2016-05-01

Roadway Safety Analysis Methodology

Samuel Thomas Mineer
Brigham Young University

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Samuel Thomas Mineer

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Grant G. Schultz, Chair
Mitsuru Saito
Daniel P. Ames

Department of Civil and Environmental Engineering

Brigham Young University

May 2016

ABSTRACT

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Samuel Thomas Mineer
Department of Civil and Environmental Engineering, BYU
Master of Science

The Utah Department of Transportation (UDOT) Traffic and Safety Division continues to advance the safety of the state roadway network through network screening and decision making tools. In an effort to aid UDOT in meeting this goal, the Department of Civil and Environmental Engineering at Brigham Young University (BYU) has worked with the Statistics Department in developing analysis tools for highway safety, specifically the Utah Crash Prediction Model (UCPM) and the Utah Crash Severity Model (UCSM). Additional tools and methodologies, such as the "Hot Spot Identification and Analysis," have been created to summarize the roadway characteristics, crash data, and possible countermeasures of roadway segments with safety problems.

This research focuses on the creation of a three part "Roadway Safety Analysis" methodology, which applies and automates the cumulative work of recently completed highway safety research conducted for UDOT. The first part is to prepare the roadway data and crash data for the statistical analysis. The second part is to perform the network screening statistical analysis; rank the segments by state, UDOT Region, and county; and select segments of interest. The third part is to compile and publish the Roadway Safety Analysis reports for the selected segments of interest. These parts are accomplished using the automation tools and graphical user interfaces (GUIs), which are documented in three respective volumes of user manuals. The automation tools and GUIs were developed with checks and processes to allow the Roadway Safety Analysis methodology to be completed with new, updated roadway and crash datasets.

The Roadway Safety Analysis methodology allows future iterations of the UCPM and UCSM analysis and compilation of the Roadway Safety Analysis reports to be conducted in a user friendly environment. A series of critical data columns were identified to communicate the need for data consistency for future iterations of this safety research. An example of the entire process of the Roadway Safety Analysis methodology is given to illustrate how the three parts tie together. The overall process has automated data processing tasks, which saves time and resources for the analyst to investigate possible safety measures for segments of interest. Recommendations for future highway safety research are given, including continued development of the Roadway Safety Analysis methodology, an analysis of intersections and horizontal curves, the implementation of the Roadway Safety Analysis methodology to other states, and the advancement of safety countermeasures and geospatial tools for highway safety research.

Keywords: crash analysis, highway safety research, Numetric, roadway characteristics, Roadway Safety Analysis, UCPM, UCSM

ACKNOWLEDGEMENTS

This research was made possible with funding from the Utah Department of Transportation and Brigham Young University. I would like to acknowledge those who had an impact in this research and who have supported me through my academic career. First, I would like to thank the members of the Utah Department of Transportation Technical Advisory Committee and the Traffic and Safety Division, including W. Scott Jones, Travis Jensen, and Tim Taylor. This research has also been positively impacted by the professors and students involved in this research, who have provided candid feedback and contributions for creating an excellent final product. Second, I would also like to thank Dr. Schultz, Dr. Saito, and Dr. Ames for their support and feedback as members of my graduate committee. I would like to thank Dr. Schultz as my graduate committee chair for his guidance and support, helping me to grow through my undergraduate and graduate program, preparing me to succeed as a future professional engineer. Third, I would like to thank the faculty and staff in the Civil and Environmental Engineering Department at Brigham Young University for providing an environment to develop faith, character, and technical ability; helping me transform into a leader eager to do good in the world. Most of all, I would like to thank my wife Glenna; parents Don and Karen; siblings Steve, Melanie, and Angela; near and extended family members; and my peers and friends; who have been my biggest support throughout my academic career and who have encouraged me to do good and be good in the world.

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1 INTRODUCTION

The Utah Department of Transportation (UDOT) Traffic and Safety Division continues to advance the safety of the state roadway network. UDOT has continually placed safety at the forefront of their priorities and continues to develop and publicize the "Zero Fatalities: A Goal We Can All Live With™" campaign to increase awareness of the importance of highway safety (Zero Fatalities 2016). UDOT has also continued at the forefront of research and education through their active participation and membership in the Transportation Research Board (TRB) Highway Safety Performance Committee and their willingness to invest in safety research. The Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO) are also continually working to aid states in safety analysis, primarily with the release of the AASHTO *Highway Safety Manual* (HSM) to aid in the analysis of transportation safety data (AASHTO 2010). This chapter provides the background information of this research, the objectives of this research, as well as a brief overview of the organization of this thesis.

1.1 Background

In 2014, there were 54,036 reported crashes on Utah public roadways. These crashes involved 134,182 persons, resulting in 23,364 injuries and 256 fatalities (UDPS 2015). As illustrated in Figure 1-1, the number of fatal crashes on state roadways has been in decline since 2006, with a slight increase in 2014. The total number of crashes on state roadways has remained below 60,000 crashes since 2007 (UDPS 2015). As illustrated in Figure 1-2, the fatality rate per 100 million vehicle miles traveled (VMT) in Utah has been lower than the U.S. rate since 2001. The reduction in fatality rates on Utah public roadways has been attributed to multiple efforts and factors, such as traffic safety programs to increase public awareness of safety issues, improved safety of motor vehicles and engineering of roadways, and advancements in emergency response and treatment (UDPS 2014). Figure 1-3 illustrates that the number of fatalities on Utah roadways has remained under 300 since 2004. The reported number of fatalities for 2015 is 275 (Zero Fatalities 2016). In light of the progress that has been made in the past decade, there is a need to continue promoting motor vehicle safety in Utah and find possible roadway safety improvements, with the end goal of reducing the number of motor vehicle fatalities on public roadways to zero.

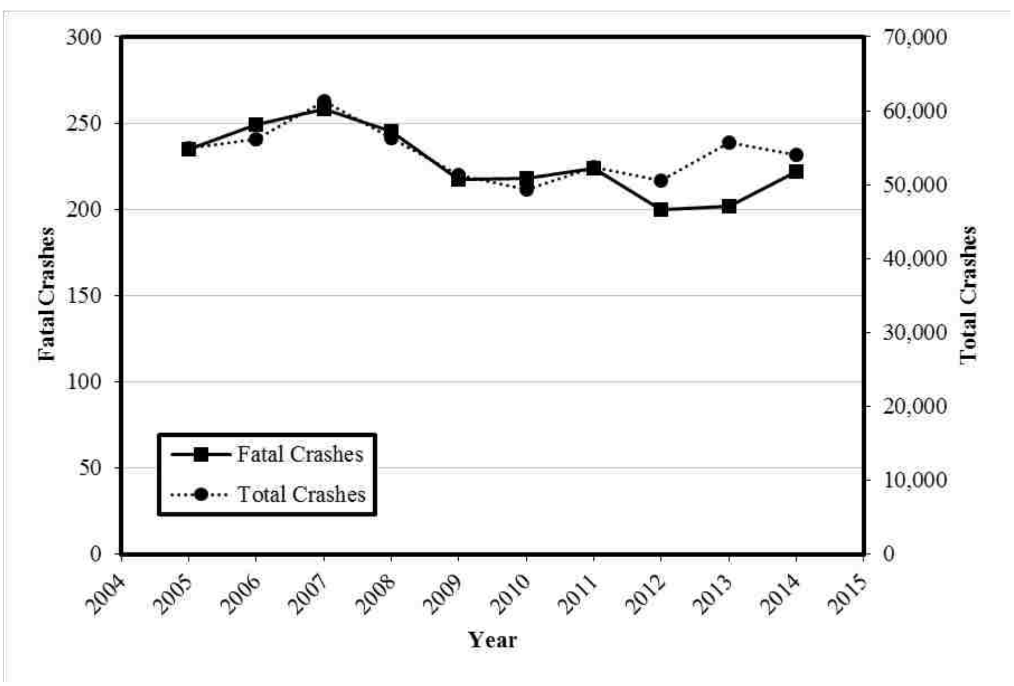


Figure 1-1: Fatal and total crashes in Utah, 2005-2014 (UDPS 2015).

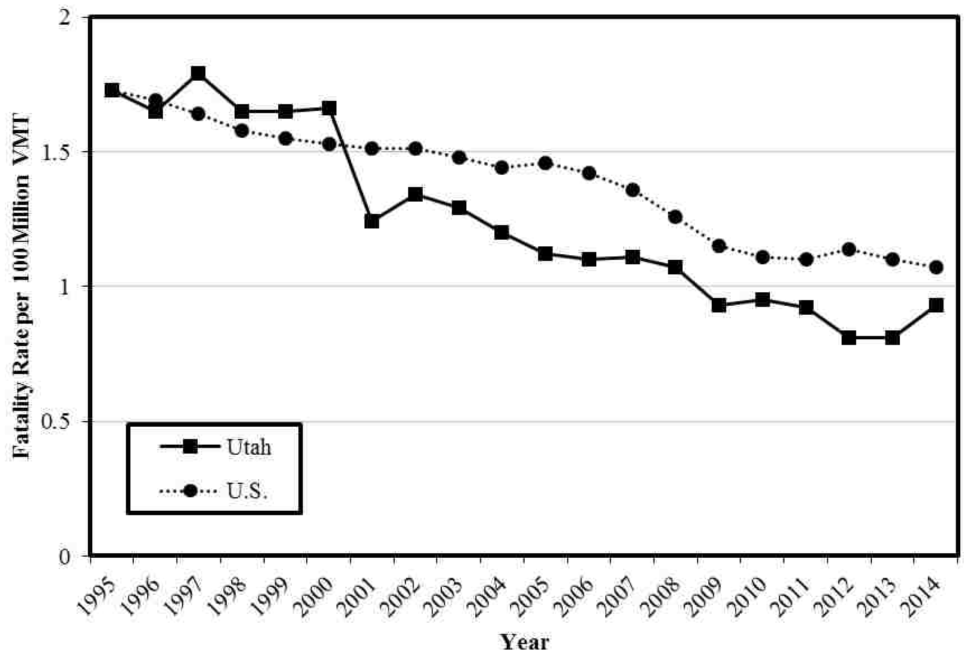


Figure 1-2: Utah vs. U.S. fatality rate per 100 Million VMT, 1995-2014 (UDSP 2015).

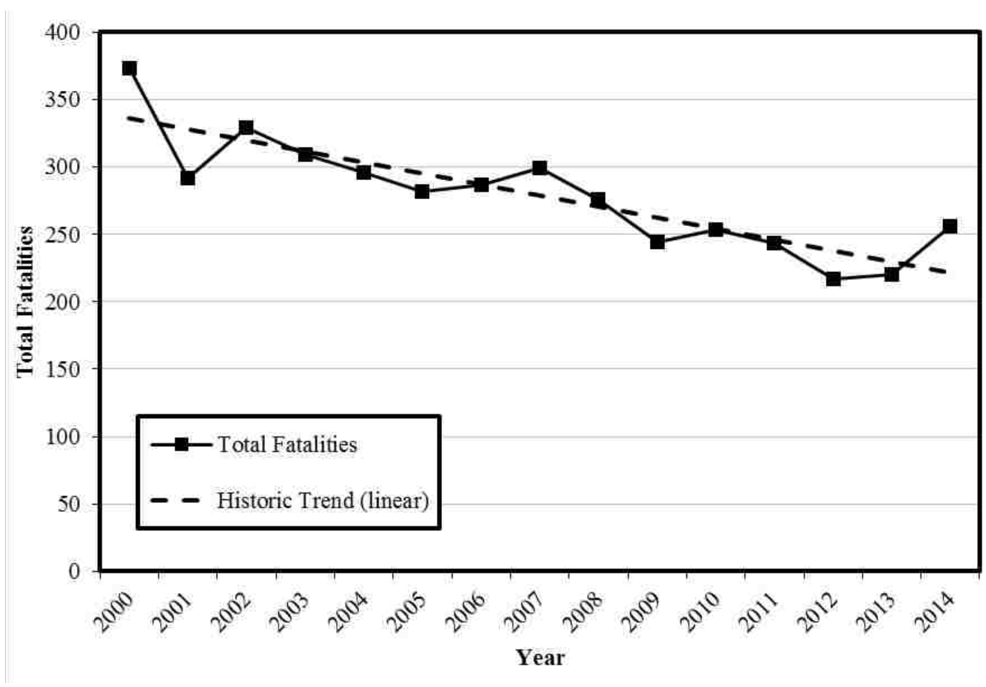


Figure 1-3: Total fatalities on Utah roadways, 2000-2014 (Zero Fatalities 2016).

To aid UDOT in meeting their goal of advancing the safety of roadway sections throughout the state, Brigham Young University (BYU) has worked with UDOT in developing safety analysis tools. The most recent efforts include the development of network screening statistical analyses tools, the Utah Crash Prediction Model (UCPM) and the Utah Crash Severity Model (UCSM). The UCPM and UCSM, combined with previous research focused around the evaluation of safety improvements, calibration of crash safety models, and development of a basic framework for safety mitigation, have helped to set the stage for the research described in this thesis (Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013a, Schultz et al. 2015). The focus of the research summarized in this thesis is to apply existing safety analysis tools through automation tools and graphical user interfaces (GUIs), so that these tools and methodologies can be executed in an efficient manner and assist the UDOT Safety Programs Engineer, UDOT Region directors, and other interested users in the statewide project selection and prioritization process.

1.2 Objectives

The primary objective of this research is to apply and automate recently completed highway safety research conducted for UDOT into the creation of the "Roadway Safety Analysis" methodology. The Roadway Safety Analysis methodology introduces new and improves automation tools and GUIs for the purpose of automating the statistical network screening analysis (i.e., the UCPM and UCSM) and other elements of the "Hot Spot Identification and Analysis" methodology in a user friendly environment. This thesis provides details of the structure of the Roadway Safety Analysis methodology, beginning at the roadway and crash data preparation and concluding at the compilation of and publication of the Roadway Safety

Analysis reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users, with preliminary ties to the Numetric web-based crash analytic tool.

1.3 Organization

This thesis includes the body of the report, with a list of references, list of acronyms, and appendices following the body of the report. The body of the report and appendices are organized into the following chapters:

- Chapter 1 includes the background and objectives of this highway safety research.
- Chapter 2 includes a literature review of national and local crash analytical tools, safety countermeasures, and UDOT's Numetric web-based crash record analysis platform.
- Chapter 3 includes a discussion of the general data considerations, use of data, managing the data, automation tools, GUIs, and documentation related to this research.
- Chapter 4 outlines the first part of the Roadway Safety Analysis methodology; the preparation and segmentation of roadway and crash data for network screening statistical analysis.
- Chapter 5 outlines the second part of the Roadway Safety Analysis methodology; the execution of the UCPM and UCSM and interpreting the output of the analysis.
- Chapter 6 outlines the third part of the Roadway Safety Analysis methodology; the report compilation for the segments of interest and publishing the reports.
- Chapter 7 provides an example of the Roadway Safety Analysis methodology, beginning at the crash and roadway segmentation, centered on the statistical network screening of the roadway data using the UCPM and UCSM, and concluding with the compilation of the Roadway Safety Analysis reports.

- Chapter 8 is a conclusion and summary of the findings of this research and recommended topics for future highway safety research.
- Appendix A is a summary of the safety objectives and countermeasures discussed in the National Cooperative Highway Research Program (NCHRP) Report 500 series volumes.
- Appendix B is a collection of tables summarizing the critical data columns used in this research for the crash database, roadway segmentation process, and compilation of Roadway Safety Analysis reports.
- Appendix C is a summary of several report codes from the traffic crash reports.

2 LITERATURE REVIEW

A literature review was performed on transportation safety and the optimization of the safety analysis tools in Utah and the United States. This chapter includes a literature review of seven topics relevant to highway safety research. The first is a discussion of current state crash analysis tools used in the United States. The second topic is a definition of the crash severity levels in Utah and the United States and the UDOT Safety Index. The third topic is a summary of the cumulative work by researchers at BYU in the development and improvement of crash analysis methodologies in Utah, which is applied and automated in the research summarized in this thesis. The fourth topic is a description of the network screening safety statistical model and analysis techniques in Utah. The fifth topic is a discussion of national crash countermeasures strategies. The sixth topic is a description of a developing process by UDOT to identify possible countermeasures based on roadway characteristics and crash data. The seventh topic in this literature review is an overview of the features and tools of the recently developed UDOT web-based crash record analysis platform, Numetric. References to the previous research are given for the reader's benefit in order to understand the full scope of work invested into improving roadway safety and research in Utah.

2.1 State Crash Analysis Tools in the United States

There are several crash analysis tools available in the United States, which assist state agencies address safety issues on their roadways. The following subsections address three tools and processes which have been developed to date, including FHWA's *SafetyAnalyst*, the geospatial "Crash Analysis" toolbox by Esri, and a strategy adopted by the Illinois Department of Transportation (IDOT) to integrate safety into the transportation decision making process.

2.1.1 SafetyAnalyst

One of the existing tools for analyzing state highway safety is *SafetyAnalyst*. *SafetyAnalyst* is a set of software tools for state highway safety management (AASHTO 2016, FHWA 2010). *SafetyAnalyst* can be used to identify locations for potential highway safety improvement projects, suggest safety improvements, and evaluate the effectiveness of the potential roadway improvement projects. The tools and modules developed in *SafetyAnalyst* are designed to be compatible with the Highway Safety Improvement Program (HSIP). As of the 2014 fiscal year, 12 states/provinces had licenses for *SafetyAnalyst*, with educational licenses at eight universities, as summarized in Table 2-1 (AASHTO 2016).

Table 2-1: SafetyAnalyst Licenses (AASHTO 2016)

State/Provincial Licenses		Educational Licenses
		Brigham Young University (Utah)
Arizona	Nevada	Carleton University (Canada)
Illinois	New Hampshire	Cleveland State University (Ohio)
Kansas	Ohio	United Arab Emirates University
Kentucky	Pennsylvania	University of Alaska
Michigan	Washington	University of Missouri
Missouri	Ontario (Canada)	University of North Carolina at Charlotte
		University of Texas at Austin

2.1.2 Geospatial Analysis – Crash Analysis Toolbox

One of the geospatial tools offered by Esri is the "Crash Analysis" ArcMap toolbox. This ArcMap toolbox has three tools designed to prepare the datasets, merge roadway segments, assign crashes to roadway segments, and create four crash risk maps (Esri 2015a). The maps created by these tools highlight crash density, crash rate, crash rate ratio, and potential crash savings. These map outputs are designed to inform decision makers about safety improvement priorities and mitigation measures. Instructions are given so that the input data from the user can be compatible with the crash analysis tools. An example of the potential crash savings map for the state of Indiana using data provided in the tool's instructions is shown in Figure 2-1.

2.1.3 Illinois: Integrating Safety into the Transportation Decision Making Process

IDOT recognizes the need for reducing the number of fatalities and serious injuries on their roadway. One of the steps in their policy to improve transportation safety is to "establish procedures and utilize technology to explicitly incorporate safety into the transportation management process to evaluate and improve transportation safety performance" (Tobias 2016). One of the products of this effort was the development of Safety Performance Functions (SPFs), Potential for Safety Improvements (PSI) scoring system, and the Safer Roads Index (SRI). The SPF creates a distribution of expected crash occurrence for the given segments or intersections. The PSI represents how much a given segment or intersection exceeds the predicted number of crashes indicated by the SPF. The PSI is used to determine the SRI and safety tiers of the roadway network. The safety tiers identify the critical (top 5 percent), high (5 to 10 percent), medium (10 to 25 percent), low (25 to 50 percent), and minimum (bottom 50 percent) safety improvement locations in the state.

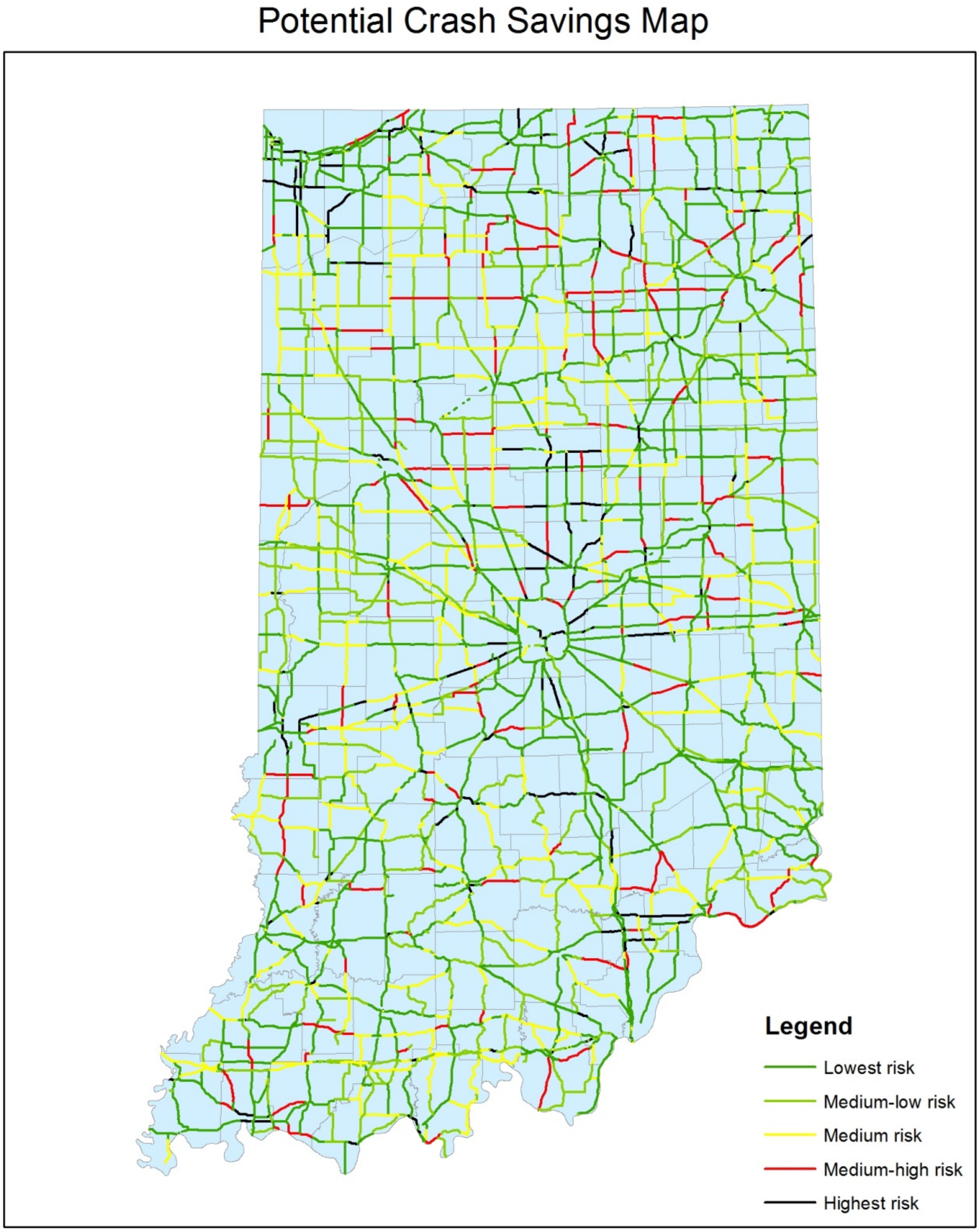
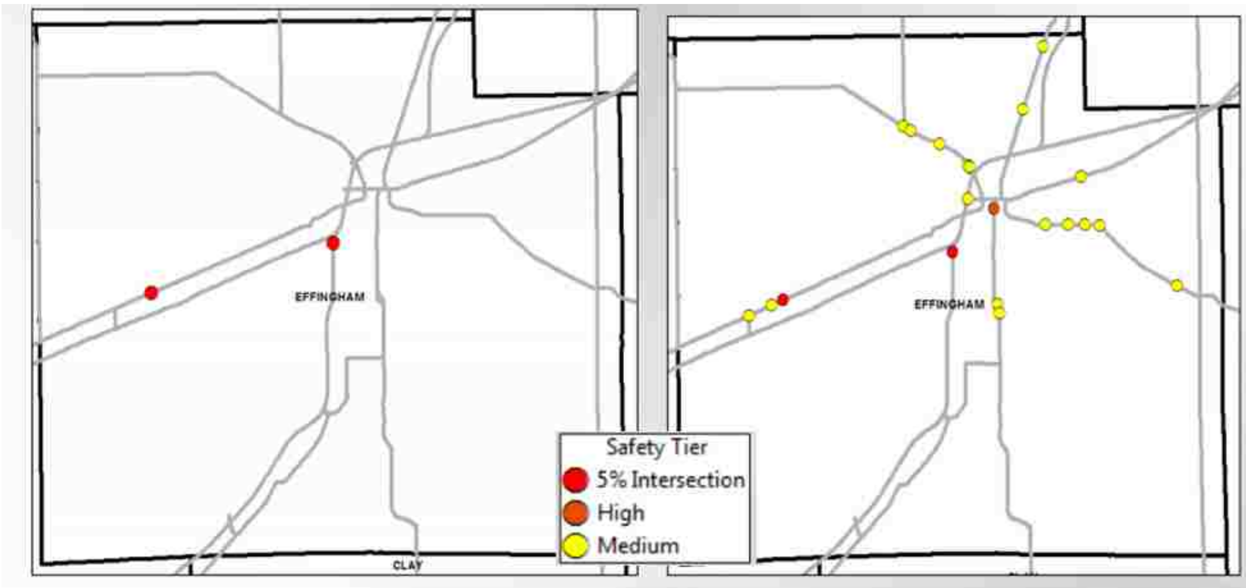


Figure 2-1: "Potential Crash Savings" map for Indiana created using the Crash Analysis tools from ArcGIS.com.

Initially, the critical tier of segments became the focus of project prioritization. After further analysis, it was found that analyzing the top three tiers (i.e., critical, high, and medium tiers) instead of only the critical tier helped to identify roadway corridors in need of safety improvements. Figure 2-2 provides an example of how analyzing the top three tiers helps to identify a cluster of roadways along a corridor that needs safety improvement, compared to analyzing only the critical locations.

Another use of the safety tiers and SRI in IDOT is to overlay the SRI with the infrastructure performance measures. When comparing the SRI to the Condition Rating System (CRS) and International Roughness Index (IRI), decision makers are able to identify locations which are in need of simultaneous safety improvements and infrastructure investment. To illustrate this methodology, two rural highway segments are shown in Figure 2-3, which parallel one another. The southern corridor has a CRS value less than 5.5 throughout a majority of the corridor, indicating the need for infrastructure improvement; however, this corridor doesn't appear to have any safety issues within the top three safety tiers. The northern corridor has a CRS value less than 5.5 and has roadway segments that were classified in the top three safety tiers, which indicates the need for simultaneous infrastructure and safety improvements. When comparing these two corridors for selection of roadway improvement projects, the northern corridor is more likely to receive priority and become a candidate for additional safety and cost/benefit analysis, as it demonstrates the need for simultaneous safety and roadway infrastructure improvements.



(a) (b)

Figure 2-2: Example of analyzing (a) only critical locations for safety improvements and (b) the top three tiers for safety improvements (Tobias 2016).

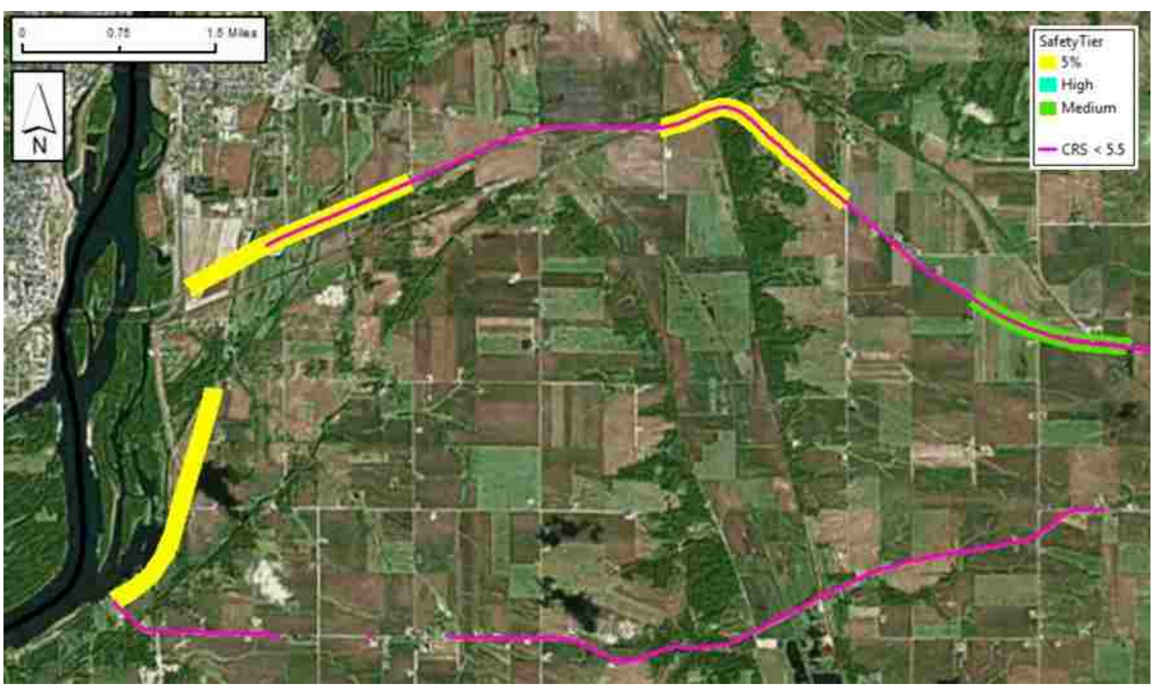


Figure 2-3: Comparing two rural roadways on their safety and infrastructure condition indices (Tobias 2016).

2.2 Utah Crash Severities and UDOT Safety Index

The crash severity is based on the most severe injury to any person involved in a crash. The numerical 5 to 1 scale used in Utah matches the national letter "KABCO" severity rating system (NHTSA 2012). Table 2-2 summarizes the significance of the different crash severities. The numerical severity scale is used throughout the Roadway Safety Analysis methodology.

UDOT developed the Safety Index, with the purpose of assessing roadway safety and prioritizing projects. The Safety Index is a value that combines multiple safety factors into a single, zero to 10, numerical scale. The value of 10 represents the worst safety conditions, when compared to other roadways in the network (Esri 2015b). The Safety Index is comprised of four factors, each given a zero to five score (Allen 2013):

1. Ratio of crash rate vs. statewide average crash rate, S_{CR}
2. Number of crashes per mile per year, S_{CPM}
3. Ratio of severe crash rate vs. statewide average severe crash rate, $S_{Sev\ CR}$
4. Number of severe crashes per mile per year, $S_{Sev\ CPM}$

These four factors receive their respective zero to five score, are summed, and divided by two to create the final UDOT Safety Index value, as shown in Equation 2–1 (Allen 2013). The calculation of the UDOT Safety Index addresses the high frequency of crashes occurring (S_{CR} and S_{CPM}) and gives equal weight to high severity crashes ($S_{Sev\ RC}$ and $S_{Sev\ CPM}$), which makes this crash rating system comprehensive in the context of the state roadway network.

Table 2-2: Crash Severity Ratings (NHTSA 2012)

UDOT Numeric Scale	Federal Letter Scale	Injury Status
5	K	Fatal Injury: injury that results in death within 30 days of crash
4	A	Suspected Serious Injury: serious injury not resulting in fatality; incapacitating injury results from the crash
3	B	Suspected Minor Injury: minor injury evident at the scene of the crash, not serious injury or fatality
2	C	Possible Injury: injuries reported but not evident at the scene of the crash
1	O	No Apparent Injury: the person receive no bodily hard; property damage only (PDO)

$$Safety\ Index = \frac{S_{CR} + S_{CPM} + S_{Sev\ CR} + S_{Sev\ CPM}}{2} \tag{2-1}$$

where: S_{CR} = score for crash rate
S_{CPM} = score for crashes per mile
$S_{Sev\ CR}$ = score for severe crash rate
$S_{Sev\ CPM}$ = score for severe crashes per mile

2.3 Development of Utah Crash Analysis Methodology and Reports

The work and development presented in this thesis applies and automates the cumulative work by researchers at BYU in the development and improvement of roadway safety measures and analyses in Utah. The following subsections provide a brief summary of the recent highway safety research work conducted by BYU for UDOT between 2010 and 2015, which have advanced the roadway highway safety research in the state of Utah. The first of the recent highway safety research included the publication of three volumes on transportation safety data and analysis (Saito et al. 2010, Schultz et al. 2010, Schultz et al. 2011). The next research investigated the use of statewide modeling and geospatial tools to prepare the statewide datasets for statistical analysis (Schultz et al. 2012). After identifying the benefits of the geospatial tools, the Hot Spot Identification and Analysis methodology was developed as a network screening statistical tool to identify problem spots and analyze the safety aspects of the roadway (Schultz et al. 2013a). The Hot Spot Identification and Analysis methodology was improved by investigating the roadway attributes, which could be used to identify possible countermeasures for safety problem roadways (Schultz et al. 2015).

2.3.1 Transportation Safety Data and Analysis

Three volumes of research work were published in 2010 and 2011 to discuss the findings and research related to transportation safety data and analysis. The first volume addressed some of the limitations of safety measurements and described how the use of advanced statistical methodologies can help bridge the limitations of traditional safety measurements (Schultz et al. 2010). Specifically in this research, the effectiveness of raised medians and cable barriers were investigated with 10 years of crash data. The results of the statistical analysis illustrated a reduction in crash frequency and crash severity with the use of raised medians and a reduction in crash severity and cross-median crashes with the use of cable barriers. Full details and results are provided in the literature (Schultz et al. 2010).

The second volume addressed the calibration of the SPFs in the HSM and the development of a negative binomial prediction model for analyzing the safety of rural two-lane two-way roadway segments in Utah. The findings of this research illustrated that the calibration factor for Utah's two-lane two-way rural roads is approximately 1.16, which suggests that the HSM underestimated the number of crashes on the rural roadways in Utah. Additional statistical analysis of the factors of rural roadway crashes showed that speed was a significant factor, which was not accounted for in the HSM model. This study illustrated that there are strengths, weaknesses, and opportunities for improving roadway analysis with and beyond the HSM SPF. Full details and results are provided in the literature (Saito et al. 2011).

The third volume addressed the framework for highway safety mitigation and the implementation of the framework by employees at UDOT for Utah. The framework was summarized into six steps and discussed in further detail in the literature (Schultz et al. 2011). With the framework developed, in conjunction with adequate training provided by FHWA, the National Highway Institute (NHI), and the Institute of Transportation Engineers (ITE), UDOT can be better prepared with an action plan for addressing safety concerns on their roadways. Full details and information regarding this framework and training are provided in the literature (Schultz et al. 2011).

2.3.2 Statewide Model and Geospatial Modeling

With the development of a safety statistical model, there came a need to present the results using the capabilities of Geographic Information System (GIS) software (Schultz et al. 2012). One of the identified benefits of using GIS software was the capability of merging roadway attributes spatially or linearly. Another benefit of using GIS software was the capability to visually display crash data and roadway feature by color or size of the symbol. As data are processed using GIS software, the data can also be filtered to display data of interest. This report provided an example of using a combination of GIS tools to prepare the data for the statistical analysis and graphically display the result of the statistical analysis. Full details and information regarding the use of GIS software related to highway safety is provided in the literature (Schultz et al. 2012).

2.3.3 Hot Spot Identification and Analysis Methodology

To accompany the statistical model development, a methodology was developed to enhance the steps of screening, diagnosing, and identifying possible countermeasures in the highway safety mitigation process. The Hot Spot Identification and Analysis methodology is comprised of the following seven steps (Schultz et al. 2013a):

1. Identify problematic segments with safety concerns
2. Identify problem spots within the segments
3. Micro-analysis of problematic segments and hot spots
4. Define the segment roadway characteristics
5. Define the problem
6. Evaluate possible countermeasures
7. Select and recommend feasible countermeasures

The problematic segments were identified from the results of the network screening statistical analysis model, the UCPM. Problem spots were identified in the problematic segments by using GIS analysis tools, such as the "Strip Analysis" tool and "Sliding Scale Analysis" tool. The micro-analysis involved a definition of the roadway characteristics through site visits and other tools to identify possible problems and feasible countermeasure to mitigate future crashes at the hot spot. Full details and information regarding the development and example of using this methodology is provided in the literature (Schultz et al. 2013a).

2.3.4 Use of Roadway Attributes in Hot Spot Identification and Analysis

The Hot Spot Identification and Analysis methodology was improved upon by developing the UCSM and incorporating roadway characteristics in the analysis of individual roadway segments, including median, intersections per mile (IPM), signs per mile (SPM), shoulder, grade, horizontal curve, auxiliary lane, wall, barrier, and rumble strip data. In addition to summarizing current roadway conditions, the Hot Spot Identification and Analysis methodology was enhanced with the creation of two-page reports to be distributed to the UDOT Region directors across the state. Full details and information regarding the development of the UCSM and the analysis reports are provided in the literature (Schultz et al. 2015).

2.4 Network Screening Safety Statistical Models and Analysis Techniques in Utah

Crash analysis techniques and methodologies are critical for improving traffic safety. The 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act –A Legacy for Users (SAFETEA-LU) established the need for a HSIP. A manual for the HSIP was created in 2010, which outlines the program components for improving highway safety. As illustrated in Figure 2-4, one of the first steps of the HSIP is to identify highway safety problems (Herbel et al. 2010). Roadway safety problems can be determined by fatalities, injuries, crashes, crash rates, fatality rates, or a number of other measures or methodologies. Each methodology has advantages and disadvantages, depending on the intent of the analysis and the availability of crash and roadway data (Herbel et al. 2010, Schultz et al. 2012).

Two models have been developed by BYU for UDOT for the purpose of identifying problem spots in regards to safety on state roadways. Sequentially, the first developed is the UCPM, followed by the UCSM. These two models each have strengths and limitations for identifying roadway segments with safety concerns. These models are designed to be used in conjunction with one another, not to replace nor supersede the results of one or the other, so long that the correct analysis steps have been taken. A brief discussion of these models and their outputs from previous research is presented in the following subsections.

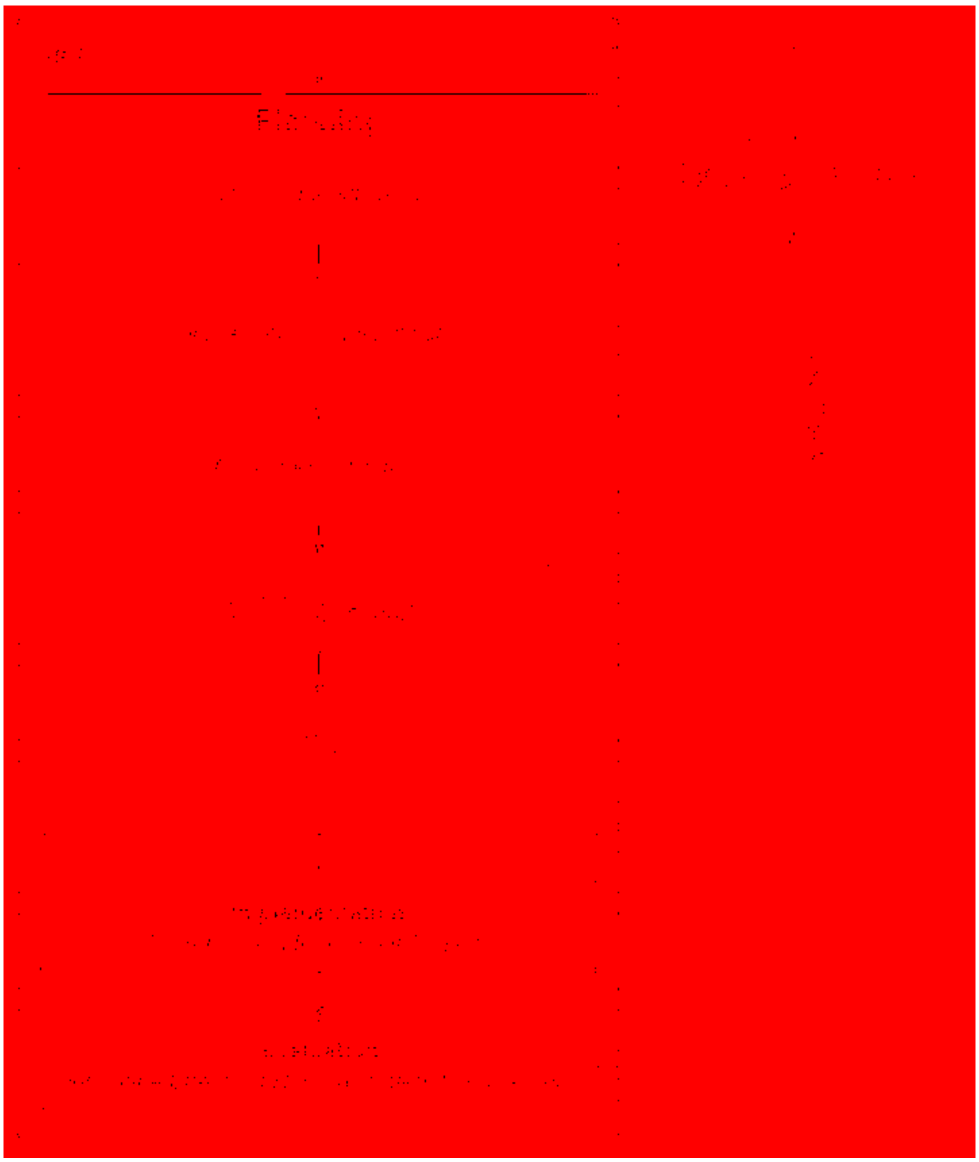


Figure 2-4: Highway Safety Improvement Program Components (Herbel et al. 2010).

2.4.1 UCPM – Utah Crash Prediction Model

The UCPM was developed as the core analysis tool of the Hot Spot Identification and Analysis methodology (Schultz et al. 2013a). The purpose of the UCPM is to identify where more crashes are occurring on roadways than what would be expected. The roadway segments of a similar route and similar functional classification are analyzed, with the ultimate goal of finding the roadway segments which are experiencing more crashes than what is expected. The number of crashes in the analysis could include all five crash severities or focus on the higher crash severities. In the UCPM analysis, a distribution of the predicted number of crashes is calculated, based on the significant parameters identified using the Bayesian horseshoe selection method.

