approaches
14. Potential for spillover with short turn lanes and heavy traffic volumes on NB and SB approaches

Proposed Strategies

1. Install right-turn lane on southbound approach
2. Consider installing additional thru lane on northbound approach
3. Enhance enforcement of speeds on mainline
4. Resurface to enhance pavement friction
5. Extend existing turn lanes on NB and SB approaches to reduce spillover

INTERSECTION 8681

Prevalent Crash Types

- 91% right-angle (statewide average: 43%)
    - Approximately 50% of these result in injury
- Limited rear-ends and not many running the stop sign
- ~50% are age 35 and younger
- 30% in wet conditions
- 50% failure to yield right-of-way
- The most involvement is from the approach with the lowest volume

Observations/Issues

1. Schools south of intersection
2. Residential on other approaches
3. All-way stop-control
4. Crosswalks on east and south legs
5. Sidewalks on southwest, southeast, and half of northeast corner (none on northwest)
    a. Northern side of east leg is sidewalk to nowhere
6. Downgrade on eastbound approach
7. Sight obstruction (privacy/noise wall) on northwest corner
8. Potential for pedestrians in the crosswalks confusing drivers as to who has right-of-way
9. Advance stop ahead on EB approach

Proposed Strategies

1. Mini roundabout (~60' diameter)
2. Check signal warrant based on crashes
3. Education campaign at schools

Other Strategies Considered (deemed not feasible by NHDOT)

1. Install supplemental signing to encourage drivers to take turns

INTERSECTION 37259

Prevalent Crash Types

- 1 Crash
  - Right-angle
  - Occurred from 7 AM and 8 AM
  - Occurred on Saturday
  - Wet conditions
  - Daylight
- 2 Vehicles involved
  - Driver Inattention/Distraction and Skidding were the contributing factors
  - No vision obscurements noted
  - West and North vehicle direction
  - 28 & 55 years old

Observations/Issues

1. Uncontrolled 3-legged intersection – no stop or yield control
   a. North leg is skewed to the NW
   b. Driveway located on south side of intersection (looks like vehicle pulling out of driveway and WB moving vehicle collided for only crash in this location?)
   c. East leg is a dead end at rural residence
   d. No stop bars, no crosswalks or pedestrian signals available
2. Very rural area with extremely low AADT

Proposed Strategies

1. Install stop or yield control on southbound minor road approach
2. Reduce skew to lower turning speeds

INTERSECTION 58744

Prevalent Crash Types

- 9, 30% rear-end (statewide average: 44%)
- 5, 17% right-angle (statewide average: 27%)
- 30 Crashes (1 A, 8 B, and 2 C injuries)
  - 47% (14) occurred between 1 and 5 PM
  - Monday (7) and Friday (7) account for 47% of crashes
  - 30% Wet (8) or Snow/Slush (1)
  - 60% (18) daylight
  - 13% (4) with fixed object
  - 20% of crashes involved > 2 vehicles
- Driver Inattention/Distraction (7) and Disregard for Traffic Control Device (4) most common contributing factor = 16% (11)
- NB accounts for 50% of crashes
- 56% of drivers < 35 YRS

Observations/Issues

1. Four-legged signalized intersection
   a. One of largest shopping centers in the state with stores/restaurants and a gas station at all four corners
   b. Near turnpike and just north of Massachusetts border
   c. Relatively low volume on east leg
   d. North, South, and West legs are primary movements/traffic volume
   e. Red light indicator light on NB approach
   f. Cameras on all four mast arms
   g. Intersection lighting at each corner except SE
   h. ‘Do Not Block Intersection’ signage on all 4 mast arms
   i. All lanes marked with directional arrows
   j. Post mounted signage included with directional arrows as well
   k. Fixed objects in close proximity
2. Northbound/southbound
   a. NB has 2 dedicated left turn lanes (marked), 1 through (unmarked) and 1 through/right (marked)
      i. Narrow concrete median with ‘no u-turn signage’
      ii. Mast arm with signal for each lane with backplates (non-reflective)
         1. Signal for both LT lanes also has signage for LT only with arrow displays
         2. Street name sign on mast arm
      iii. Stop bar with no cross walk or pedestrian signal
         1. Pedestrian pathway along roadside
   b. SB has 1 dedicated left turn lane, 2 through, and 1 through/right

        i. Narrow concrete median
        ii. Mast arm with signal for each lane with backplates (non-reflective)
            1. 1 LT signal also on SE mast arm base with backplate (non-reflective)
                a. Both LT signals have arrow displays
            2. 1 right/through signal on SW mast arm base with backplate (non-reflective)
            3. Street name sign on mast arm
        iii. Stop bar with no cross walk or pedestrian signal, pedestrian pathway along roadside

3. Eastbound/westbound (minor road)
    a. EB has 1 dedicated LT lane, 1 through lane, and 2 dedicated RT lanes
        i. EB leg turn into dead end road after intersection with business that would have CMVs heading to it
        ii. Center concrete median with possible 'no u-turn sign' (knocked down in Streetview)
        iii. Mast arm with 3 signal heads
            1. 2 RT signal heads have directional arrows and backplates (non-reflective)
            2. 1 through lane signal head has no backplate
            3. 1 signal head located on NE corner mast arm base for LT with directional arrows and no backplate
        iv. Stop bar and crosswalk present, but no pedestrian signals
            1. Pedestrian walkway alongside roadway
    b. WB has 1 dedicated LT lane, 1 through lane, and 1 dedicated RT lane
        i. Center concrete median (no signage for WB traffic)
        ii. Mast arm with 2 signal heads
            1. 1 LT signal head with no backplate
            2. 1 signal head for through and RT only lanes with backplate (non-reflective)
4. Limited pedestrian facilities as shown in Figure 16

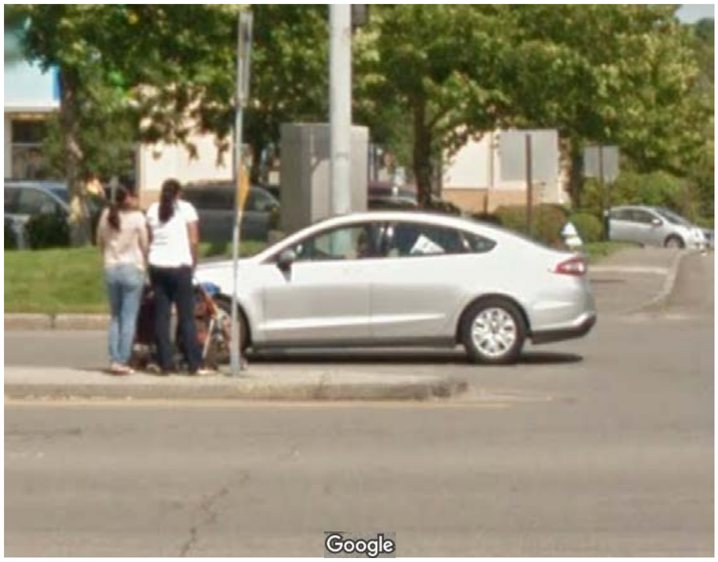


Figure 16. Screenshot. Pedestrians in concrete median in absence of crosswalk. Image source: Google Maps/Earth™(16).

Selected Strategies

1. Install additional crosswalks (north, south, and east legs)
2. Install pedestrian signals with countdown timers
3. Optimize timing and coordinate with intersection to the south
4. Install reflective tape on backplates
5. Install backplates on EB and WB left-turn signals
6. Relocate lane use sign on EB approach further in advance (address sideswipe crash potentially)
7. Install red light indicator lights on SB, EB, and WB approaches and enhance enforcement during busy times
8. Relocate fixed objects further from intersection and roadway

Other Strategies Considered (deemed not feasible by NHDOT)

1. Close driveway to gas station on northbound approach (2 driveways on minor road already). NHDOT noted the driveway on major road may be needed to allow fuel deliveries.