Once the statistically significant parameters have been determined for the dataset (roadway and crash data), the UCPM analysis is executed. The output of the UCPM is a distribution of the number of crashes that would be expected for the segments, based off of the parameters selected by the Bayesian horseshoe selection method. The percentile is determined by a measure of deviation between the predicted number of crashes to the actual number of crashes that occurred on the roadway. A higher percentile (near 1.0) would indicate that the actual number of crashes is far greater than the predicted number of crashes on the segment and a lower percentile (near zero) would suggest the opposite. The segments with a high percentile become the focus of further safety analyses. The development and full description of the UCPM are described in the literature (Schultz et al. 2013a, Schultz et al. 2015).

An analysis using the UCPM was conducted on roadway and crash data from 2008 to 2012, analyzing the non-incapacitating injury, incapacitating injury, and fatal crashes (i.e., crash severities 3, 4, and 5). The Bayesian horseshoe selection method identified the parameters listed in Table 2-3 as statistically significant variables in the UCPM analysis. The top 20 problem roadway segments from the analysis are listed in Table 2-4. The full analysis of these segments is discussed in additional detail in the literature (Schultz et al. 2013a, Schultz et al. 2015).

2.4.2 UCSM – Utah Crash Severity Model

The UCSM was developed in the improvement of the Hot Spot Identification and Analysis methodology (Schultz et al. 2015). The purpose of the UCSM is to identify where more severe crashes are occurring on roadways than what would be expected. Considering all other factors equal, the UCSM predicts a severe crash rate and compares it to the actual severe crash rate. The severe crash rate is determined by the sum of severe crashes divided by the total number of crashes on the roadway segment. The UCSM differs from the UCPM in that the analysis factors in all crashes on a roadway segment and a group of high severity crashes, whereas the UCPM analyzes only a group of crash severities and does not factor in the total number of crashes. In the UCSM analysis, a distribution of the predicted severe crash rate is developed, based on the significant parameters identified using the Bayesian horseshoe selection method.

Once the statistically significant parameters have been determined for the dataset (roadway and crash data), the UCSM analysis is executed. The output of the UCSM includes a distribution of the predicted severe crash rate for the segments, based off of the parameters selected by the Bayesian horseshoe selection method. The predicted severe crash rate and predicted number of severe crashes is compared to the actual severe crash rate and actual number of severe crashes. The roadway segments with a higher severe crash rate than what is expected would become the focus of further safety analysis. The development and full description of the UCSM are described in detail in the literature (Schultz et al. 2015).

Using the same data as the UCPM analysis (2008 to 2012 roadway and crash data), an analysis using the UCSM was conducted for all the crash counts and the incapacitating injury and fatal crashes (i.e., crash severity 4 and 5). The Bayesian horseshoe selection method identified the parameters listed in Table 2-5 as statistically significant variables in the UCSM analysis. The top 20 roadway segments where the number of actual severe crashes was greater than the number of expected severe crashes are listed in Table 2-6. The full analysis of these segments is discussed in additional detail in the literature (Schultz et al. 2015).

2.5 National Crash Countermeasures Strategies

One of the planning steps in the HSIP is the identification of countermeasures, as shown in Figure 2-4. The countermeasure identification process is accomplished in four steps: first, analyze the crash data, contributing crash factors, and crash patterns; second, assess site conditions, such as the roadway geometry, land use, etc.; third, identify potential countermeasures; and fourth, assess countermeasure effectiveness (Herbel et al. 2010). The following subsections discuss different resources for identifying the possible countermeasures and their effectiveness, including the 23 volume reference series "NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan," "Countermeasures That Work," and the Crash Modification Factor (CMF) Clearinghouse website.

Table 2-3: UCPM Parameters for the 2013 Analysis (Schultz et al. 2013a)

From Roadway Data	From Crash Data
Number of Lanes Speed Limit Total Percent Trucks VMT	Distracted Domestic Animal Intersection Motorcycle Night Single Vehicle

Table 2-4: Segments Analyzed in the 2013 UCPM Analysis (Schultz et al. 2013a)

Segment	Route Label	Beginning MP	End MP	UDOT Region	Percentile	Actual Crash Count (Severities 3, 4, and 5)	Model Predicted Crashes	Difference
1	0089P	388.438	389.123	1	1.000000	37	14	23
2	0015P	250.923	253.557	3	0.999989	28	11	17
3	0089P	415.425	415.994	1	0.999911	35	16	19
4	0015P	292.596	293.634	2	0.999733	25	11	14
5	0089P	369.036	369.532	2	0.999311	31	16	15
6	0089P	267.346	276.210	4	0.999144	17	6	11
7	0089P	386.955	388.438	1	0.998678	44	26	18
8	0089P	345.017	346.455	3	0.998622	34	18	16
9	0089P	431.317	433.164	1	0.998589	16	6	10
10	0068P	48.314	49.312	2	0.998567	39	22	17
11	0015P	296.093	297.314	2	0.998389	41	24	17
12	0015P	303.414	304.427	2	0.997989	30	16	14
13	0089P	335.590	336.030	3	0.997944	28	15	13
14	0015X	357.554	361.920	1	0.997600	23	11	12
15	0089P	347.360	347.664	3	0.996500	21	11	10
16	0015X	275.279	276.064	3	0.996278	26	14	12
17	0089P	349.471	350.056	3	0.996256	32	18	14
18	0015P	248.845	250.923	3	0.995800	13	5	8
19	0089P	386.346	386.801	1	0.995600	21	11	10
20	0089P	413.927	414.220	1	0.995211	17	8	9

Table 2-5: UCSM Parameters for the 2015 Analysis (Schultz et al. 2015)

From Roadway Data	From Crash Data
Annual Average Daily Traffic (AADT) Number of Lanes Speed Limit Total Percent Trucks VMT	None

Table 2-6: Segments Analyzed in 2015 UCSM Analysis(Schultz et al. 2015)

Segment	Route Label	Beginning MP	End MP	UDOT Region	Probability (Severe Crash Occurrence)	Total Crash Count (Severities 1 to 5)	Severe Crash Count (Severities 4 and 5)	Expected Severe Crash Count	Difference
1	0080P	3.993	41.278	2	0.000	83	16	5.242	10.758
2	0068P	11.638	23.934	3	0.000	62	11	3.165	7.835
3	0006P	290.894	300.359	4	0.001	16	5	0.791	4.209
4	0015P	82.253	94.453	4	0.002	84	12	4.747	7.253
5	0173P	8.516	8.775	2	0.002	46	6	1.309	4.691
6	0080P	41.278	48.940	2	0.002	15	5	0.947	4.053
7	0134P	13.451	14.067	1	0.001	6	3	0.239	2.761
8	0048P	7.000	7.400	2	0.003	71	6	1.424	4.576
9	0071P	8.843	9.212	2	0.003	49	6	1.453	4.547
10	0039P	38.173	42.336	1	0.002	15	5	1.040	3.960
11	0089P	303.160	305.530	3	0.002	26	5	0.996	4.004
12	0006P	25.250	27.100	4	0.002	8	3	0.297	2.703
13	0191P	128.890	129.260	4	0.002	2	2	0.087	1.913
14	0089P	328.550	328.847	3	0.006	52	6	1.726	4.274
15	0089P	376.770	377.324	2	0.008	94	8	3.038	4.962
16	0089P	24.910	28.620	4	0.005	13	4	0.774	3.226
17	0080X	3.993	41.278	2	0.009	83	11	5.242	5.758
18	0092P	13.230	22.600	3	0.006	43	4	0.754	3.246
19	0111P	2.811	4.900	2	0.010	75	7	2.528	4.472
20	0089P	351.984	352.710	3	0.007	20	4	0.824	3.176

2.5.1 NCHRP Report 500 Series

The development of potential crash countermeasures stems back to 1998 with the creation of the Strategic Highway Safety Plan (SHSP). This document was created by the AASHTO "Standing Committee for Highway Traffic Safety," with the help of FHWA, the National Highway Traffic Safety Administration (NHTSA), and the TRB committee on Transportation Safety Management. In response to the 1998 SHSP, NCHRP developed several volumes of manuals to assist state and local agencies in reducing injuries and fatalities for a given problem or crash type. The 23 volume reference series, published between 2005 and 2009, is the "NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan" (Neuman et al. 2003f).

Each volume of the NCHRP Report 500 series targets a specific highway crash type. The topic and number of countermeasures suggested for each volume are summarized in Table 2-7. Several objectives were identified for each crash type, with specific strategies and countermeasures for obtaining the given objective. Each countermeasure is categorized as proven (P), tried (T), experimental (E), or not available (NA) if data were not available (Neuman et al. 2003f). The 374 countermeasures described in these volumes do not summarize every possible countermeasure for the different crash types but provide a reliable foundation of possible solutions to begin the process of addressing highway safety issues.

As part of the development of the UCPM, the countermeasures of 13 of the 23 volumes of the NCHRP Report 500 volumes were discussed and summarized, including a description of the problem crash type, a list of objectives to mitigate the crash type, and a list of countermeasures and strategies (Schultz et al. 2013a). These countermeasures were tabulated, which became a useful tool when analyzing the roadways and creating the "Safety Analysis on

Hot Spot Segments” reports (Schultz et al. 2015). Appendix A tabulates the objectives and countermeasures provided in the NCHRP Report 500 volumes.

Table 2-7: Summary of NCHRP 500 Report Topics

Vol.	Report Title	Counter-measures
1	“A Guide for Addressing Aggressive-Driving Collisions” (Neuman et al. 2003f)	5
2	“A Guide for Addressing Collisions Involving Unlicensed Drivers and Drivers with Suspended or Revoked Licenses” (Neuman et al. 2003e)	10
3	“A Guide for Addressing Collisions with Trees in Hazardous Locations” (Neuman et al. 2003c)	6
4	“A Guide for Addressing Head-On Collisions” (Neuman et al. 2003d)	7
5	“A Guide for Addressing Unsignalized Intersection Collisions” (Neuman et al. 2003b)	51
6	“A Guide for Addressing Run-Off-Road Collisions” (Neuman et al. 2003a)	14
7	“A Guide for Reducing Collisions on Horizontal Curves” (Torbic et al. 2004)	20
8	“A Guide for Reducing Collisions Involving Utility Poles” (Lacy et al. 2004)	10
9	“A Guide for Reducing Collisions Involving Older Drivers” (Potts et al. 2004)	19
10	“A Guide for Reducing Collisions Involving Pedestrians” (Zegeer et al. 2004)	16
11	“A Guide for Increasing Seatbelt Use” (Lucke et al. 2004)	7
12	“A Guide for Reducing Collisions at Signalized Intersections (Antonucci et al. 2004)	28
13	“A Guide for Reducing Collisions Involving Heavy Trucks” (Knipling et al. 2004)	15
14	“A Guide for Reducing Crashes Involving Drowsy and Distracted Drivers” (Stutts et al. 2005)	13
15	“A Guide for Enhancing Rural Emergency Medical Services” (Torbic et al. 2005)	16
16	“A Guide for Reducing Alcohol-Related Collisions” (Goodwin et al. 2005)	15
17	“A Guide for Reducing Work Zone Collisions” (Antonucci et al. 2005)	22
18	“A Guide for Reducing Collisions Involving Bicycles” (Raborn et al. 2008)	23
19	“A Guide for Reducing Collisions Involving Young Drivers” (Goodwin et al. 2007)	14
20	“A Guide for Reducing Head-on Crashes on Freeways” (Neuman et al. 2008)	11
21	“Safety Data and Analysis in Developing Emphasis Area Plans” (Council et al. 2008)	0 (zero)
22	“A Guide for Addressing Collisions Involving Motorcycles” (Potts et al. 2008)	26
23	“A Guide for Reducing Speeding-Related Crashes” (Neuman et al. 2009)	26

2.5.2 Countermeasures That Work

A supplementary guide for evaluating possible safety countermeasures is "Countermeasures That Work," first published by Hedlund (2005). This guide was created to be a basic reference to assist State Highway Safety Officials (SHSO) in selecting effective, science-based traffic safety countermeasures (Hedlund 2005). This guide draws upon the countermeasures discussed in the NCHRP Report 500 series volumes and discussing different collision types. With the publication of the eighth edition by Goodwin (2015), nine safety problem areas are discussed in depth, as summarized in Table 2-8 (Goodwin et al. 2015).

Table 2-8: Summary of "Countermeasures That Work" Safety Topics (Goodwin et al. 2015)

Safety Topic	Countermeasures Discussed
Alcohol- and Drug-Impaired Driving	32
Seat belts and Child Restraints	14
Speeding and Speed Management	8
Distracted and Drowsy Driving	8
Motorcycle Safety	9
Young Drivers	11
Older Drivers	8
Pedestrians	14
Bicyclists	12

For each safety problem, there is a summary of major strategies and countermeasures to address the safety problem. For the countermeasures, there is a summary of the use, effectiveness, costs, and implementation time. These measurements of use, effectiveness, costs, and implementation time are represented by scores or sub-categories, which are outlined in Figure 2-5. These category measurements are developed from existing research related to the implementation and evaluation of countermeasures. These measurements can vary from state to state and community to community, but provide an approximate expectation for the countermeasure's value and safety impact. These ratings are updated as the guide is updated biannually (Goodwin et al. 2015). References to the studies related to the application and use of these countermeasures are given in the guide, if additional details and case-studies are desired. Figure 2-6 provides an example of the countermeasures and scores for some of the available measures discussed for distracted and drowsy driving.

2.5.3 CMF Clearinghouse

Another resource for evaluating the effectiveness of countermeasures is the CMF Clearinghouse website. The CMF Clearinghouse website serves three important roles as a web-based database: first, it provides CMF data in a comprehensive and searchable database; second, it educates CMF users of the appropriate use of CMFs; and third, it facilitates CMF research and provides published needs to make the database more robust (FHWA 2016). The user can search for a given topic and the search results provide a list of categories of roadway features, subcategories for application, and countermeasures. The listed countermeasures provides a suggested CMF value, a crash reduction factor (CRF), the type of crash the countermeasure can address, the application area, and references for the derivation of the provided values. Figure 2-7 provides a screenshot of some of the search results for "raised median."

Effectiveness:

★★★★★ - Demonstrated to be effective by several high-quality evaluations with consistent results

★★★★ - Demonstrated to be effective in certain situations

★★★ - Likely to be effective based on balance of evidence from high-quality evaluations or other sources

★★ - Effectiveness still undetermined; different methods of implementing this countermeasure produce different results

★ - Limited or no high-quality evaluation evidence

Effectiveness is measured by reductions in crashes or injuries unless noted otherwise. See individual countermeasure descriptions for information on effectiveness size and how effectiveness is measured.

Cost to implement:

$$$: requires extensive new facilities, staff, equipment, or publicity, or makes heavy demands on current resources
$$: requires some additional staff time, equipment, facilities, and/or publicity
$: can be implemented with current staff, perhaps with training; limited costs for equipment, facilities, and publicity

These estimates do not include the costs of enacting legislation or establishing policies.

Use:

High: more than two-thirds of the States, or a substantial majority of communities
Medium: between one-third and two-thirds of States or communities
Low: less than one-third of the States or communities
Unknown: data not available

Time to implement:

Long: more than one year
Medium: more than three months but less than one year
Short: three months or less

These estimates do not include the time required to enact legislation or establish policies.

Figure 2-5: Countermeasure evaluation scoring categories for effectiveness, cost to implement, use, and time to implement (Goodwin et al. 2015).

1. Laws and Enforcement

Countermeasure	Effectiveness	Cost	Use	Time
1.1 GDL requirements for beginning drivers	★★★★★†	$	High	Medium
1.2 Cell phone and text messaging laws	★★	$	Medium	Short
1.3 High visibility cell phone/text messaging enforcement	★★★★	$$$	Low	Medium
1.4 General drowsiness and distraction laws	★	Varies	High††	Short

† Effectiveness proven for nighttime and passenger restrictions

†† Included under reckless driving; use of explicit drowsiness and distraction laws is low

2. Communications and Outreach

Countermeasure	Effectiveness	Cost	Use	Time
2.1 Drowsy driving	★	$$	Unknown	Medium
2.2 Distracted driving	★	$$	High	Medium

3. Other Countermeasures

Countermeasure	Effectiveness	Cost	Use	Time
3.1 Employer programs	★★	$	Unknown	Short
3.2 Education regarding medical conditions and medications	★	Variable	Unknown	Medium

Figure 2-6: Countermeasures for distracted and drowsy driving (Goodwin et al. 2015).

Figure 2-7: Example of the CMF search results for "raised median" (FHWA 2016).

2.6 UDOT Process to Identify Potential Countermeasures

UDOT is developing a logical process to produce a list of roadway improvements as potential countermeasures to mitigate crashes in the future. As of December 2015, there were 20 possible roadway improvements programmed into the potential countermeasure identification process, as outlined in Table 2-9. The number of possible roadway improvements may be expanded in the future. This procedure analyzes a collection of crashes along a roadway segment, factoring the presence or absence of certain roadway features, to identify whether certain roadway improvements would be relevant for mitigating future crashes. The criteria for each of the 20 roadway improvements are unique to one another and are evaluated for each crash along a given segment. The result of the potential countermeasure compilation process is a table appended to the crash data, summarizing the feasibility of the possible roadway improvements for each crash event. This summary is designed to provide possible options for roadway improvements, rather than dictate which roadway improvements should be applied to a given roadway. It is left to engineering judgment whether a given countermeasure is chosen or not for implementation.

Table 2-9: UDOT Roadway Improvements as Potential Countermeasures

Right-Turn Lane	Shoulder Barrier
Left-Turn Lane	Median Barrier
Intersection Lighting	Two-Way Left Turn Lane (TWLTL) or Raised Median
Dilemma Zone Detection	Curve Signing or Delineation
Left-Turn Phasing Changes	Wildlife Warning Sign
Traffic Signal	Bicycle Warning Sign
Centerline Rumble Strips	Runaway Truck Ramp
Shoulder Rumble Strips	New/Extended Passing Lane
Pave or Widen Shoulder	Pavement Resurfacing
Clear Zone Improvements	Drainage Improvements

For illustrative purposes, the process of evaluating the feasibility of installing shoulder rumble strips to improve roadway safety is summarized. In order for a shoulder rumble strip installation to be suggested as a potential roadway improvement as a response to a given crash, certain criteria must be met, as outlined in Table 2-10. If there was evidence of roadway departure, a vehicle ran off the roadway to the right, and shoulder rumble strips are not currently installed, then installing shoulder rumble strips becomes a potential countermeasure for the given crash on a segment. If a majority of the crashes on a segment suggest installing shoulder rumble strips, then the analyst might have evidence for justifying installing shoulder rumble strips on the roadway. Engineering judgment is needed to validate the possible countermeasures suggested by this logical process.

Table 2-10: Logic for Selecting "Shoulder Rumble Strips" Treatment

Shoulder Rumble Strips			
Crash Field	*Value*	*Definition*	
Roadway Departure	Yes		And
Sequence of Events 1-2	1	Ran off Road Right	
Feature Check: Rumble Strip Data	Shoulder Rumble Strip Not Installed		

2.7 Numetric – Crash Record Analysis Platform

To assist with the spatial analysis of crash data for UDOT employees, a web-based crash record analysis platform was created by Numetric, a business-intelligence, data analysis service based in Highland, Utah (Numetric 2016a). The online crash record analysis platform allows the user to analyze crash data within Utah, which is found at https://udot.numetric.com (Numetric 2016c).

As of April 2016, the Numetric platform allows for the general public to view a general summary of the crash data. The public portal is designed to summarize crash data for those without the credentials to access all of the crash data, as a means to protect the integrity of the sensitive information contained in the crash data. An example of the public's interface with the Numetric platform is given in Figure 2-8.

Full access to the crash analysis platform is limited to UDOT employees and those given special permission. A full access user can use several tools or applications (apps) to analyze the available crash data in Utah. The apps are organized into one of two groups, "Traffic and Safety" and "Asset Management," with the potential of additional apps being developed and added to the Numetric interface in the future.

Figure 2-8: Sample of crash data available to public (Numetric 2016c).

As of April 2016, there were three Traffic and Safety apps available for users. The first is the "Crash Query" app. This app allows for exploration and analysis of crash data, with an option to create reports based on the filter criteria (Numetric 2016b). The user can search for specific types of crash types, specific routes, or analyze all types of crashes for a specific UDOT Region or county. The crashes can be represented as points or as crash rates along a segment, which allows the user to visually explore the crashes in the crash database.

The second Traffic and Safety app is the "Network Screening" app. This app provides a review of previous safety metrics, such as the UDOT Safety Index, the UCPM, and the UCSM. As discussed in Section 2.2, the UDOT Safety Index looks at the crash rate, severe crash rate, crashes per mile, and severe crashes per mile of a given segment and ranks that segment versus all other segments in the network (Numetric 2016b). In addition to the UDOT Safety Index, this app currently features previous outputs of the UCPM and UCSM analyses. Future iterations of the UCPM, UCSM, and other safety models will be featured in this app. An example of navigating through the Network Screening app is illustrated in Figure 2-9.

The third Traffic and Safety app is the "Safety Analysis" app. This app is designed for analyzing a specific corridor or section of roadway to identify potential safety treatments, which allows for comparing roadway segments and prioritizing roadway projects (Numetric 2016b).

As of April 2016, there were two Asset Management apps available for users. The first is the "Project Design" app. This app allows the user to efficiently design a roadway rehabilitation project and develop the associate cost estimate (Numetric 2016b). The app has built in parameters and cost estimates but allows the user to change the cost or other project parameters.

The second Asset Management app is the "Asset Query" app. This app allows the user to review and summarize roadway assets in terms of location, type, condition, attribute, cost, and quantity (Numetric 2016b). Additional apps and tools on the Numetric interface are being developed to enhance the decision making process for project selection and prioritization on state roadways in Utah.

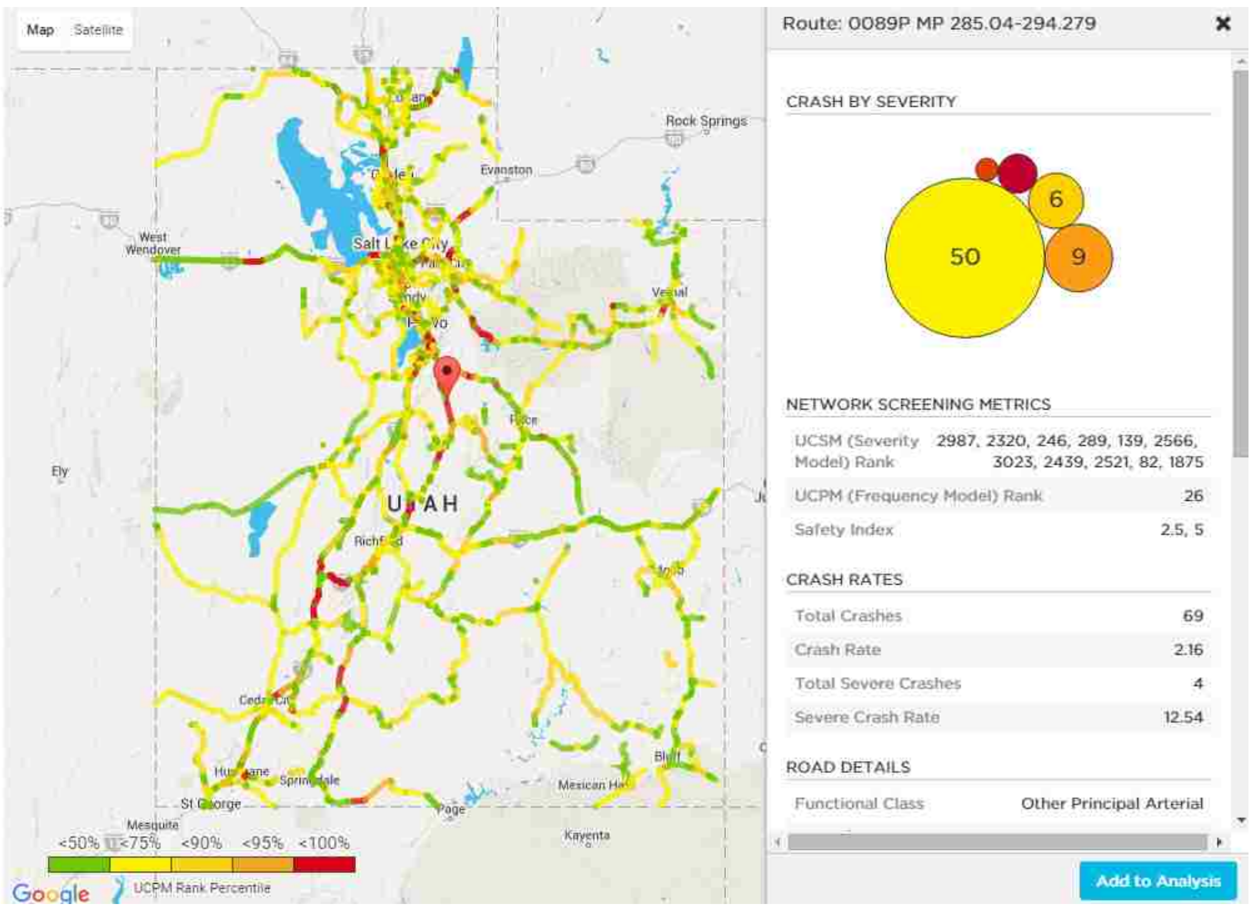


Figure 2-9: Interface of "Network Screening" app on the Numetric website (Numetric 2016c).

2.8 Chapter Summary

A literature review was performed on transportation safety and the optimization of the safety analysis tools in Utah and the United States. The literature review in this chapter includes seven topics relevant to highway safety research. The first topic discussed current state crash analytical tools used in the United States, including *SafetyAnalyst*, geospatial Crash Analysis tools published by Esri, and strategies used by IDOT to integrate safety into the transportation decision making process. The second topic defined the crash severity levels in Utah and the United States and the UDOT Safety Index. The third topic summarized the cumulative work by researchers at BYU in the development and improvement of the crash analysis methodologies in Utah between 2010 and 2015, which is applied and automated in the research summarized in this thesis. The fourth topic described the UCPM and UCSM as safety statistical models for network screening in Utah, including their purpose, model output, and summary of previous results. The fifth topic discussed national crash countermeasures strategies, including the NCHRP Report 500 series volumes, "Countermeasures That Work," and the CMF Clearinghouse website. The sixth topic described a developing process by UDOT to identify possible countermeasures based on roadway characteristics and crash data. The seventh topic provided an overview of the features and tools of the UDOT web-based crash record analysis platform, Numetric, which can be used to spatially display the results of the Roadway Safety Analysis methodology.

This research is focused on applying and automating recently completed highway safety research for UDOT, specifically the use of the UCPM and UCSM and summarizing the findings in the Roadway Safety Analysis reports for the selected segments on interest. Chapter 3 reviews and discusses the data needs for this project and analysis process. Chapter 4, Chapter 5, and Chapter 6 discuss the three parts of the Roadway Safety Analysis methodology.

3 DATA AND AUTOMATION TOOLS

The availability and quality of data are limiting factors in determining the type and methodology for crash analysis. The level of analysis can be limited if data are missing or inconsistencies in the data are present. Updated and well documented tools for processing data also become important factors for safety analysis. If the data processing tools become obsolete, unavailable for use, or require debugging, then the process of analyzing highway safety can be delayed significantly. This chapter includes a discussion of four topics related to data and automation tools in this research. The first topic is a summary of the general data considerations. The second topic is a summary of the datasets utilized in the Roadway Safety Analysis methodology. The third topic is a discussion of the data management and systemization strategies for this research. The fourth topic is a summary of the project data tasks of the Roadway Safety Analysis methodology. Additional information related to data and automation tools is available in the literature (Schultz et al. 2012, Schultz et al. 2013a, Schultz et al. 2015).

3.1 General Data Considerations

Accuracy, availability, coverage, and usability are some of the general considerations of the datasets which may be used in the Roadway Safety Analysis methodology. Accuracy of data relates to the correctness and precision of the data. Inaccurate data can be propagated by errors in automation tools, which can lead to ineffective analysis results. Data availability can limit the types and depth of analysis that can be accomplished. Long-term data collection methods, consistent documentation, and storage of data can allow for data to be accessed for a number of years. Data coverage relates to the range and completeness of information available. Coverage limitations decrease the output of the analysis and skew the results. The usability of data can be determined by the format the data are available. Data can become compatible with the improvement of conversion tools and data management tools. A more complete discussion of these general data considerations can be found in the literature (Schultz et al. 2015).

3.2 Datasets Utilized

There were two main sources for the data used in this research: the UDOT Open Data website and the UDOT Traffic and Safety Division. The UDOT Open Data website contains public data layers of roadway attributes provided for informational purposes only. It is recommended that the data from the UDOT Open Data website be verified in the field before project design (UDOT 2015c). The UDOT Traffic and Safety Division provided access to sensitive data not available to the public, such as the horizontal roadway curvature and historic crash data. Data can be accessed in a GIS shapefile format or in comma separated values (CSV) file format. The shapefile format is advantageous for spatial or linear relationship analyses in ArcMap or other GIS software. The CSV file format is advantageous for processing the data in a workbook environment and the statistical analysis. Table 3-1 provides a summary of the datasets used in the Roadway Safety Analysis methodology. Further information of the development of the use of these datasets can be found in the literature (Schultz et al. 2012, Schultz et al. 2013a, Schultz et al. 2015).

Table 3-1: Utilized Datasets in the Roadway Safety Analysis Methodology

Dataset	Source	Downloaded as:		Update Rate
		Shapefile	CSV	
UDOT Routes Linear Referencing System (LRS)	UDOT Open Data	X		Regularly
Crash Data	Traffic and Safety		X	Annually
Crash Location	Traffic and Safety		X	Annually
Crash Rollup	Traffic and Safety		X	Annually
Vehicle Crash Data	Traffic and Safety		X	Annually
AADT	UDOT Open Data		X	Annually
Truck AADT	UDOT Open Data		X	Annually
Functional Classification	UDOT Open Data		X	Regularly
Speed Limit	UDOT Open Data		X	Biennially
Through Lanes	UDOT Open Data		X	Regularly
Urban Code	UDOT Open Data		X	Regularly
Auxiliary Lanes	UDOT Open Data	X		Biennially
Barriers	UDOT Open Data	X		Biennially
Curvature	Traffic and Safety	X		Biennially
Intersections	UDOT Open Data	X		Biennially
Medians	UDOT Open Data	X		Biennially
Route Grade	UDOT Open Data	X		Biennially
Rumble Strips	UDOT Open Data	X		Biennially
Shoulder	UDOT Open Data	X		Biennially
Sign Face	UDOT Open Data	X	X	Biennially
Walls	UDOT Open Data	X		Biennially

In Utah, the crash database originates from traffic crash reports completed by a police officer at the scene of a crash, commonly referred to as DI-9 reports. The traffic crash reports are completed when there is a death, injury, or property damage over $1,500 resulting from a crash (UHP 2016). Once the crash reports are completed by a police officer, the crash records are added to a central crash database. The crash data contains sensitive information, protected under Title 23 Section 409 of the United States Code, also referred to as 23 USC 409 (USGPO 2012). As of April 2016, plans were announced to grant responsibility of hosting and maintaining the crash database in a partnership with the University of Utah in the summer or fall of 2016. For the scope of this research, the crash data between 2010 and 2014 as delivered by the Traffic and Safety Division were used in the development of the Roadway Safety Analysis methodology.

3.3 Data Management and Systemization

One objective of this research is to improve upon the existing data management and systemization developed in previous research (Schultz et al. 2013a, Schultz et al. 2015). With the development of the UCSM to accompany the UCPM, it became important to develop the documentation and debug the process of using these models in an analysis, so that future iterations and studies can be conducted in a consistent format. The following subsections discuss the steps to achieving data uniformity, improvements to the automation tools and development of a series of GUIs, and documentation of the overall process for future iterations of the Roadway Safety Analysis methodology.

3.3.1 Data Uniformity

When completing an analysis of the roadways using multiple datasets, an important key is to maintain data uniformity. While the attribute data may vary from dataset to dataset (e.g., number of lanes compared to AADT), the use of uniform data fields allows for these different datasets to be related linearly or spatially. As shown in Table 3-2, five roadway identification data fields were used or created to accurately relate the datasets linearly or spatially and for the statistical analyses (Schultz et al. 2013a, Schultz et al. 2015). These fields correspond with the UDOT state routes LRS dataset.

The “ROUTE_ID” field corresponds to the federal and state highway numbering system. The “DIRECTION” field describes the direction of traffic flow, with a description of the fields given in Table 3-3. In this research, the surrogate “X” for negative direction (“N”) roadways applies only to the southbound or westbound portion of divided highways (Schultz et al. 2012). Based on UDOT’s list of divided highways, the following roadway systems were identified as needing the “P” and “X” notation for direction in this research: I-15, I-70, I-80, I-84, SR-85, and I-215 (UDOT 2015a). The “LABEL” field is a combination of the route identification number and the direction of traffic flow (e.g., “0015” + “P” = “0015P”). The “BEG_MILEPOINT” and “END_MILEPOINT” identify the extents of the roadway segment characteristics using the milepoint (MP) of the roadway. Additional information about data uniformity and the development of these fields can be found in the literature (Schultz et al. 2012, Schultz et al. 2013a, Schultz et al. 2015).

Table 3-2: Uniform Data Fields for Multiple Datasets (Schultz et al. 2013a)

Data Field	Meaning
“ROUTE_ID”	Contains four numeric digits with the route number and leading zeros
“DIRECTION”	Contains “P” “N” or “X” corresponding to route direction
“LABEL”	Five digit code with the ROUTE_ID and DIRECTION fields joined
“BEG_MILEPOINT”	Beginning MP of the segment
“END_MILEPOINT”	Ending MP of the segment

Table 3-3: Definition of Direction Codes (Schultz et al. 2012, Schultz et al. 2013a)

Direction Code	Description	Applies to
“P”	MP values are increasing in positive direction of travel (west to east, south to north)	All Roadways
“N”	MP values are increasing in negative direction of travel (east to west, north to south)	Divided Roadways only
“X”	Surrogate measure for “N” using same MP values of positive direction of travel	Divided Roadways only

In this research, two additional actions were taken to maintain data uniformity. First, the "LABEL" field in the State Route LRS shapefile was modified for the divided highway features (i.e., I-15, I-70, I-80, I-84, SR-85, and I-215), so that the direction notation would match and allow the roadway and crash data features to be geospatially drawn correctly. Second, the 3-mile roadway "089AP" near Kanab, Utah was renamed to "0011P" to reduce error in identifying crashes and roadway features with the main US-89 highway. This change was also reflected in the State Route LRS shapefile for spatially mapping these modified route names.

With the dynamic nature of the roadway and crash databases, a collection of critical data columns was created to communicate the important data fields in the Roadway Safety Analysis methodology. Some of the critical data columns reflect the expected column headings in the dataset as available from UDOT, while other critical data columns reflect column headings created in the Roadway Safety Analysis methodology. If these critical data columns are omitted or missing, then the Roadway Safety Analysis methodology cannot be completed as originally intended. An example of a list of critical data columns for the AADT data is given in Table 3-4. Appendix B includes a table for each input roadway and crash dataset in the Roadway Safety Analysis methodology, listing the expected heading and a description of the critical data column. To check for the critical data columns, a "Check Headers" workbook tool was created to ensure that the input data column headers contained the critical data columns for a given task. If the expected critical data column has a different name in the input data field, then the analyst is prompted to select the correct column of data to match the critical data column.

Table 3-4: Critical Data Columns for AADT Data

From UDOT	
Heading	**Description**
ROUTE	Route ID: numeric route number for a given roadway segment
DIRECTION	Direction: route direction (i.e. P, N, or X)
BEGMP	Beginning MP: beginning milepost of the roadway segment
ENDMP	End MP: end milepost of the roadway segment
STATION	Station Number: seven digit number, identifying the traffic counter station number
AADT_[YEAR]	AADT [YEAR]: historical dataset of Annual Average Daily Traffic data from each year; at least 7 years of this data are needed (i.e. AADT2014)
NumST	Single Truck Count: number of single trailer trucks per segment
NumCT	Combo Truck Count: number of combination trailer trucks per segment
CUTrk2014	Single Truck Percent: percent of single trailer trucks per segment

3.3.2 Automation Tools and GUI Development

Automation tools were developed and refined to assist with the task of processing and interpreting the roadway and crash data. Automation can increase efficiency by reducing time and effort needed for perform redundant and tedious tasks. These tools were designed to minimize variance in interpreting the data and to create uniform data outputs. Several GUIs were created to allow the analyst to use these tools in a user-friendly environment without needing to modify the automation tools directly.

The automation tools and GUIs were developed in Microsoft (MS) Excel and Esri ArcMap. In MS Excel, several macros and functions were written in Visual Basic for Applications (VBA) code to assist with the tedious tasks of preparing, analyzing, and summarizing the roadway and crash data. Several GUIs were created to allow the analyst to access the automation tools in a user-friendly environment, without the need to modify the VBA code or statistical analysis scripts directly. The GUI appearance and functionality in MS Excel varies from the use of custom user forms to pre-designed workbooks. In ArcMap, several Model

Builder models and Python scripts were prepared to assist with the repetitive process of geospatially analyzing the roadway and crash data. GUIs were created to accompany the ArcMap tools, allowing the analyst to select the appropriate inputs and execute the prepared automation tools in a user-friendly environment. The documentation of these automation tools and GUIs are discussed in Section 3.3.3 and provided in the literature (Gibbons et al. 2016, Mineer et al. 2016, Siegel et al. 2016). Examples of the appearance and function of the GUIs developed in this research are given in Chapter 7.

3.3.3 Documentation of Methodology and Automation Tools

Documentation is a critical aspect for reproducing consistent and repeatable analyses. User manuals serve the purpose of documenting the step-by-step instructions to complete a series of tasks and providing information for the tools and automated processes used to complete the tasks. Documenting the function, input, and expected output of the automation tools is important for debugging and applying the tools in future iterations of work. Previously created user manuals (Schultz et al. 2013b) and automation tools were reviewed for functionality and completeness. It was found that many of the automation tools were developed for a one-time use for a given dataset, which was not beneficial for adapting to new datasets for future iterations of the Roadway Safety Analysis methodology. Additional comments and functions were added to existing tools, to allow the tools to adapt to changing data structure and data inputs. New tools were developed for tasks where automation tools did not exist previously.

The result of the documentation effort in this research is three volumes of user manuals. These volumes outline the steps and tools used for a complete iteration of the three part Roadway Safety Analysis methodology. The first volume addresses the step-by-step process of segmenting the roadway and crash data, which is described in Chapter 4 (Gibbons et al. 2016). The second volume addresses the step-by-step process of conducting the statistical analysis using the roadway and crash data and interpreting the results, which is described in Chapter 5 (Siegel et al. 2016). The third volume addresses the step-by-step process of summarizing the roadway and crash data for the selected segments of interest and compiling the Roadway Safety Analysis reports for publication, which is described in Chapter 6 (Mineer et al. 2016).

3.4 Project Data Tasks

There are three main parts of the Roadway Safety Analysis methodology that incorporate the use of the datasets outlined previously in Table 3-1. These three parts are oriented around the use of the UCPM and UCSM, which identifies problem roadway segments that can be analyzed for possible countermeasures. The first part prepares the roadway and crash data for use in the statistical analyses. The second part is the execution of the statistical network screening safety analysis models, interpreting the results, and identifying segments of interest for the report compilation process. The third part is the report compilation for each segment of interest, which results in a collection of two-page reports to be published through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. The following paragraphs describe how the data are used in these parts.

The safety statistical models require an input dataset containing roadway attributes and a count of crash severities as defined by the analyst. This input files is based off a segmented roadway and crash datasets, created through a segmentation process and compilation of crash records. The roadway segmentation process combines the roadway data from five separate datasets (i.e., AADT, functional classification, number of through lanes, speed limit, and urban code) to create a single dataset of roadway segments with homogeneous roadway characteristics. The compilation of crash data combines four crash datasets (i.e., crash data, crash location, crash rollup, and vehicle crash data) into a single crash dataset. This combined crash dataset provides information related to the location of the crash and the severity of the crashes. The roadway and crash data are segmented into homogenous segments in preparation for use in the statistical models. The procedures and processes of this task are discussed in detail in Chapter 4 and the related user manual (Gibbons et al. 2016).

After the segmentation of the roadway and crash data, the safety statistical models are executed. The analyst specified crash severities are tabulated and the variable selection process is used to determine the most relevant variables for the statistical analysis. After the statistical analysis is complete, the output provides a safety ranking for the segments. The output file is then used in the creation of a statewide map, UDOT Region maps, or county maps to spatially display the results. The output file is also used to select segments of interest for the report compilation process. The procedures and processes of this task are discussed in detail in Chapter 5 and the related user manual (Siegel et al. 2016).

The compilation of the Roadway Safety Analysis reports for each of the segments of interest requires the output of the statistical models, the crash data, and additional roadway characteristics. The output of the statistical models identifies the problem segments and the scope of the micro-analysis of crash data. The crash data are used to extract and summarize crash factors and other details that can help identify possible countermeasures. The roadway attribute data is a combination of 10 roadway features for the selected segments, including: barrier type, horizontal curvature, vertical grade, IPM, auxiliary lanes, median width and type, rumble strip presence, shoulder type and width, SPM, and walls presence. The roadway attribute data are summarized for the process of identifying relevant countermeasures for a given problem segment. Other relevant data concerning the roadway data are collected through site visits and internet tools, such as UDOT's Roadview Explorer (UDOT 2016a) and Google Earth (Google, Inc. 2016a). The final step is to publish the Roadway Safety Analysis reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. The procedures and processes of this task are discussed in detail in Chapter 6 and the related user manual (Mineer et al. 2016).

3.5 Chapter Summary

The availability and quality of data and automation tools available for analyzing the data are limiting factors in the Roadway Safety Analysis methodology. This chapter included a discussion of four topics related to data and automation tools in this research. The first topic summarized the general data considerations. The second topic summarized the datasets utilized in this research, which were derived from the UDOT Open Data website and the UDOT Traffic and Safety Division. The third topic discussed the data management and systemization strategies used in this research, including data uniformity techniques, automation tools and GUI development, and documentation of the analysis methodology and automation tools. The fourth topic summarized the project data tasks in the Roadway Safety Analysis methodology.

The following chapters describe the three parts of the Roadway Safety Analysis methodology, which is centered on the network screening statistical analysis models, the UCPM and UCSM. Chapter 4 discusses the process of preparing the roadway and crash data as inputs for the UCPM and UCSM analyses. Chapter 5 discusses the network screening statistical analysis, interpretation of the results, as selection of roadway segments for the report compilation process. Chapter 6 discusses the process of compiling the Roadway Safety Analysis reports for each of the selected segments, culminating in the publication of the reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users.