APPENDIX G: CRASH MODIFICATION FACTORS

CMF Description	Current Control Type	Applicable Crash Severity/Type	CMF	Reference
Adaptive signal control	Signalized	Total/Total	0.79	CMF Clearinghouse ID 6858
Advance intersection warning sign with street name	Rural, 4-leg minor stop	Total/Total	0.60	Intersection Safety: A Manual for Local Rural Road Owners
All way stop	Rural, 4-leg minor stop	Total/Total	0.52	CMF Clearinghouse ID 315
Channelize right turn	Signalized	Injury/Total	0.87	CMF Clearinghouse ID 283
Channelize right turn	Signalized	PDO/Total	0.81	CMF Clearinghouse ID 284
Convert Yield control to STOP control	Yield	Total/Total	0.71	CMF Clearinghouse ID 1734
Convert two lane to four lanes	Corridor	Fatal and injury/Total	0.37	CMF Clearinghouse ID 7568
Convert two lane to four lanes	Corridor	PDO/Total	0.35	CMF Clearinghouse ID 7567
Coordinate signals	Signalized	Total/Total	0.90	Signalized Intersections Informational Guide
Crosswalk	Signalized	Total/Vehicle-pedestrian	0.60	CMF Clearinghouse ID 4123
Double left turn	Signalized	Fatal and injury/Total	0.71	Signalized Intersections Informational Guide
Double left turn	Signalized	PDO/Total	0.74	Signalized Intersections Informational Guide
Double stop sign	Minor stop	Total/Angle	0.45	CMF Clearinghouse ID 1661
Fixed object relocation	All	Total/Total	0.62	CMF Clearinghouse ID 1024
ICWS on major and minor	Rural, 4-leg, minor stop	Total/Total	0.70	Himes et al.
ICWS on major and minor	Rural, 4-leg, minor stop	Total/Angle	0.80	Himes et al.
ICWS on minor road	Rural, 4-leg, minor stop	Total/Total	0.89	Himes et al.
Lane designation signing	Signalized	Total/Rear-end	0.90	Signalized Intersections Informational Guide
Lane designation signing	Signalized	Total/Sideswipe	0.80	Signalized Intersections Informational Guide
Left turn lane	Rural, 3-leg, minor stop	Fatal and injury/Total	0.73	CMF Clearinghouse ID 7852
Left turn lane	Rural, 4-leg, minor stop	Total/Total	0.52	CMF Clearinghouse ID 268
Lighting	Intersections	Fatal/Total	0.23	CMF Clearinghouse ID 437
Lighting	Intersections	Injury/Total	0.50	CMF Clearinghouse ID 438
Lighting	Intersections	PDO/Total	0.69	CMF Clearinghouse ID 434
Median Leftover	Intersections	Fatal and injury/Total	0.93	CMF Clearinghouse ID 5465
Mini roundabout	Urban, 4-leg, multiway stop	Fatal and injury/Total	0.54	CMF Clearinghouse ID 4933
Pavement friction enhancement	Signalized	Total/Total	0.80	CMF Clearinghouse ID 2263
Pedestrian signal upgrade	Signalized	Total/Vehicle-pedestrian	0.45	CMF Clearinghouse ID 5273
Pedestrian signal time	Signalized	Total/Vehicle-pedestrian	0.50	CMF Clearinghouse ID 4115
Permissive to protected-permissive phasing	Signalized	Total/Left turn	0.84	CMF Clearinghouse ID 4578
Red light indicator lights	Signalized	Total/Disobey signal	0.68	Himes et al.
Reflective tape on backplates	Signalized	Total/Total	0.85	CMF Clearinghouse ID 1410

CMF Description	Current Control Type	Applicable Crash Severity/Type	CMF	Reference
Right turn lane	Signalized	Fatal and injury/Total	0.91	CMF Clearinghouse ID 288
Roundabout	Signalized	Total/Total	0.79	CMF Clearinghouse ID 4184
Roundabout	Signalized	Injury/Total	0.34	CMF Clearinghouse ID 4185
Roundabout	Rural, 4-leg, minor stop	Total/Total	0.29	CMF Clearinghouse ID 229
RTOR prohibition	Signalized	Total/Total	0.98	CMF Clearinghouse ID 5194
Signal head	Signalized	Fatal and injury/Total	0.83	CMF Clearinghouse ID 1415
Signal head	Signalized	PDO/Total	0.69	CMF Clearinghouse ID 1416
Signal head upgrade and reflective backplates	Signalized	Fatal and injury/Total	0.71	CMF Clearinghouse ID 3491
Signal head upgrade and reflective backplates	Signalized	PDO/Total	0.79	CMF Clearinghouse ID 3493
Skew angle	Rural, 4-leg, minor stop	Total/Total	F(x)	CMF Clearinghouse ID 5189
Split phasing	Signalized	Total/Total	0.44	CMF Clearinghouse ID 4120
Stop ahead pavement markings	Rural, 4-leg, minor stop	Total/Total	0.77	CMF Clearinghouse ID 403
Stop bar	Rural, 4-leg stop	Total/Total	0.85	Intersection Safety: A Manual for Local Rural Road Owners
Traffic signal	Rural, minor stop	Total/Angle	0.23	CMF Clearinghouse ID 326
Traffic signal	Rural, minor stop	Total/Total	0.56	CMF Clearinghouse ID 325
Traffic signal	Urban, 4-leg, multiway stop	Fatal and injury/Total	0.77	CMF Clearinghouse ID 319
Transverse rumble strips	Rural, 4-leg, minor stop	Fatal and injury/Total	0.91	CMF Clearinghouse ID 2704
Triangle sight distance	4-leg	Fatal and injury/Total	0.53	CMF Clearinghouse ID 307
Triangle sight distance	4-leg	PDO/Total	0.89	CMF Clearinghouse ID 308
Turn lane extension	Signalized	Total/Total	0.85	Signalized Intersections Informational Guide
Yellow interval	Signalized	Total/Total	0.92	CMF Clearinghouse ID 4219

APPENDIX H: COUNTERMEASURE COST DATA

Strategy	Cost	Unit	Reference
Adaptive signal control	$65,000	Intersection	http://www.itslessons.its.dot.gov/its/benecost.nsf/ID/5A53F0D1919AA5EE852579830081 9B6E?OpenDocument&Query=Home
Crosswalk installation	$2,500	Approach	(http://guide.saferoutesinfo.org/engineering/marked_crosswalks.cfm
Excavation	$8	Cu. Yd.	Previous NH RSAs
High friction surface	$35	Sq. Yd.	http://www.fhwa.dot.gov/publications/research/safety/14065/14065.pdf
Intersection skew	$250,000	Intersection	Previous NH RSA (Tilton Report)
Island installation	$50	Sq. Yd.	
Median installation	$125	Sq. Yd.	http://www.dot.nd.gov/pacer/AABP2011E.pdf
Mini roundabout	$250,000	Intersection	http://safety.fhwa.dot.gov/intersection/innovative/roundabouts/fhwasa10007/
New intersection	$250,000	Intersection	http://www.ct.gov/dot/lib/dot/documents/dcontractdev/ESTIMATING_ENGLISH.pdf
No RTOR sign	$350	Sign	http://guide.saferoutesinfo.org/engineering/traffic_signals.cfm
Pavement marking symbol	$150	Symbol	https://www.nysdot.gov/divisions/engineering/design/dqab/dqab-repository/USC_RSWAIP0110_1210.pdf
Pedestrian signal upgrade	$2,500	Crossing	NHDOT
Phasing/Optimization	$3,000	Signal	http://www.itscosts.its.dot.gov/its/benecost.nsf/0/215F723DB93D293C8525725F00786FD8
Prohibit parking	$500	Side of road	
Reflective tape on backplates	$500	Intersection	FHWA Technical Summary FHWA-SA-15-007
Relocate utility poles	$5,000	Pole	Assumed same as lighting
Retro-reflective backplates	$6,000	Intersection	NHDOT ongoing systemic project costs
Roundabout installation	$1,000,000	Intersection	Three recent NHDOT roundabout projects
Signal head upgrades	$2,500	Signal head	http://www.itscosts.its.dot.gov/its/benecost.nsf/0/215F723DB93D293C8525725F00786FD8
Street light enhancement	$5,000	Light	1. http://www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=2550 2. http://www.smgov.net/Departments/PublicWorks/ContentCivEng.aspx?id=8621
Transverse rumble strips	$3,000	Intersection	http://www.dot.state.mn.us/trafficeng/safety/docs/transverserumblestripsummary.pdf
Trimming vegetation	$8,000	Acre	Previous NH RSAs
Trimming vegetation	$0	Acre	For very minor trimming
Turn lane addition	$100,000	Turn lane	NHDOT
Turn lane extension	$50,000	Turn lane	NHDOT
Two-way to all-way stop	$5,000	Intersection	http://www.ncdot.org/doh/preconstruct/traffic/safety/Reports/completed_files/docs/4Way033110.pdf