4 CRASH AND ROADWAY DATA SEGMENTATION

The first part of the Roadway Safety Analysis methodology is designed to segment the roadway and crash data. The roadway and crash data are used in the network screening statistical analysis process, driven by the UCPM and UCSM analyses. This chapter discusses four tasks of the first part of the Roadway Safety Analysis methodology. The first task is to prepare the crash database. The second task is to prepare the roadway data. The third task is to segment the roadway data. The fourth task is to calculate a few of the statistically significant interactions for each roadway segment. The end result of these tasks is a crash database and segmented roadway database, which are used in the statistical network screening analysis discussed in Chapter 5. As this chapter discusses the procedures outlined in Figure 4-1, the step-by-step instructions and documentation for the automated tools are provided in the user manual (Gibbons et al. 2016).

4.1 Crash Database Preparation

A fundamental data source for this research is the crash database for state roadways in Utah. The statistical models typically use 3 to 5 years of crash data to determine which roadways are considered to be problem segments within the network. The crash data are currently available in multiple files from the Traffic and Safety Division at UDOT. These date files include general crash, location, rollup, and vehicle crash data. Each data file contains a unique 8-digit crash identification (ID) number, which is used as an index when combining the crash data together.

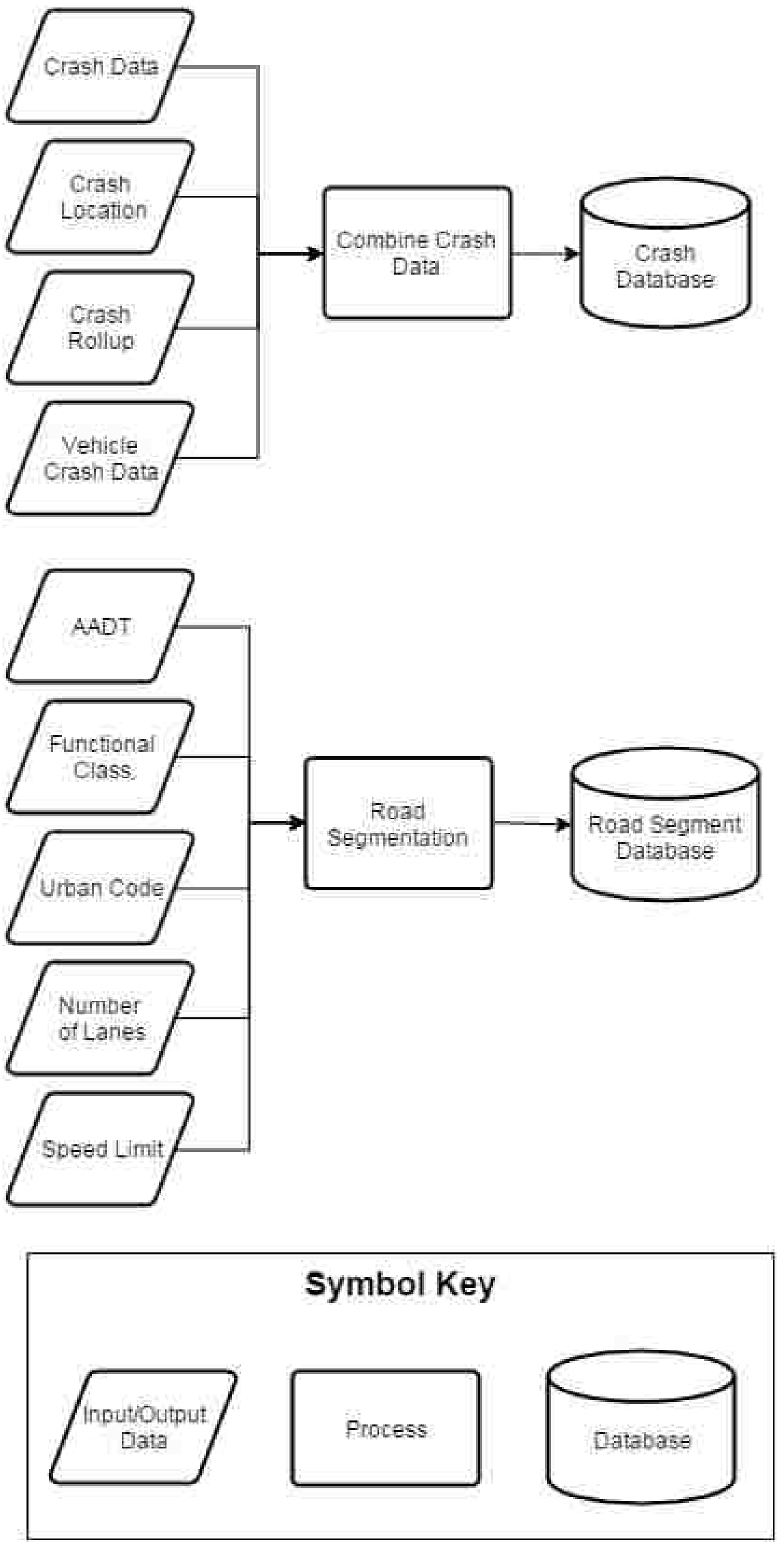


Figure 4-1: Schematic illustration of crash and roadway data segmentation process.

The general crash data provides information concerning crash severity, manner of collision, and first harmful event. Table 4-1 summarizes the crash severities by year for the 2010 to 2014 crash data used in this research, which only includes crashes on the mainline of the state routes (i.e., route number less than 491 and ramp crashes excluded). In other words, not all crashes that have occurred on Utah roadways between 2010 and 2014 are represented in Table 4-1. The crash location data provides the route and approximate MP where the crash occurred. The crash rollup data provides possible crash factors determined at the scene of the crash. In this research and as of April 2016, there were 29 crash factors from the crash rollup data file used to identify crash patterns and trends, as summarized in Table 4-2. For each of the crash factors, a "Y" and an "N" are used to indicate whether a given crash factor was relevant or not to a crash event, respectively. UDOT has plans to add another crash factor in 2016 to identify whether a crash was caused by someone failing to obey a traffic control device. Another important crash dataset is the vehicle crash data. The vehicle crash data is used as a supplemental dataset in the segmentation process and is used later in the micro-analysis of the segments of interest. A list of the critical data columns for these crash data files are provided in Appendix B.

Table 4-1: Crash Severity Distribution of 2010 to 2014 Crash Data (State Route, Mainline, Non-Ramp Crashes)

Crash Severity	Year				
	2010	2011	2012	2013	2014
1 – Property Damage Only	20,174	19,365	20,519	22,884	21,012
2 – Possible Injury	5,111	4,944	4,892	5,196	5,266
3 – Injury	2,928	3,040	3,225	3,244	3,150
4 – Incapacitating Injury	615	550	656	692	702
5 – Fatal	152	161	144	135	147
Total	30,426	29,634	31,240	34,595	32,306

Table 4-2: Crash Factors Used in Roadway Safety Analysis Method

Pedestrian Involved	Wild Animal Related
Bicyclist Involved	Domestic Animal Related
Motorcycle Involved	Roadway Departure
Improper Restraint	Overturn/Rollover
Unrestrained	Commercial Motor Vehicle Involved
Driving Under the Influence (DUI)	Interstate Highway
Aggressive Driving	Teenage Drive Involved
Distracted Driving	Older Driver Involved
Drowsy Driving	Urban County
Speed Related	Night/Dark Condition
Intersection Related	Single Vehicle
Adverse Weather	Train Involved
Adverse Roadway Surface Conditions	Railroad Crossing
Roadway Geometry Related	Transit Vehicle Involved
	Collision with Fixed Object

The crash database is created using MS Excel, with the aid of VBA macros. The crash data are combined by using the 8-digit crash ID as a unique identifier, as the crash ID is consistently used in each crash data file. Using the crash ID, the general crash data, location, and rollup data are joined together. The vehicle crash data is used to determine the direction the vehicles were traveling when involved in the crash. Once the crash data is combined together, the non-state route crashes and ramp crashes are removed from this crash database, as this analysis is designed for the mainline of state roadways. The state routes are those with the numerical route numbers less than 491 (UDOT 2015b). The crashes on interstate ramps are removed because of the errors they create in the analysis of the statewide roadway network. The end result of the crash database preparation is a collection of crash data for the state roadways, which allows the crash severity data to have locational attributes. The specific steps to combine the crash data are explained in the user manual (Gibbons et al. 2016).

4.2 Roadway Data Preparation

Five roadway data files are used as inputs for the statistical safety models, which includes: historic AADT (with truck percentage), functional classification, speed limit, number of through lanes, and urban code. The historic AADT data provides AADT for the past 5 to 7 years and truck data for the most recent year. AADT is the average of the 24-hour vehicle counts collected every day of a given year, which helps to establish traffic volume trends and identify high-impact roadways (AASHTO 2011). The truck data provides the percentage of single-unit and combo-unit trucks, which becomes an important variable in the statistical analysis of the roadways. According to the 2014 AADT data from the UDOT Open Data website (UDOT 2015d), approximately 80 percent of all state routes by length have an AADT less than 10,000 vehicles per day, as summarized in Table 4-3.

Table 4-3: 2014 AADT Distribution of Utah State Roadways (UDOT 2015d)

AADT	Percentage of State Roadways
0-999	32.5%
1,000-1,999	15.2%
2,000-2,999	9.0%
3,000-3,999	6.3%
4,000-4,999	3.1%
5,000-5,999	3.2%
6,000-6,999	3.1%
7,000-7,999	3.8%
8,000-8,999	1.5%
9,000-9,999	1.8%
> 10,000	20.5%
Total	**100.0%**

The functional classification dataset identifies the level of access and mobility for a given roadway (AASHTO 2011). According to the functional classification data from the UDOT Open Data website, approximately 72 percent of all state routes by length are Interstates, Other Freeways, Other Principal Arterials, and Minor Arterials, as summarized in Table 4-4. These roadway types are designed to provide more mobility to drivers than access.

The speed limit data provides the posted speed limit of the state roadway. The speed limit data are derived from the sign face data, which contains the posted speed limit for a given roadway. The sign containing the speed limit is classified in the Manual for Uniform Traffic Control Device (MUTCD) as sign type "R2-1" (FHWA 2009). According to the approximate speed limit data from the UDOT Open Data website, approximately 77 percent of all state routes by length have a posted speed limit of 55 miles per hour (MPH) or higher, as summarized in Table 4-5.

The number of through lanes and urban code provides the physical through lane configuration and location descriptions of the roadways segments. According to the lane data from the UDOT Open Data website, approximately 82 percent of all state routes by length have 2 or fewer lanes, as summarized in Table 4-6. According to the urban code data from the UDOT Open Data website, approximately 74 percent of all state routes by length are located in rural areas, as summarized in Table 4-7.

Table 4-4: Functional Classification Distribution of Utah State Roadways (UDOT 2015d)

Code	Functional Classification Name	Percentage of State Roadways
1	Interstate	15.9%
2	Other Freeway and Expressway	0.9%
3	Other Principal Arterial	30.1%
4	Minor Arterial	24.6%
5	Major Collector	27.5%
6	Minor Collector	0.5%
7	Local	0.5%
	Total	100.0%

Table 4-5: Approximate Speed Limit Distribution of Utah State Roadways (UDOT 2015d)

Posted Speed Limit (MPH)	Percentage of State Roadways
< 25	0.63%
30	1.86%
35	2.81%
40	6.88%
45	5.30%
50	5.49%
55	16.62%
60	5.94%
65	28.97%
70	5.50%
75	6.38%
80	13.19%
Not Reported	0.44%
Total	**100.0%**

Table 4-6: Number of Through Lanes Distribution of Utah State Roadways (UDOT 2015d)

Through Lanes	Percentage of State Roadways
< 2	82.1%
3	7.1%
4	8.5%
> 5	2.3%
Total	**100.0%**

Table 4-7: Urban Code Distribution of Utah State Roadways (UDOT 2015d)

Code	Urban Code Description	Percentage of State Roadways
50959	Logan	1.22%
64945	Ogden - Layton	5.43%
72559	Provo-Orem	4.25%
77446	St. George	1.05%
78499	Salt Lake City	7.51%
99998	Small Urban	5.43%
99999	Rural	74.38%
00000	Unknown	0.73%
	Total	100.0%

These five roadway data files are prepared for segmentation using MS Excel, with the aid of macros and VBA scripts. Each roadway data file is processed to contain the five uniform data fields outlined previously in Section 3.3.1. A list of the critical data columns for the roadway data are provided in Appendix B. The specific steps to prepare the roadway data files for the segmentation process are explained in the user manual (Gibbons et al. 2016).

4.3 Roadway Segmentation Process

Once the roadway data files have been prepared, they are joined together through a segmentation process. The uniform data fields outlined previously in Section 3.3.1 are used as an index for creating homogeneous roadway segments, delineated by roadway characteristic or by length of roadway. The selection of creating roadway segments by attribute or by length is left to the discretion of the analyst, depending on the purpose of the analysis. The segmentation process is automated, as explained in the user manual (Gibbons et al. 2016).

When the roadway data are delineated by homogeneous roadway segments, the roadway characteristics (i.e., AADT, functional classification, speed limit, number of through lanes, and urban code) are constant for a given length of roadway. A previous segment ends and a new one begins when one of the five characteristics change. The roadway segments do not need to be the same length. Table 4-8 provides an example of segmenting the roadway data by homogeneous trait, with some columns hidden for this example. Each segment of roadway data connects to one another and lists the unique roadway attributes of the given roadway segment. The highlighted cells in Table 4-8 identify the roadway attribute that was different than the prior roadway segment. The updated segmentation process creates approximately 5,900 homogeneous roadway segments for the statistical analysis.

If the roadway data are segmented by length, such as 0.1 mile increments, then the dominant roadway feature for that given length will represent that roadway segment. With approximately 5,800 miles of state roadway, this process could create over 75,000 segments for the statistical analysis. It is left to the discretion of the analyst, based on an understanding the purpose of the analysis, to decide which segmentation method to implement, as the number of segments may affect the statistical analysis.

Table 4-8: Example of Segmented Roadway for US-6, Millard County (Other Principal Arterial)

Beg. MP	End MP	Length (miles)	AADT (2012)	Total Percent Trucks	Speed Limit (MPH)	Num. Thru Lanes	Urban Code
0.00	0.19	0.19	325	48.2%	45	2	Rural
0.19	24.50	24.31	325	48.2%	65	2	Rural
24.50	25.25	0.75	325	48.2%	50	2	Rural
25.25	27.10	1.85	325	48.2%	35	2	Rural
27.10	27.81	0.71	325	48.2%	50	2	Rural
27.81	46.02	18.21	325	48.2%	65	2	Rural
46.02	77.55	31.53	340	50.9%	65	2	Rural
77.55	82.08	4.53	420	42.7%	65	2	Rural
82.08	82.36	0.28	420	42.7%	55	2	Rural
82.36	82.89	0.53	420	42.7%	40	2	Rural
82.89	83.47	0.58	1570	34.6%	40	2	Rural

4.4 Statistical Interactions

Before the data are ready for the statistical analysis, several interactions of the roadway characteristics are calculated. An interaction is the multiplicative product of two independent variables, which can be used to derive statistical significance of independent variables which would not be significant on their own (Ramsey and Shafer 2013). The following list is a summary of the interactions calculated in the Roadway Safety Analysis methodology, after the roadway data have been processed into homogeneous segments. These interactions were identified as statistically significant variables in previous research studies (Schultz et al. 2013a, Schultz et al. 2015).

1. VMT (Vehicle Miles Traveled = AADT*Segment_Length)
2. VMT^2
3. $Total\_Percent\_Trucks^2$
4. $Speed\_Limit^2$
5. Num_Lanes^2
6. VMT*Percent_Trucks
7. VMT*Speed_Limit
8. VMT*Num_Lanes
9. Speed_Limit*Num_Lanes
10. Speed_Limit*Total_Percent_Trucks

4.5 Chapter Summary

The purpose of this first of three parts of the Roadway Safety Analysis methodology is to segment the roadway and crash data for the safety statistical analysis. This first part of the Roadway Safety Analysis methodology is broken down into four tasks. The first task is to prepare the crash database, which combines the crash data, crash location, crash rollup, and vehicle crash data files into a centralized crash database. The second task is to prepare the roadway data for segmentation, including the AADT, functional classification, number of through lanes, speed limit, and urban code data. The third task is to segment the roadway data by either change in characteristic or by length. The fourth task is to calculate statistical interactions for each roadway segment, which are used in the statistical analysis. The specific step-by-step procedure for accomplishing there tasks are described in the user manual (Gibbons et al. 2016).

Chapter 5 discusses the second part of the Roadway Safety Analysis methodology, which is to use the segmented roadway and crash data created in Chapter 4 in the statistical network screening analyses (i.e., the UCPM and UCSM).

5 STATISTICAL NETWORK SCREENING OF ROADWAY DATA

The second part of the Roadway Safety Analysis methodology is designed to execute the statistical network screening process using the UCPM and UCSM. The UCPM and UCSM assigns a hierarchal safety ranking to the roadway segments, based on hierarchal Bayesian modeling. The output of the UCPM and UCSM are then classified to hierarchal and categorical rankings on a statewide, UDOT Region, and county level, which are used to identify segments of interest for further analysis described in Chapter 6. This chapter discusses the background of the statistical model development and six tasks of the second part of the Roadway Safety Analysis methodology. The first task is to create the input file for the statistical analysis. The second task is to select the variables for the statistical analysis. The third task is to execute the statistical analysis in R, a statistical software program. The fourth task is to interpret the output of the statistical analysis. The fifth task is to spatially display the statistical analysis results. The sixth and final task is to select the segments of interest for the report compilation process. The end result of these tasks is an output of the statistical analysis models and a selection of roadway segments for report compilation discussed in Chapter 6. As this chapter discusses the procedures outlined in Figure 5-1, the step-by-step instructions for executing the statistical analysis are provided in the user manual (Siegel et al. 2016).

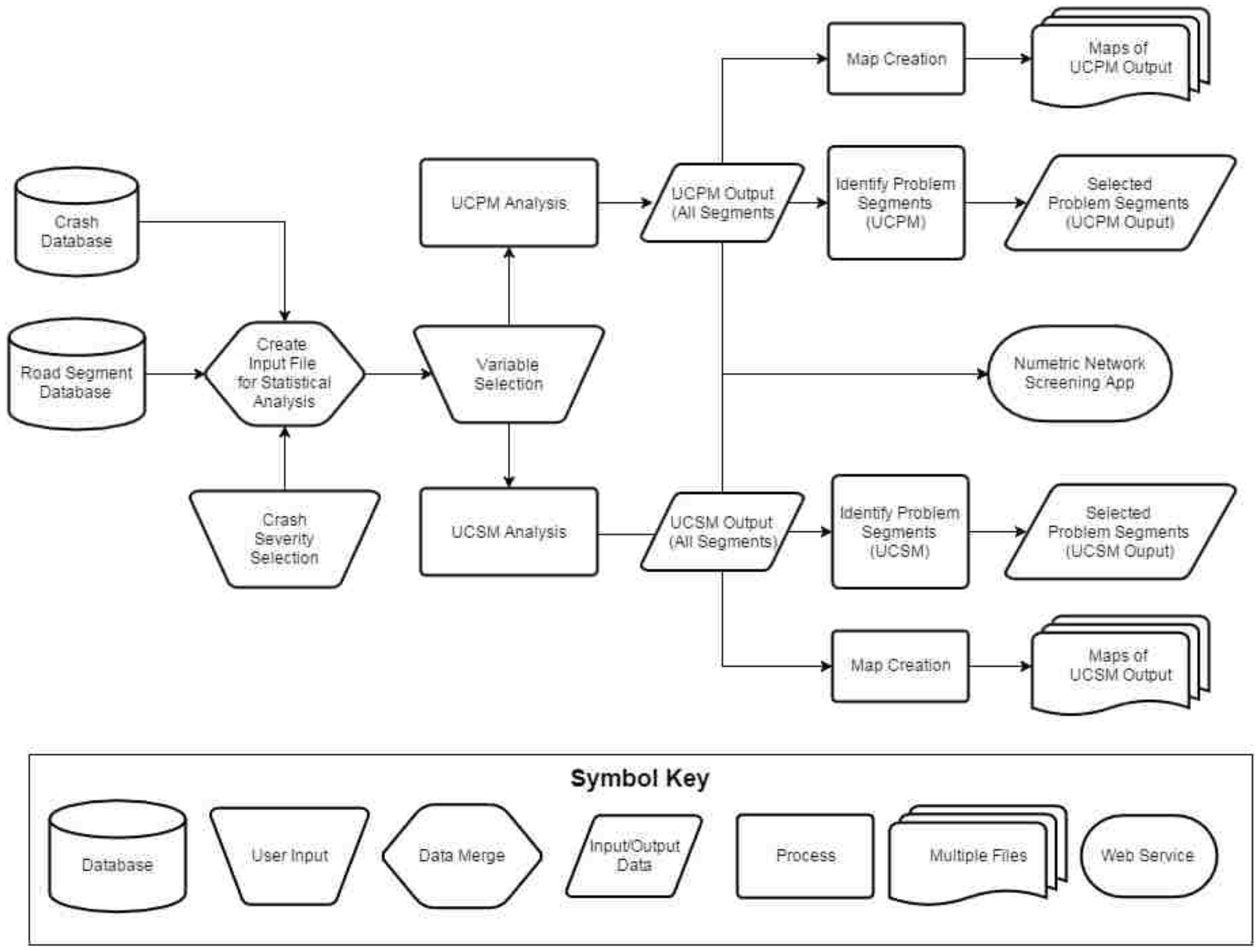


Figure 5-1: Schematic illustration of statistical network screening of roadway data.

5.1 Statistical Model Development Background

As discussed in Section 2.3.1, advanced statistical models can bridge limitations of traditional safety measurements. The UCPM and UCSM were developed to identify roadways within the state that were not performing as expected in regards to crash frequency and crash severity, based on a hierarchical Bayesian statistical analysis. The result from these models may or may not evaluate roadway safety the same way as the UDOT Safety Index, due to the statistical methodology utilized. The advantage of the UCPM and UCSM are that they identify roadway segments which are not performing as safely as expected, giving a different perspective of the safety of the state roadways than the UDOT Safety Index.

The UCPM and UCSM were developed using the R programming language, a free statistical software program which is versatile in statistical computations (RPSC 2016). The backbone of the UCPM and UCSM is a hierarchical Bayesian regression analysis, which compares the roadway segments to one another and creates a hierarchical ranking of their performance in relation to the other segments in the analysis. The functionality of the hierarchical Bayesian regression process in the UCPM and UCSM was modified from the procedures outlined in the literature (Schultz et al. 2013a, Schultz et al. 2015) to an automated process, which can adapt to new inputs and parameters given by the analyst without the need to modify the R code directly. In addition to the R program, the Just Another Gibbs Sampler (JAGS) program was used as a supplementary statistical program that works in tandem with R and is designed for the analysis of Bayesian hierarchical models using Markov Chain Monte Carlo (MCMC) simulation (JAGS 2016). The combined use of R and JAGS has allowed for the UCPM and UCSM to be programmed to adapt to the inputs from the analyst and to conduct the statistical analysis in accordance with previous UDOT highway safety research. Additional detail on the statistical models used in the UCPM and UCSM can be found in the literature (Schultz et al. 2013a, Schultz et al. 2015).

5.2 Create Input for Statistical Analysis

For executing the UCPM and UCSM, the input file is created from the roadway and crash data, which were created through the processes described previously in Chapter 4. Of the five crash severity levels outlined previously in Table 2-2, the analyst determines the range of crash severities to include in the statistical analysis. The goal is to select the range of crash severities that provides the most benefit as those crash types are mitigated. Additionally, the selected severity levels dictate the amount of data available for the statistical analysis. For example, selecting only fatal crashes for the analysis might not provide enough data for the analysis, whereas selecting all crash types might distract from the purpose of identifying areas with high severity crashes. As summarized in Section 2.4, the 2013 UCPM analysis included non-incapacitating injury, incapacitating injury, and fatal crashes (i.e., crash severities 3, 4, and 5) and the 2015 UCSM analysis included incapacitating injury and fatal crashes (i.e., crash severities 4 and 5).

In addition to summarizing the crash severity, the analyst can summarize the crash factors (i.e., data from the crash rollup data file) based on the selected crash severity for the analysis. For each of the crashes tabulated with the desired severity for the analysis, the crash factors are also summarized, to help identify contributing factors to the crashes. As summarized previously in Table 4-2, each crash factor in the crash rollup data file has a yes or no ("Y" or "N") value to represent whether the given crash factor is relevant to the crash or not. The frequency of "Y" values is summed for each of the crash factors, which can be used to determine a pattern of common crash factors between the severe crashes for a given roadway segment.

After the severity range is selected by the analyst, the input file is created by tabulating the crash data with the roadway segment data. This process is accomplished using the GUI and automation tools prepared, as described in the user manual (Siegel et al. 2016).

5.3 Variable Selection Process

Before running the UCPM and UCSM, statistically significant variables are selected. The UCPM and UCSM use a selection of variables from the roadway attributes or crash factor to determine a relationship between the variables and the expected number of crashes or predicted severe crash rate. Selecting insignificant variables can cause a false correlation between the variables and the expected number of crashes and crash rates. The selection of variables is done through the GUI for executing the UCPM and UCSM, as described in the user manual (Siegel et al. 2016).

The preferred technique for identifying statistically significant variables in a dataset for the UCPM and UCSM is the Bayesian horseshoe selection method or a similar statistically based variable selection method. In this research, the Bayesian horseshoe selection method identifies statistically significant parameters from the given datasets which should be included in the statistical analysis. With the large number of possible statistically significant variables from the roadway data and crash factors, the horseshoe variable selection method is a computationally time intensive process. The details of the horseshoe selection methodology are described in the literature (Schultz et al. 2015).

The non-preferred alternative to the Bayesian horseshoe selection method is the manual variable selection method. This non-statistically based method looks at previous iterations of the statistical analysis and uses the variables from those analyses. A practical application of the manual variable selection method is to select the same variables identified from a previous version of the horseshoe method using the same input data. The manual variable selection method can also be used for trial and error analysis using the same input data. The limitation of the manual variable selection methodology is assuming statistical significance of variables when the datasets are dynamic from year to year, such as changing AADT or change in frequency of a given crash factor. It is recommended that the manual variable selection method be used judiciously and that the horseshoe selection methodology be used wherever possible to adjust for changes to the roadway network, such as new AADT data, changes to speed limits, functional classification, or new crash factors in the crash database.

5.4 Statistical Analysis in R

The statistical computations are handled in the R program using the prepared R code for the UCPM and UCSM. These models have been programmed to adapt to the inputs from the analyst, which include: input data file, working directory to save outputs, number of iterations, burn-in iterations, and the selected significant variables. The number of iterations is the number of times the model will repeat the analysis, affecting the run time of the analysis. The appropriate number of iterations is important to obtain reliable results. In previous research (Schultz et al. 2013a, Schultz et al. 2015), 100,000 iterations were used for a complete analysis and 10,000 iterations were used for a test analysis. In general, more iterations used in the analysis provide more reliable results than using fewer iterations. The number of burn-in iterations calibrates the model and is used to estimate the value of the model parameters. The number of burn-in iterations is recommended to be between 5 percent and 10 percent of the total number of iterations. If 10,000 burn-in iterations are specified with an analysis of 100,000 iterations, then 10,000 iterations will be used to calibrate the model and 90,000 iterations will be used in the model analysis of the roadway segments. The typical run time for each statistical model depends on the number of iterations, the severities to analyze, and the central processing unit (CPU) power of the machine executing the statistical analysis. Instructions are given in the user manual for initiating the statistical analysis in R and optimizing the computing process of the statistical analysis (Siegel et al. 2016).

5.5 Interpreting Output of Statistical Analysis

After the UCPM and UCSM have finished with the statistical analysis, a series of output files are created to summarize the findings of the statistical analysis. One of these output files is a CSV file of the roadway data, crash data tabulations, and output calculations from the statistical analysis. This CSV file is used for spatially representing the results of the statistical analysis and identifying the segments of interest in the roadway network for the report compilation process.

Another output of the statistical analysis is a portable document format (PDF) file documenting the safety statistical model, the number of iterations, number of burn-in iterations, start time of analysis, end time of analysis, the deviance information criterion (DIC) of the analysis, the input file used in the analysis, the regression equation used, a series of convergence plots for the model parameters, and a series of density plots for the model parameters. The purpose of this PDF is to provide documentation of the statistical analysis, so that future iterations of the UCPM and UCSM can be compared to one another and improved upon. In general, the models producing smaller DIC values are preferred (Ramsey and Schafer 2013), which may require trial and error to find the most appropriate model before continuing in the Roadway Safety Analysis methodology. The model parameters are represented as β_0, β_1, β_2, β_3, etc., where β_0 represents the y-intercept and the β_1, β_2, β_3, etc. represents the input parameters defined by the analyst (e.g., AADT, Total Percent Trucks, Speed Limit, etc.). An example of the documentation of the statistical analysis is given in Figure 5-2, as it is produced in R. The trace plots document the convergence of the model parameters through the iterations of the analysis, as shown in Figure 5-3. Ideally, the values for each model parameter should converge to a value before the end of the analysis. Too few iterations or too many variables may inhibit the ability of the model to find the most correct parameter values. The lack of convergence can be addressed by increasing the number of iterations or reducing the number of model parameters. The posterior density plots for the model parameters document the most probable value for the given model parameters given at the peak of the plot for the analysis, as illustrated in Figure 5-4. It is recommended that additional interpretation of the convergence plots and density plots be provided through the assistance of a professional statistician.

```
Utah Crash Severity Model Analysis

  Iterations:  20000
  Burn-In Iterations:  2000
    Start Time:  2016-05-09 09:48:40
    End Time:  2016-05-09 09:52:16
```

	DIC	Explanatory Variables
[1,]	9470	AADT_2014
[2,]		Total_Percent_Trucks
[3,]		SPEED_LIMIT
[4,]		Num_Lanes
[5,]		VMT

```
Input File:  J:/groups/udot2015/2_Model_Execution_in_R/RGUI/UCPM-UCSMinput_Sev45_5-6-2016_8-46-40_AM.csv
 Model:
 model {
for (i in 1:ndat){
y[i] ~ dbin(p[i],n[i]);
logit(p[i]) = b0 + b1*AADT_2014[i] + b2*Total_Percent_Trucks[i] + b3*SPEED_LIMIT[i] + b4*Num_Lanes[i] + b5*V
}
b0 ~ dnorm(0,1)
 b1 ~ dnorm(0,1)
 b2 ~ dnorm(0,1)
 b3 ~ dnorm(0,1)
 b4 ~ dnorm(0,1)
 b5 ~ dnorm(0,1)
}
```

Figure 5-2: Example of documenting the statistical analysis.

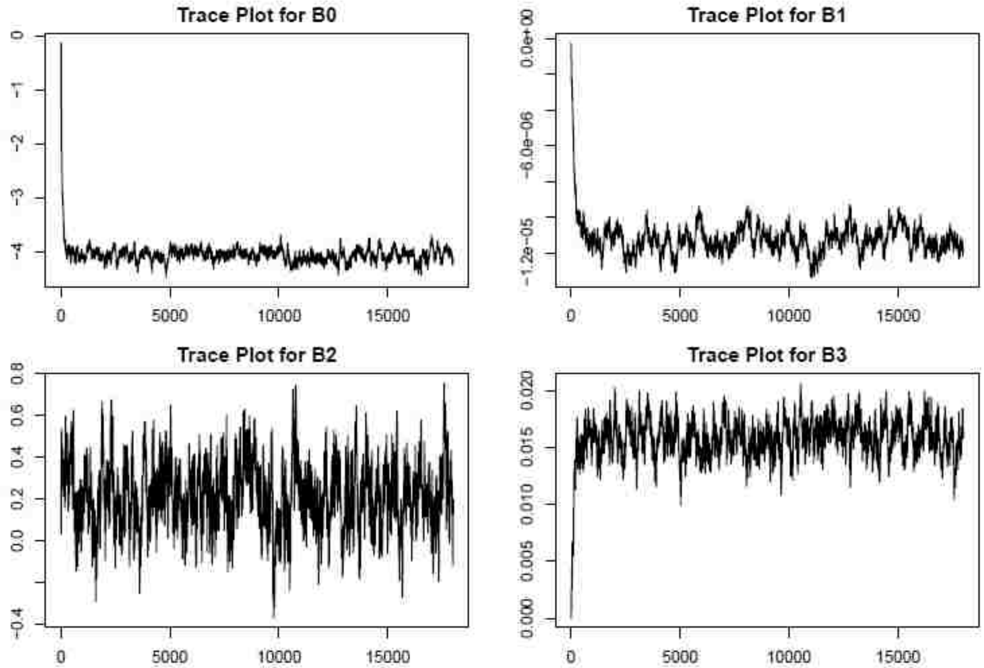


Figure 5-3: Example of trace plots from statistical analysis.

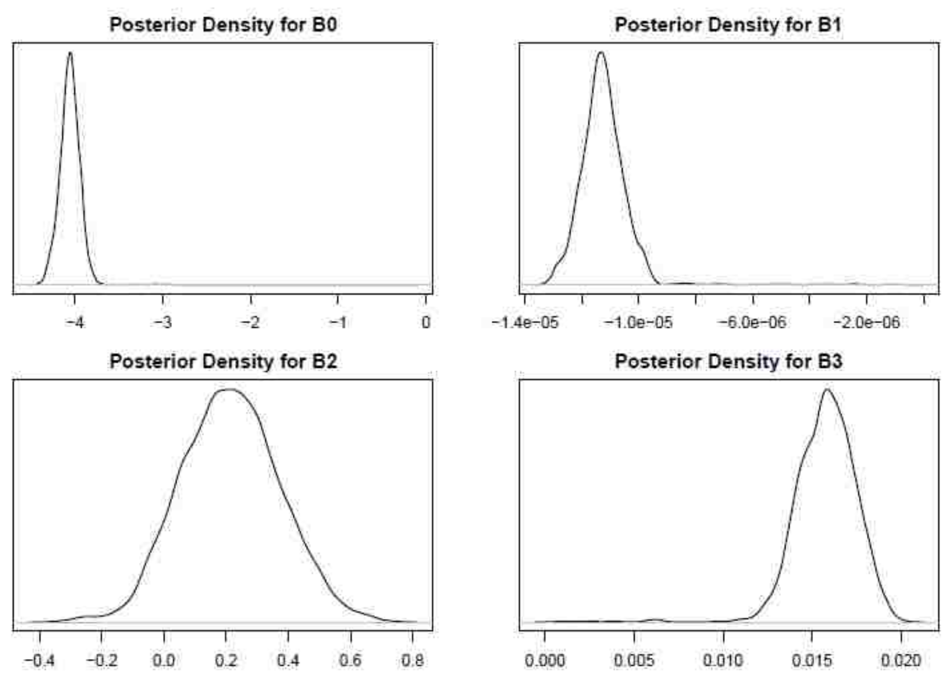


Figure 5-4: Example of posterior density plots from statistical analysis.

The following subsections include a discussion of: the interpretation of the UCPM results; the interpretation of the UCSM results; the hierarchical ranking system for the state, per UDOT Region, and per county; and the categorical ranking of the output of the statistical analyses. These processes, including the interpretation of the statistical models, are described in the user manual (Siegel et al. 2016).

5.5.1 Interpreting the UCPM Results

The output of the UCPM includes several values appended to the input data file, including the predicted number of crashes, the distribution percentile, and difference between actual and predicted number of crashes. The predicted number of crashes for a given segment is calculated from the model parameters. The distribution percentile represents the measure of deviation between the predicted number of crashes and the actual number of crashes for the given roadway segment. As illustrated in Figure 5-5, the predicted number of crashes is shown at the peak of the curve (solid vertical line) and the actual number of crashes is shown by the dashed vertical line. The roadway segments where the actual number of crashes was greater than the predicted number of crashes have a higher distribution percentile value (i.e., near 1.0). The roadway segments where the actual number of crashes is less than the predicted number of crashes have a lower distribution percentile value (i.e., near zero). The difference is the numeric difference between the actual number of crashes and the predicted number of crashes for the given roadway segment. A positive difference suggests more crashes occurred than predicted, while a negative difference suggest fewer crashes occurred on the given roadway segment than predicted.

The output of the UCPM is ranked by sorting the segments from largest to smallest by using the normalizing metric shown in Equation 5-1. Ranking the output by the distribution percentile identifies the most problematic segments at the top of the list and the least problematic segments at the bottom of the list, in regards to the number of crashes occurring throughout the roadway network.

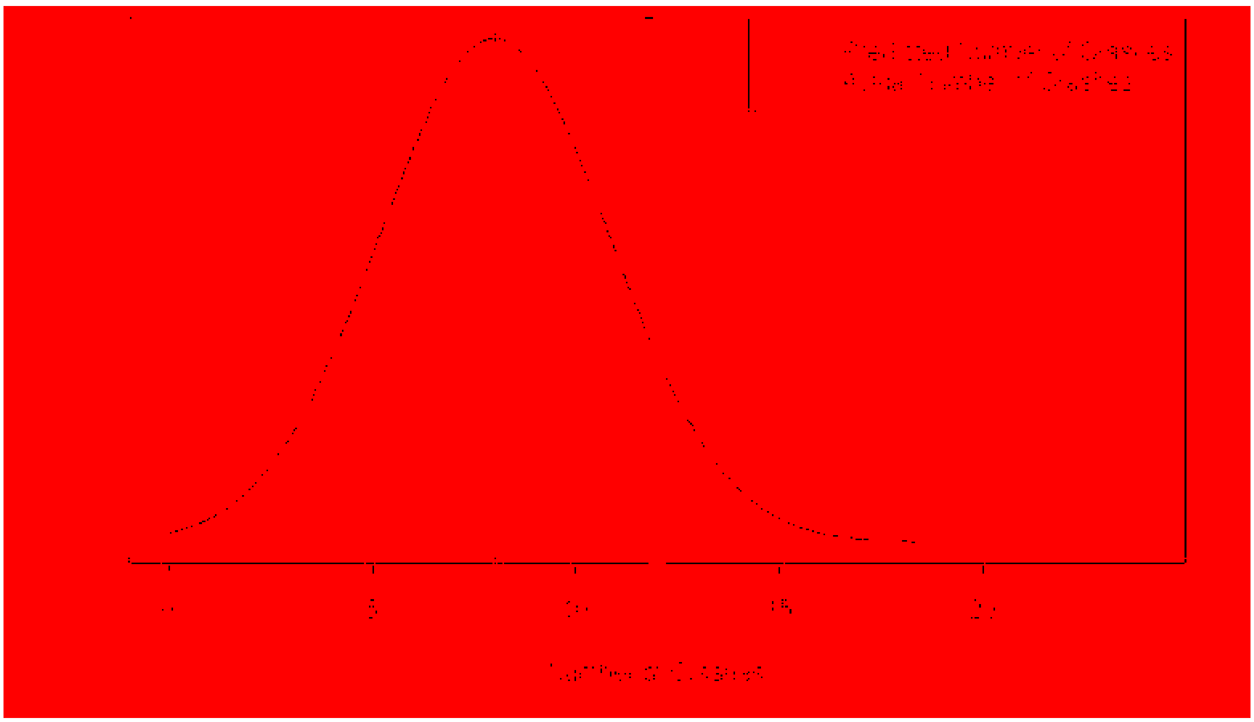


Figure 5-5: Example of comparing the predicted number of crashes to actual number of crashes from the UCPM analysis.

$$UCPM\ Normalizing\ Index = \ Perc \tag{5-1}$$

where: *Perc* = Deviation between predicted number of crashes and actual number of crashes (distribution percentile)

5.5.2 Interpreting the UCSM Results

The output of the UCSM includes several values appended to the input data file, including predicted severe crash rate, predicted number of severe crashes, distribution percentile, the difference between actual and predicted number of severe crashes, and a normalizing value for sorting the output. The predicted severe crash rate for a given segment is calculated from the model parameters. The predicted number of severe crashes is calculated by multiplying the predicted crash rate by the total number of crashes for the given segment. The distribution percentile represents the measure of deviation between the predicted severe crash rate and the actual severe crash rate for the given roadway. As illustrated in Figure 5-6, the predicted severe crash rate is shown at the peak of the curve (solid vertical line) and the actual severe crash rate is shown by the dashed vertical line. The roadway segments where the actual severe crash rate was greater than the predicted severe crash rate have a higher distribution percentile value (i.e., near 1.0). The roadway segments where the actual severe crash rate was lower than the predicted severe crash rate have a lower distribution percentile value (i.e., near zero). The difference is the numeric difference between the actual number of severe crashes and the predicted number of severe crashes for the given roadway segment. A positive difference suggests more severe crashes occurred than predicted, while a negative difference suggest fewer severe crashes occurred on the given roadway segment than predicted.

The output of the UCSM is ranked by sorting the segments from largest to smallest by using the normalizing metric shown in Equation 5-2. In order to distinguish the roadway segments with few severe crashes and a high severe crash rate compared to the segments with more severe crashes and a lower severe crash rate, the distribution percentile is multiplied with the difference. The product of the distribution percentile and difference allows for the segments with more severe crashes to be ranked higher than those with fewer severe crashes. This metric identifies the most problematic segments at the top of the list and the least problematic segments at the bottom of the list, in regards to the severe crash rate occurring throughout the roadway network.

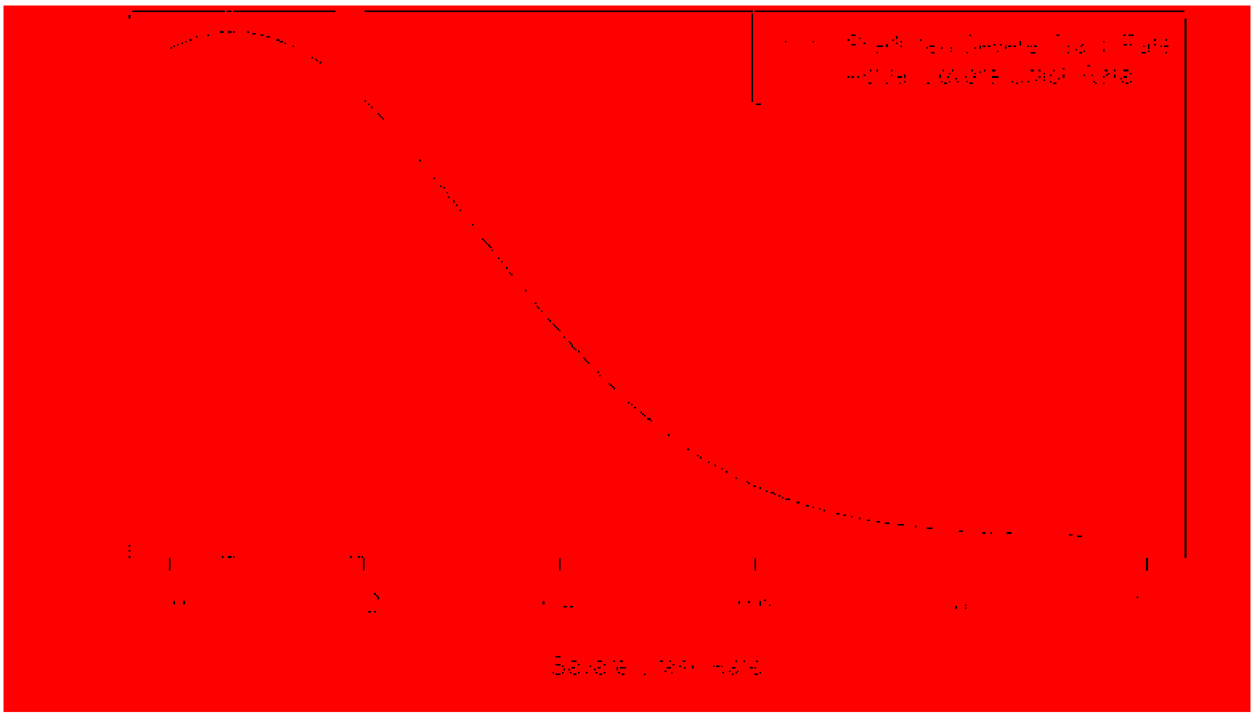


Figure 5-6: Example of comparing the predicted severe crash rate to the actual severe crash rate from the UCSM analysis.

$$UCSM\ Normalizing\ Metric = Perc * Diff \tag{5-2}$$

where: *Perc* = Deviation between predicted severe crash rate and actual severe crash rate (distribution percentile)

Diff = Positive or negative numeric difference between actual number of severe crashes and predicted number of severe crashes

5.5.3 State, Region, County Hierarchical Ranking

The output of the UCPM and UCSM contains a hierarchical ranking for each of the segments, ordering the segments from 1 to "n," where "n" is the number of segments in the dataset. The hierarchical rankings are provided on a statewide level, a UDOT Region level, and a county level. A segment with a ranking near "1" is considered to be performing poorly compared to the other segments within the ranking group in regards to safety. For the statewide ranking, each segment is compared to all other segments in the state roadway network. The UDOT Region and county ranking are analyzed based on the order of the statewide ranking; however, the UDOT Region ranking compares roadway segments to only other segments within the same UDOT Region and the county ranking compares roadway segments to other segments within the same county. This multi-level hierarchal ranking system can be used as a cross-reference to one another, to provide context of the safety issues of the problem within the UDOT Region and the county.

Using results from the 2013 UCPM analysis illustrated in Table 5-1, Route 89 (MP 470.371 to 471.607) was ranked #60 in the state; however, this segment was ranked #19 for UDOT Region 1 and ranked #1 for roadway segments in Cache County. This multi-level hierarchical ranking system can help UDOT Region directors and other interested users identify problem segments within their jurisdiction from the statewide analysis. This ranking system is programmed to be automatically completed as part of the statistical analysis, so that the ranking can be consistent from analysis to analysis.

Table 5-1: Example of State, Region, County Ranking System for 2013 UCPM Analysis(Schultz et al. 2013a)

Route Label	Beginning MP	End MP	County	UDOT Region	State Rank	Region Rank	County Rank
0089P	388.438	389.123	DAVIS	1	1	1	1
0015P	250.923	253.557	UTAH	3	2	1	1
0089P	415.425	415.994	WEBER	1	3	2	1
0015P	292.596	293.634	SALT LAKE	2	4	1	1
0089P	369.036	369.532	SALT LAKE	2	5	2	2
0089P	267.346	276.21	SANPETE	4	6	1	1
0089P	386.955	388.438	DAVIS	1	7	3	2
0089P	345.017	346.455	UTAH	3	8	2	2
0089P	431.317	433.164	BOX ELDER	1	9	4	1
0068P	48.314	49.312	SALT LAKE	2	10	3	3
…	…	…	…	…	…	…	…
0089P	233.46	238.035	SANPETE	4	57	4	4
0080P	146.876	150.724	SUMMIT	2	58	21	1
0126P	8.738	9.126	WEBER	1	59	18	6
0089P	470.371	471.607	CACHE	1	60	19	1

5.5.4 Categorical Ranking

The statewide hierarchal ranking can be re-grouped to a categorical ranking system. The five categorical ranks can be used to group the segments, identifying them as “most problematic” segments in the state to “least problematic” segments in the state. As discussed previously in Section 2.1.3 and outlined in Table 5-2, IDOT uses a comparable technique for ranking their roadways into safety tiers (Tobias 2016). To be consistent with previous research in Utah, the categorical ranking distribution from UDOT is used in this research for categorically ranking the results of the UCPM and UCSM.

Table 5-2: Safety Categorical Ranking Percentiles (Schultz et al. 2015, Tobias 2016)

UDOT Classification	UDOT Percentile	IDOT Classification	IDOT Percentile
Most Problematic	0% - 5%	Critical	0% - 5%
More Problematic	5% - 20%	High	5% - 10%
Some Problematic	20% - 80%	Medium	10% - 25%
Less Problematic	80% - 95%	Low	25% - 50%
Least Problematic	95% - 100%	Minimum	50% - 100%

5.6 Spatial Display of Statistical Analysis Results

As discussed previously in Section 2.3.2, a benefit of using GIS software is the capability to visually display roadway features by color or size, highlighting the most problematic segments and the least problematic segments. For this research, the results of the statistical analysis can be spatially displayed for the state, by UDOT Region, and by county. Observing the results at a UDOT Region or county level can help UDOT Region directors and other interested users have a better perspective to prioritize projects within their jurisdiction. An example of the statewide, UDOT Region, and county map for the statistical analysis results are given in Chapter 7. Another method for spatially displaying the results of the statistical analysis is to publish the results on the UDOT Numetric Network Screening app. The specific steps to creating a statewide map, UDOT Region maps, and county maps of the statistical analysis results are detailed in the user manual (Siegel et al. 2016).

5.7 Selection of Segments of Interest

Once the roadway segments are ranked on a state, UDOT Region, and county level, a select number of roadways are identified for the compilation of the Roadway Safety Analysis reports. In previous research conducted for UDOT, the top 20 segments from the UCPM and

UCSM statewide ranking were selected and analyzed for identifying possible countermeasures (Schultz et al. 2013a, Schultz et al. 2015). In this research, it was found that the top roadway segments in the state were not the only roadway segments which could benefit from the Roadway Safety Analysis methodology. Other appropriate selection groups may include the top 30 roadway segments for a UDOT Region, the top 20 roadway segments for a county, or the roadway segments along a corridor with planned maintenance, rehabilitation, or reconstruction work. The procedure for summarizing the roadway characteristics, crash data, and possible countermeasures for the segments of interest is design to adapt to any number of segments selected.

5.8 Chapter Summary

The purpose of this second of three parts of the Roadway Safety Analysis methodology is execute the network screening statistical process using the UCPM and UCSM. The UCPM and UCSM were modified into dynamic models to be analyzed using R and JAGS, which allows the statistical models to respond and adapt to the inputs from the analyst. The second part of the Roadway Safety Analysis methodology is broken down into six tasks. The first task is to create the input file for the statistical analysis, which is a tabulation of the crash data for each segment to be included in the analysis. The second task is to select the variables for the statistical analysis using the Bayesian horseshoe selection method or the manual variable selection method. The third task is to execute the statistical analysis in R. The fourth task is to interpret the output of the statistical analysis, which includes documentation of the analysis and the hierarchical ranking the analyzed segments by state, UDOT Region, and county. The fifth task is to spatially display the statistical analysis results into statewide map, UDOT Region maps, county maps, or on the UDOT Numetric "Network Screening" app. The final task is to select the segments of interest for the report compilation process. The specific step-by-step procedure for accomplishing these tasks are described in the user manual (Siegel et al. 2016).

Chapter 6 discusses the third part of the Roadway Safety Analysis methodology, which is to use selected segments of interest created in Chapter 5 for the report compilation processes, abridge the full reports to two-page summaries, and publish the two-page reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users.

6 REPORT COMPILATION FOR SEGMENTS OF INTEREST

The third and final part of the Roadway Safety Analysis methodology is designed to compile the Roadway Safety Analysis reports for the selected segments of interest, which are published through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. This chapter discusses the five tasks of the third part of the Roadway Safety Analysis methodology. The first task is to combine the segments of interest with roadway characteristics and crash datasets. The second task is to auto-populate the reports with roadway data, crash data, and possible countermeasures. The third task is to complete the full report by the analyst. The fourth task is to create a two-page abridgement of the full report. The fifth and final task is to publish the Roadway Safety Analysis reports. The end result of these tasks is a collection of two-page Roadway Safety Analysis reports for the selected segments of interest, which can be distributed through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. As this chapter discusses the procedure outlined in Figure 6-1, the step-by-step instructions and documentation for the compiling the Roadway Safety Analysis reports for the selected segments of interest is provided in the user manual (Mineer et al. 2016).

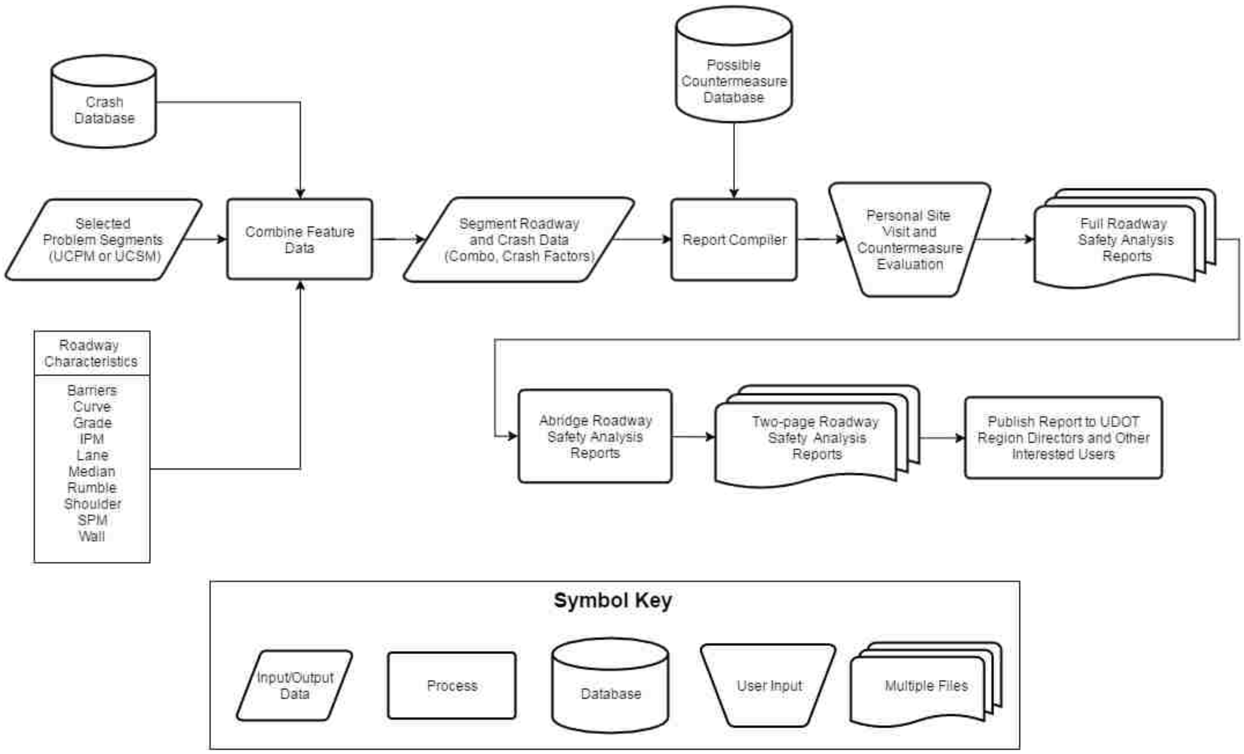


Figure 6-1: Schematic illustration of report compilation for segments of interest.

6.1 Combining Segments of Interest with Roadway Characteristics and Crash Data

As previously described in Section 5.7, the selection of roadway segments of interest from the statistical analysis for additional safety analysis was discussed. The segments of interest could be the top 50 segments within the state, the top 30 segments within a UDOT Region, the top 20 segments within a county, or segments along a corridor which have planned maintenance or rehabilitation. Once the segments of interest have been identified, the roadway characteristics are summarized for the segments of interest. The roadway characteristics allow the analyst to identify deficiencies in the roadway infrastructure that could be addressed to improve the safety of the roadway. The roadway characteristics in Table 6-1 are summarized for each of the segments of interest, which are derived or obtained from data on the UDOT Open Data website

(UDOT 2015d). The IPM data are derived from the intersection data, counting the number of intersection along a given roadway segment. The SPM data are derived from the sign face data, counting the number of signs within 50 meters (164 feet) from the given roadway segments. The horizontal curve data are derived using the Horizontal Alignment Finder (HAF) Algorithm, which identifies curves from data collected through light detection and ranging (LiDAR) technology. The method for obtaining or deriving the data is explained in the respective user manuals (Brown et al. 2016, Mineer et al. 2016).

Table 6-1: Roadway Characteristics in the Roadway Safety Analysis Reports

Characteristic	Data Source
Median	UDOT Open Data
IPM	Derived from Intersection data, from UDOT Open Data
SPM	Derived from Sign Face data, from UDOT Open Data
Shoulder	UDOT Open Data
Grade	UDOT Open Data
Curve	Derived using HAF Algorithm (Brown et al. 2016)
Lanes	UDOT Open Data
Wall	UDOT Open Data
Barrier	UDOT Open Data
Rumble strips	UDOT Open Data

Once the roadway characteristics and crash data have been prepared, the data are spatially combined with the segmented roadway data. This is accomplished using the "Spatial Join To Excel" Python Script tool in Esri ArcMap. This tool is designed to spatially join the 10 roadway data files and crash data with the segments of interest and export the data to a common folder in MS Excel format. The respective ArcMap tools and GUIs available to assist with this analysis are described in the user manual (Mineer et al. 2016).

Filtering through the roadway characteristic data and crash data can be a laborious task if completed by hand. Engineering judgment is needed to accurately summarize the roadway characteristics and provide a simplified description for the roadway characteristics of the given segment of interest. To expedite the process, these roadway features are summarized using the automation tools created in MS Excel, with engineering judgment guiding the automation tools. The judgment used to summarize each roadway characteristic is summarized in Table 6-2. The end result of the automated process includes the data fields shown in Table 6-3. This process is described in detail in the respective user manual (Mineer et al. 2016).

6.2 Auto-populating Reports with Roadway Data, Crash Data, Possible Countermeasures

The purpose of combining the roadway data, crash data, and possible countermeasures is to summarize multiple data sources into a succinct report, which can help the analyst identify effective roadway improvements for a given roadway segment. The methodology for summarizing these data was developed in previous research conducted for UDOT, which required the interpretation of the roadway and crash data manually (Schultz et al. 2013a, Schultz et al. 2015). The research summarized in this thesis has automated the process of summarizing the roadway data, crash data, and possible countermeasures for the Roadway Safety Analysis report with the use of MS Excel macros. The automated steps for summarizing these data are broken into three respective parts, which are described in the following subsections. The first part is to identify each segment of interest and summarize the characteristics of the roadway. The second part is to conduct a micro-analysis of the crash data, summarizing the crash factors (i.e., data from the crash rollup data file) and vehicle crash data. The third part is to produce a list of possible countermeasures, which provides a starting point for the analyst to identify approximately 10 possible countermeasures to the roadway safety concerns. The automated tools designed to assist the analyst in the process of summarizing the data are explained in the user manual (Mineer et al. 2016).

Table 6-2: Engineering Judgment for Summarizing Roadway Characteristic Data

Characteristic	Data
Median	Identify the most prevalent median type (by length), most prevalent island type (by length), and calculate average median width. Return median type, average median width, and island type.
IPM	Identify intersection count along segment. Return count of intersection and IPM (count/length).
SPM	Identify sign face count along segment. Return count of sign faces and SPM (count/length).
Shoulder	Identify the most prevalent shoulder material (by length), most prevalent shoulder edge type (by length), and calculate average shoulder width. Return shoulder material, shoulder type, and average shoulder width.
Grade	Identify the greatest vertical grade along segment. Return value for maximum vertical grade, number of vertical grade changes along segment, and greatest vertical change.
Curve	Identify the sharpest curve (curve class). Return curve class, curve degree, curve radius, and curve length.
Lanes	Count the greatest number of a given auxiliary lane, including left turn, right turn, acceleration, deceleration, TWLTL, passing lane, bicycle lane, and high occupancy vehicle (HOV) lane. Return value for left turn, right turn, acceleration, deceleration, TWLTL, passing lane, bicycle lane, and HOV lane.
Wall	Check if a wall exists. Return a "W" to represent presence of wall and return "B" and barrier information (common center barrier, common outside barrier).
Barrier	Check if a barrier exists and barrier type. Return a "B" to represent the presence of a barrier and the common center barrier and outside barrier type.
Rumble strips	Check if rumble strips exist. Return a "Y" if rumble strips exist along segment.

Table 6-3: Roadway Characteristics Summarized for Selected Segments

Characteristic	Data
Median	Median Type Mean Median Width (ft) Island Type
IPM	Intersection Count Intersection per Mile (Count/Length)
SPM	Sign Count Signs per Mile (Count/Length)
Shoulder	Common Shoulder Material Common Shoulder Edge Type Mean Shoulder Width (ft)
Grade	Maximum Vertical Grade Number of Vertical Grade Changes Greatest Vertical Grade Change
Curve	Horizontal Curve Class Horizontal Curve Degree Horizontal Curve Radius (ft) Horizontal Curve Length (ft)
Lanes	Number of Left Turn Lanes Number of Right Turn Lanes Number of Acceleration Lanes Number of Deceleration Lanes Number of TWLTLs Number of Passing Lanes Number of Bicycle Lanes Number of HOV Lanes
Wall	Presence of Walls (W)
Barrier	Presence of Barriers (B) Common Center Barrier Common Outside Barrier
Rumble strips	Presence of Rumble Strips (Y/N)

6.2.1 Segment Identification and Roadway Characteristics

The first part of auto-populating the Roadway Safety Analysis reports summarizes the segment identification and roadway characteristics into three data tables. The three data tables include the segment metadata, the segment functional characteristics, and roadway characteristics.

The data table for the segment metadata follows the structure outlined in Figure 6-2. The roadway name, direction, MPs, length, UDOT Region, and county define the extent of the roadway. The statistical model, hierarchical ranking (i.e., statewide, UDOT Region, and county rank), date ranges of crash data, and date of analysis provide context to the reader when the analysis was conducted and the relevance of the data.

The data table for the segment functional characteristics follows the structure outlined in Figure 6-3. This table includes the AADT, functional classification, number of through lanes, and speed limit of the roadway. These characteristics provide context to the functionality of the roadway and how the roadway serves the local community.

The data table for the roadway characteristics follows the structure outlined in Figure 6-4. This table includes the MPs of the roadway, median, IPM, SPM, shoulder, vertical grade, horizontal curvature, lane count, walls, barriers, and rumble strips. These roadway characteristics are described with the fields given in Table 6-3, with the summarization process described in Section 6.1. These roadway characteristics can be used to help identify deficiencies in the roadway that could be improved to enhance roadway safety.

Road Name:	______	UC Model Used:	______
Road Direction:	______	State Rank:	______
Beginning, Ending MP:	______	Rank, Region:	______
Length (miles):	______	Rank, County:	______
Dates of Data Source:	______	Date of Analysis:	______

Figure 6-2: Segment metadata for Roadway Safety Analysis report.

Function Classification:	______	AADT:	______
Number of Thru Lanes:	______	Speed Limit (MPH):	______

Figure 6-3: Segment functional characteristics for Roadway Safety Analysis report.

MP	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/ Barrier	Rumble
______	______	______	______	______	______	______	______	______	______

Figure 6-4: Roadway characteristics for Roadway Safety Analysis report.

6.2.2 Micro-Analysis of Crash Data

The second part of auto-populating the Roadway Safety Analysis reports summarizes the crash data into three data tables. The three data tables include the crash count and severity summary, the top eight (8) crash factors, and data from the crash and vehicle datasets.

The data table for the crash count by severity follows the structure outlined in Figure 6-5. This table summarizes the MPs of the roadway segment; the total number of crashes identified along the segment; and the number non-incapacitating, incapacitating, and fatal injuries included in the statistical analysis. If only incapacitating and fatal injuries were included in the analysis, the analyst would note the absence of data for non-incapacitating injury crashes.

The data table for the top 8 crash factors follows the structure outlined in Figure 6-6. This table summarizes 8 of the 29 possible crash factors for two reasons: first, not all of the possible crash factors are relevant to the safety problems along the segment, which means that including all the crash factors may not provide useful information in the report; and second, there is limited space to summarize the detailed crash factors in the Roadway Safety Analysis reports. This table summarizes the MP for each crash in the statistical analysis and a "Y" or an "N" in relation to the top 8 crash factors. The crash factor with the highest frequency of "Y" values becomes crash factor #1, with the next highest frequency next in the list.

The data table for the vehicle and crash data follows the structure outlined in Figure 6-7. This table summarizes the MP, first harmful event, manner of collision, event sequence, most harmful event, and vehicle maneuver for each crash in the statistical analysis. These crash data fields are useful for identifying prevalent vehicle movement patterns or events which could identify safety concerns for a given segment. The first harmful event identifies the first harmful event that resulted from the crash (e.g., run off road, delineator post, work zone, or ditch). The manner of collision identifies how multiple vehicles collided (e.g., angle, sideswipe same direction, parked vehicle, etc.) or if the crash involved a single vehicle. The event sequence is similar to the most harmful event, as it identifies the sequential events related to a crash, if multiple vehicular movements occurred as a result of a crash. The most harmful event summarizes the event sequence which produced the most harm to the people involved in the crash. The vehicle maneuver lists the motor vehicle movement which occurred before the crash occurred (e.g., turning right, changing lanes, parked, or stopped in traffic lane). The possible values for these fields are recorded in numerical codes, which are translated from numerical code to text description and auto-populated into the Roadway Safety Analysis report. The possible values for these fields are summarized in Appendix C.

MP	Total Crashes on Roadway	Severity 5 (Fatal)	Severity 4 (Incap. Injury)	Severity 3 (Non-incap. Injury)
_______	_______	_______	_______	_______

Figure 6-5: Crash count and severity summary for Roadway Safety Analysis report.

Crash ID	MP	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Segment Total		______	______	______	______	______	______	______	______

Figure 6-6: Top 8 crash factors for Roadway Safety Analysis report.

Crash ID	MP	First Harmful Event	Manner of Collision	Event Sequence (1)	Event Sequence (2)	Event Sequence (3)	Event Sequence (4)	Most Harmful Event	Vehicle Maneuver
____	____	____	____	____	____	____	____	____	____

Figure 6-7: Data from crash and vehicle datasets for Roadway Safety Analysis report.

6.2.3 Possible Countermeasures

The third part of auto-populating the Roadway Safety Analysis reports summarizes a list of possible countermeasures for the individual roadway segments. The auto-populated list of possible countermeasures provides many alternatives, after which engineering judgment can be used to select the most relevant countermeasures for the given roadway. The possible countermeasures were derived from the NCHRP Report 500 volumes and cross tabulated with the crash factors from the UDOT crash rollup data, as shown in Table 6-4. As shown in Table 6-4, some of the UDOT crash factors from the rollup data do not have a corresponding list of possible countermeasures from the NCHRP 500 Report volumes, including adverse weather and transit vehicle involved collisions. In these cases, the analyst would need to research possible countermeasures for these crash types, if additional countermeasures are needed for improving the roadway safety. As mentioned previously in Section 2.5, additional resources beyond the NCHRP Report 500 volumes are available to identify relevant, effective, and innovative countermeasures that help address the safety concerns on the given segment, including "Countermeasures That Work" and the CMF Clearinghouse website.

6.3 Complete Full Report by Analyst

After the reports have been auto-populated with the roadway data, crash data, and possible countermeasures, an analyst completes the report by verifying the data summarized in the reports. The work done by the analyst to finish the reports can be summarized into three tasks, which are described in the following subsections. The first task is to review the roadway and crash data to identify and summarize prevalent safety problems related to the specific route. The second task is to summarize the historical and current conditions of the roadway through a site visit, internet tools, and communicating with experts. The third task to be completed by the analyst is to use the roadway and crash data to identify approximately 10 possible countermeasures for improving the safety problems along the segment. The instructions for the analyst to complete these tasks are given in the user manual (Mineer et al. 2016).

Table 6-4: Possible Countermeasures from NCHRP500 Report for UDOT Crash Factors

UDOT Crash Factors from Rollup Data	Related NCHRP 500 Report
PEDESTRIAN_INVOLVED	Volumes 10, 18 (Zegeer et al. 2014, Raborn et al. 2008)
BICYCLIST_INVOLVED	Volumes 10, 18 (Zegeer et al. 2014, Raborn et al. 2008)
MOTORCYCLE_INVOLVED	Volume 22 (Potts et al. 2008)
IMPROPER_RESTRAINT	Volume 11 (Lucke et al. 2004)
UNRESTRAINED	Volume 11 (Lucke et al. 2004)
DUI	Volume 16 (Goodwin et al. 2005)
AGGRESSIVE_DRIVING	Volume 1 (Neuman et al. 2003f)
DISTRACTED_DRIVING	Volume 14 (Stutts et al. 2005)
DROWSY_DRIVING	Volume 14 (Stuffs et al. 2005)
SPEED_RELATED	Volume 23 (Neuman et al. 2009)
INTERSECTION_RELATED	Volumes 5, 12 (Neuman et al. 2003b, Antonucci et al. 2004)
ADVERSE_WEATHER	No corresponding volumes
ADVERSE_ROADWAY_SURF_CONDITION	No corresponding volumes
ROADWAY_GEOMETRY_RELATED	Volume 6 (Neuman et al. 2003a)
WILD_ANIMAL_RELATED	No corresponding volumes
DOMESTIC_ANIMAL_RELATED	No corresponding volumes
ROADWAY_DEPARTURE	Volumes 6, 7 (Neuman et al. 2003a, Torbic et al. 2004)
OVERTURN_ROLLOVER	Volumes 6, 7 (Neuman et al. 2003a, Torbic et al. 2004)
COMMERCIAL_MOTOR_VEH_INVOLVED	Volume 13 (Knipling et al 2004)
INTERSTATE_HIGHWAY	Volume 20 (Neuman et al. 2008)
TEENAGE_DRIVER_INVOLVED	Volume 19 (Goodwin et al. 2008)
OLDER_DRIVER_INVOLVED	Volume 9 (Potts et al. 2004)
URBAN_COUNTY	No corresponding volumes
NIGHT_DARK_CONDITION	No corresponding volumes
SINGLE_VEHICLE	Volumes 2, 6, 14, 23 (Neuman et al. 2003e, Neuman et al 2003a, Stutts et al. 2005, Neuman et al 2009)
TRAIN_INVOLVED	No corresponding volumes
RAILROAD_CROSSING	No corresponding volumes
TRANSIT_VEHICLE_INVOLVED	No corresponding volumes
COLLISION_WITH_FIXED_OBJECT	Volumes 3, 8 (Neuman et al. 2003c, Lacy et al. 2004)

6.3.1 Safety Problem Summary

As the analyst reviews the roadway and crash data, safety problem patterns can be identified. As these patterns are identified, the analyst can summarize the most prevalent patterns observed in the roadway and crash data. Creating this summary helps the analyst have an understanding of the safety problems, which can help identify possible countermeasures. When the full reports are abridged to the two-page length, the safety problem summary retains key crash data information as the crash data tables are reduced in size, communicating the most prevalent safety problems for the UDOT Safety Programs Engineer, UDOT Region directors, and other interested users.

6.3.2 Historical Perspective, Current Conditions, Site Visit

To accompany the automatically summarized roadway and crash data, the analyst checks the accuracy of the data by summarizing the historical perspective and current conditions through a site visit, internet tools, and communicating with experts. The historical perspective and current conditions allows the analyst to review the history and functionality of the roadway. Looking into historical data can help identify if there have been major roadway construction projects on the roadway segment or if there has been a change to the roadway that would impact the roadway safety. The current conditions summary allows the analyst and other interested parties to understand what exists in the field for the segment of interest.

Conducting a site visit provides an opportunity to confirm the roadway characteristics summarized using the automation tools and to identify possible problems that the roadway characteristics and crash factors were not able to identify. The site visit could include observations of traffic that were not evident in the roadway and crash data. Conducting a site visit also provides an opportunity to evaluate the feasibility of countermeasures or the discovery of a possible countermeasure not previously identified.

Several internet based tools are available to evaluate the current conditions of a roadway, as a supplement to an in-person site visit, including Google Earth (Google, Inc. 2016a), Google Maps (Google, Inc. 2016b), UDOT's Roadview Explorer (UDOT 2016a), or UDOT's Virtual Geomatics Web Navigator (UDOT 2016b). These tools allow users to become more familiar with the locations being analyzed, as a supplement to the site visit. Web databases also provide historic data, which can enhance the process of summarizing the historical perspective of the roadway. Internet tools also help by providing a different perspective of the problem segment, such as an overhead view of the roadway, as well as the street view, as data are available. In light of the expanding databases available on the internet, internet data sources should be reviewed manually for accuracy and quality (Schultz et al. 2013a, Schultz et al. 2015). Internet tools are recommended to be a supplement to personal site visits, rather than serving as the sole source of information for the safety analysis.

When a personal site visit and internet tools are not able to provide historical or current insight of a problem segment, communicating with experts familiar with the problem segment can provide valuable insight. Law enforcement agencies, local and state government officials, traffic engineers, and local department of transportation employees provide a wealth of past, present, and future information concerning state roadways. Public opinion and possible stakeholders also become a source of information for the problem segments. Information gained by communicating with experts, stakeholders, and the public provides greater understanding of the problem segment and possible countermeasures to improve roadway safety (Schultz et al. 2013a, Schultz et al. 2015).

6.3.3 Review and Narrow List of Possible Countermeasures

After the analyst has reviewed the data provided in the report, the third task is to identify approximately 10 possible countermeasures from the fill auto-populated list of possible countermeasures. The auto-populated list can possibly produce hundreds of possible countermeasures. It is necessary for the analyst to narrow that list and to add possible innovative countermeasures not automatically tabulated.

6.4 Two-Page Abridgement of Roadway Safety Analysis Reports

After the full data in the Roadway Safety Analysis reports have been completed for the segments of interest, the analyst creates a two-page abridgement of the full reports to summarize the key findings of the reports. Table 6-5 summarizes the relationship between the full and abridged two-page Roadway Safety Analysis reports. The full report contains all of the data summarized by the automation tools and as edited by the analyst. The two-page report is designed to be a snapshot summary of the full analysis that took place to investigate the safety aspects of the given roadway. For example, the segment identification data carries over to the two-page reports. However, not all of the crash factor and vehicle data are carried to the two-page report, as the crash data can be very detailed and lengthy. The historical perspective, current conditions, and site visit notes are combined, keeping the most relevant observation notes that could help identify safety problems on the roadway. The reduced list of possible countermeasures is included in the abridged report, to provide alternatives for improving roadway safety. Once these sections of the report have been reduced, a two-page report containing succinct information concerning the safety features of the given roadway is generated for publication. The full-report may be kept as a review of the data and notes that were used to create the abridged reports.

Table 6-5: Comparing Full Analysis and Two-Page Reports

Report Section	Full Analysis	Two-Page Report
Segment Identification		
Segment Metadata	X	X
Segment Characteristics	X	X
Roadway Characteristics	X	X
Micro-Analysis of Crash Data		
Crash Count and Severity	X	X
Top 8 Crash Factors	X	Reduced
Crash and Vehicle Data	X	Omitted
Safety Problem Summary	X	X
Historical Perspective, Current Conditions, Site Visit Notes		
Historical Perspective	X	Combined
Current Conditions	X	
Site Visit Notes	X	
Potential Countermeasures		
Potential Countermeasures	X	Reduced

6.5 Publication of the Roadway Safety Analysis Reports

Once the Roadway Safety Analysis two-page reports have been created, these reports are published through the UDOT Safety Programs Engineer to the UDOT Region directors and other interested users. If additional reports are requested, the process can be repeated by identifying a new group of segments of interest and repeating the report compilation process. In addition, the output of the statistical analyses can be published on the UDOT Numetric Network Screening app, which allows a side by side comparison of the results of the statistical analysis with the UDOT Safety Index.

The state crash database is planned to be hosted on a server at the University of Utah beginning sometime in the summer or fall of 2016. It is anticipated that this change will accommodate the distribution of the two-page reports through the Numetric website rather than being distributed individually. The details of this integration of the Roadway Safety Analysis reports on the Numetric website will need to be finalized in a future research project.

6.6 Chapter Summary

The purpose of the third and final part of the Roadway Safety Analysis methodology is to compile the Roadway Safety Analysis reports for the selected segments of interest, which are published through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. The third part of the Roadway Safety Analysis methodology is broken down into five tasks. The first task is to combine the segments of interest with 10 roadway characteristics and crash datasets. The second task is to auto-populate the reports with the roadway data, crash data, and possible countermeasures. The third task is to complete the full report by an analyst, using the auto-populated reports as a starting point to summarize the safety problems, conduct a site visit, and identity approximately 10 possible countermeasures for each segment of interest. The fourth task is to create a two-page abridgement for each segment of interest, summarizing the key findings of the full report. The final task is to publish the Roadway Safety Analysis reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. The specific step-by-step procedure for accomplishing these tasks are described in the respective user manual (Brown et al. 2016, Mineer et al. 2016).

Chapter 7 provides an example of the Roadway Safety Analysis methodology described in Chapter 4, Chapter 5 and Chapter 6, beginning at the crash and roadway segmentation, centered on the statistical analysis, and concluding with the creation and publication of the two-page Roadway Safety Analysis reports.

7 EXAMPLE OF ROADWAY SAFETY ANALYSIS METHODOLOGY

The product of this research is the creation of the Roadway Safety Analysis methodology, connecting each of the elements described in Chapter 4, Chapter 5, and Chapter 6 of this thesis. This chapter provides an example the three parts of the Roadway Safety Analysis methodology from beginning to end, highlighting the tools and GUIs created to apply and automate the work of previous research project conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015). The first section in this chapter provides an example of preparing the crash data and segmenting the roadway data. The second section provides an example of executing the statistical analysis of the roadway data. The third section provides an example of compiling the reports for the segments of interest. The culmination of this work is the creation of two-page reports for the segments of interest, which are published by the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. While the general process is illustrated in this chapter, the specific step-by-step instructions and supporting documentation can be found in the respective user manuals developed for this research (Gibbons et al. 2016, Mineer et al. 2016, Siegel et al. 2016).

7.1 Crash Data Preparation and Roadway Data Segmentation

The first step in the Roadway Safety Analysis methodology is to create the crash and segmented roadway datasets. The following subsections include an example of creating the crash database and segmenting the roadway data and calculating several variable interactions for the statistical analysis. These tasks are accomplished with the use of automation tools, GUIs, and the instructions given in the user manual (Gibbons et al. 2016).

7.1.1 Crash Database Preparation

In order to prepare the crash database for the statistical analysis and create the Roadway Safety Analysis reports, the historic crash data needs to be combined into a multiyear dataset and a separate vehicle crash data file. Raw crash data were provided by UDOT's Traffic and Safety Division, including separate files for crash data, crash location, crash rollup (i.e., data from the crash rollup data file), and vehicle crash data. The crash data contains sensitive information, protected under 23 USC 409 (USGPO 2012). These separate data files need to be combined to display only state roadway, non-ramp crashes in a single data file, with the vehicle crash data formatted for future use in the creation of the Roadway Safety Analysis reports. The MS Excel workbook "Roadway and Crash Data Preparation" includes the automation tools and GUIs designed specifically for this process. An illustration of the GUI for the users to access the automation tools for summarizing the crash data is shown in Figure 7-1. Using this interface, the analyst selects a series of command buttons to open and process the crash data. If there is a mismatch in the expected critical data columns to what is actually given in the data, the "Check Headers" tool prompts the analyst through a GUI to select the correct data field for the critical data column, as shown in Figure 7-2. For the infrequent chance that a new header has been added to the crash rollup dataset, a workbook tool was designed to check for new headers and to allow the analyst to add the critical data columns to the master list for future iterations. As each of the crash data fields are loaded and processed, the analyst is given an update on the progress on the main GUI for the workbook, as shown in Figure 7-3.

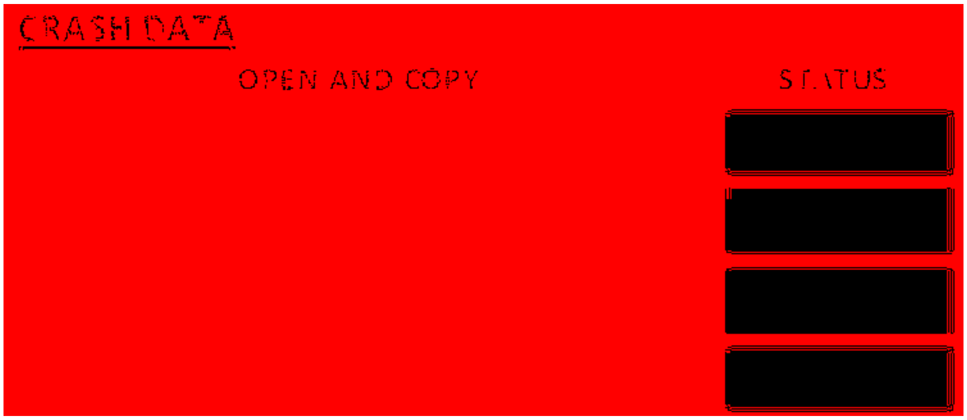


Figure 7-1: GUI for processing the crash data.

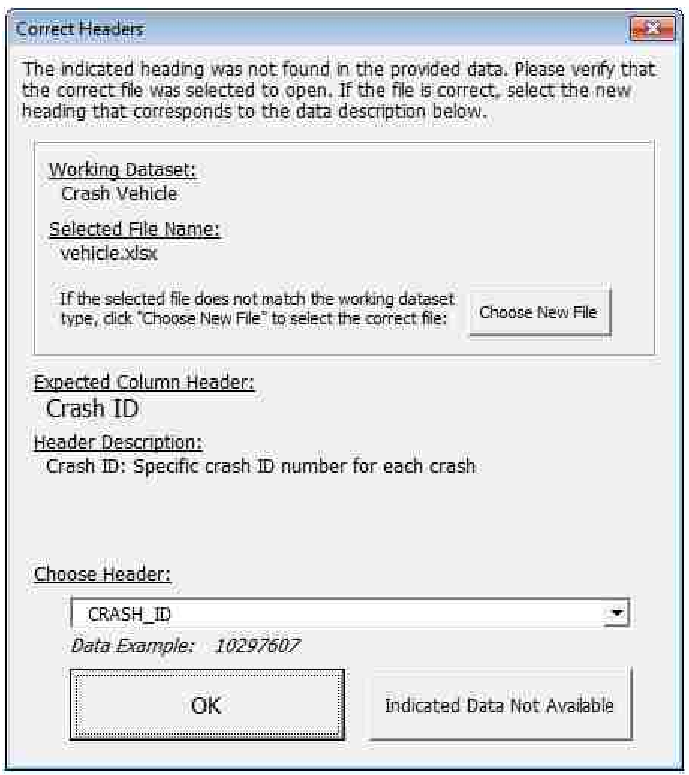


Figure 7-2: Example of "Check Headers" tool interface.

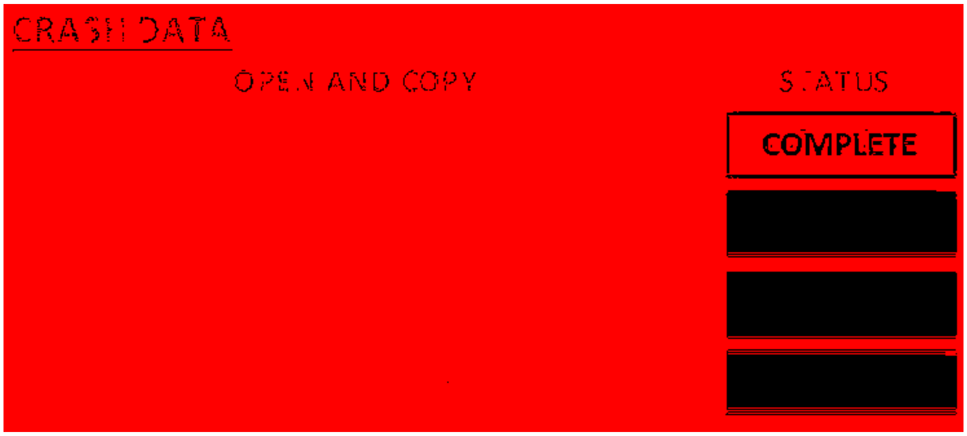


Figure 7-3: Example of status update for crash data preparation.

The output of these steps is the creation of the crash database, which includes the combined crash, rollup, and location data and a separate file for the vehicle data. The combined crash data file is used in the statistical analysis and Roadway Safety Analysis report compilation process. The vehicle data is used for the Roadway Safety Analysis report, summarizing the contributing vehicular movements to the given crashes along the segment.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), summarizing the crash data required approximately 2-3 hours of uninterrupted CPU power to combine 250,000 lines of crash data, with limited adaptability of the previously designed tools to new crash datasets. As a result of this research, the run time for preparing the crash data has been reduced to 30 minutes for combining 150,000 lines of crash data, with increased adaptability to data format and data content.

7.1.2 Roadway Data Preparation, Segmentation, and Statistical Interactions

In order to prepare the roadway segment data for the statistical analysis and Roadway Safety Analysis reports, the raw data needs to be obtained for the roadway. The roadway data are publicly available on UDOT's Open Data website, which includes separate files for AADT, speed limit, number of lanes, functional classification, and urban code. These files are combined into a single data file representing homogeneous roadway segments; homogeneous by length or by characteristic. The MS Excel workbook "Roadway and Crash Data Preparation" includes the automation tools and GUI designed specifically for this process. An illustration of the GUI for the users to access the automation tools for the roadway segmentation is shown in Figure 7-4.