APPENDIX I: ECONOMIC ANALYSIS RESULTS

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
2194	•		•		Upgrade pedestrian signals to countdown signals, Install reflective tape on backplates, Install RLIL	$ 795,947	$ 13,500	58.96
3468		•			Prohibit RTOR, Upgrade Sign Heads and Install Reflective Backplates, Upgrade Pedestrian Signals to Countdown Signals	$ 670,707	$ 33,850	19.81
4798	•		•		Install Right-Turn Lane , Resurface to Enhance Pavement Friction, Extend Turn Lanes to Reduce Spillover	$ 1,214,767	$ 235,000	5.17
6421			•		Add Lane Designation Through Signing and Striping at Intersection and Advance, Install Retroreflective Tape on Backplates, Upgrade Pedestrian Signals to Countdown Signals	$ 107,055	$ 14,850	7.21
8681				•	Install Mini Roundabout	$ 1,417,766	$ 250,000	5.67
8944		•		•	Install Signal if Warranted, Prohibit Parking to Improve Sight Distance	$ 524,649	$ 250,500	2.09
10677		•		•	Trim Vegetation and Remove Trees within Corners of Intersection and Along Sides of Old Rochester Road to Improve Sight Distance, Install Signal if Warranted	$ 1,194,157	$ 254,800	4.69
14404		•			*Error in crash data*	*No crashes*	*No project*	*0.00*

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
15305		•			Consider Installing Street Light, Install Second Stop Sign	$ 63,212	$ 5,350	11.82
16729	•		•	•	Extend Turn Lanes to Reduce Spillover, Install Roundabout	$ 1,618,550	$ 1,200,000	1.35
19266			•		Install Reflective Tape on Backplate, Update Pedestrian Signals to Include Countdown Timers	$ 81,642	$ 10,500	7.78
20710	•		•	•	Install Right Turn Lane, Upgrade Pedestrian Signals to Countdown Signals, Install Reflective Tape on Backplates, Convert Phasing from Permissive to Protected-Permissive, Install RLIL , Add Signal Head	$ 589,414	$ 121,500	4.85
23133				•	Improve sight distance by trimming and removing trees in NE corner., Install intersection collision warning system (ICWS) on major and minor road.	$ 105,966	$ 51,200	2.07
24673		•			Install Reflective Backplates and Move Side-Mount Signal Heads to Overhead, Upgrade Pedestrian Signals to Countdown Signals, Eliminate Parking Near the Corners of the Intersection, Trim Vegetation and Remove Trees in NE Corner to Improve Intersection Sight Distance, Install RLIL	$ 718,257	$ 22,000	32.65
27897		•			Install ICWS	$161,299	$50,000	3.23

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
31393	•		•	•	Install Crosswalk and Pedestrian Countdown Signals, Upgrade Signal Heads to 12 in. LED with Reflective Backplates, Check Coordination with Nearby Signals, Install RLIL	$ 1,084,526	$ 52,000	20.86
32239	•	•		•	Trim Vegetation to Improve Sight Distance, SE and NE Quadrants, Reduce Embankment on NE Corner to Improve Sight Distance, Install Traffic Signal if Warranted	$ 1,130,249	$ 298,600	3.79
37259		•			Install STOP or Yield Control on Shaker Road, Reduce Skew	$ 99,969	$ 250,350	0.40
41342	•	•		•	Channelize Right Turn, Install Reflective Tape on Backplates, Enhance Pedestrian Facilities	$ 631,552	$ 12,000	52.63
41420				•	Trim Vegetation and Remove Trees, Install Roundabout, Install Intersection Lighting	$ 5,860,799	$ 1,010,800	5.80
43086	•		•	•	Upgrade Pedestrian Signal to Countdown Signal, Install Reflective Tape on Backplates, Convert Median Opening from Full Movement to Leftover, Install RLIL	$ 349,712	$ 43,000	8.13