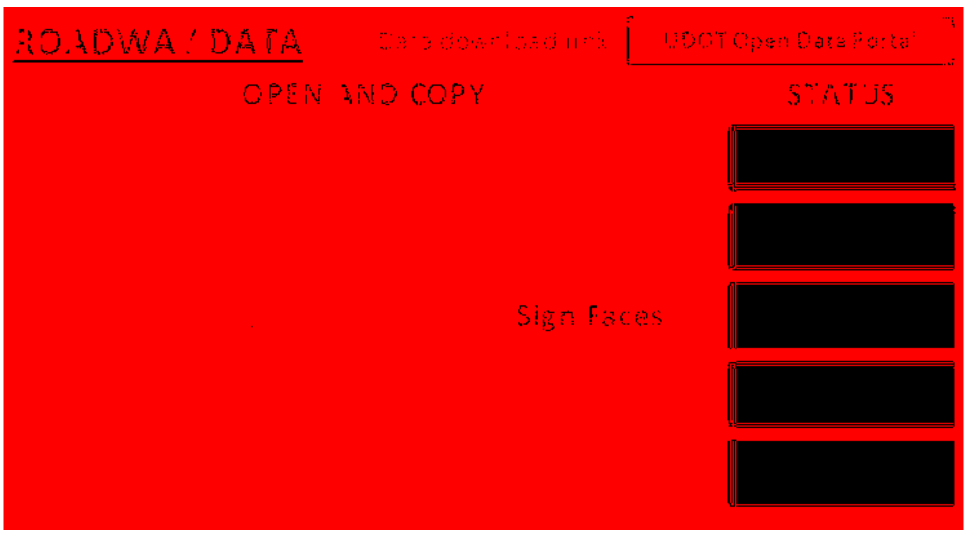


Figure 7-4: GUI for processing the roadway data.

Using this interface, the analyst selects a series of command buttons to open and process the roadway data. If there is a mismatch in the expected critical data columns to what is actually given in the data, the "Check Headers" tool prompts the analyst through a GUI to select the correct data field for the critical data column. Based on the feedback from the analyst, the "Check Headers" tool corrects each instance of a mismatch of what was expected for a data column and what actually came in. The AADT, functional classification, number of through lanes, speed limit, and urban code data files are processed by creating the "LABEL" and "DIRECTION" fields before they are segmented together. As each of the roadway data files are loaded and processed, the analyst sees updates on the progress of the process, as shown in Figure 7-5.

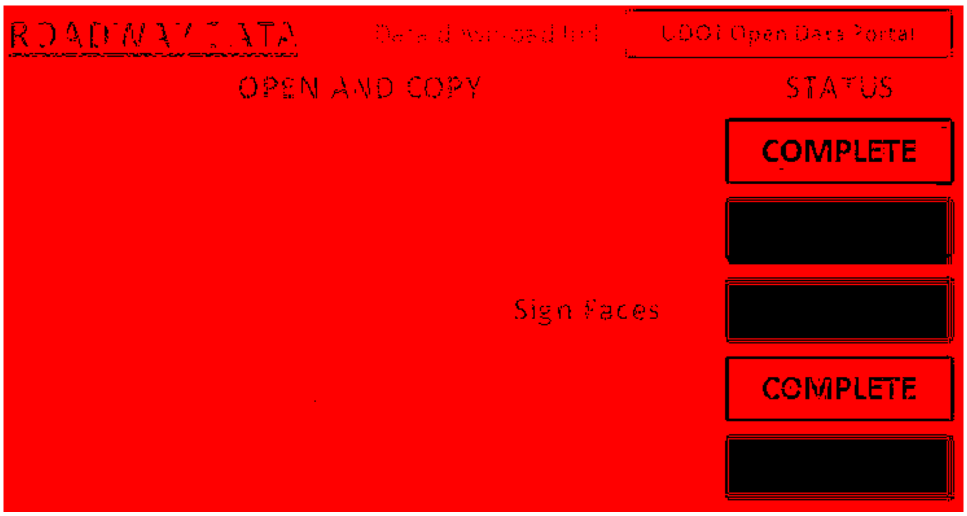


Figure 7-5: Example of status update for roadway segment data preparation.

When the roadway data files are created, the next step is to segment the roadway data. The GUI allows the analyst to use the automated tools to segment the roadway data into homogeneous roadway segments, either by change of roadway characteristic or by a length defined by the analyst, as shown in Figure 7-6 and Figure 7-7, respectively. Selecting the option to segment to roadway data by roadway characteristic produces approximately 5,900 roadway segments for the statistical analysis. Selecting the option to segment the roadway data by 0.1 mile length produces approximately 75,000 roadway segments for the statistical analysis.

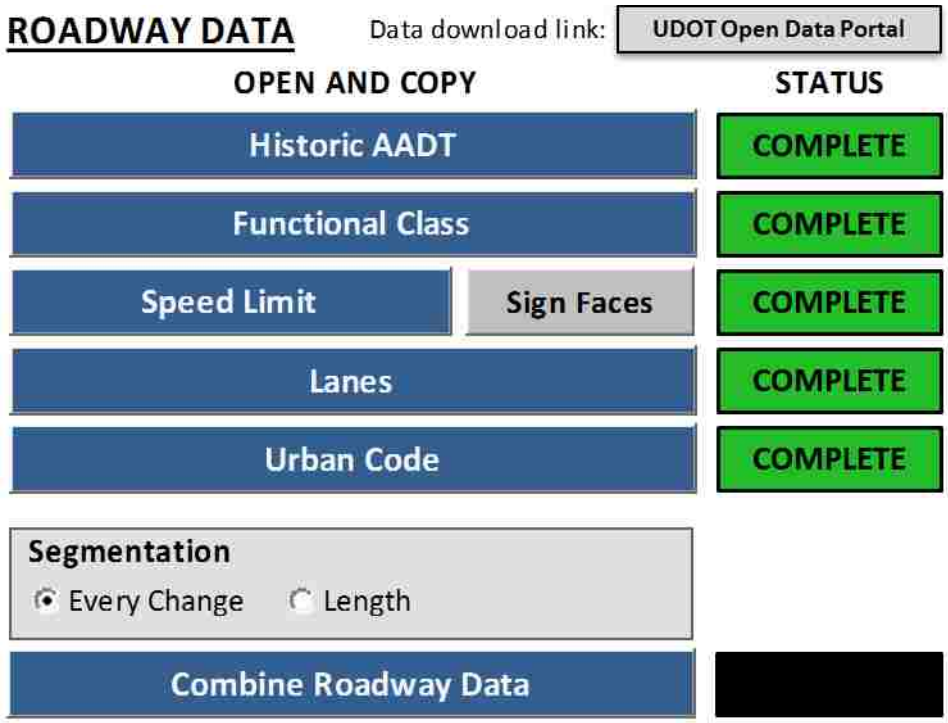


Figure 7-6: GUI for selecting segmentation option at "Every Change."

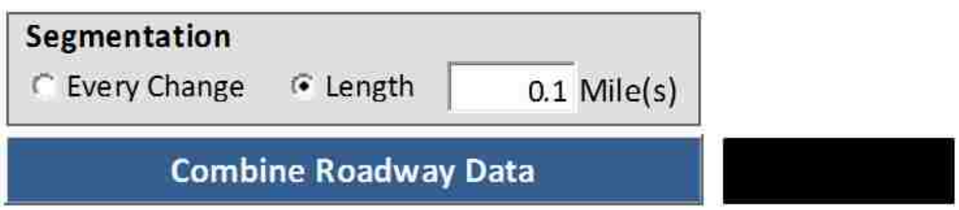


Figure 7-7: GUI for selecting the segmentation option at every 0.1 mile.

After the roadway data have been segmented, the statistical interaction values are automatically calculated. As outlined previously in Section 4.4, 10 statistical interaction values are calculated, including VMT, VMT^2, VMT*Speed_Limit, plus seven other interactions. These statistical interactions are appended onto the roadway segment data.

The output of these steps is the creation of the segmented roadway data file, which is a combination of the AADT, functional classification, number of through lanes, speed limit, and urban code of the state roadways, with 10 statistical interactions added to the roadway data. The segmented roadway data are used in the statistical analysis, which becomes the backbone of the Roadway Safety Analysis report compilation process.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), the five roadway files needed to be processed individually in separate MS Excel workbooks, with limited adaptability to new or updated roadway data. Once the five datasets were processed individually, the roadway data were segmented using the "Overlay" tool in ArcMap, which created approximately 4,000 roadway segments in the roadway data file. As a result of this research, the five roadway files are processed in MS Excel and segmented together within one MS Excel workbook, producing approximately 5,900 homogeneous roadway segments with statistical interactions calculated. The updated automation tools and corresponding new GUI allows the analyst to complete these actions within one MS Excel workbook, with adaptability to new or updated roadway datasets.

7.2 Statistical Network Screening of Roadway Data

The second step in the Roadway Safety Analysis methodology is to execute the UCPM and UCSM statistical analyses with the roadway segment and crash data created in the previous step. The following subsections include: an example of creating the input file for the statistical analysis; selecting the variables for the statistical analysis and executing the statistical analysis; interpreting the statistical hierarchical ranking of the segments and creating the spatial display of the results; and selecting problem segments for the report compilation process. While the actual statistical analysis and output of the UCPM and UCSM differ from each other, the steps to prepare the input data are the same for both models. These tasks are accomplished with the use of automation tools, GUIs, and the instructions given in the user manual (Siegel et al. 2016).

7.2.1 Create Input File for Statistical Analysis

The UCPM and UCSM both require an input data file of the segments; the UCPM requires a count of crash severities defined by the analyst for each segment and the UCSM requires a count of crash severities defined by the analyst and all crashes for each segment. The MS Excel workbook "R GUI" includes the automation tools and GUIs designed specifically for the process of creating the input file for the UCPM and UCSM analysis. A single input file can be used for either statistical model.

When first loading the "R GUI" MS Excel workbook, the first GUI appears, as shown in Figure 7-8. This GUI allows the analyst to select the working directory and the Rscript.exe program. By default, the working directory is the location of the "R GUI" workbook. The working directory is used to determine the location of the output data from the statistical analysis. The Rscript.exe program is a version of the R statistical program which allows the statistical analyses to be executed from the command line through MS Excel, without directly opening the R program. When this GUI is first initialized, a process in the background verifies if the required R libraries for the UCPM and UCSM analyses have been installed on the analyst's computer. If these files are not on the analyst's computer, then the files can be downloaded with a click of the "Install R Packages" command button, as shown in Figure 7-8.

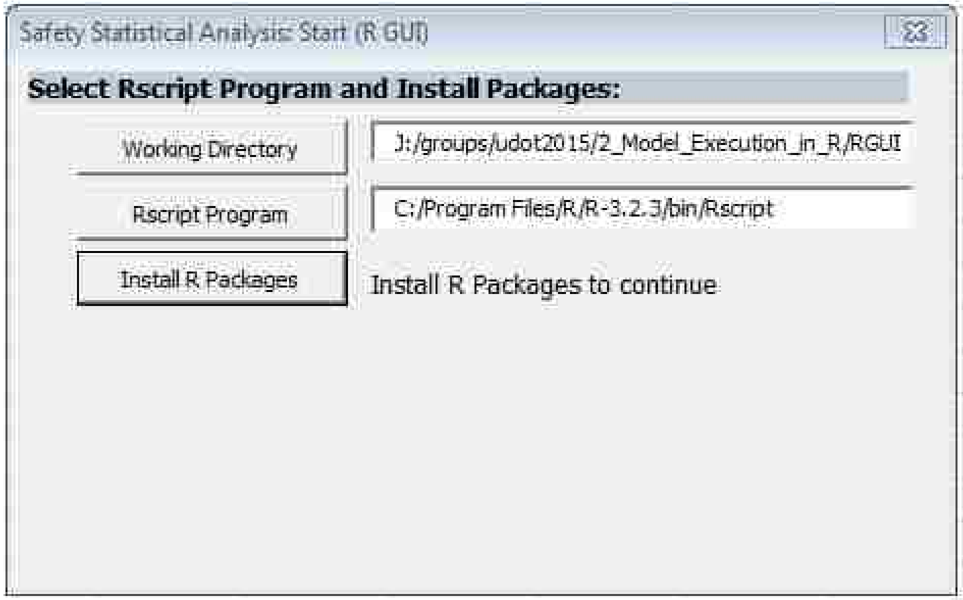


Figure 7-8: GUI for beginning the R statistical process, with the prompt to update the R library files.

When the R libraries have been updated, the analyst is allowed to select the statistical model to proceed with the analysis. The "R GUI" workbook is programmed to initiate the analysis for the statistical models, as shown in Figure 7-9. Once the statistical model has been selected from the list, the command buttons to "Create Input File" and "Use Existing Input File" becomes visible on the GUI. The option to "Use Existing Input File" bypasses the process of creating the input file, as it uses an input file previously created. The following steps illustrate the GUI interface after selection the option to "Create Input File" for the UCPM and UCSM.

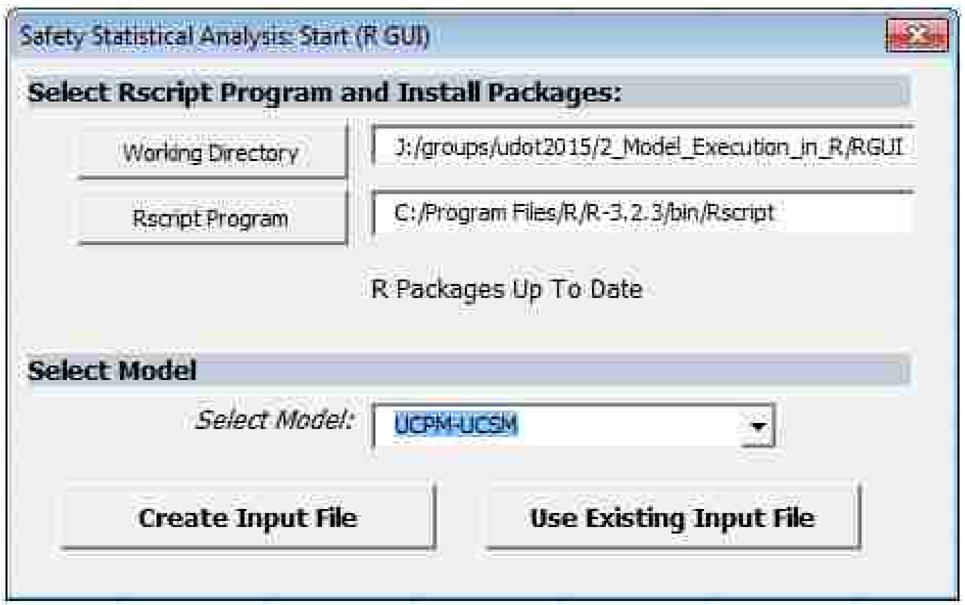


Figure 7-9: Model selection in the "R GUI" MS Excel workbook.

Once the command button to "Create Input File" option has been clicked, another GUI window appears, as shown in Figure 7-10. This GUI allows the analyst to input the roadway segment file, the crash data file, and the crash severities for the statistical analysis. As an optional command, the analyst may also select to summarize the crash factors from the crash rollup data file. If selected, the automated tools provides a summary of the crash factors from the rollup data, counting the frequency of given crash factors along the segment matched to the selected severities. Summarizing the crash factors provides additional variables for the variable selection process, but slightly increases the required processing time for merging the roadway and crash data. Once the input files and crash severities have been selected, the GUI appears similar to what is shown in Figure 7-11. Clicking the "Create Input Data for Statistical Analysis" command button begins the process of merging the roadway and crash data to an input file for the statistical analysis.

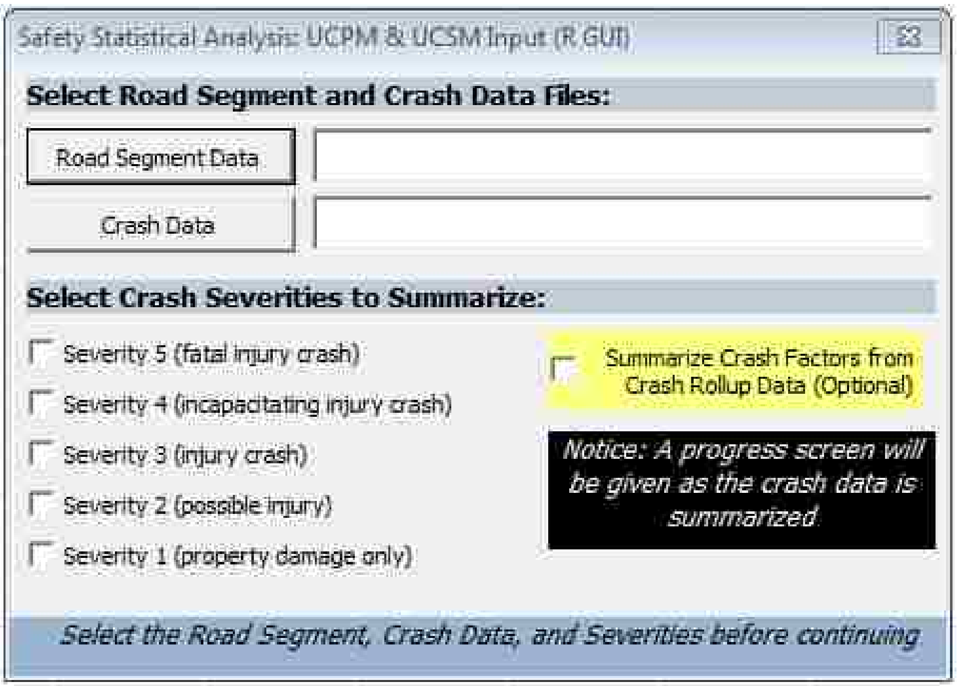


Figure 7-10: Input file creator GUI for the statistical analysis.

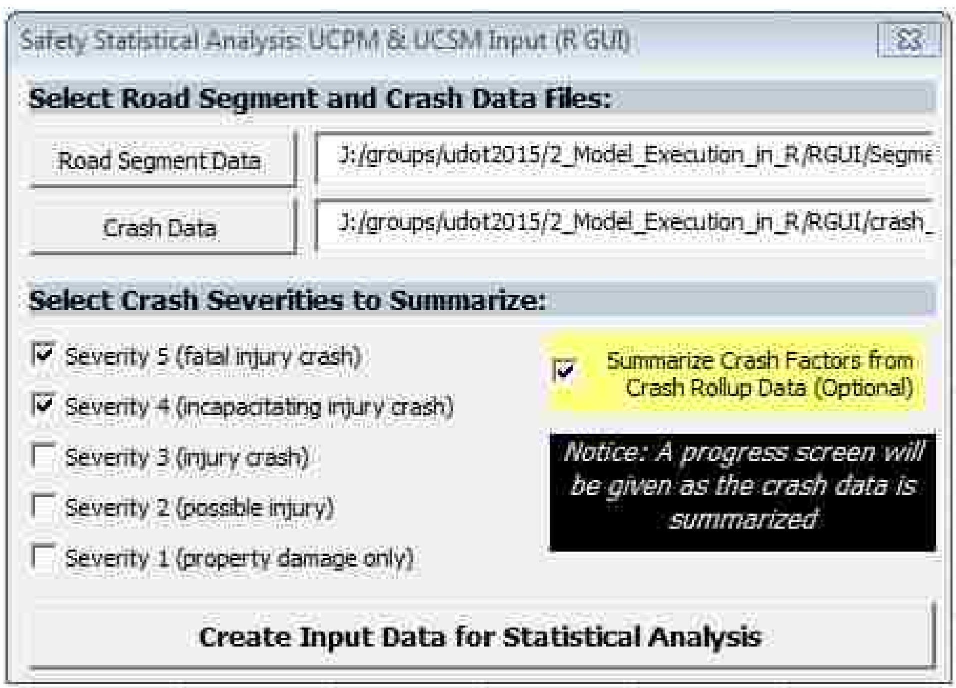


Figure 7-11: Files selected for the input file creator GUI for the statistical analysis.

Once the "Create Input Data for Statistical Analysis" command button is clicked, the GUI closes and the automated tools for creating the input file for the statistical analysis begins. The data columns are checked for the critical data columns, to verify data uniformity before creating the input data file. As the roadway and crash data are being combined into the input file, a progress screen periodically updates, as shown in Figure 7-12. The number of segments in the data file is dynamically updated for each dataset to provided reference for the analyst on the progress of creating the input file. It is common for the workbook screen to look frozen or locked up for one of two reasons: the large size of the crash data freezes up MS Excel momentarily; and the screen updating feature is suspended to increase the working speed of the automation tools. When the process of creating the input file is completed, the next GUI window appears for the variable selection process, as shown in Figure 7-13. The GUI shown in Figure 7-13 is blank to prompt the analyst to fill in the information before proceeding.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), the process of creating the input file for the statistical analysis required the use of ArcGIS tools and exporting the data to CSV format for the statistical analysis. As a result of this research, the process of summarizing the roadway and crash data can be done using a single MS Excel workbook, which can create the input dataset within 3 to 6 minutes of uninterrupted CPU power.

Progress Screen	
Roadway Segment	520 of 5914 segments...
Crash Row	4.03%
Start Time	10:08:56 AM
Update Time	10:09:39 AM
End Time	

Figure 7-12: Progress screen for creating the input file for the statistical.

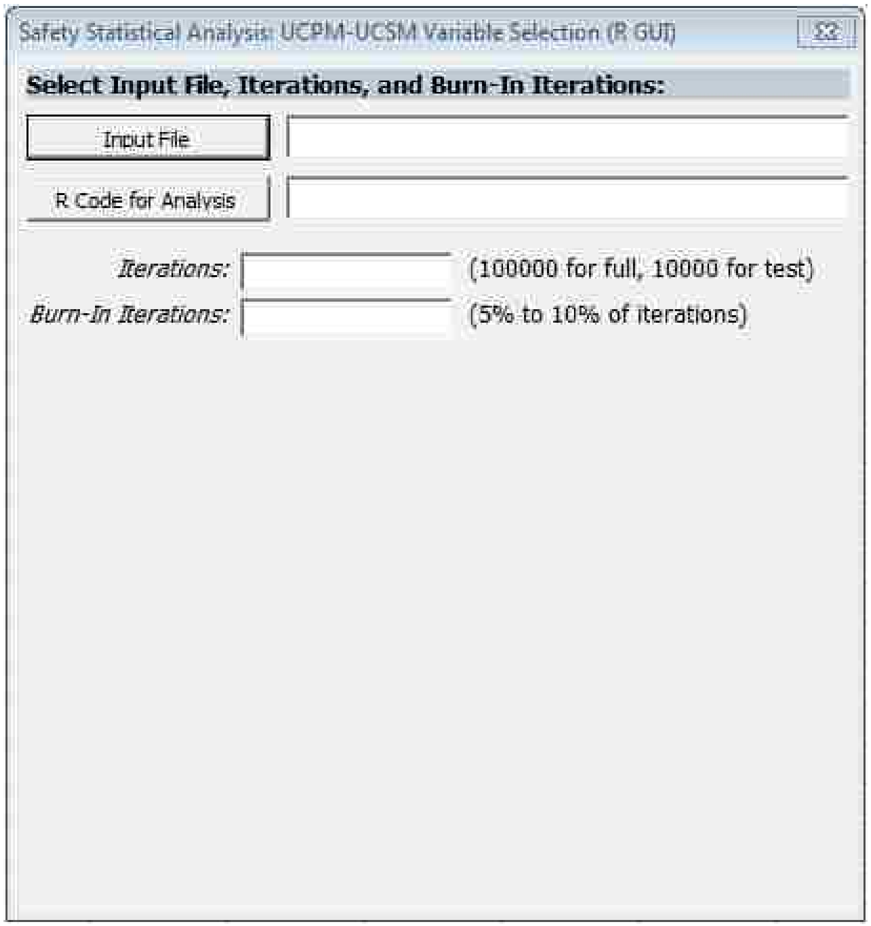


Figure 7-13: Input File, R Code, and Iteration selection GUI.

7.2.2 Variable Selection Process, Model Execution

Once the input file for the statistical analysis has been created, the significant variables are selected for the statistical analysis using the GUI shown in Figure 7-13. With the input file for the statistical analysis, R code for the statistical analysis, number of iterations, and number of burn-in iterations identified by the analyst, the significant variables can be selected using the horseshoe selection method or a manual selection method. The horseshoe selection method is preferred for the dynamic nature of the input data for the statistical analysis. However, the manual selection method can be used for trial and error analyses.

If the “Horseshoe Selection Method” option is selected, the GUI updates to look similar to the one shown in Figure 7-14. The statistical analysis begins when the analyst clicks the “Start Analysis with Horseshoe Method” command button, which prompts the statistical analysis script to run the horseshoe selection method, which will identify the most statistically significant variables for the analysis. The variables identified by the horseshoe selection method will be recorded in the output files of the statistical analysis.

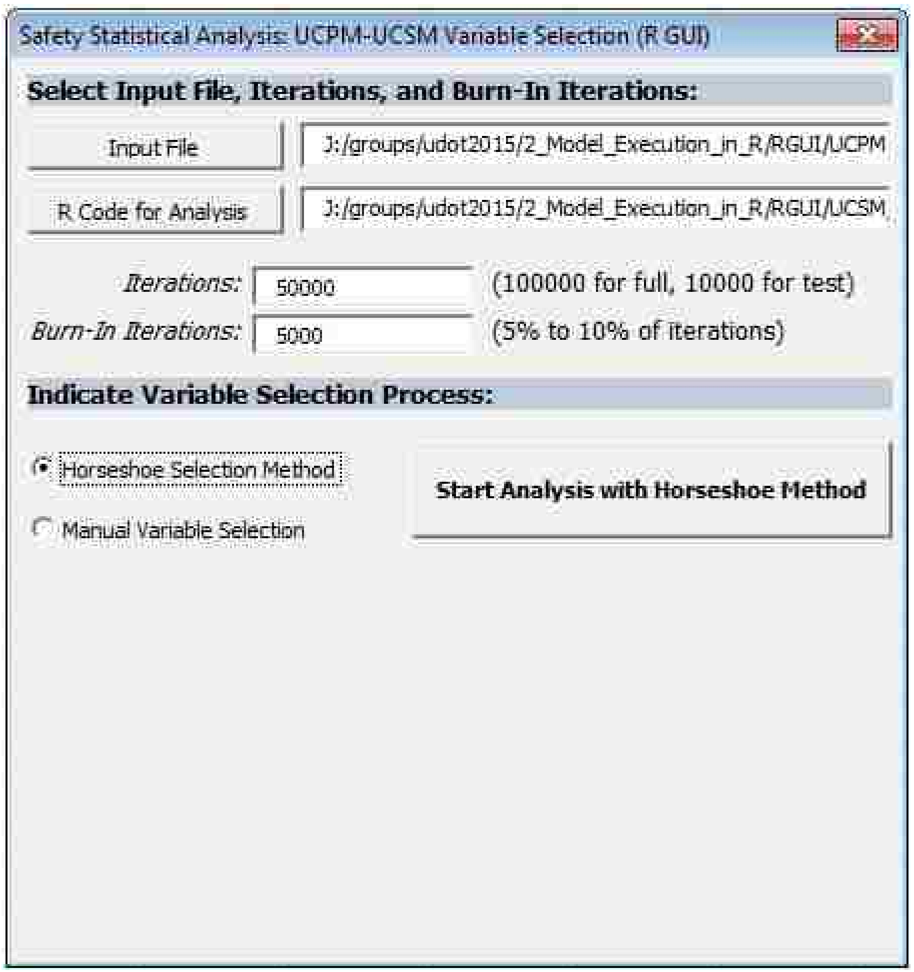


Figure 7-14: Horseshoe selection method GUI.

If the "Manual Variable Selection" option is selected, the GUI updates to look similar to the one shown in Figure 7-15. This non-statistically based method for selecting variables is programmed to load statistically significant variables that must be included in each analysis: speed limit, number of lanes, total percent trucks, and VMT. These variables were identified to be statistically significant in previous research (Schultz et al. 2013a, Schultz et al. 2015). The automated tools tied to this GUI are also programmed to remove insignificant variables from being included in the analysis, such as route number, route direction, MPs, and number (count) of trucks. Once the GUI has loaded the possible variables and significant variables, the analyst can select variables to include in the statistical analysis. The GUI allows the analyst to prepare different combinations of variables to include in the statistical analysis, with the functionality to clear the selection if desired. Once the significant variables have been manually selected, the statistical analysis is initiated by clicking the "Start Statistical Analysis" command button. Once the statistical analysis has begun, the Rscript.exe window appears on the screen, similar to the one shown in Figure 7-16. The Rscript.exe window provides periodic updates of the process of the statistical analysis.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), the horseshoe selection method was programmed into the R code of the UCPM and UCSM, but changes to the number of iterations, burn-in iterations, input file location, working directory, or the model itself required manual modification of the R code. This process was limited in its capability to adapt to new parameters. As a result of this research, the variable selection method has been expanded to include a GUI for selecting model variables manually or with the horseshoe selection methodology. The automation tools and GUI allow for the statistical models to be executed with increased flexibility to new input datasets. Changes to the number of iterations, burn-in iterations, input file location, and working directory can be done through the GUI, which eliminates the need to modify the R code. The runtime of the UCPM and UCSM depends on the number of iterations, number of roadway segments, the number of model parameters included in the analysis, and the CPU power of the machine executing the statistical analysis.

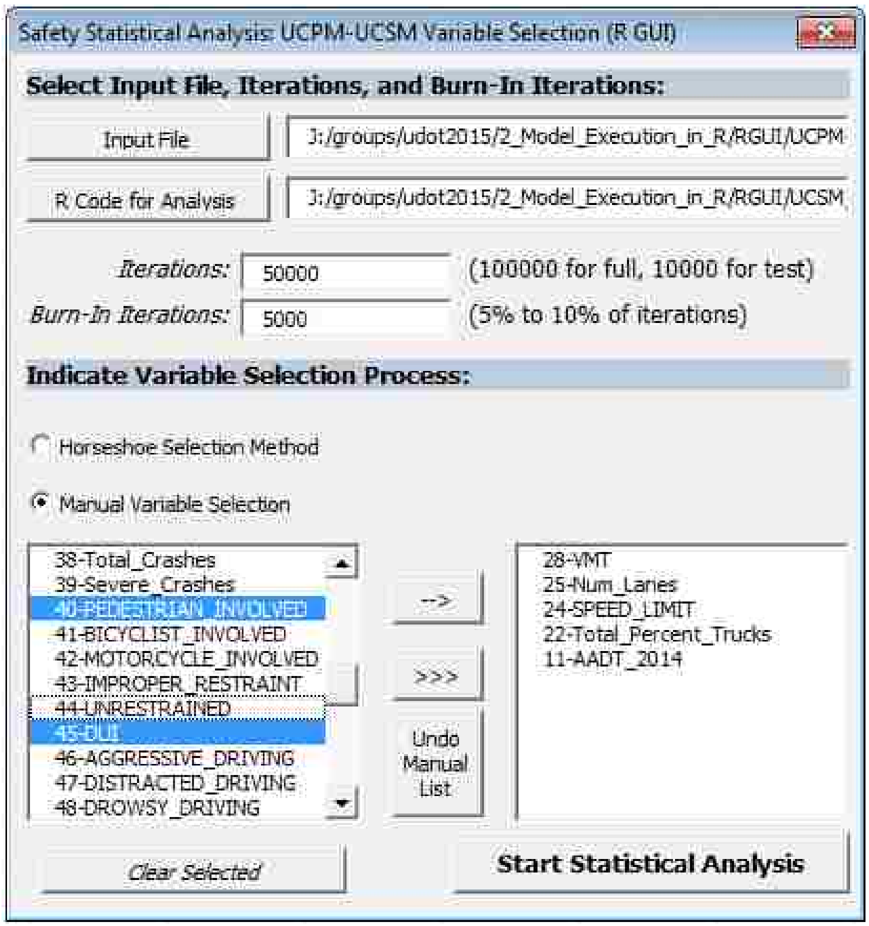


Figure 7-15: Manual variable selection method GUI.

Figure 7-16: Rscript.exe window with statistical analysis being executed.

7.2.3 Interpreting Output, Spatial Display of Statistical Analysis

Once the statistical analysis has completed running, an output CSV file is generated. The CSV file contains the statewide, UDOT Region, and county hierarchical rank for each of the segments included in the statistical analysis. These rankings can be spatially drawn on a statewide, UDOT Region, and county level using GIS software, such as ArcMap. Using ArcMap, the output of the statistical analysis can be spatially displayed using the "Plot Statistical Model Results" custom model tool, as shown in Figure 7-17, a modification of the "Make Route Event Layer" tool.

Once the routes have been created from the "Plot Statistical Model Results" tool, the symbology of the shapefile can be changed to reflect the categorical ranking outlined previously in Table 5-2. The selected symbology allows for the most problematic segments to be distinguished from the least problematic segments throughout the roadway network.

Once the routes have been created and the desired symbology applied, the "Map Creator" Python Script tool is available for creating a statewide map, UDOT Region maps, or county maps. The GUI for activating this Python Script is shown in Figure 7-18. The GUI allows the analyst to display the results of the statistical analysis on a statewide map, a series of UDOT Region maps, or a series of county maps. The output of selecting the option to create a statewide map is a single PDF file that includes a map of the state of Utah and the output of the statistical analysis. The output of selecting the option to create a series of UDOT Region maps is a single PDF file that includes multiple maps, one map for each UDOT Region, highlighting the output of the statistical analysis for each UDOT Region. The output of selecting the option to create a series of county maps is a single PDF file that includes multiple maps, one for each county in Utah, highlighting the output of the statistical analysis of each UDOT Region. An example of the statewide map, UDOT Region 3 map, and Salt Lake County map is given in Figure 7-19, Figure 7-20, and Figure 7-21, respectively.

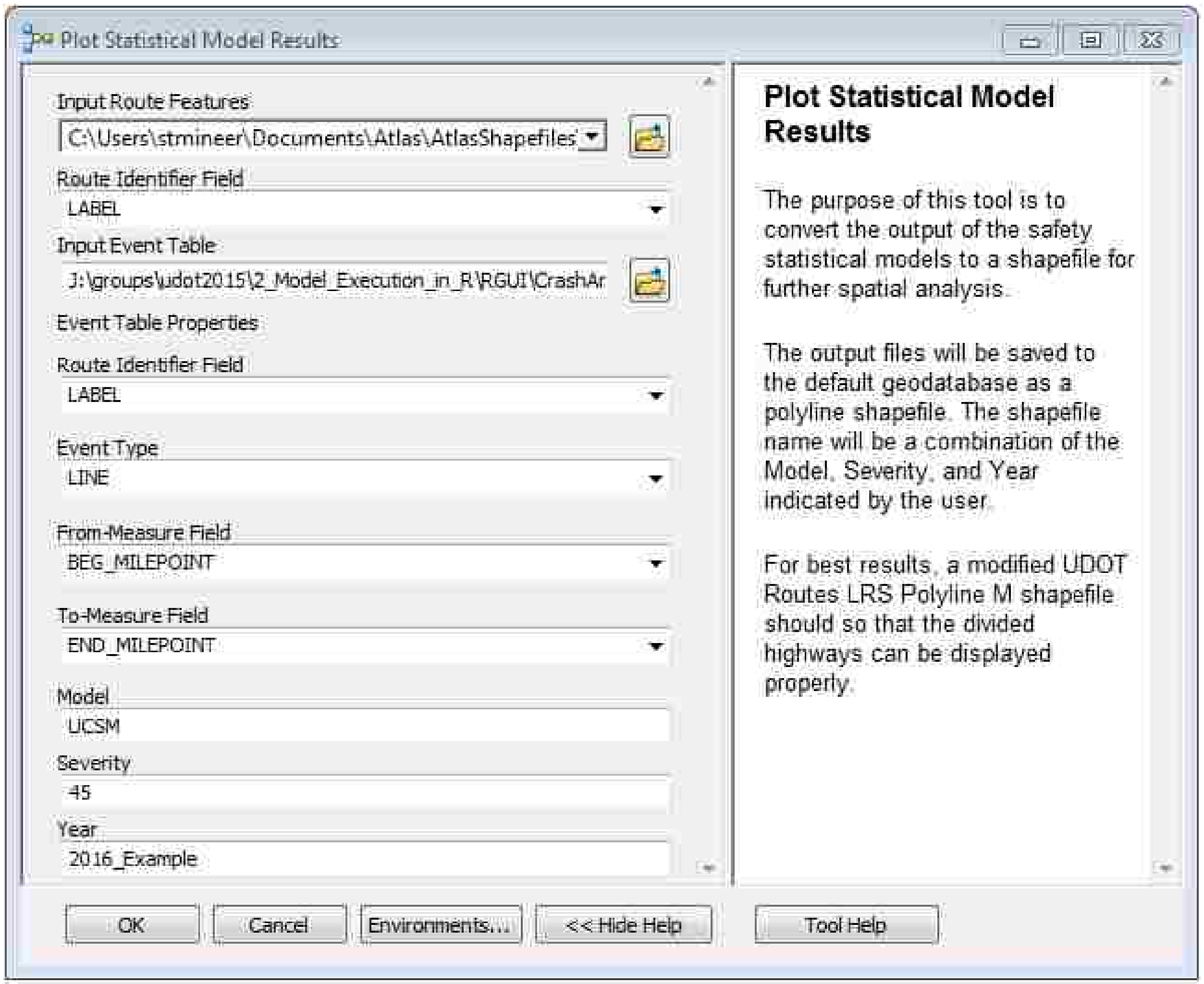


Figure 7-17: "Plot Statistical Model Results" ArcMap tool for plotting the results of the statistical analysis.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), the interpretation of the statistical analysis was limited to ranking on the statewide level. The interpretation and ranking of the output file was done outside of the R code, which created chances for discontinuity in the interpretation of the results. The county maps creation tool was available but limited in functionality, requiring direct editing of the Python code in order to run the script without a GUI interface. As a result of this research, the interpretation of the statistical analysis has been structured and expanded to include state, UDOT Region, and county ranking, which provides better context for the UDOT Safety Programs Engineer, UDOT Region directors, and other interested users to better understand the most important roadways within their jurisdiction. The tools in ArcMap have been expanded to provide a user friendly interface for creating a statewide map, UDOT Region maps, and county maps with improved flexibility customizing the text on the map.

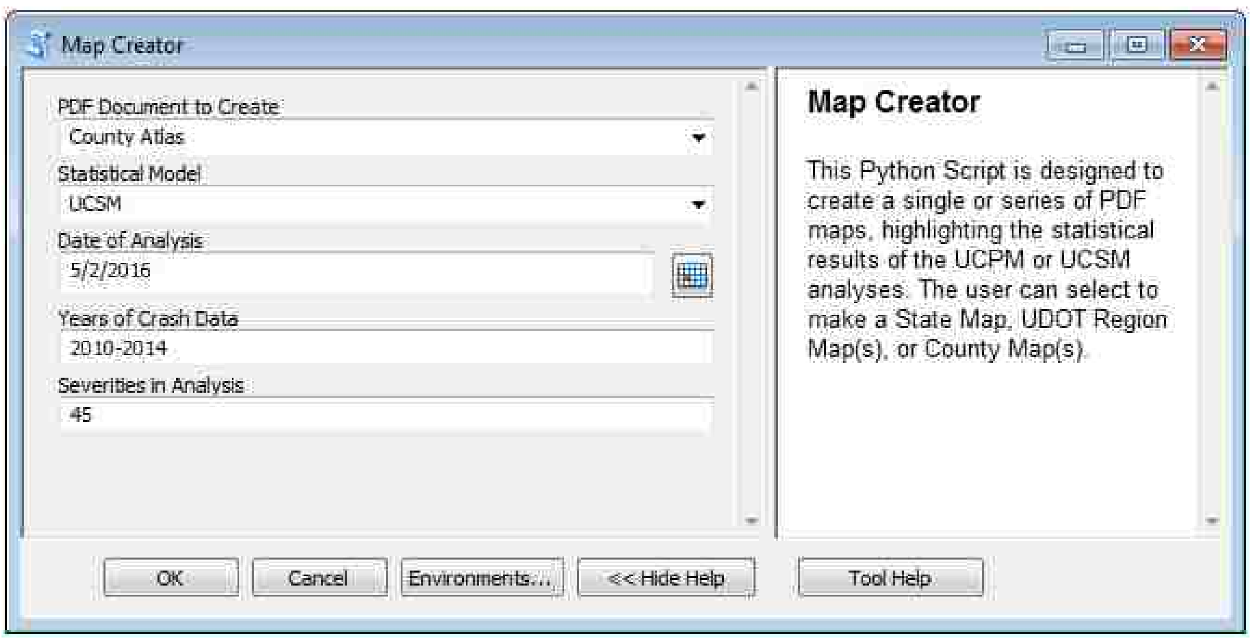


Figure 7-18: "Map Creator" ArcMap tool interface for creating maps displaying results from statistical analysis.