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
46353	•		•	•	Convert Thru Lane to Exclusive Left Turn Lane for Two Left Turn Lanes and Re-Time Signal, Upgrade Signing, Install Reflective Tape on Backplates, Add Signal Head Per Lane to Have One Signal Head Per Lane, Install RLIL	$ 1,805,729	$ 38,800	46.54
47078	•		•		Add Pedestrian Countdown Signals, Retime Signal (Increase Yellow Clearance), Install Retroreflective Tape on Backplates, Install High Friction Surface Treatment on Intersection Approaches	$ 615,982	$ 103,500	5.95
47849	•		•		Install Crosswalk, Upgrade Pedestrian Countdown Signals, Install Reflective Tape on Backplates, Enhance Coordination with Nearby Signals, Install RLIL , Add Right Turn Lane	$ 283,451	$ 121,500	2.33
52047		•			Install Left Turn Lane	$ 69,956	$ 100,000	0.70
57403		•			Install Stop Bars on Minor Roads, Install Advance Intersection Warning Sign with Street Name, Install ICWS	$ 133,796	$ 51,950	2.58

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
58744	•		•		Install Crosswalk, Upgrade Pedestrian Countdown Signals, Install Reflective Tape on Backplates, Enhance Coordination with Nearby Signals, Install RLIL , Relocate Fixed Objects further from Intersection	$ 1,322,402	$ 74,000	17.87
62679	•		•		Trim Vegetation and Remove Trees in NW, SW, and NE Quadrants to Improve Sight Distance, Cut Embankment in SW Quadrant to Improve Sight Distance, Consider ICWS on Minor Road, Consider Doubling or Using Oversize STOP Sign on Minor Roads	$ 1,274,473	$ 130,700	9.75
62868		•		•	Install Stop Bar , Trim Vegetation in NE and SE Quadrants to Improve Sight Distance, Consider ICWS	$ 475,532	$ 52,450	9.07
65409		•			Double-Up and Oversize STOP Signs, Install Intersection Lighting, Trim Vegetation in SW Corner to Improve Sight Distance	$ 750,272	$ 6,350	118.15
66065	•		•	•	Install Reflective Tape on Backplates, Upgrade Pedestrian Signals to Countdown Signals	$ 57,939	$ 10,500	5.52

ID #	Crash Frequency Measure	Crash Rate Measure	EB Expected Measure	EB Expected Excess Measure	Suggested Improvements	Estimated Benefits	Estimated Costs	BCR
67283		•			Oversize and Double-up Stop Signs , Relocate Advance STOP AHEAD Warning Sign and Install Supplemental STOP AHEAD Pavement Markings, Install Roundabout	$ 592,129	$ 1,001,000	0.59
69212	•		•	•	Install Left Turn Lanes, Trim Vegetation in NW Quadrant to Improve Sight Distance	$ 697,855	$ 200,500	3.48
71726	•		•	•	Define Lane Use for Approach and Receiving Lanes, Add Signal Head to Have One Per Lane, Upgrade Pedestrian Signals to Countdown Signals, Enhance Intersection Lighting, Increase Pedestrian Signal Time, Install Reflective Backplates, Consider Split Phasing, Install RLIL	$ 4,469,722	$ 44,600	100.22
75487		•			Designate Lane Use with Pavement Markings and Signage, Enhance Intersection Lighting, Install Roundabout, Open Sight Triangles	$ 890,663	$ 1,007,250	0.88

For More Information:

Stuart Thompson
Stuart.Thompson@dot.gov
202-366-8090

Federal Highway Administration
Office of Safety
1200 New Jersey Avenue SE
Washington, DC 20590
http://safety.fhwa.dot.gov/

Publication # FHWA-SA-16-103