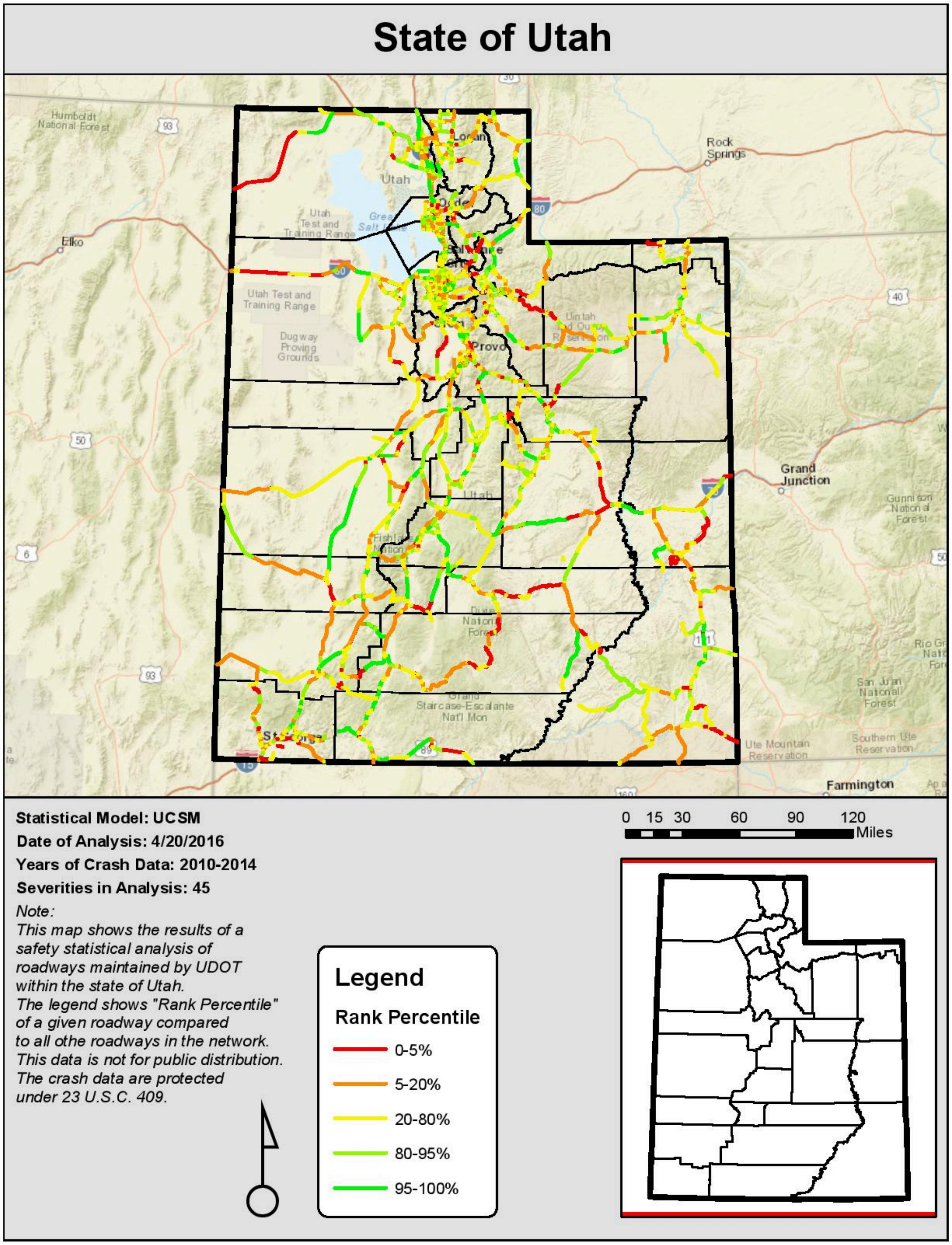


Figure 7-19: Example of statewide map displaying results of statistical analysis.

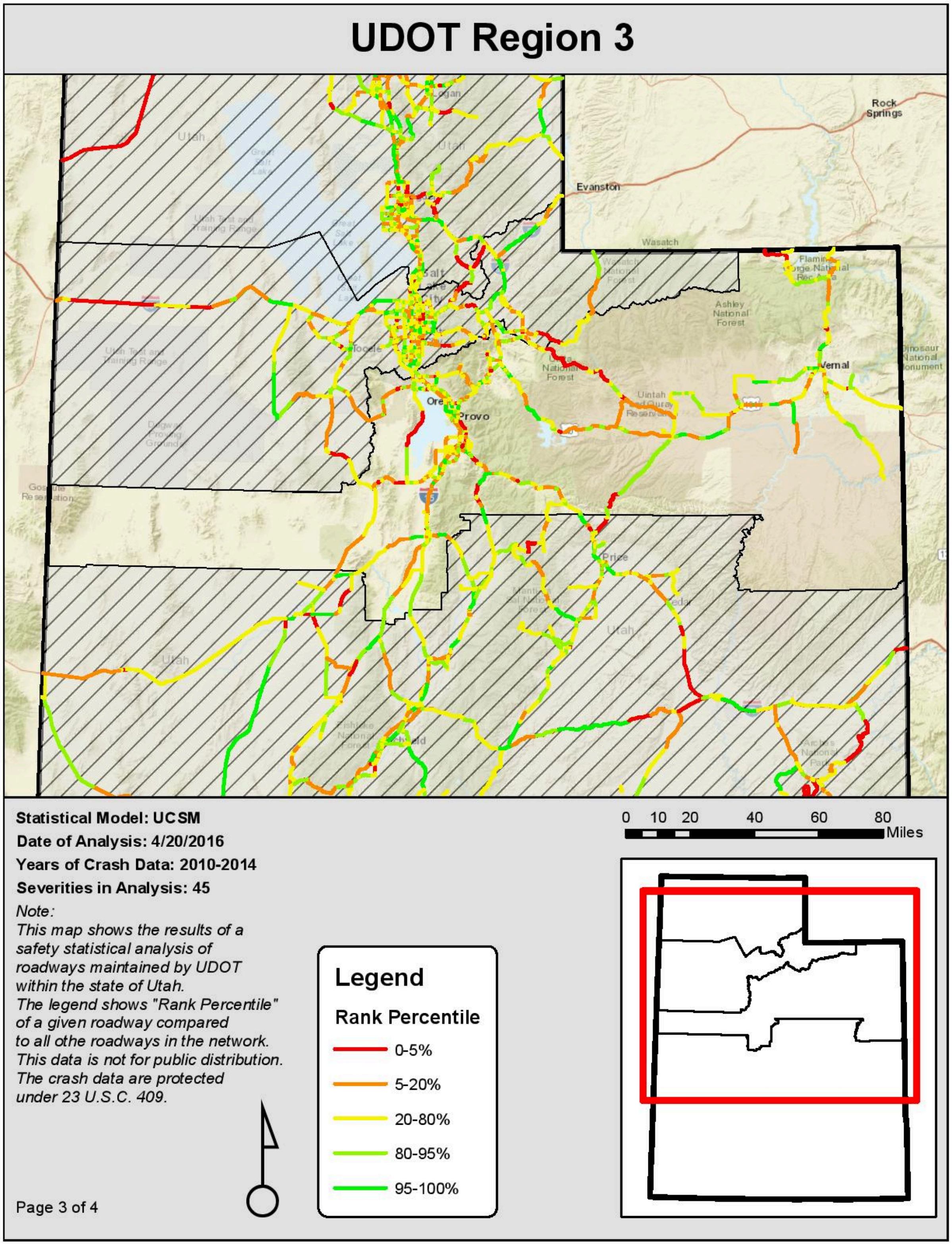


Figure 7-20: Example of Region 3 map displaying the results of the statistical analysis.

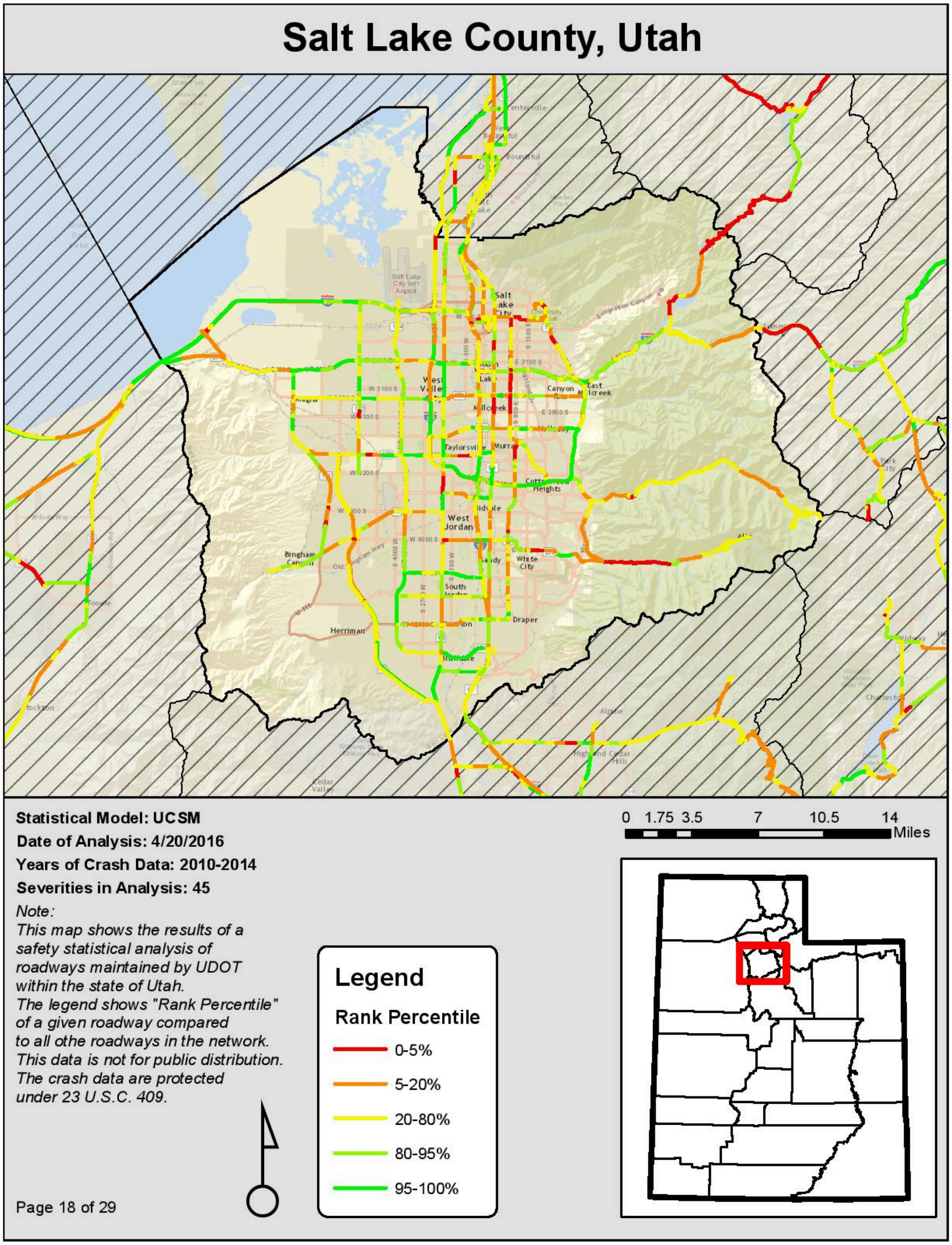


Figure 7-21: Example of Salt Lake County map displaying results of statistical analysis.

7.2.4 Selection of Segments of Interest

After reviewing the results of the statistical analysis, segments of interest can be selected for the report compilation process. Of all the state roadway segments, the most problematic segments are those hierarchically ranked highest in the state, respective UDOT Region, or respective county. For the Roadway Safety Analysis report compilation process, the analyst can select a number of segments within their jurisdiction, such as the top 50 in the state, top 30 in the UDOT Region, or a specific corridor with planned maintenance or rehabilitation. This process is done manually in ArcMap, so that the analyst can pick the specific segments for the report compilation process, as explained in Section 7.3. This process is similar to what was done in previous research (Schultz et al. 2013a, Schultz et al. 2015).

7.3 Report Compilation for Segments of Interest

The third and final step in the Roadway Safety Analysis methodology is to compile the Roadway Safety Analysis reports for the selected segments of interest. The following subsections include an example of: combining and summarizing roadway and crash data of the selected segments of interest; compiling the Roadway Safety Analysis reports for each of the segments of interest by tabulating the roadway characteristics, crash data, possible countermeasures, historical conditions, and current conditions; abridging the full Roadway Safety Analysis reports to a two-page summary; and publishing the two-page summary reports through the UDOT Safety Programs Engineer to the UDOT Region directors and other interested users. These tasks are accomplished with the use of automation tools, GUIs, and the instructions given in the respective user manuals (Brown et al. 2016, Mineer et al. 2016).

7.3.1 Combine and Summarizing Segment Data with Roadway and Crash Data

The roadway characteristics and the crash data must be identified for the selected segments of interest. This can be accomplished using spatial analysis tools, such as ArcGIS and ArcMap. As discussed previously in Section 6.1, seven roadway datasets can be used as-is from the UDOT Open Data website, while the IPM and SPM information is derived from the intersection and sign face data, respectively. The count of intersection and sign face data along the selected segments of interest can be tabulated with the use of the “Generate IPM SPM” custom model tool, as shown in Figure 7-22. The horizontal curve data are derived by processing the LiDAR curve data using the HAF Algorithm, which is based on tools and GUIs developed in MS Excel and ArcMap outside the scope of this thesis. The crash data with the selected crash severity can be spatially displayed from the CSV of the crash data using “Plot Crash Severity” custom model tool, as shown in Figure 7-23. This tool allows the analyst to select the crash severity range used in the statistical analysis, so that the same crash severity range can summarized in the Roadway Safety Analysis reports.

Once the 10 roadway characteristic datasets and crash data have been loaded to the map, they are spatially joined with the segments of interest using the “Spatial Join To Excel” Python Script tool, as shown in Figure 7-24. This tool merges the datasets together and exports the 11 files to a single folder for the report compilation process.

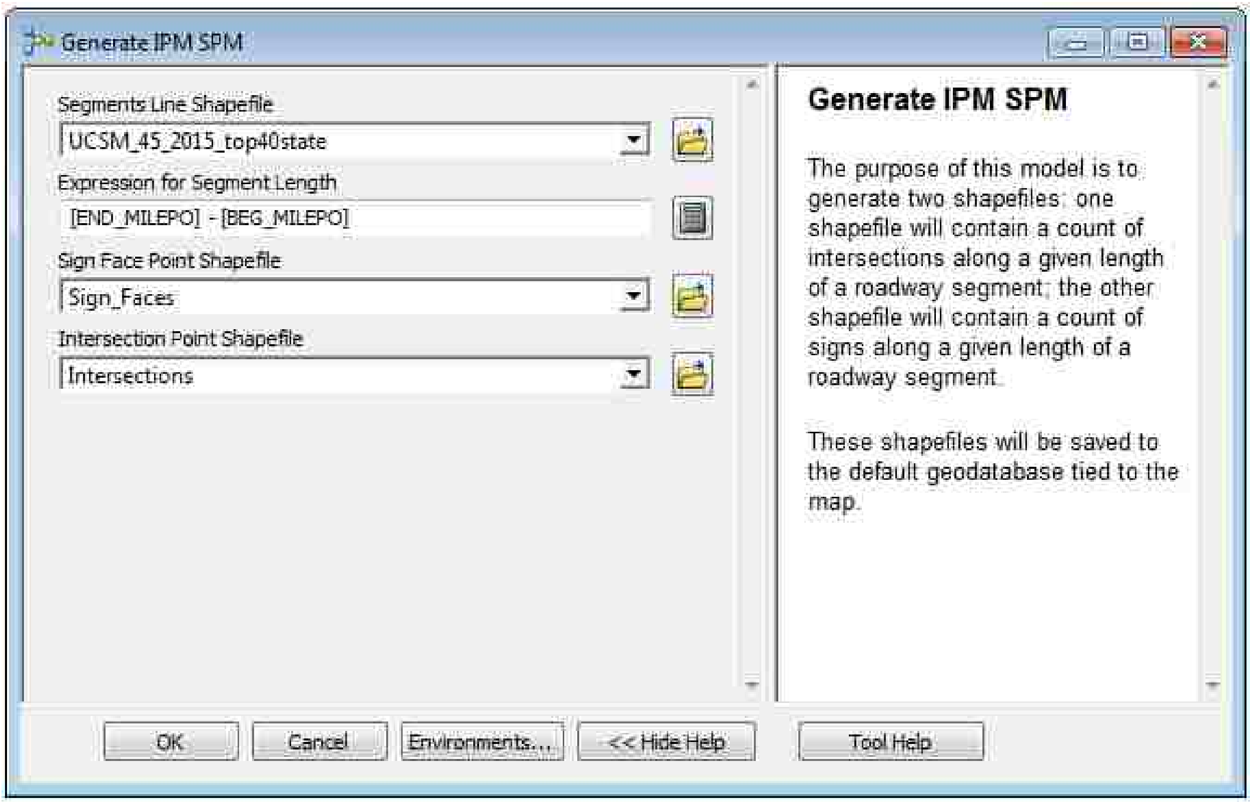


Figure 7-22: "Generate IPM SPM" ArcMap tool to analyze the intersection and sign face frequency along the selected segments of interest.

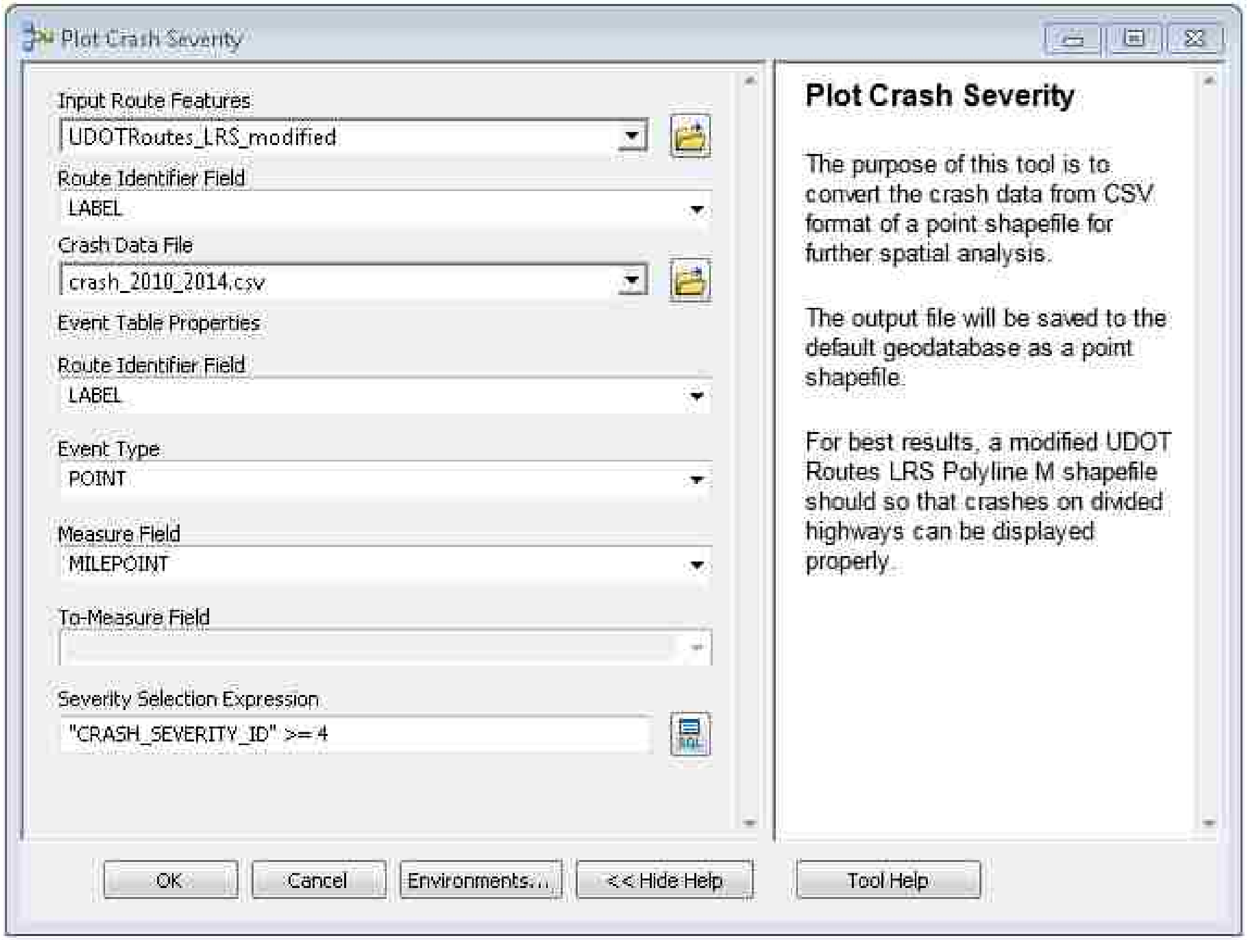


Figure 7-23: "Plot Crash Severity" ArcMap tool to plot the selected crash data based on severity.

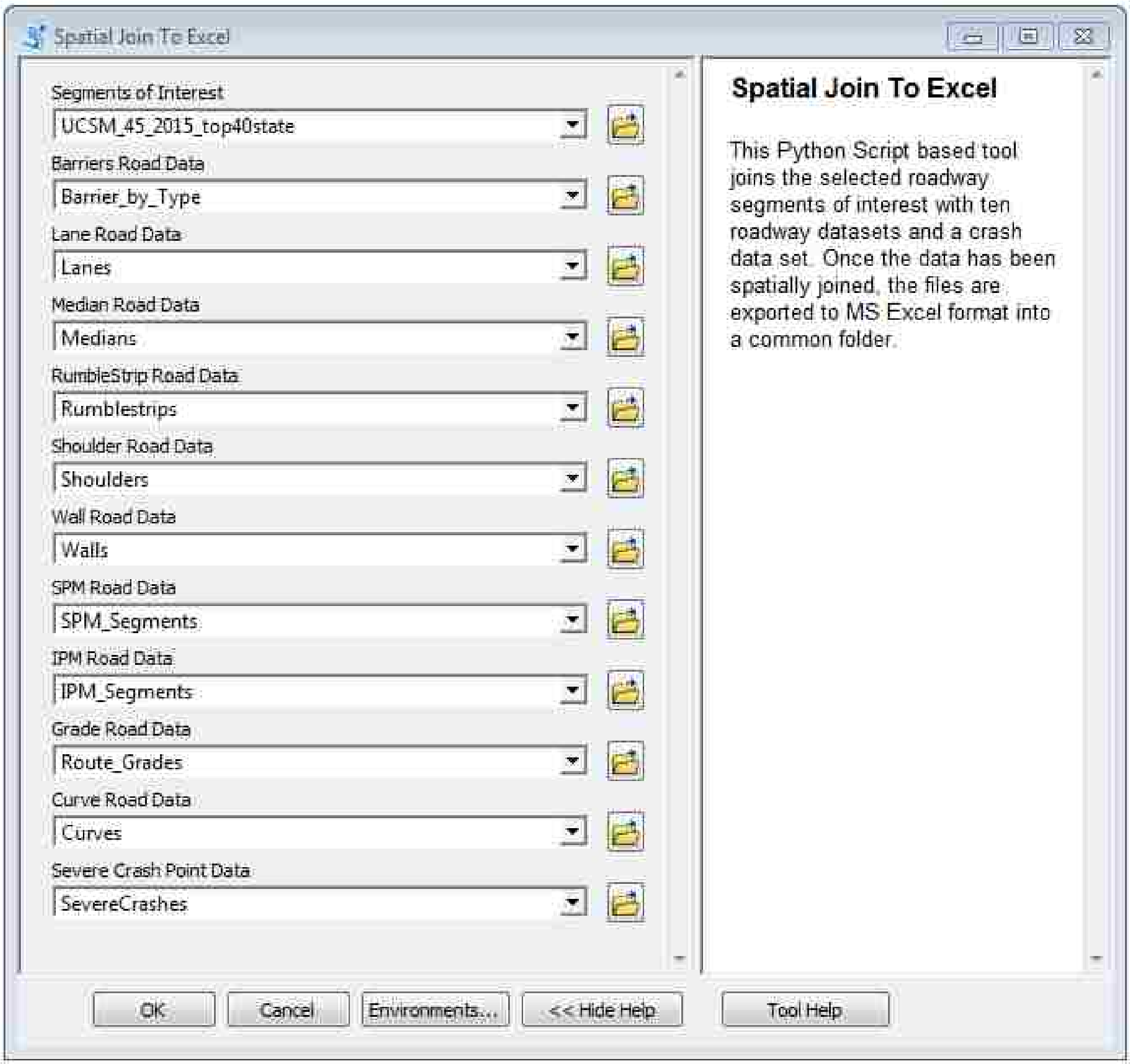


Figure 7-24: "Spatial Join to Excel" ArcMap tool to spatially join roadway characteristics and crash data with selected roadway segments.

After the ArcMap tool is finished running, the 11 data files are then combined together to create the "Combo" data and the "CrashFactors" worksheets. The MS Excel workbook "Combine Feature Data" includes the automation tools and GUI designed specifically to combine these 11 files together to create the Roadway Safety Analysis reports. An illustration of the GUI to access these automated tools in the “Combine Feature Data” workbook is shown in Figure 7-25.

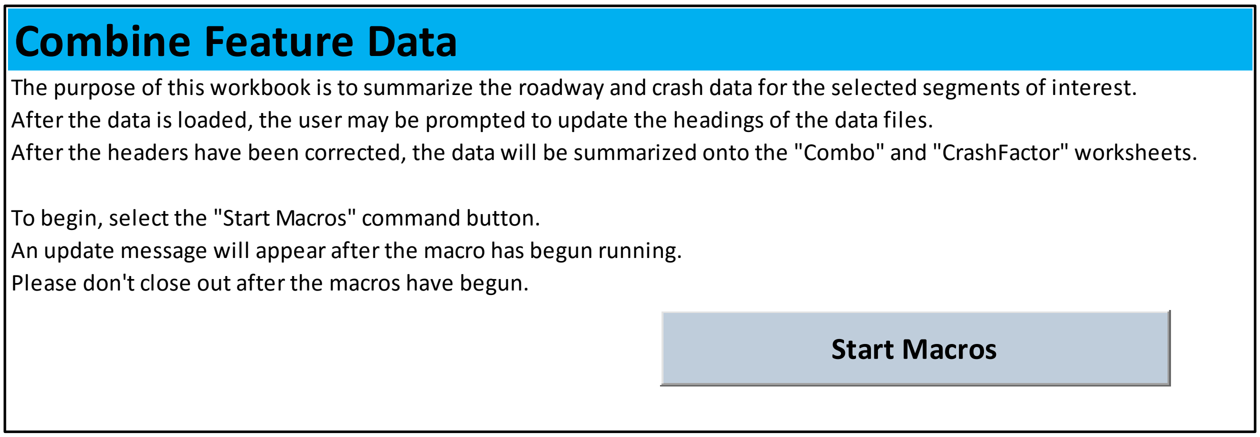


Figure 7-25: GUI for combining the roadway characteristics and crash data for the Roadway Safety Analysis reports.

When the “Combine Feature Data” workbook is opened, a series of VBA macros are initialized to begin the process of combining and summarizing the 10 roadway and crash datasets. The GUI prompts the analyst to select the folder containing the 11 datasets. The automated tools are programmed to cycle through each file in the folder and load the data into the “Combine Feature Data” workbook. If there are mismatch in the expected critical data columns to what is actually given in the data, the “Check Headers” tool prompts the analyst through a GUI to select the input data field which matches the expected critical data column field, similar to the GUI shown previously in Figure 7-2. After the column fields are corrected, the automated tools resumes and continues work to combine and summarize the data from the different datasets into a summary “Combo” worksheet for the roadway features and a “CrashFactors” worksheet for the crash data.

Once the series of VBA macros have completed running, the 11 datasets are combined together into the “Combo” and “CrashFactors” worksheets. The “Combo” worksheet contains the roadway characteristics and other roadway metadata that have been summarized to create the Roadway Safety Analysis reports. The “CrashFactors” worksheet contains the crash data and other crash factors visually separated and summarized for each of the roadway segments, which is used to create the Roadway Safety Analysis reports. An example of the appearance of the “Combo” worksheet is shown in Figure 7-26. An example of the appearance of the “CrashFactors” worksheet is shown in Figure 7-27.

In previous research conducted for UDOT (Schultz et al. 2015), the process of combining and summarizing the segments of interest with the roadway and crash data was done using MS Excel workbooks, a series of ArcMap tools, and manually reviewing the data. As a result of this research, the process of combining and summarizing the segment data with the roadway and crash data was consolidated to four ArcMap tools and a single MS Excel workbook, created to combine the functionality of multiple tools into a single tool interface and to prepare the “Combo” and “CrashFactors” worksheets used in the process to auto-populate the reports.

7.3.2 Compilation of Roadway Safety Analysis Reports

After the “Combo” and “CrashFactors” worksheets have been created, the Roadway Safety Analysis reports can be created and auto-populated with roadway characteristics, crash data, and possible countermeasures for each of the segments of interest. The MS Excel workbook “Report Compiler” includes the automation tools and GUI designed specifically for this process. An illustration of the GUI for this workbook is shown in Figure 7-28.

Segment of Interest	LABEL	BEG_MILEPOINT	END_MILEPOINT	Type (Median)	Mean Width [ft] (Median)	Island Type	Intersection Count	IPM	Sign Count	SPM	Common Material (Shoulder)	Common Edge Type (Shoulder)	Mean Width [ft] (Shoulder)	Max Grade	# Vertical Grade Changes	Greatest Vertical Change	Curve Class	Curve Degree	Curve Radius [ft]	Curve Length [ft]	Left Turn Lane
1	0203P	1.479	2.29	No Median	0.0	No Island	13	7.0	75	40.4	None	Curb/Gutter	3.1	4.0	13	1.0					2
2	0209P	7.36	7.859	No Median	4.7	Median Island	14	8.5	346	210.1	None	Curb/Gutter	1.3	2.0	3	0.0					4
3	0015P	82.253	94.453	Depressed Median	118.3	No Island	9	0.3	257	10.0	Asphalt	UBC	9.3	1.0	12	1.0					0
4	0068P	48.314	49.312	No Median	8.5	No Island	53	11.6	343	75.1	None	Curb/Gutter	0.0	1.0	3	1.0					4
5	0068P	11.648	23.709	Undivided	0.0	No Island	36	1.6	144	6.5	Asphalt	UBC	3.7	4.0	123	0.0					0
6	0171P	8.1	9.221	No Median	0.0	No Island	10	5.7	79	45.0	None	Curb/Gutter	0.0	1.0	13	0.0					2
7	0039P	8.923	13.285	Undivided	2.6	No Island	11	2.2	155	30.3	None	UBC	0.0	6.0	55	1.0	E	16.05	2022.7	464.1	1
8	0080P	3.993	30.982	Depressed Median	274.5	No Island	0	0.0	175	4.5	Asphalt	UBC	12.4	0.0	1	0.0					0
9	0071P	14.593	15.522	No Median	1.4	No Island	13	13.7	36	37.8	Asphalt	Curb/Gutter	11.5	4.0	10	4.0					2
10	0204P	1.311	2.084	Undivided	1.8	No Island	24	11.6	98	47.4	None	Curb/Gutter	5.3	4.0	6	4.0					2
11	0071P	10.719	11.71	No Median	0.0	No Island	25	12.6	118	59.4	Asphalt	Curb/Gutter	5.3	2.0	15	0.0					2
12	0068P	49.312	50.311	No Median	2.8	No Island	25	11.7	199	92.8	None	Curb/Gutter	0.0	4.0	16	0.0					4
13	0009P	4.249	7.308	No Median	3.1	No Island	18	3.6	91	18.0	Asphalt	UBC	8.1	5.0	29	0.0	A	1.96	2918.6	1122.9	2
14	0091P	29.017	29.819	No Median	0.0	No Island	20	6.4	152	48.4	Asphalt	Curb/Gutter	5.6	1.0	8	0.0					2
15	0080P	30.982	41.278	Depressed Median	299.2	No Island	0	0.0	142	3.2	Asphalt	UBC	8.0	2.0	3	1.0					0
16	0070P	164.547	175.585	Depressed Median	176.7	No Island	10	0.4	225	9.8	Asphalt	UBC	9.9	4.0	29	1.0					0
17	0204P	4.139	4.6	Undivided	1.4	No Island	13	13.9	41	43.9	None	UBC	7.3	1.0	7	1.0					2
18	0070P	138.697	146.478	Other Divided	79.1	No Island	0	0.0	283	11.1	Asphalt	UBC	10.0	6.0	27	1.0					0
19	0014P	12.224	17.454	Undivided	0.0	No Island	4	0.4	146	14.1	None	UBC	17.0	8.0	61	1.0	E	23.19	1915.7	941.7	0
20	0089P	373.589	374.296			Median Island	19	11.8	74	45.9	Asphalt	Curb/Gutter	8.6	0.0	2	0.0					2
21	0089P	372.721	373.589	Painted Median	4.7	Median Island	30	12.9	184	79.1	Asphalt	Curb/Gutter	3.3	2.0	12	0.0					2
22	0089P	415.425	416.006	Undivided	2.4	No Island	23	16.9	130	95.7	Asphalt	Curb/Gutter	4.9	1.0	3	0.0					2
23	0080P	139.45	141.815	Depressed Median	64.9	No Island	0	0.0	86	22.6	Asphalt	UBC	9.9	6.0	11	1.0					0
24	0070P	131.509	138.697	Depressed Median	127.3	No Island	0	0.0	249	8.3	Asphalt	UBC	8.6	6.0	27	1.0					0
25	0173P	8.514	8.775	No Median	4.7	No Island	3	4.1	34	46.0	Asphalt	None	4.0	2.0	3	1.0					2

Figure 7-26: Example of roadway data summarized in "Combo" worksheet for the selected roadway segments.

OBJECTID	CRASH_ID	CRASH_DATETIME	LABEL	First_Veh_Direction	MILEPOINT	CRASH_SEVERITY_ID	LIGHT_CONDITION_ID	WEATHER_CONDITION_ID	MANNER_COLLISION_ID	ROADWAY_SURF_CONDITION_ID	ROADWAY_JUNCT_FEATURE_ID	WORK_ZONE_RELATED_YNU	WORK_ZONE_WORKER_PRESENT_YNU	HORIZONTAL_ALIGNMENT_ID	VERTICAL_ALIGNMENT_ID	ROADWAY_CONTRIB_CIRCUM_ID	FIRST_HARMFUL_EVENT_ID	NUMBER_VEHICLES_INVOLVED	NUMBER_FATALITIES	NUMBER_FOUR_INJURIES	NUMBER_THREE_INJURIES	NUMBER_TWO_INJURIES	NUMBER_ONE_INJURIES	PEDESTRIAN_INVOLVED	BICYCLIST_INVOLVED	MOTORCYCLE_INVOLVED	IMPROPER_RESTRAINT	UNRESTRAINED	DUI	AGGRESSIVE_DRIVING	DISTRACTED_DRIVING	DROWSY_DRIVING	SPEED_RELATED
289	10388655	Dec 13, 2010 3:54:00 PM	0203P	1	1.85	5	1	1	1	1	4	N	N	1	1	0	20	2	1	0	1	2	0	N	N	N	N	N	N	N	N	N	N
147	10432455	Jan 24, 2011 6:54:00 AM	0203P	2	1.99	4	2	1	3	1	0	N	N	2	3	0	20	2	0	1	1	0	0	N	N	N	N	N	N	N	N	N	N
275	10433815	Feb 11, 2011 7:31:00 PM	0203P	2	1.61	4	2	1	2	1	0	N	N	1	1	0	20	3	0	1	3	0	2	N	N	N	N	Y	N	N	N	N	Y
61	10438522	May 26, 2011 11:10:00 PM	0203P	1	1.63	4	2	1	1	1	0	N	N	1	1	0	20	2	0	1	0	0	1	N	N	N	N	N	N	N	N	N	N
318	10439452	Jun 14, 2011 9:25:00 PM	0203P	2	2.29	4	2	1	1	1	20	N	N	1	1	0	20	2	0	2	0	0	0	N	N	N	Y	N	N	N	N	N	N
322	10447460	Sep 7, 2011 2:20:00 PM	0203P	2	2.29	4	1	1	1	1	20	N	N	1	1	0	20	2	0	1	0	0	1	N	N	Y	N	N	N	N	N	N	N
107	10459596	Nov 4, 2011 3:04:00 PM	0203P	1	2.29	4	1	2	1	1	20	N	N	1	1	0	20	2	0	1	1	0	2	N	N	N	N	N	N	N	Y	N	N
309	10533217	Aug 3, 2012 5:44:00 PM	0203P	1	2.29	4	1	1	1	1	20	N	N	1	1	0	20	2	0	1	0	0	1	N	N	N	Y	N	Y	N	N	N	N
229	10562228	Aug 1, 2013 3:34:00 PM	0203P	1	1.826	4	1	2	2	1	20	N	N	1	2	0	20	2	0	1	0	3	0	N	N	N	Y	N	N	N	N	N	N
15	10566396	Aug 21, 2013 5:00:00 PM	0203P	3	1.982	4	1	1	96	1	0	N	N	1	2	0	23	1	0	1	0	0	1	N	Y	N	N	N	N	N	N	N	N
165	10576363	Jan 12, 2013 11:37:00 AM	0203P	1	2.03	4	1	1	2	3	20	N	N	1	1	3	20	3	0	1	0	0	3	N	N	N	N	N	N	N	N	Y	Y
90	10583820	Oct 14, 2013 5:17:00 PM	0203P	4	2.288	4	1	1	1	1	20	N	N	1	1	0	20	2	0	1	0	2	0	N	N	N	N	N	N	N	N	N	N
71	10592609	Nov 16, 2013 9:55:00 PM	0203P	1	2.046	4	2	4	96	2	21	N	N	1	1	0	22	1	0	1	0	0	2	Y	N	N	N	N	N	N	N	N	N
264	10600034	Dec 12, 2013 6:04:00 PM	0203P	2	2.289	4	2	1	3	1	20	N	N	1	1	0	20	3	0	1	2	0	3	N	N	N	Y	N	N	N	N	N	N
48	10601056	Dec 18, 2013 5:56:00 PM	0203P	2	2.13	4	2	1	1	1	0	N	N	1	1	0	20	2	0	2	0	0	1	N	N	N	Y	N	N	N	Y	N	N
5	10665489	Sep 19, 2014 1:36:00 PM	0203P	2	2.225	4	1	1	1	1	3	N	N	1	1	0	20	2	0	1	0	0	1	N	N	Y	N	N	N	N	N	N	N
158	10670788	Oct 8, 2014 1:31:00 PM	0203P	4	1.582	4	1	1	1	1	20	N	N	1	1	0	20	4	0	2	2	0	1	N	N	Y	N	N	N	N	N	N	N
																			1	19	10	7	19	1	1	3	5	1	1	0	2	1	2
																			2%	34%	18%	13%	34%	0.1	0.1	0.2	0.3	0.1	0.1	0.0	0.1	0.1	0.1

Figure 7-27: Example of the crash data summarized in the "CrashFactors" worksheet for a segment of interest.

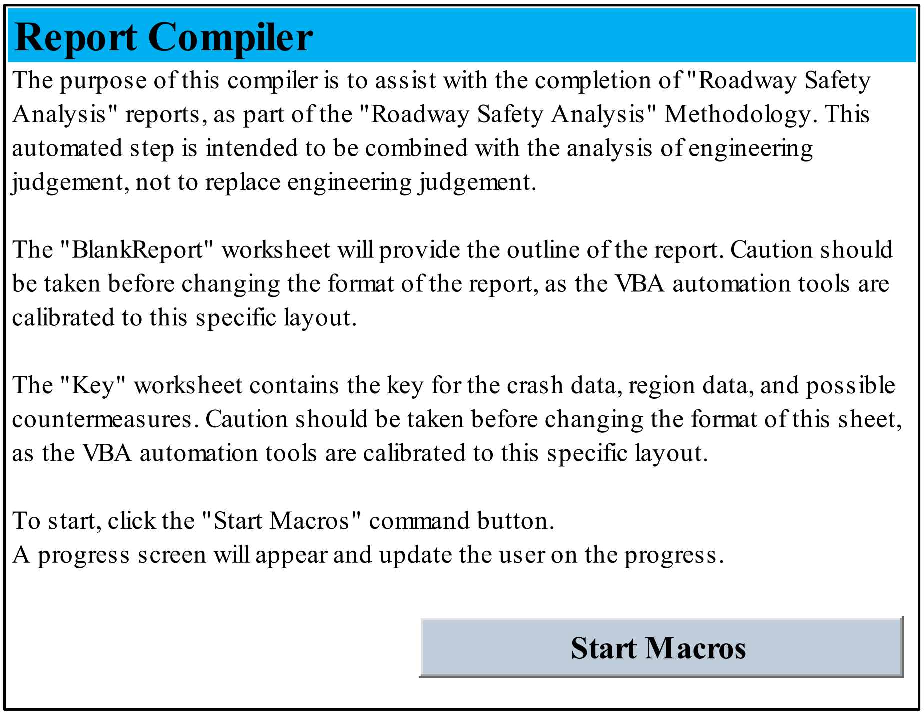


Figure 7-28: GUI for summarizing roadway characteristics, crash data, and possible countermeasures for Roadway Safety Analysis reports.

The process of summarizing the roadway characteristics, crash data, and possible countermeasures for the Roadway Safety Analysis reports is initiated by running a series of VBA macros, which uses a template for all reports to be created. The analyst is prompted to indicate the statistical model used, the range of data for the data sources (e.g., 2010 to 2014), the file containing the "Combo" and "CrashFactors" worksheets, the file containing the vehicle crash data, and the desired output location of the auto-populated Roadway Safety Analysis reports. As the reports are being complied one segment at a time, a progress screen updates the analyst on the number of reports that have been created. If no severe crashes were reported for a given segment, then the reports are compiled with the roadway data and without crash data or crash factors, due to the absence of crash data in the analysis. After a new report is created, the output folder selected by the analyst begins to populate with individual reports and the main "Report Compiler" workbook.

Figure 7-29, Figure 7-30, and Figure 7-31 provides an example of a Roadway Safety Analysis report being auto-populated with the roadway characteristics, crash data, and possible countermeasures, respectively. The analyst must complete the remainder of the report manually by providing a safety problem summary, documenting the historical perspective and current conditions through a site visit, and identifying approximately 10 possible countermeasures. Internet tools and communication with experts can be used to supplement engineering judgment to assess possible countermeasures which could have a meaningful safety impact for the given roadway. Resources identified previously in Section 2.5 are available to identify new and innovative safety countermeasures not identified through the automation tools.

Segment Identification and Roadway Characteristics

Table 1: Segment Metadata

Road Name:	SR-68		**UC Model Used:**	UCSM	
Road Direction:	Positive		**State Rank:**	5	
Beginning, Ending MP:	11.648	23.709	**Rank, Region:**	1	3
Length (miles):	12.061		**Rank, County:**	1	UTAH
Dates of Data Source:	2010-2014		**Date of Analysis:**	To be completed by engineer…	

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	1,165
Number of Thru Lanes:	2	**Speed Limit (MPH):**	55

Table 3: Roadway Characteristics

MPs	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/ Barrier	Rumble
11.648-23.709	Undivided, 0 ft	36/1.6	144/6.5	Asphalt, 4 ft	4 (max)	None	2 Thru	No (Wall), No (Barrier)	No

Figure 7-29: Example of a Roadway Safety Analysis report being auto-populated with information with the roadway characteristics.

Micro-Analysis of Crash Data

Crash Data Summary

Table 4: Crash Count and Severity

MPs	Total Crashes on Roadway	Severity 5 (Fatal)	Severity 4 (Incap. Injury)	Severity 3 (Non-Incap. Injury)
11.648-23.709	63	4	54	--

Table 5: Top 8 Crash Factors

Crash ID	MP	URBAN COUNTY	SINGLE VEHICLE	INTERSECTION RELATED	OVERTURN ROLLOVER	NIGHT DARK CONDITION	ROADWAY DEPARTURE	SPEED RELATED	ROADWAY GEOMETRY RELATED
10349772	11.8	Y	Y	N	Y	Y	Y	N	Y
10351891	7.59	Y	N	Y	N	N	N	N	N
10352569	7.59	Y	Y	Y	N	N	N	Y	N
10354978	84.7	N	Y	N	Y	N	N	N	N
10361476	21.2	Y	Y	N	Y	N	Y	Y	Y
10362936	7.6	Y	N	Y	N	N	N	N	N
10364008	7.59	Y	N	Y	N	N	N	N	N
10364263	7.6	Y	N	Y	N	Y	N	N	N
10370997	90	N	Y	N	Y	Y	Y	Y	N

Table 6: Data from Crash and Vehicle Datasets

Crash ID	MP	First Harmful Event	Manner of Collision	Event Sequence (1)	Event Sequence (2)	Event Sequence (3)	Event Sequence (4)	Most Harmful Event	Vehicle Maneuver
10349772	11.8	Overturn/ Rollover	N/A	ROR Right	Crossed Median/Centerline	Overturn/ Rollover	Not Applicable	Overturn/ Rollover	Straight Ahead
10351891	7.59	Motor Vehicle in Transit	Angle	Operating Motor Vehicle	Not Applicable	Not Applicable	Not Applicable	Operating Motor Vehicle	Turning Left, Turning Left
10352569	7.59	Utility Pole/Light Support	N/A	Operating Motor Vehicle	Not Applicable	Not Applicable	Not Applicable	Operating Motor Vehicle	Straight Ahead
10354978	84.7	Motor Vehicle in Transit	N/A	ROR Right	Other Fixed Object	Utility Pole/Light Support	Not Applicable	Utility Pole/Light Support	Changing Lanes
10361476	21.2	Overturn/ Rollover	N/A	Operating Motor Vehicle	ROR Right	Crossed Median/Centerline	Overturn/ Rollover	Overturn/ Rollover	Straight Ahead

Figure 7-30: Example of a Roadway Safety Analysis report being auto-populated with information with the crash data.

Possible Countermeasures

The following is a list of possible countermeasure realted to the top 8 crash factors listed in Table 5. The countermeasures listed were compiled using the coutermeasures from the NCHRP 500 Report volumes. (P) = Proven (T) = Tried (E) = Experimental (NA) = Data not available.

(NA) No countermeasures available from the NCHRP 500 Report volumes for "Urban County" related collisio
Target enforcement (T)
Conduct educational and public information campaigns (T)
Educate and impose sanctions against repeat offenders (E)
Change or mitigate the effects of identified elements in the environment (E)
Reduce nonrecurring delays and provide better information about these delays (E)
Increase enforcement in selected areas (T)
Routinely link citations to driver record (T)
Create and distribute "hot sheets" (T)
"Stripe" license plate (P)
Impound license plate (P)
Immobilize/impound/seize vehicle (P)
Install ignition interlock device (IID) (P)
Monitor electronically or "house arrest" (P)
Incarcerate (P)
Provide alternative transportation service (P)
Install shoulder rumble strips (T)
Install edgeline "profile marking," edgeline rumble strips or modified shoulder rumble strips on sections wit
Install midlane rumble strips (E)
Provide enhanced shoulder or in lane delineation and marking for sharp curve (P)
Provide improved highway geometry for horizontal curves (P)
Provide enhanced pavement markings (T)
Provide skid resistant pavement surfaces (E)
Eliminate shoulder drop-offs (shoulder treatment) (E)
Widen and/or pave shoulder (shoulder treatment) (P)
Design safer slopes and ditches to prevent rollovers (P)
Remove/relocate objects in hazardous locations (P)
Delineate trees or utility poles with retroreflective tape (E)

Figure 7-31: Example of a Roadway Safety Analysis report being auto-populated with information with the possible countermeasures.

In previous research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015), the process of creating and filling the report with the roadway data, crash data, and possible countermeasures was done manually. The analyst was required to transcribe the information by hand and interpret the numerical codes for the crash data into written descriptions. As a result of this research, the process of creating and filling the report with the roadway data, crash data, and possible countermeasures is done using the automated tools and GUIs in the “Report Compiler”

MS Excel workbook. This workbook quickly and efficiently reads the roadway data and crash data into the Roadway Safety Analysis reports. This automated process allows the analyst to have more time to use engineering judgment to review the auto-populated data; document the historical perspective, current conditions, and site visit notes; and identify approximately 10 possible countermeasures from the full list.

7.3.3 Two-Page Abridgement of Roadway Safety Analysis Reports

After completing the full Roadway Safety Analysis reports, the information for each segment is abridged to a two-page report to summarize the key findings of the full report. The analyst manually reduces and summarizes the data from the full reports to a two-page format, using the criteria summarized previously in Section 6.4. The two-page reports contain the segment identification; a reduced version of the crash data and safety problem summary; the documentation of the historical perspective, current conditions, and site visit notes; and a list of approximately 10 possible countermeasures.

The two-page abridgement allows for a decision maker to have a brief overview of the Roadway Safety Analysis methodology and to understand the safety issues and possible safety countermeasures for a given roadway. An example of a completed two-page Roadway Safety Analysis is shown in Figure 7-32 (page 1) and Figure 7-33 (page 2).

7.3.4 Publication of the Roadway Safety Analysis Reports

Once the two-page Roadway Safety Analysis reports have been created for each of the segments of interest, these reports are published by the UDOT Safety Programs Engineer to UDOT Region directors and other interested users, to evaluate the safety of roadway segments within their jurisdiction. The report creation process can be repeated if additional reports are desired for a specific UDOT Region or roadway project. In addition, the output of the statistical analyses can be published on the Numetric Network Screening app, which allows a side by side comparison of the results of the statistical analysis with the UDOT Safety Index. An example of comparing the results of the UCPM and UCSM to the Safety Index on the Numetric Network Screening app as of April 2016 is illustrated in Figure 7-34.

The reader should note that it is possible for the statistical analysis to provide results which are different than the UDOT Safety Index. The purpose of the UCPM and UCSM is to identify roadways in the state where more crashes or higher severity crashes are occurring than what would be expected or that can be explained statistically. If there are perceived conflicts in the ranking of the UCPM and UCSM, the UDOT Safety Index, engineers, analysts, and other interested users are encouraged to conduct a site visit and to make personal recommendations for the priority of safety improvements for the given segments.

This research anticipates that the launching of the crash database server at the University of Utah in the summer or fall of 2016 will change how these reports can be shared through UDOT. As the database at the University of Utah comes online, the published Roadway Safety Analysis reports are planned to be published through the Numetric web interface rather than personal distribution. This will expand the number of tools and resources available for other UDOT employees to assess roadway safety within their jurisdiction.

Roadway Safety Analysis Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified segment of interest. This report includes identification of the roadway segment and sub-segments, micro-analysis of the crash data, site visit notes, and a list of possible countermeasures.

Segment Identification and Roadway Characteristics

Table 1: Segment Metadata

Road Name:	SR-68		**UC Model Used:**	UCSM	
Road Direction:	Positive		**State Rank:**	5	
Beginning, Ending MP:	11.648	23.709	**Rank, Region:**	1	3
Length (miles):	12.061		**Rank, County:**	1	UTAH
Dates of Data Source:	2010-2014		**Date of Analysis:**	4/29/2015	

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	1,165
Number of Thru Lanes:	2	**Speed Limit (MPH):**	55

Table 3: Roadway Characteristics

MPs	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/ Barrier	Rumble
11.648-23.709	Undivided, 0 ft	36/1.6	144/6.5	Asphalt, 4 ft	4 (max)	None	2 Thru	No (Wall), No (Barrier)	No

Micro-Analysis of Crash Data

Crash Data

Table 4: Crash Count and Severity

MPs	Total Crashes on Roadway	Severity 5 (Fatal)	Severity 4 (Incap. Injury)	Severity 3 (Non-Incap. Injury)
11.648-23.709	63	4	54	--

Table 5: Top 8 Crash Factors

	URBAN COUNTY	SINGLE VEHICLE	INTERSEC TION RELATED	OVERTUR N ROLLOVER	NIGHT DARK CONDITIO N	ROADWAY DEPARTU RE	SPEED RELATED	ROADWAY GEOMETRY RELATED
Segment Total	47/58	24/58	25/58	20/58	21/58	18/58	16/58	16/58

Safety Problem Summary

There are a significant amount of rollover incidents, which may be attributed to the many curves along the segment. These rollover incidents have caused fatal and incapacitating unjuries to the persons involved. Some of the possible contributing factors to the problem are roadway geometry (horizontal curvature), speed, light conditions, and improper restraint.

Figure 7-32: Example of a two-page Roadway Safety Analysis report, page 1.

Historical Perspective, Current Conditions, Site Visit Notes

It was observed that the 12 mile segment of SR-68, located south of Saratoga Springs, UT, is a two lane-two way highway. There are no rumble strips in the centerline or 2 foot asphalt shoulder of the road. In the proximity of a Geneva Rock facility, located near mile post 23, the shoulder the road is expanded from 2 feet to 11 feet, to accommodate for heavy truck traffic to the site. Using Roadview Explorer, there were no apparent changes to the geometry or features of the roadway, other than a portion of the road segment being repaved in in 2012. An image from Roadview Explorer in 2014 is given in Figure 1, which highlights the need for improved signage on curves.

In a site visit conducted on 4/29/2015, it was observed that there are many horizontal curves along the roadway, with some rolling effect in the vertical transition. While the site visit was done during the day, it was noted at the curves may not be visible during the night time. Driving at the posted speed limit through the curves created a "roller coaster" effect.

Figure 1: Roadway curvature without chevron markings (taken from Roadview Explorer 2014 image).

Possible Countermeasures

The following is a list of possible countermeasure realted to the top 8 crash factors listed in Table 5. The countermeasures listed were compiled using the coutermeasures from the NCHRP 500 Report volumes. (P) = Proven (T) = Tried (E) = Experimental (NA) = Data not available.

Install shoulder rumble strips (T)
Install midlane rumble strips (E)
Implement other roadway improvements to reduce the likelihood/severity of run-off-road collisions (P)
Set speed limits which account for roadway design, traffic, and environment (T)
Implement variable speed limits (T)
Improve speed limit signage (T)
Implement active speed warning signs (T)
Improve design of roadside hardware (T)
Improve design and application of barrier and attenuation systems (T)
Provide advance warning of unexpected changes in horizontal alignments (T)
Enhance delineation along the curve (T)
Provide adequate sight distance (T)
Improve lighting along roadway (P)

This report is protected under 23 U.S.C. 409 *Page 2*

Figure 7-33: Example of a two-page Roadway Safety Analysis report, page 2.

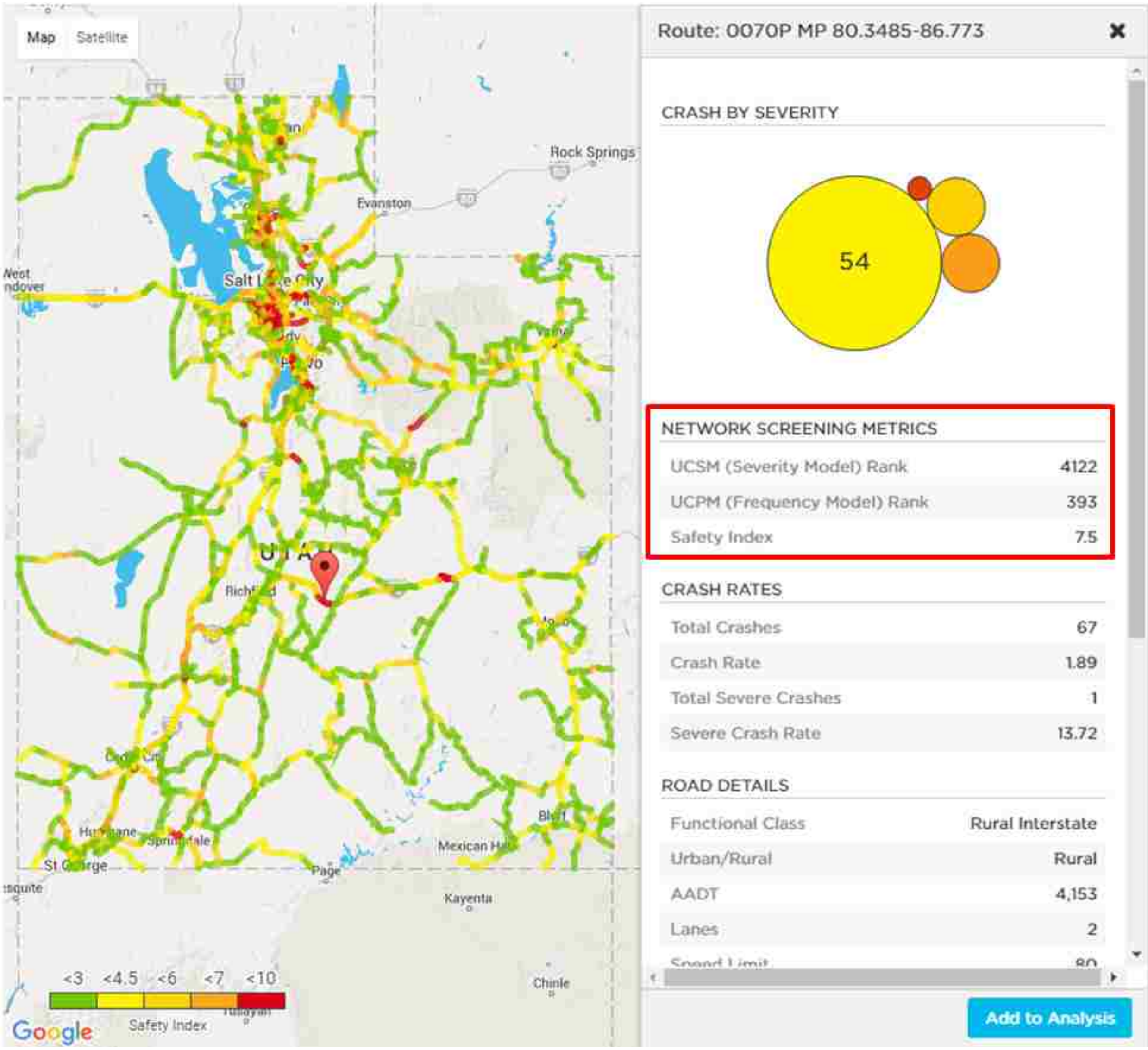


Figure 7-34: Comparing the UCPM, UCSM, and Safety Index on the Numetric "Network Screening" app. (Numetric 2016c).

7.4 Chapter Summary

The product of this research is the creation of the Roadway Safety Analysis methodology, connecting each of the elements described in Chapter 4, Chapter 5, and Chapter 6 of this thesis. This chapter provided an example of the three parts of the Roadway Safety Analysis methodology from beginning to end, highlighting the tools and GUIs created to apply and automate the cumulative work of previous research projects conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015). The first section in this chapter provided an example of preparing the crash data and segmenting the roadway data, which can be done in a single MS Excel workbook. The second section provided an example of executing the statistical analysis of the roadway and crash data in an automated, user-friendly GUI environment. Several ArcMap tools were created to spatially display the results to allow for segments of interest to be selected. The third section provided an example of compiling the Roadway Safety Analysis reports, which includes the combination of 10 roadway datasets and the crash data. The auto-populated reports are then completed by the analysts and abridged to two-page reports, which are published by the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. Automating the Roadway Safety Analysis methodology allows for consistent interpretation of the statistical analysis for future iterations, repeatability of future analyses, and decreased data processing time. Chapter 8 summarizes the findings and deliverables of the research documented in this thesis and discuss possible topics for future highway safety research in Utah and nationally.

8 CONCLUSIONS

UDOT has continually placed safety at the forefront of their priorities, with the goal of "Zero Fatalities" on the state highway system. To aid UDOT in meeting their goal of advancing roadway safety across the state, BYU has worked consistently with UDOT in the developing safety analysis tools. The most recent efforts include the development of the network screening statistical analysis tools, the UCPM and the UCSM, and the Hot Spot Identification and Analysis methodology. The purpose of the research summarized in this thesis was to apply and automate the cumulative work of previous highway safety research conducted for UDOT into the Roadway Safety Analysis methodology, a three part methodology with automation tools and GUIs to allow for the highway safety analysis tools to be implemented and interpreted uniformly across the state. This chapter summarizes the three part Roadway Safety Analysis methodology and provides recommendations for future highway safety research.

8.1 Roadway Safety Analysis Methodology Summary

The Roadway Safety Analysis methodology is an automated application of previous highway safety research conducted for UDOT (Schultz et al. 2013a, Schultz et al. 2015). Figure 8-1 summarizes the overall elements and tasks of the Roadway Safety Analysis methodology, beginning at the crash and roadway data segmentation, centered on the statistical network screening of the state roadways using the UCPM and UCSM, and concluding with the creation and publication of the Roadway Safety Analysis reports. The following subsections outline each of the three parts of the Roadway Safety Analysis methodology, which are described in Chapter 4, Chapter 5, and Chapter 6, respectively. The first part is to prepare the roadway and crash data and segment the roadway data into homogeneous segments by roadway characteristics or roadway length. The second part is to conduct the statistical analysis of the segmented roadway data, interpreting the results of the analysis, and selecting segments of interest for the report compilation process. The third part is to compile the Roadway Safety Analysis reports for the segments of interest, create the full and abridged reports for each segment, and publish the reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. The tasks accomplished in these three parts were documented in their respective volume of user manuals, which were designed to provide step-by-step instructions for completing these tasks (Gibbons et al. 2016, Mineer et al. 2016, Siegel et al. 2016).

8.1.1 Crash and Roadway Data Segmentation

The first step in the Roadway Safety Analysis methodology is to create the crash and segmented roadway datasets. This is completed by using the tools and GUIs developed in the "Roadway and Crash Data Preparation" MS Excel workbook. One of the main features in the "Roadway and Crash Data Preparation" workbook is a "Check Headers" workbook, which ensures that the input data columns contain the critical data columns for a given analysis task. The "Check Headers" tool allows for the safety analysis process to adapt to changes in the format or structure of the roadway and crash data.

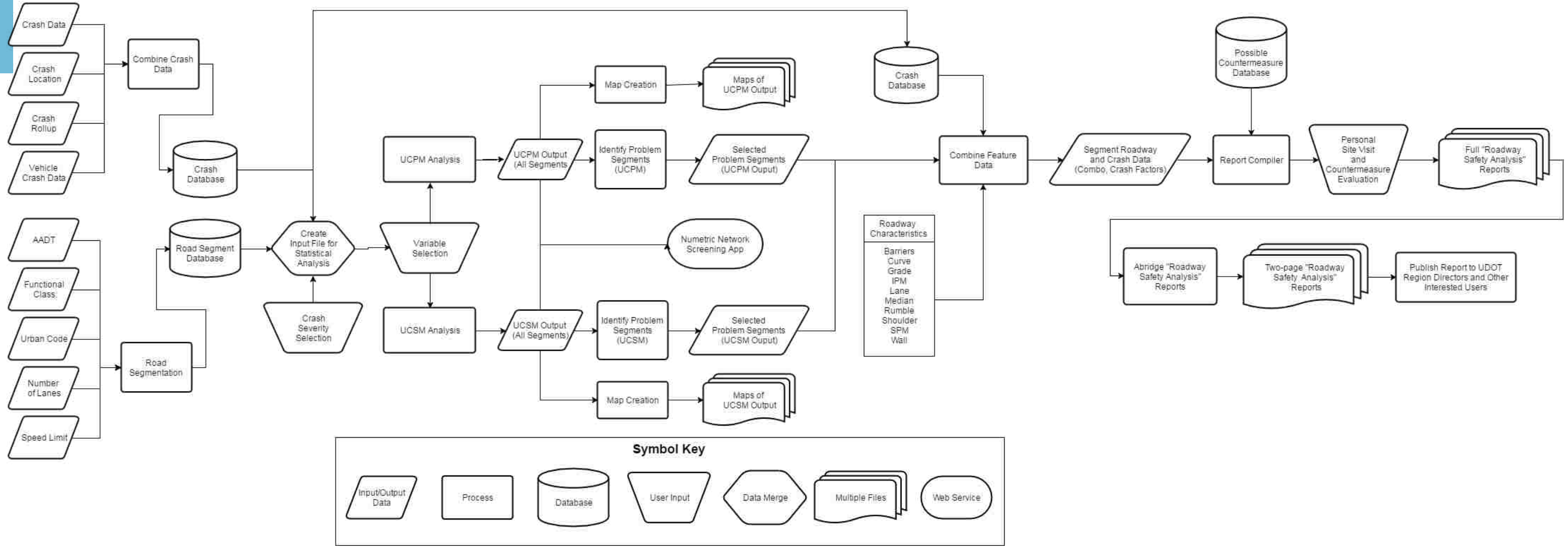


Figure 8-1: Schematic illustration of Roadway Safety Analysis methodology.

By improving the data processing syntax, the time required to prepare the crash database was reduced from 2 to 3 hours of uninterrupted CPU power to approximately 30 minutes. The roadway segmentation process was developed to allow the analyst to segment the roadway data into homogenous segments by roadway characteristics or by length (e.g., 0.1 mile or 0.5 mile length). The product of this first part is a crash database file and segmented roadway data file, which become inputs for the statistical analysis. These processes were designed to be accomplished using a single MS Excel workbook with automation tools and user friendly GUIs.

8.1.2 Statistical Network Screening of Roadway Data

The second step in the Roadway Safety Analysis methodology is to execute the UCPM and UCSM statistical analyses and interpret the results of the analysis. This is completed using the tools and GUIs developed in the "R GUI" MS Excel workbook, R code statistical scripts, and Python Script tools developed in ArcMap. The input data for the UCPM and UCSM can be created as specified by the analyst using the GUI and associated automated tools. The variable selection process was expanded to allow the analyst to conduct a Bayesian horseshoe variable selection process or to manually input significant variables. The analysis tools and subsequent GUI allow to the analyst to pass the input data, number of iterations, number of burn-in iterations, and statistically significant variables into the statistical model and to initialize the R code statistical models without having to modifying the R code directly. The structure of the R code allows for the statistical analysis to adapt to the different parameters specified by the analyst.

The outputs of the UCPM and UCSM are a single PDF document summarizing the specifications of the statistical analysis and a CSV file of the roadway segments and statistical values ranked in comparison to one another. The statewide, UDOT Region, and county hierarchically ranking was programmed to be done automatically to remove opportunities for error in the interpretation of the results of the statistical analysis. Previously developed ArcMap Python scripts were expanded to allow for a statewide map, UDOT Region maps, or county maps to be created to summarize the results from the statistical analysis.

8.1.3 Report Compilation for Segments of Interest

The third and final step in the Roadway Safety Analysis methodology is to compile Roadway Safety Analysis reports for each segment of interest and publish the reports through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. This is completed using the ArcMap based tools and MS Excel based tools and GUIs in the "Combine Feature Data" and "Report Compiler" MS Excel workbooks. The process to spatially join the roadway characteristics and crash data with the selected problem segments is done using the user form in ArcMap, which is designed to simultaneously create 10 worksheets with roadway data and one worksheet with crash data related to the segments of interest. These 11 worksheets are combined and summarized using the "Combine Feature Data" MS Excel workbook, which expedites the process of summarizing the roadway and crash data. The "Report Compiler" MS Excel workbook allows for the summarization of the roadway data, crash data, and possible countermeasures for each of the selected roadway segments. The automated tools in this workbook reduce the tedious work of summarizing the roadway and crash data, which allows the analyst to conduct the site visits and complete the content for the Roadway Safety Analysis reports in an efficient process. Once the full Roadway Safety Analysis reports are completed, they are abridged into two-page reports and published through the UDOT Safety Programs Engineer to UDOT Region directors and other interested users. This process can be repeated for any roadway segment to identify possible improvements to any roadway on the network that has been selected for safety or non-safety related roadway improvements.

8.2 Recommended Topics for Future Highway Safety Research

Highway safety research and efforts to reduce the number of crashes, especially severe crashes, should continue investigating new applications of innovative processes and methodologies. The research summarized in this thesis identified different topics of future research and additional applications of the Roadway Safety Analysis methodology. The following subsections suggest possible topics for future research, including: the continued development of the Roadway Safety Analysis methodology with the new crash database and evolving Numetric web interface, modifying the Roadway Safety Analysis methodology for analyzing safety at intersections, modifying the Roadway Safety Analysis methodology for analyzing safety along horizontal curves, implementing the Roadway Safety Analysis methodology using other state roadway and crash datasets, contributing to the crash countermeasure effectiveness research database, and the expanding the development of GIS tools for crash analysis.

8.2.1 Continued Roadway Safety Analysis Methodology Development

The purpose of this research was to apply and automate the process of analyzing crashes on a statewide level and summarizing data in a useful way for the UDOT Safety Programs Engineer, UDOT Region directors, and other interested users. As the processes were developed through the use of automation tools and GUIs, it became apparent that the automation tools and GUIs need continual maintenance and upkeep in order to deliver the desired results with new roadway and crash datasets. Three volumes of user manuals were created for the purpose of guiding an individual through the Roadway Safety Analysis methodology, from raw data manipulation to the creation of the Roadway Safety Analysis reports. In order to maintain pace with dynamically changing datasets and methods for hosting data, it is recommended that work continue to maintain and improve the given processes, so that these tools and GUIs can continue to be used in future highway safety analyses. Specifically, these processes should be modified to integrate efficiently with the crash database when fully functional on the University of Utah servers. For example, the interface for extracting the crash data may change, which would require the crash database preparation steps to be modified from the instructions given in this thesis and respective user manuals.

Another example is improving the method for listing and summarizing possible countermeasures based on the roadway data, as UDOT is beginning to do. Improving the process by challenging the currently developed tools by suggesting innovative alternatives allows for the most significant advancements in the field of highway safety research.

Another possible topic is the process of normalizing the results of the statistical analysis for the UCPM and UCSM. The current ranking systems have been generalized to provide structure for future iterations of the statistical analysis. These ranking systems have room for improvement, to verify if the generalized methods are appropriate or if there is a better normalizing equation for the UCPM and UCSM for interpreting the results more efficiently on a statewide level.

8.2.2 Statewide Analysis of Intersections

Using the Roadway Safety Analysis methodology outlined in the literature and this thesis, the procedure can be adapted to the analysis of intersections on the state roadway network. According to the 2010 to 2014 crash data, approximately 35 percent of all mainline, non-ramp crashes were intersection related crashes, as summarized in Table 8-1. This presents an opportunity to specifically analyze roadway safety at intersections, as opposed to roadway segments that include intersections, in order to reduce the number of intersection related crashes in the state.

Table 8-1: Intersection Related Crash Percentages in Utah, 2010 to 2014

Intersection Related	Percent of Crashes
No:	65.4%
Yes:	
Severity 1	21.8%
Severity 2	7.5%
Severity 3	4.5%
Severity 4	0.8%
Severity 5	0.1%
Total	100.0%

8.2.3 Statewide Analysis of Horizontal Curves

Another application of the roadway safety statistical analysis is to analyze horizontal curves in the state roadway network. According to the 2010 to 2014 crash data, approximately 12 percent of all mainline, non-ramp crashes were horizontal alignment (curve) related crashes, as summarized in Table 8-2. This presents an opportunity to specifically analyze roadway safety along horizontal curves, as opposed a combination of tangent and curved roadways, in order to reduce the number of horizontal curve related crashes in the state.

Table 8-2: Horizontal Alignment (Curve) Related Crash Percentages in Utah, 2010 to 2014

Horizontal Alignment	Percent of Crashes
Straight:	87.0%
Curve:	
Severity 1	8.5%
Severity 2	1.6%
Severity 3	1.4%
Severity 4	0.4%
Severity 5	0.1%
Not Provided	0.6%
Not Applicable	0.0%
Unknown	0.4%
Total	100.0%

8.2.4 Implementation of Roadway Safety Analysis Methodology in Other States

As the Roadway Safety Analysis methodology is automated and improved, it is possible for the methodology to be applied to other state roadway and crash databases. The automation tools are designed to be adaptable to different datasets, so long as the critical data columns tabulated in Appendix B are present in the dataset. Using the procedures outlined in this thesis and in the respective user manuals (Gibbons et al. 2016, Mineer et al. 2016, Siegel et al. 2016), the Roadway Safety Analysis methodology can be applied for other states, assisting them in the process of identifying safety problem segments in their roadway network and finding possible countermeasures.

8.2.5 Contribute to Countermeasure Effectiveness Research Database

As countermeasures are implemented, state agencies have the opportunity to document the use of the countermeasures in roadway improvement projects and the impact it has on safety.

As these reports are produced, they can be submitted to the NHTSA. Additional studies of existing and new countermeasures have the opportunity to validate effective countermeasures and produce new ideas for enhancing highway safety.

As described in Section 2.5, references such as "Countermeasures That Work" address only nine of the 23 volumes of the NCHRP Report 500 series volumes. As more studies are compiled, the two databases of countermeasure effectiveness measures could possibly be merged and expanded. The CMF Clearinghouse also can benefit from additional research related to the calculation of CMFs across the nation.

8.2.6 Expand GIS Tools for Crash Analysis

During the review of available GIS crash analysis tools, it became apparent that some of the previously developed GIS tools for analyzing crashes were no longer available or supported, such as the sliding scale, spot analysis, and strip analysis tools (Esri 2015c). While some analysis tools are available for analyzing crashes and creating risk maps, there is an opportunity to expand the current GIS tools and re-construct previously created GIS tools to enhance highway safety research.

8.3 Concluding Remarks

UDOT has continually placed safety at the forefront of their priorities, with the goal of "Zero Fatalities" on the state highway system. To aid UDOT in meeting their goal of advancing roadway safety across the state, BYU has worked consistently with UDOT in the developing safety analysis tools. The most recent efforts include the development of the network screening statistical analysis tools, the UCPM and the UCSM, and the Hot Spot Identification and Analysis methodology. The product of the research summarized in this thesis was the development of the three part Roadway Safety Analysis methodology. This three part methodology has been developed with automation tools, GUIs, and three volumes of user manuals to allow for the highway safety analysis tools to be implemented and interpreted uniformly across the state. Recommended future topics for research in Utah and nationally include:

- Continued Roadway Safety Analysis methodology development
- Statewide analysis of intersections
- Statewide analysis of horizontal curves
- Implementation of the Roadway Safety Analysis methodology in other states
- Contribute to safety countermeasure effectiveness research database
- Expand GIS tools for crash analysis

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
BYU	Brigham Young University
CMF	Crash Modification Factor
CPU	Central Processing Unit
CRF	Crash Reduction Factor
CRS	Condition Rating System
CSV	Comma Separated Values
DIC	Deviance Information Criterion
FHWA	Federal Highway Administration
GIS	Geographic Information System
GUI	Graphical User Interface
HAF	Horizontal Alignment Finder
HOV	High Occupancy Vehicle
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
ID	Identification
IDOT	Illinois Department of Transportation

IPM	Intersections Per Mile
IRI	International Roughness Index
ITE	Institute of Transportation Engineers
JAGS	Just Another Gibbs Sampler
LiDAR	Light Detection and Ranging
LRS	Linear Referencing System
MCMC	Markov Chain Monte Carlo
MP	Milepoint
MPH	Miles Per Hour
MS	Microsoft
MUTCD	Manual for Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
NHTSA	National Highway Traffic Safety Administration
PDF	Portable Document Format
PDO	Property Damage Only
PSI	Potential for Safety Improvement
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act –A Legacy for Users
SHSO	State Highway Safety Officials
SHSP	Strategic Highway Safety Plan
SPF	Safety Performance Function
SPM	Signs Per Mile

SRI	Safer Roads Index
TRB	Transportation Research Board
TWLTL	Two-Way Left Turn Lane
UCPM	Utah Crash Prediction Model
UCSM	Utah Crash Severity Model
UDOT	Utah Department of Transportation
USC	United States Code
VBA	Visual Basic for Applications
VMT	Vehicle Miles Traveled

APPENDIX A SUMMARY OF NCHRP REPORT 500 COUNTERMEASURES

Appendix A is a collection of countermeasure matrices based on the 23 volumes of the NCHRP Report 500 series, with Table A-1 summarizing the tables included in this appendix. The reader should note that there are no specific countermeasures given in volume 21, "Safety Data and Analysis in Developing Emphasis Area Plans," as this volume provides guidance on the source of safety data needed and on procedures for both choosing the best countermeasures and targeting those treatment strategies to either roadway locations or road-user subgroups (Council et al. 2008). Table A-2 through Table A-23 included all objectives and associated countermeasures to those objectives from their respective volumes. The strategy type is noted in the countermeasure description, reflecting whether the countermeasure is proven (P), tried (T), experimental (E), or if data are not available (NA) in measuring the effectiveness of the countermeasure. These countermeasures are used in creating the list of "Possible Countermeasures" for the Roadway Safety Analysis reports. As discussed in Section 6.2.3, this list does not dictate the specific actions which should be taken for a given segment, but provides a starting point for the analyst to determine the most appropriate course of action. Additional discussion of some of the tabulated countermeasures can be found in the literature (Schultz et al. 2013a).

Table A-1: Index of NCHRP 500 Series Reports Summarized in Appendix A

Vol.	Report Title	Appendix Table
1	"A Guide for Addressing Aggressive-Driving Collisions"	Table A-2
2	"A Guide for Addressing Collisions Involving Unlicensed Drivers and Drivers with Suspended or Revoked Licenses"	Table A-3
3	"A Guide for Addressing Collisions with Trees in Hazardous Locations"	Table A-4
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22	"A Guide for Addressing Collisions Involving Motorcycles"	Table A-22
23	"A Guide for Reducing Speeding-Related Crashes"	Table A-23

Table A-2: "Aggressive Driving Collisions" Objectives and Countermeasures (Neuman et al. 2003a)

Objective	Countermeasure
Deter aggressive driving in specific populations, including those with a history of such behavior, and at specific locations	Target enforcement (T)
	Conduct educational and public information campaigns (T)
	Educate and impose sanctions against repeat offenders (E)
Improve the driving environment to eliminate or minimize the external "triggers" of aggressive driving	Change or mitigate the effects of identified elements in the environment (E)
	Reduce nonrecurring delays and provide better information about these delays (E)

Table A-3: "Collision Involving Unlicensed, Suspended, Revoked Licenses" Objectives and Countermeasures (Neuman et al. 2003b)

Objective	Countermeasure
Apply special enforcement practices	Increase enforcement in selected areas (T)
	Routinely link citations to driver record (T)
	Create and distribute "hot sheets" (T)
Restrict mobility through license plate modification or removal	"Stripe" license plate (P)
	Impound license plate (P)
Restrict mobility through vehicle modification	Immobilize/impound/seize vehicle (P)
	Install ignition interlock device (IID) (P)
Restrict mobility through direct intervention with offender	Monitor electronically or "house arrest" (P)
	Incarcerate (P)
Eliminate need to drive	Provide alternative transportation service (P)

Table A-4: "Collisions with Trees in Hazardous Location" Objectives and Countermeasures (Neuman et al. 2003c)

Objective	Countermeasure
Prevent Trees from Growing in Hazardous Locations	Develop, revise, and implement planting guidelines to prevent placing trees in hazardous locations (T)
	Mowing and vegetation control guidelines (P)
Eliminate the hazardous condition and/or reduce the severity of the crash	Remove trees in hazardous locations (P)
	Shield motorists from striking trees (P)
	Modify roadside clear zone in the vicinity of trees (P)
	Delineate trees in hazardous locations (E)

Table A-5: "Head-on Collisions" Objectives and Countermeasures (Neuman et al. 2003d)

Objective	Countermeasure
Keep vehicles from encroaching into opposite lane	Install centerline rumble strips for two-lane roads (T)
	Install profiles thermoplastic strips for centerlines (T)
	Provide wider cross sections on two-lane roads (E)
	Provide center two-way, left turn lanes for four- and two-lane roads (T)
	Reallocate total two-lane roadway width (lane and shoulder) to include a narrow "buffer median" (T)
Minimize the likelihood of crashing into an oncoming vehicle	Use alternating passing lanes for four-lane sections as key locations (T)
	Install median barriers for narrow-width medians on multilane roads (T)
Improve management of access near unsignalized intersections	Implement driveway closures/relocations (T)
	Implement driveway turn restrictions (T)
Reduce the frequency and severity of intersection conflicts through geometric design improvements	Provide left turn lanes at intersections (P)
	Provide longer left turn lanes at intersections (T)
	Provide offset left turn lanes at intersections (T)
	Provide bypass lanes on shoulders at T-intersections (T)
	Provide left turn acceleration lanes at divided highway intersections (T)
	Provide right turn lanes at intersections (P)
	Provide longer right turn lanes at intersections (T)
	Provide offset right turn lanes at intersections (T)
	Provide right turn acceleration lanes at intersections (T)
	Provide full width paved shoulders in intersection areas (T)
	Restrict or eliminate turning maneuvers by signing (T)
	Restrict or eliminate turning maneuvers by providing channelization or closing median openings (T)
	Close or relocate "high risk" intersection (T)
	Convert four legged intersections to two T-intersections (T)
	Convert offset T-intersection to four legged intersection (T)
	Realign intersection approaches to reduce or eliminate intersection skew (P)
	Use indirect left turn treatments to minimize conflicts at divided highway intersections (T)
	Improve pedestrian and bicycle facilities to reduce conflicts between motorists and nonmotorists (T)

Table A-6: "Unsignalized Intersection Collisions" Objectives and Countermeasures (Neuman et al. 2003e)

Objective	Countermeasure
Improve sight distance at unsignalized intersections	Clear sight triangles on stop or yield controlled approaches to intersections (T)
	Clear sight triangles in the medians of divided highways near intersections (T)
	Change horizontal and/or vertical alignment of approaches to provide more sight distance (T)
	Eliminate parking that restricts sight distance (T)
Improve availability of gaps in traffic and assist drivers in judging gap sizes at unsignalized intersections	Provide an automated real time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers (E)
	Provide roadside markers or pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers (E)
	Retime adjacent signal to create gaps at stop controlled intersections (T)
Improve driver awareness of intersections as viewed from the intersection approach	Improve visibility of intersections by providing enhanced signing and delineation (T)
	Improve visibility of the intersection by providing lighting (P)
	Install splitter islands on the minor road approach to an intersection (T)
	Provide a stop bar (or provide a wider stop bar) on minor road approaches (T)
	Install larger regulatory and warning signs at intersections (T)
	Call attention to the intersection by installing rumble strips on intersection approaches (T)
	Provide dashed marking (extended left edgelines) for major road continuity across the median opening at divided highway intersections (T)
	Provide supplementary stop signs mounted over the roadway (T)
	Provide pavement markings with supplementary messages such as STOP AHEAD (T)
	Provide improved maintenance of stop signs (T)
	Install flashing beacons at stop controlled intersections (T)

Table A-6 Continued

Objective	Countermeasure
Choose appropriate intersection traffic control to minimize crash frequency and severity	Avoid signalizing through roads (T)
	Provide all way stop control at appropriate intersections (P)
	Provide roundabouts at appropriate locations (P)
Improve driver compliance with traffic control devices and traffic laws at intersections	Provide targeted enforcement to reduce stop sign violations (T)
	Provide targeted public information and education on safety problems at specific intersections (T)
Reduce operating speeds on specific intersection approaches	Reduce operating speeds on specific intersection approaches (T)
	Provide targeted speed enforcement (P)
	Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices (P)
	Post appropriate speed limit on intersection approaches (T)
	Guide motorists more effectively through complex intersections (T)
	Provide turn path marking (T)
	Provide a double yellow centerline on the median opening of a divided highway at intersections (T)
	Provide lane assignment signing or marking at complex intersections (T)

Table A-7: "Run-off Road Collisions" Objectives and Countermeasures (Neuman et al. 2003f)

Objective	Countermeasure
Keep vehicles from encroaching on the roadside	Install shoulder rumble strips (T)
	Install edgeline "profile marking," edgeline rumble strips or modified shoulder rumble strips on sections with narrow or no paved shoulders (E)
	Install midlane rumble strips (E)
	Provide enhanced shoulder or in lane delineation and marking for sharp curve (P)
	Provide improved highway geometry for horizontal curves (P)
	Provide enhanced pavement markings (T)
	Provide skid resistant pavement surfaces (E)
	Eliminate shoulder drop-offs (shoulder treatment) (E)
	Widen and/or pave shoulder (shoulder treatment) (P)
Minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the shoulder	Design safer slopes and ditches to prevent rollovers (P)
	Remove/relocate objects in hazardous locations (P)
	Delineate trees or utility poles with retroreflective tape (E)
Reduce the severity of the crash	Improve design of roadside hardware (T)
	Improve design and application of barrier and attenuation systems (T)

Table A-8: "Collisions on Horizontal Curve" Objectives and Countermeasures (Torbic et al. 2004)

Objective	Countermeasure
Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	Provide advance warning of unexpected changes in horizontal alignments (T)
	Enhance delineation along the curve (T)
	Provide adequate sight distance (T)
	Install shoulder rumble strips (P)
	Install centerline rumble strips (T)
	Prevent edge dropoffs (T)
	Provide skid resistant pavement surfaces (T)
	Provide grooved pavement (T)
	Provide lighting of the curve (T)
	Provide dynamic curve warning system (T)
	Widen the roadway (P)
	Improve or restore superelevation (P)
	Modify horizontal alignment (P)
	Install automated anti-icing system (T)
	Prohibit/restrict trucks with very long semitrailers on roads with horizontal curves that cannot accommodate truck offtracking (T)
Minimize the adverse consequences of leaving the roadway at a horizontal curve	Design safer slopes and ditches to prevent rollovers (P)
	Remove/relocate object in hazardous locations (P)
	Delineate roadside objects (E)
	Add or improve roadside hardware (T)
	Improve design and application of barrier and attenuation systems (T)

Table A-9: "Collisions Involving Utility Poles" Objectives and Countermeasures (Lacy et al. 2004)

Objective	Countermeasure
Treat specific utility poles in high-crash and high-risk spot locations	Remove poles in high crash location (P)
	Relocate poles in high crash locations farther from the roadway and/or to less vulnerable locations (P)
	Use breakaway devices (T)
	Shield drivers from poles in high crash locations (P)
	Improve the drivers' ability to see poles in high crash locations (E)
	Apply traffic calming measures to reduce speeds on high risk sections (T)
	Develop, revise, and implement policies to prevent placing or replacing poles with the recovery area (T)
Treat several utility poles along a corridor to minimize the likelihood of crashing into a utility pole if a vehicle runs off the road	Place utilities underground (P)
	Relocate poles along the corridor farther from the roadway and/or to less vulnerable locations (P)
	Decrease the number of poles along the corridor (P)

Table A-10: "Collisions Involving Older Drivers" Objectives and Countermeasures (Potts et al. 2004)

Objective	Countermeasure
Plan for an aging population	Establish a broad-based coalition to plan for addressing older adults' transportation needs (T)
Improve the roadway and driving environment to better accommodate older drivers' special needs	Provide advanced warning signs (T)
	Provide advanced guide signs and street name signs (T)
	Increase size and letter height of roadway signs (T)
	Provide all-red clearance intervals at signalized intersections (T)
	Provide more protected left-turn signal phases at high-volume intersections (T)
	Provide offset left-turn lanes at intersections (T)
	Improve lighting at intersections, horizontal curves, and railroad grade crossings (T)
	Improve roadway delineation (T)
	Replace painted channelization with raised channelization (P)
	Reduce intersection skew angle (T)
	Improve traffic control at work zones (T)
Identify older drivers at increased risk of crashing and intervene	Strengthen the role of medical advisory boards (T)
	Update procedures for assessing medical fitness to drive (P)
	Encourage external reporting of impaired drivers to licensing authorities (T)
	Provide remedial assistance to help functionally impaired older drivers (T)
Improve the driving competency of older adults in the general driving population	Establish resource centers within communities to promote safe mobility choices (T)
	Provide educational and training opportunities to the general older driver population (T)
Reduce the risk of injury and death to older drivers and passengers involved in crashes	Increase seatbelt use by older drivers and passengers (P)

Table A-11: "Collisions Involving Pedestrian" Objectives and Countermeasures (Zegeer et al. 2004)

Objective	Countermeasure
Reduce pedestrian exposure to vehicular traffic	Provide sidewalks/walkways and curb ramps (P)
	Install or upgrade traffic and pedestrian signals (P)
	Construct pedestrian refuge island and raised medians (P)
	Provide vehicle restriction/diversion measures (P)
	Install overpasses/underpasses (P)
Improve sight distance and/or visibility between motor vehicles and pedestrians	Provide crosswalk enhancements (P)
	Implement lighting/crosswalk illumination measures (P)
	Eliminate screening by physical objects (T)
	Signals to alert motorists that pedestrians are crossing (T)
	Improve reflectorization/conspicuity of pedestrians (T)
Reduce vehicle speed	Implement road narrowing measures (T)
	Install traffic calming-road sections (P)
	Install traffic calming-intersections (P)
	Provide school route improvements (T)
Improve pedestrian and motorist safety awareness and behavior	Provide education, outreach, and training (P)
	Implement enforcement campaigns (T)

Table A-12: "Increase Seatbelt Use" Objectives and Countermeasures (Lucke et al. 2004)

Objective	Countermeasure
Maximize use of occupant restraints by all vehicle occupants	Conduct highly publicized enforcement campaigns to maximize restraint use (P)
	Provide enhanced public education to population groups with lower than average restraint use rates (P)
	Encourage the enactment of local laws that will permit standard enforcement of restraint laws (T)
Insure that restraints, especially child and infant restraints, are properly used	Provide community locations for instruction in proper child restraint use, including both public safety agencies and health care providers, that are almost always available (T)
	Conduct high-profile "child-restraint inspections" events at multiple community locations (P)
	Train law enforcement personnel to check for proper child restrain use in all motorist encounters (T)
Provide access to appropriate information, materials, and guidelines for those implementing programs to increase occupant restraint use	Create state-level clearing houses for materials that offer guidance in implementing programs to increase restrain use (E)

Table A-13: "Collisions at Signalized Intersections" Objectives and Countermeasures (Antonucci et al. 2004)

Objective	Countermeasure
Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	Employ multiphase signal operation (P)
	Optimize clearance intervals (P)
	Restrict or eliminate turning maneuvers (including right turns on red) (T)
	Employ signal coordination along a corridor or route (P)
	Employ emergency vehicle preemption (P)
	Improve operation of pedestrian and bicycle facilities at signalized intersections (P)
	Remove unwarranted signal (P)
Reduce frequency and severity of intersection conflicts through geometric improvements	Provide/improve left turn channelization (P)
	Provide/improve right turn channelization (P)
	Improve geometry of pedestrian and bicycle facilities (P)
	Revise geometry of complex intersections (P)
	Construct special solutions (T)
Improve sight distance at signalized intersection	Clear sight triangles (T)
	Redesign intersection approaches (P)
Improve driver awareness of intersections and signal control	Improve visibility of intersections on approaches (T)
	Improve visibility of signals and signs at intersections (T)
Improve driver compliance with traffic control devices	Provide public information and education (P)
	Provide targeted conventional enforcement of traffic laws (T)
	Implement automated enforcement of red light running (P)
	Implement automated enforcement of approach speeds (T)
	Control speed on approaches (E)
Improve access management near signalized intersections	Restrict access to properties using driveways closures or turn restrictions (T)
	Restrict cross median access near intersections (T)
Improve safety through other infrastructure treatments	Improve drainage in intersection and on approaches (T)
	Provide skid resistance in intersection and on approaches (T)
	Coordinate closely spaced signals near at-grade railroad crossings (T)
	Relocate signal hardware out of clear zone (T)
	Restrict or eliminate parking on intersection approaches (P)

Table A-14: "Collisions Involving Heavy Trucks" Objectives and Countermeasures (Knipling et al. 2004)

Objective	Countermeasure
Reduce fatigue-related crashes	Increase efficiency of use of existing parking spaces (E)
	Create additional parking spaces (T)
	Incorporate rumble strips into new and existing roadways (E)
Strengthen CDL program	Improve test administration for the CDL (T)
	Increase fraud detection of state and third party testers (T)
Increase knowledge "Sharing the Road"	Incorporate "Share the Road" information into driver materials (T)
	Promulgate "Share the Road" information through print and electronic media (T)
Improve maintenance of heavy trucks	Increase and strengthen truck maintenance programs and inspection performance (E)
	Conduct post crash inspections to identify major problems and problem conditions (E)
Identify and correct unsafe roadway infrastructure and operational characteristics	Identify and treat truck crash roadway segments-signing (E)
	Install interactive truck rollover signing (P)
	Modify speed limits and increase enforcement to reduce truck and other vehicle speeds (T)
Improve and enhance truck safety data	Increase the timeliness, accuracy, and completeness of truck safety data (NA)
Promote industry safety initiatives	Perform safety consultations with carrier safety management (P)
	Promote development and deployment of truck safety technologies (E)

Table A-15: "Crashes Involving Drowsy and Distracted Drivers" Objectives and Countermeasures (Stutts et al. 2005)

Objective	Countermeasure
Make roadway safety for drowsy and distracted drivers	Install shoulder and/or centerline rumble strips (P)
	Implement other roadway improvements to reduce the likelihood and severity of run-off-road and/or head-on collisions (P)
	Implement roadway improvements to reduce the likelihood and severity of other types of distracted and drowsy driving crashes (T)
Prove safe stopping and resting areas	Improve access to safe stopping and resting areas (T)
	Improve rest area security and services (T)
Increase driver awareness of the risks of drowsy and distracted driving and promote driver focus	Conduct education and awareness campaigns targeting the general driving public (T)
	Visibly enforce existing statutes to deter distracted and drowsy driving (E)
Implement programs that target populations at increased risk of drowsy or distracted driving crashes	Strengthen graduated driver licensing requirements for young drivers (P)
	Incorporate information on distracted/fatigued driving into education programs and materials for young drivers (T)
	Encourage employers to offer fatigue management programs to employees working nighttime or rotating shifts (P)
	Enhance enforcement of commercial motor vehicle hours of service regulations (P)
	Encourage trucking companies and other fleet operators to implement fatigue management programs (T)
	Implement targeted interventions for other high risk populations (T)

Table A-16: "Enhancing Rural Emergency Medical Services" Objectives and Countermeasures (Torbic et al. 2005)

Objective	Countermeasure
Provide or improve management and decision-making tools	Develop resource and performance standards unique to the specific rural EMS (T)
	Identify, provide, and mandate efficient and effective methods for collection of necessary EMS data (T)
	Identify and evaluate model rural EMS operations (T)
	Provide evaluation results to elected and administrative officials at the county and local levels (T)
Provide better education opportunities for rural EMS	Utilize technology-based instruction for rural EMS training (P)
	Establish an exchange program to allow rural EMS providers to spend a specific number of hours in urban/suburban systems (E)
	Include principles of traffic safety and injury prevention as part of EMS continuing education (E)
	Require first care training for all public safety emergency response personnel, including law enforcement officers (T)
	Educate rural residents about the availability, capability, and limitations of existing systems (T)
	Provide "bystander care" training programs targeting new drivers, rural residents, truck drivers, interstate commercial bus drivers, and motorcyclists (T)
	Provide EMS training programs in high schools in rural areas (T)
Reduce time from injury to appropriate definitive care	Improve cellular telephone coverage in rural areas (T)
	Improve compliance of rural 9-1-1 centers with FCC wireless "Phase II" automatic location capability (T)
	Utilize GPS technology to improve response time (T)
	Integrate automatic vehicle location (AVL) and computer-aided navigation (CAN) technologies into all computer-aided dispatch (CAD) systems (T)
	Equip EMS vehicles with multi-service and/or satellite-capable telephones (T)

Table A-17: "Alcohol-Related Collisions" Objectives and Countermeasures (Goodwin et al. 2005)

Objective	Countermeasure
Reduce excessive drinking and underage drinking	Increase the state excise tax on beer (T)
	Require responsible beverage service policies for alcohol servers and retailers (P)
	Conduct well-publicized compliance checks of alcohol retailers to reduce sales to underage persons (T)
	Employ screening and brief interventions in health care settings (T)
Enforce DWI Laws	Conduct regular well-publicized DWI checkpoints (P)
	Enhance DWI detection through special DWI patrols and related traffic enforcement (T)
	Publicize and enforce zero tolerance laws for drivers under age (P)
Prosecute, impose sanctions on, and treat DWI offenders	Suspend driver's license administratively upon arrest (P)
	Establish stronger penalties for BAC test refusal than for test failure (T)
	Eliminate diversion programs and plea bargains to non-alcohol offenses (T)
	Screen all convicted DWI offenders for alcohol problems and require treatment when appropriate (P)
Control high-BAC and repeat offenders	Seize vehicles or vehicle license plates administratively upon arrest (P)
	Require ignition interlocks as a condition for license reinstatement (P)
	Monitor all convicted DWI offenders closely (P)
	Incarcerate offenders (P)

Table A-18: "Work Zone Collisions" Objectives and Countermeasures (Antonucci et al. 2005)

Objective	Countermeasure
Reduce the number, duration, and impact of work zones	Improve maintenance and construction practices (P)
	Utilized full time roadway closure for construction operations (T)
	Utilize time related contract provisions (P)
	Use nighttime road work (P)
	Use demand management programs to reduce volume through work zones (P)
	Design future work zone capacity into new or reconstructed highways (T)
Improve work zone traffic control devices	Implement ITE strategies to improve safety (E)
	Improve visibility of work zone traffic control devices (T)
	Improve visibility of work zone personnel and vehicles (T)
	Reduce flaggers' exposure to traffic (T)
Improve work zone design practices	Establish work zone design guidance (T)
	Implement measures to reduce work space intrusions (and limit consequences of intrusions) (T)
	Improve work zone safety for pedestrians, bicyclists, motorcycles, and heavy truck drivers (T)
Improve drive compliance with work zone traffic controls	Enhance enforcement of traffic laws in work zones (T)
	Improve credibility of signs (E)
	Improve application of increased drive penalties in work zones (T)
Increase knowledge and awareness of work zones	Disseminate work zone safety information to road users (T)
	Provide work zone training programs and manuals for designers and field staff (T)
Develop procedures to effectively manage work zones	Develop or enhance agency level work zone crash data systems (T)
	Improve coordination, planning, and scheduling of work activities (T)
	Use incentives to create and operate safety work zones (T)
	Implement work zone quality assurance procedures (T)

Table A-19: "Collisions Involving Bicycles" Objectives and Countermeasures (Raborn et al. 2008)

Objective	Countermeasure
Reduce bicycle crashes at intersections	Improve visibility at intersections (T)
	Improve signal timing and detection (T)
	Improve signing (T)
	Improve pavement markings at intersections (T)
	Improve intersection geometry (T)
	Restrict right turn on red movements (E)
	Accommodate bicyclists through roundabouts (T)
	Provide an overpass or underpass (T)
Reduce bicycle crashes along roadways	Provide safe roadway facilities for parallel travel (T)
	Provide contraflow bicycle lanes (T)
	Improve bicyclists' visibility (T)
	Improve roadway signage (T)
	Provide bicycle-tolerable shoulder rumble strips (T)
Reduce motor vehicle speeds	Implement traffic calming techniques (P)
	Implement speed enforcement (T)
Reduce bicycle crashes at midblock crossings	Improve driveway intersections (T)
	Implement access management (T)
Improve safety awareness and behavior	Provide bicycle skill education (T)
	Improve enforcement of bicycle-related laws (T)
Increase use of bicycle safety equipment	Increase use of bicycle helmets (P)
	Increase rider and bicycle conspicuity (T)
Reduce effects of hazards	Fix or remove surface irregularities (T)
	Provide routine maintenance of bicycle facilities (T)

Table A-20: "Collisions Involving Young Drivers" Objectives and Countermeasures (Goodwin et al. 2007)

Objective	Countermeasure
Implement or improve graduate driver licensing systems	Enact a graduate licensing system (P)
	Require at least 6 months of supervised driver for beginners starting at age 16 (P)
	Implement a nighttime driving restriction that begins at 9 p.m. (P)
	Implement a passenger restriction allowing no young passengers (T)
	Prohibit cell phone use by drivers with a GDL license (T)
Publicize, enforce, and adjudicate laws pertaining to young drivers	Publicize and enforce GDL restrictions (E)
	Publicize and enforce laws pertaining to underage driving and driving (P)
	Publicize and enforce safety belt laws (P)
Assist parents in managing their teens' driving	Facilitate parental supervision of learners (T)
	Facilitate parental management of intermediate drivers (E)
	Encourage selection of safer vehicles for young drivers (E)
Improve young driver training	Improve content and delivery of drive education/training (E)
Employ school-based strategies	Eliminate early high school start times (i.e., before 8:30 a.m.) (T)
	Review transportation plans for new/expanded high school sites (E)

Table A-21: "Head-On Crashes on Freeways" Objectives and Countermeasures (Neuman et al. 2008)

Objective	Countermeasure
Keep vehicles from departing the traveled way	Install left shoulder rumble strips (T)
	Provide enhanced pavement markings and median delineation (T)
	Provide improved pavement surfaces (T)
Minimize the likelihood of head-on crashes with an oncoming vehicle	Provide wider medians (P)
	Improve median design for vehicle recovery (i.e., pavement edge drop off, install paved median shoulders, and design safer slopes) (T)
	Install median barriers for narrow width medians (P)
	Implement channelization, signing and striping improvements at interchanges susceptible to wrong way movements (T)
Reduce the severity of median barrier crashes that occur	Improve design and application of barrier and attenuation systems (T)
Enhance enforcement and awareness of traffic regulations	Designate "Highway Safety Corridors" (T)
	Conduct public information and education campaigns (T)
Improve coordination of agency safety initiatives	Enhance agency crash data system (T)

Table A-22: "Collisions Involving Motorcycles" Objectives and Countermeasures (Potts et al. 2008)

Objective	Countermeasure
Incorporate motorcycle-friendly roadway design, traffic control, construction, and maintenance policies and practices	Provide full paved shoulder to accommodate roadside motorcycle recovery and breakdowns (T)
	Consider motorcycles in the selection of roadside barriers (E)
	Identify pavement markings, surface materials, and other treatments that reduce traction for motorcycles and treat or replace with high-traction material (T)
	Maintain the roadway to minimize surface irregularities and discontinuities (T)
	Maintain roadway surfaces in work zones to facilitate safe passage of motorcycles (T)
	Reduce roadway debris from the roadway and roadside (such as gravel, shorn treads, snow, ice treatments, other debris) (T)
	Provide advanced warning signs to alert motorcyclists of reduced traction and irregular roadway surfaces (T)
	Incorporate motorcycle safety considerations into routine roadway inspection (E)
	Provide a mechanism to notifying highway agencies of roadway conditions that present a potential problem to motorcyclists (E)
Reduce the number of motorcycle crashes due to rider impairment	Increase motorcyclist awareness of the risks of impaired motorcycle operation (T)
	Expand existing impaired driving prevention programs to include motorcycle riders and specific motorcycle events (T)
	Target law enforcement to specific motorcycle rider impairment behaviors that have been shown to contribute to crashes (T)
Reduce the number of motorcycle crashes due to unlicensed or untrained motorcycle riders	Increase awareness of the causes of crashes due to unlicensed or untrained motorcycle riders (E)
	Ensure that licensing and rider training programs adequately teach and measure skills and behaviors required for crash avoidance (T)
	Identify and remove barriers to obtaining a motorcycle endorsement (T)
Increase the visibility of motorcyclists	Increase the awareness of the benefits of high-visibility clothing (E)
	Identify and promote rider visibility-enhancement methods and technology (T)
Reduce the severity of motorcycle crashes	Increase the use of FMCSS 218 compliant helmets (P)
	Increase the use of protective clothing (T)

Table A-22 Continued

Objective	Countermeasure
Increase motorcycle rider safety awareness	Form strategic alliances with motorcycle user community to foster and promote motorcycle safety (T)
	Increase awareness of the consequences of aggressive riding, riding while fatigued or impaired, unsafe riding, and poor traffic strategies (T)
	Educate operators of the other vehicles to be more conscious of the presences of motorcyclists (T)
Increase safety enhancements for motorcyclists	Include motorcycles in the research, development, and deployment of ITS (E)
Improve motorcycle safety research, data and analysis	Develop and implement standardized data gathering and reporting for motorcycle crashes (NA)
	Include motorcycle attributes in vehicle exposure data collection programs (NA)
	Develop a set of analysis tools for motorcycle crashes (NA)

Table A-23: "Speeding Related Crashes" Objectives and Countermeasures (Neuman et al. 2009)

Objective	Countermeasure
Set appropriate speeds	Set speed limits which account for roadway design, traffic, and environment (T)
	Implement variable speed limits (T)
	(High speeds only) Implement differential speed limits for heavy vehicles if appropriate (T)
Heighten driver awareness of speeding-related safety issues	Increase public awareness of the risk of driving at unsafe speeds (T)
	Increase public awareness of potential penalties for speeding (T)
	Increase public awareness of risks of not wearing seatbelts (T)
	(Low speeds only) Implement neighborhood speed watch/traffic management programs (T)
	Implement "Safe Community" programs (T)
Improve efficiency and effectiveness of speed enforcement efforts	Use targeted conventional speed enforcement programs at locations known to have speeding related crashes (P)
	Implement automated speed enforcement (T)
	Increase penalties for repeat and excessive speeding offenders (T)
	Strengthen the adjudication of speeding citations to enhance the deterrent effects of fines (T)
	Increase fines in special areas (T)
Communicate appropriate speeds through use of traffic control devices	Improve speed limit signage (T)
	Implement active speed warning signs (T)
	Use in-pavement measures to communicate the need to reduce speeds (T)
	(High speeds only) Implement variable message signs (T)

Table A-23 Continued

Objective	Countermeasure
Ensure that roadway design and traffic control elements support appropriate and safe speeds	Use combinations of geometric elements to speeds (horizontal and vertical curves, cross sections), including providing design consistency along an alignment (T)
	Effect safe speed transitions through design elements and on approaches to lower speed areas (T)
	Provide appropriate intersection design for speed of roadway (T)
	Provide adequate change and clearance intervals at signalized intersections (P)
	Operate traffic signals appropriately for intersections and corridors (signal progression) (T)
	Provide adequate sight distance for expected speeds (P)
	(High speeds only) Implement protected only signal phasing for left turns at high speed signalized intersections (T)
	(High speeds only) Install lighting at high speed intersections (T)
	(Low speeds only) Reduce speeds and/or volume on both neighborhood and downtown streets with the use of traffic calming and other related countermeasures (T)

APPENDIX B CRITICAL DATA COLUMNS

Appendix B is a collection of tables, which provide a list of the critical data columns for each dataset used in the safety analysis of state roadways. The critical data columns are used in the "Check Headers" worksheet tool as new data are analyzed in the Roadway Safety Analysis methodology. As discussed previously in Section 3.3.1, some of the critical data columns reflect the expected column headings in the dataset as available from UDOT, while other critical data columns reflects column headings created in the Roadway Safety Analysis methodology. If these critical data columns are omitted or missing, then the safety analysis process cannot be completed as originally intended.

A description is given to the name of the expected header, which can be edited by the analyst through the automation tools described in this research. The tables list the expected heading and a description of the critical data column, separated by the columns expected in the data provided by UDOT and the columns created in the Roadway Safety Analysis methodology. Table B-1 to Table B-4 in Section B.1 summarize the critical data columns for the crash data. Table B-5 to Table B-10 in Section B.2 summarize the critical data columns for the roadway data in the pre-model preparation process. Table B-11 to Table B-20 in Section B.3 summarize the critical data columns for the roadway data in the creation of the Roadway Safety Analysis reports.

B.1 Critical Data Columns for Crash Database

For the following critical data columns, the files are sourced from the UDOT Traffic and Safety Division. The omission of these critical data columns will prevent the Roadway Safety Analysis methodology from proceeding as originally designed. The crash data are protected under 23 USC 409 (USGPO 2012).

Table B-1: Critical Data Columns for Crash Data (General)

From UDOT	
Heading	**Description**
CRASH_ID	Crash ID: unique crash ID number for each crash
CRASH_DATETIME	Crash Date/Time: date and time of crash
CRASH_SEVERITY_ID	Crash Severity ID: numerical severity level of crash (i.e. 1-5)
LIGHT_CONDITION_ID	Light Condition: ID for light condition at time of crash (i.e. 1-6, 88-99)
WEATHER_CONDITION_ID	Weather Condition: ID for weather condition at time of crash (i.e. 1-9, 88-99)
MANNER_COLLISION_ID	Manner Collision: ID for manner of collision in crash (i.e. 1-8, 88-99)
PAVEMENT_ID	Pavement: ID for pavement type (i.e. 1-4, 88-99)
ROADWAY_SURF_CONDITION_ID	Roadway Surface Condition: ID for roadway surface conditions (i.e. 1-9, 88-99)
ROADWAY_JUNCT_FEATURE_ID	Roadway Junction Feature: ID for roadway junction feature (i.e.1-10, 20-26, 88-99)
WORK_ZONE_RELATED_YNU	Work Zone Related: Y/N to determine whether crash occurred in work zone
WORK_ZONE_WORKER_PRESENT_YNU	Work Zone Worker Present: Y/N to determine whether worker present in work zone
HORIZONTAL_ALIGNMENT_ID	Horizontal Alignment: ID for horizontal curvature of roadway (i.e. 1-2, 88-99)
VERTICAL_ALIGNMENT_ID	Vertical Alignment: ID for vertical curvature of roadway (i.e. 1-4. 88-99)
ROADWAY_CONTRIB_CIRCUM_ID	Roadway Contributing Circumstance: ID for vehicle contributing circumstance related to the crash (i.e. 0-18, 88-99)
FIRST_HARMFUL_EVENT_ID	First Harmful Event: ID for first harmful event resulting from the crash (i.e. 0-62, 88-99)

Table B-2: Critical Data Columns for Crash Location Data

From UDOT	
Heading	**Description**
CRASH_ID	Crash ID: unique crash ID number for each crash
ROUTE	Route ID: numeric route number for a given roadway segment
ROUTE_DIRECTION	Direction: route direction (i.e. P, N, or X)
RAMP_ID	Ramp ID: ID indicating a ramp and the type (i.e. 1-4, CD)
MILEPOINT	MP: mile point location of the crash

Table B-3: Critical Data Columns for Vehicle Crash Data

From UDOT	
Heading	**Description**
CRASH_ID	Crash ID: Specific crash ID number for each crash
VEHICLE_NUM	Vehicle Number: Number assigned to each vehicle involved in a given crash
CRASH_DATETIME	Crash Date/Time: Date and time of crash
TRAVEL_DIRECTION_ID	Travel Direction: Direction value of route at the location of the crash (i.e. 1-5)
EVENT_SEQUENCE_1_ID	Event Sequence #1: ID for first crash sequence for non-collision and collision events (i.e. 0-99)
EVENT_SEQUENCE_2_ID	Event Sequence #2: ID for second crash sequence for non-collision and collision events (i.e. 0-99)
EVENT_SEQUENCE_3_ID	Event Sequence #3: ID for third crash sequence for non-collision and collision events (i.e. 0-99)
EVENT_SEQUENCE_4_ID	Event Sequence #4: ID for fourth crash sequence for non-collision and collision events (i.e. 0-99)
MOST_HARMFUL_EVENT_ID	Most Harmful Event: ID for most harmful event resulting from the crash (i.e. 0-99)
VEHICLE_MANEUVER_ID	Vehicle Maneuver: ID for the controlled maneuver prior to the crash (i.e. 1-14, 88-99)
VEHICLE_DETAIL_ID	Vehicle Detail ID: 8-digit ID number that is specific to a vehicle involved in a crash amongst all other vehicle involved in crashes

Table B-4: Critical Data Columns for Crash Rollup Data

From UDOT	
Heading	**Description**
CRASH_ID	Crash ID: unique crash ID number for each crash
NUMBER_VEHICLES_INVOLVED	Number Vehicles Involved: number of vehicles involved in the given accident
NUMBER_FATALITIES	Number of Fatalities: number of person-fatalities resulting from a given crash
NUMBER_FOUR_INJURIES	Number of incapacitating injuries: number of person-incapacitating injuries resulting from a given crash
NUMBER_THREE_INJURIES	Number of injuries: number of person-injuries resulting from a given crash
NUMBER_TWO_INJURIES	Number of possible injuries: number of person-possible injuries resulting from a given crash
NUMBER_ONE_INJURIES	Number of property damage only events: number of events for property damage only resulting from a given crash
PEDESTRIAN_INVOLVED	Pedestrian Involved: Y/N to determine whether a pedestrian was involved in the crash
BICYCLIST_INVOLVED	Bicyclist Involved: Y/N to determine whether a bicyclists was involved in the crash
MOTORCYCLE_INVOLVED	Motorcycle Involved: Y/N to determine whether a motorcycle was involved in the crash
IMPROPER_RESTRAINT	Improper Restraint: Y/N to determine whether improper restraint was a factor in the crash
UNRESTRAINED	Unrestrained: Y/N to determine whether a driver/passenger was unrestrained in the crash
DUI	DUI: Y/N to determine whether driving under the influence was a factor in the crash
AGGRESSIVE_DRIVING	Aggressive Driving: Y/N to determine whether aggressive driving was a factor in the crash
DISTRACTED_DRIVING	Distracted Driving: Y/N to determine whether distracted driving was a factor in the crash
DROWSY_DRIVING	Drowsy Driving: Y/N to determine whether drowsy driving was a factor in the crash
SPEED_RELATED	Speed Related: Y/N to determine whether speed was a factor in the crash
INTERSECTION_RELATED	Intersection Related: Y/N to determine whether the crash occurred at an intersection
ADVERSE_WEATHER	Adverse Weather: Y/N to determine whether adverse weather was a factor in the crash

Table B-4 Continued

From UDOT	
Heading	**Description**
ADVERSE_ROADWAY_SURF_CONDITION	Adverse Roadway Surface Conditions: Y/N to determine whether adverse roadway surface conditions were a factor in the crash
ROADWAY_GEOMETRY_RELATED	Roadway Geometry Related: Y/N to determine whether roadway geometry was a factor in the crash
WILD_ANIMAL_RELATED	Wild Animal Related: Y/N to determine whether a wild animal was involved in the crash
DOMESTIC_ANIMAL_RELATED	Domestic Animal Related: Y/N to determine whether a domestic animal was involved in the crash
ROADWAY_DEPARTURE	Roadway Departure: Y/N to determine whether a vehicle departed the roadway as a result of the crash
OVERTURN_ROLLOVER	Overturn/Rollover: Y/N to determine whether a vehicle overturned and/or rolled over as a result of a crash
COMMERCIAL_MOTOR_VEH_INVOLVED	Commercial Motor Vehicle Involved: Y/N to determine whether a commercial motor vehicle was involved in the crash
INTERSTATE_HIGHWAY	Interstate Highway: Y/N to determine whether the crash occurred on an interstate roadway
TEENAGE_DRIVER_INVOLVED	Teenage Drive Involved: Y/N to determine whether a teenage driver was involved in the crash
OLDER_DRIVER_INVOLVED	Older Driver Involved: Y/N to determine whether an older driver was involved in the crash
URBAN_COUNTY	Urban County: Y/N to determine whether the crash occurred in an urban area
NIGHT_DARK_CONDITION	Night/Dark Condition: Y/N to determine whether night or dark conditions was a factor in the crash
SINGLE_VEHICLE	Single Vehicle: Y/N to determine whether a single vehicle was involved in a crash (i.e. not a collision involving multiple vehicles)
TRAIN_INVOLVED	Train Involved: Y/N to determine whether a train was involved in the crash
RAILROAD_CROSSING	Railroad Crossing: Y/N to determine whether the crash occurred at a railroad crossing
TRANSIT_VEHICLE_INVOLVED	Transit Vehicle Involved: Y/N to determine whether a transit vehicle was involved in the crash
COLLISION_WITH_FIXED_OBJECT	Collision with Fixed Object: Y/N to determine whether the crash involved a fixed object (i.e. not another vehicle, nor a person)

B.2 Critical Data Columns for Roadway Segmentation Database

For the following critical data columns, the files are sourced from the UDOT Open Data website (UDOT 2015d). The omission of these critical data columns will prevent the Roadway Safety Analysis methodology from proceeding as originally designed.

Table B-5: Critical Data Columns for AADT Data

From UDOT	
Heading	**Description**
ROUTE	Route ID: numeric route number for a given roadway segment
BEGMP	Beginning Milepoint: beginning milepost of the roadway segment
ENDMP	End Milepoint: end milepost of the roadway segment
STATION	Station Number: seven digit number, identifying the traffic counter station number
AADT[YEAR]	AADT [YEAR]: historical dataset of Annual Average Daily Traffic data from each year; at least 7 years of this data are needed (i.e. AADT2012)
SUTrk2014	Single Truck Percent: percent of single trailer trucks per segment
CUTrk2014	Combo Truck Percent: percent of combination trailer trucks per segment
NumST	Single Truck Count: number of single trailer trucks per segment
NumCT	Combo Truck Count: number of combination trailer trucks per segment

Table B-6: Critical Data Columns for Functional Classification Data

From UDOT	
Heading	**Description**
ROUTE_NAME	Route ID: numeric route number for a given roadway segment
DIRECTION	Direction: route direction (i.e. P, N, or X)
BEGIN_MP	Beginning MP: beginning milepost of the roadway segment
END_MP	End MP: end milepost of the roadway segment
FC_CODE	FC_CODE: number representing the functional classification type of the road

Table B-7: Critical Data Columns for Sign Faces

From UDOT	
Heading	**Description**
ROUTE_NAME	Route ID: numeric route number for a given roadway segment
ROUTE_DIR	Direction: route direction (i.e. P, N, or X)
START_ACCUM	Beginning MP: the beginning milepost of the roadway segment
LEGEND	Legend: text printed on the sign
COLLECTED_DATE	Collection Date: date that the sign information was collected/updated
MUTCD	MUTCD: Manual on Uniform Traffic Control Devices (MUTCD) code for sign types

Table B-8: Critical Data Columns for Speed Limit

From UDOT	
Heading	**Description**
Route	Route ID: Route ID number with direction letter (i.e. 0089N)
Direction	Direction: Route direction (P, N)
Beg_MP	Beginning MP: The milepost where the sign appears
End_MP	End MP: The end milepost of the roadway segment
Speed_Limit	Speed Limit: number signifying the speed limit (in MPH) of a particular segment.

Table B-9: Critical Data Columns for Lanes (Thru Lanes)

From UDOT	
Heading	**Description**
ROUTE_NAME	Route ID: numeric route number for a given roadway segment
START_ACCUM	Beginning MP: beginning milepost of the roadway segment
END_ACCUM	End MP: end milepost of the roadway segment
THRU_LANE	Thru Lanes: number of through lanes

Table B-10: Critical Data Columns for Urban Code

From UDOT	
Heading	**Description**
ROUTE_NAME	Route ID: numeric route number for a given roadway segment
START_ACCU	Beginning MP: beginning milepost of the roadway segment
END_ACCUM	End MP: end milepost of the roadway segment
URBAN_CODE	Urban Code: number that represents a description of the surrounding area
URBAN_DESC	Urban Description: description of the surrounding area (i.e. Small-Urban, St. George, rural, etc.)

B.3 Critical Data Columns for Combining Problem Segments and Roadway Data

For the following critical data columns, some of the files come from the UDOT Open Data website (UDOT 2015d), the UDOT Traffic and Safety Division, and some of the data files are derived in the Roadway Safety Analysis methodology. The following data columns reflect the critical data columns needed, after the roadway characteristics have been spatially joined with the selected segments for analysis. The omission of these critical data columns will prevent the Roadway Safety Analysis methodology from proceeding as originally designed.

Table B-11: Critical Data Columns for Barrier

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning milepoint of the barrier roadway data
END_ACCUM	End MP (Roadway Feature): the end milepoint of the barrier roadway data
BARRIER_TY	Barrier Type: barrier type data
OMS_SIDE	Barrier Side: barrier side data
From Roadway Safety Analysis Methodology	
Heading	**Description**
LABEL	Label: Route name and direction (example: 0008P)
BEG_MILEPO	Beginning MP (Ranked Segment): the beginning milepoint of the ranked roadway segment
END_MILEPO	End MP (Ranked Segment): the end milepoint of the ranked roadway segment
FC_Type	Functional Classification Type of roadway
COUNTY	County where segment resides
REGION	UDOT Region
[AADT]	AADT of most recent Year
SPEED_LIMIT	Speed limit of roadway
Num_Lanes	Number of lanes on roadway
Urban_Ru_1	Urban Rural Name
Total_Perc	Total Percent Trucks (from AADT)
Total_Crash	Total Crashes on Roadway
Severe_Crash	Severe Crashes on Roadway
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-12: Critical Data Columns for Curve

From UDOT	
Heading	**Description**
To_MP	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
From_MP	End MP (Roadway Feature): the end mile point of the roadway feature data
Curve_Clas	Curve Class: horizontal curve class data
Curve_Degr	Curve Degree: horizontal curve degree data
Curve_Radi	Curve Radius: horizontal curve radius data
Curve_Leng	Curve Length: horizontal curve length data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-13: Critical Data Columns for Grade

From UDOT	
Heading	**Description**
BEG_MILEPO	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_MILEPO	End MP (Roadway Feature): the end mile point of the roadway feature data
Grade	Grade: vertical grade data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-14: Critical Data Columns for IPM

From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
FREQUENCY	Frequency: frequency of intersections along a given segment
Length	Length: length of a segment of IPM data
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-15: Critical Data Columns for Lane

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_ACCUM	End MP (Roadway Feature): the end mile point of the roadway feature data
RIGHT_TURN	Right Turn: count of right turn lanes along segment of lane data
LEFT_TURN_	Left Turn: count of left turn lanes along segment of lane data
ACCELL_LAN	Accell Lane: count of accelerations lanes along segment of lane data
DECELL_LAN	Decell Lane: count of deceleration lanes along segment of lane data
TWO_WAY_LE	Two Way Left Turn Lane (TWLTL): count of two way left turn lanes along segment of lane data
PASSING_LA	Passing Lane: count of passing lanes along segment of lane data
BIKE_LANE_	Bike Lane: count of bike lanes along segment of lane data
HOV_LANE_C	HOV Lane: count of HOV lanes along segment of lane data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-16: Critical Data Columns for Median

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_ACCUM	End MP (Roadway Feature): the end mile point of the roadway feature data
MEDIAN_TYPE	Median Type: median type data along segment of median data
TRAFFIC_IS	Traffic Island: traffic island type data along segment of median data
MEDIAN_WID	Median Width: median width data along segment of median data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-17: Critical Data Columns for Rumble Strips

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_ACCUM	End MP (Roadway Feature): the end mile point of the roadway feature data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-18: Critical Data Columns for Shoulder

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_ACCUM	End MP (Roadway Feature): the end mile point of the roadway feature data
EDGE_TYPE	Edge Type: shoulder edge type data along segment of shoulder data
MATERIAL	Material: shoulder material type data along segment of shoulder data
SHOULDER_W	Shoulder Width: shoulder width data along segment of shoulder data (ft)
SIDE	Side: shoulder side data along segment of shoulder data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-19: Critical Data Columns for SPM

From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
FREQUENCY	Frequency: frequency of signs along a given segment
Length	Length: length of a segment of SPM data
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

Table B-20: Critical Data Columns for Wall

From UDOT	
Heading	**Description**
START_ACCU	Beginning MP (Roadway Feature): the beginning mile point of the roadway feature data
END_ACCUM	End MP (Roadway Feature): the end mile point of the roadway feature data
From Roadway Safety Analysis Methodology	
Heading	**Description**
BEG_MILEPOINT	Beginning MP (Ranked Segment): the beginning mile point of the ranked roadway segment
END_MILEPOINT	End MP (Ranked Segment): the end mile point of the ranked roadway segment
State_Rank	State Rank: the statistical rank of the segment compared to other segments in the state
Region_Rank	Region Rank: the statistical rank of the segment compared to other segments in the same region
County_Rank	County Rank: the statistical rank of the segment compared to other segments in the same county

APPENDIX C TRAFFIC CRASH REPORT CODES

Appendix C provides a summary of the traffic crash report codes representing the most harmful event, first harmful event, manner of collision, sequence of events, and vehicle maneuver. As described previously in Section 3.2, the traffic crash reports are completed when there is a death, injury, or property damage over $1,500 resulting from a crash (UHP 2016). In Table C-1 to Table C-4, the possible fields for the crash report fields will be provided. The explanation of these fields and their meanings are summarized in the "Utah Investigators Vehicle Crash Report Instruction Manual" (UTRCC 2012) and explained on the Utah Department of Public Safety Website (UDPS 2016).

Diligence should be made that this is the most updated version of the "Crash Report Instruction Manual" when reviewing the crash data. It is also important to know that the codes were updated around 2009 and may be updated every few years. There are some codes that do not show up in the revisions that existed in the previous sets of codes; however, these missing codes (in the 80 to 99 range) denote "Unknown" or "Unavailable," which are synonymous with "Not Applicable."

Table C-1: Key for Most Harmful Event and First Harmful Event Codes (UTRCC 2012)

#	Meaning	#	Meaning
0	No Damage	40	Guardrail
1	ROR Right	41	Concrete Barrier
2	ROR Left	42	Cable Barrier
3	Crossed Median/Centerline	43	Crash Cushion
4	Equipment Failure	44	Guardrail End Section
5	Separation of Unit	45	Concrete Sloped End Section
6	Downhill Runaway	46	Cable Barrier End Section
7	Overturn/Rollover	47	Access Control Cable
8	Cargo/Equipment Loss	48	Bridge Rail
9	Jackknife	49	Bridge Pier or Support
10	Fire/Explosion	50	Bridge Overhead Structure
11	Immersion	51	Traffic Sign Support
12	Fell/Jumped from Motor Vehicle	52	Delineator Post
19	Other Non-Collision	53	Other Post/Pole/Support
20	Motor Vehicle in Transit	54	Utility Pole/Light Support
21	Parked Motor Vehicle (off roadway)	55	Traffic Signal Support
22	Pedestrian	56	Culvert
23	Pedalcycle	57	Ditch
24	Skates, Scooters, Skateboards	58	Embankment
25	Animal - Wilk	59	Snow Bank
26	Animal - Domestic	60	Tree/Shrubbery
27	Work Zone	61	Mailbox/Fire Hydrant
28	Freight Rail	62	Fence
29	Light Rail	69	Other Fixed Object
30	Passenger Heavy Rail	88	Invalid
31	Thrown/Fallen Object	89	Not Provided
39	Other Non-Fixed Object	96	Not Applicable
		99	Unknown

Table C-2: Key for Manner of Collision Codes (UTRCC 2012)

#	Meaning	#	Meaning
1	Angle	7	Rear to Side
2	Front to Rear	8	Rear to Rear
3	Head On	88	Invalid
4	Sideswipe Same Direction	89	Not Provided
5	Sideswipe Opposite Direction	96	N/A
6	Parked Vehicle	99	Unknown

Table C-3: Key for Sequence of Events Codes (UTRCC 2012)

#	Meaning	#	Meaning
0	No Damage	40	Guardrail
1	ROR Right	41	Concrete Barrier
2	ROR Left	42	Cable Barrier
3	Crossed Median/Centerline	43	Crash Cushion
4	Equipment Failure	44	Guardrail End Section
5	Separation of Unit	45	Concrete Sloped End Section
6	Downhill Runaway	46	Cable Barrier End Section
7	Overturn/Rollover	47	Access Control Cable
8	Cargo/Equipment Loss	48	Bridge Rail
9	Jackknife	49	Bridge Pier or Support
10	Fire/Explosion	50	Bridge Overhead Structure
11	Immersion	51	Traffic Sign Support
12	Fell/Jumped from Motor Vehicle	52	Delineator Post
19	Other Non-Collision	53	Other Post/Pole/Support
20	Operating Motor Vehicle	54	Utility Pole/Light Support
21	Parked Motor Vehicle (off roadway)	55	Traffic Signal Support
22	Pedestrian	56	Culvert
23	Pedalcycle	57	Ditch
24	Skates, Scooters, Skateboards	58	Embankment
25	Animal - Wilk	59	Snow Bank
26	Animal - Domestic	60	Tree/Shrubbery
27	Work Zone	61	Mailbox/Fire Hydrant
28	Freight Rail	62	Fence
29	Light Rail	69	Other Fixed Object
30	Passenger Heavy Rail	88	Invalid
31	Thrown/Fallen Object	89	Not Provided
39	Other Non-Fixed Object	96	Not Applicable
		99	Unknown

Table C-4: Key for Vehicle Maneuver Codes (UTRCC 2012)

#	Meaning	#	Meaning
1	Straight Ahead	11	Slowing in Traffic Lane
2	Backing	12	Immobile From Previous Crash
3	Changing Lanes	13	Parked
4	Overtaking/Passing	14	Parking Maneuvers
5	Turning Right	88	Invalid
6	Turning Left	89	Not Provides
7	Making U-turn	96	N/A
8	Leaving Traffic Lane	97	Other
9	Entering Traffic Lane	99	Unknown
10	Stopped in Traffic Lane		