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USING A SAFETY FORECAST MODEL TO CALCULATE FUTURE SAFETY METRICS

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Submitted By:

RSG

Authored By:

Kordel Braley, PE, PTOE
Chad Worthen

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Keeping Utah Moving
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4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

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16. Abstract

This research sought to identify a process to improve long-range planning prioritization by using forecasted safety metrics in place of the existing Utah Department of Transportation Safety Index—a metric based on historical crash data. The research team developed a Safety Forecast Model using Highway Safety Manual Safety Performance Functions and Crash Modification Factors. The research team obtained existing roadway characteristics that served as inputs for the Safety Forecast Model from uPlan. The research team also collected future condition data—such as forecast volumes and lanes—from the Utah Statewide Travel Model, a travel demand forecasting model. The Safety Forecast Model compared crashes predicted based on the current 2015–2040 UDOT Long-Range Plan (LRP) Build scenario to crashes predicted based on the No-Build scenario. The research team determined, through a case study of 15 LRP widening projects, that the project prioritization ranking changes if the ranking considers future safety impacts rather than relying solely on historical crash data. The research team also determined that the Safety Forecast Model could be used to recommend safety projects and perform systemic safety analyses.

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CMF	Crash Modification Factors
FHWA	Federal Highway Administration
FI	Fatal and Injury
HSM	Highway Safety Manual
IHSDM	Interactive Highway Safety Design Model
LRP	Long-Range Plan
MPO	Metropolitan Planning Organization
PDO	Property-Damage-Only
SPF	Safety Performance Function
SR	State Road
TWLTL	Two-Way Left-Turn Lanes
UDOT	Utah Department of Transportation
USTM	Utah Statewide Travel Model

EXECUTIVE SUMMARY

The Utah Department of Transportation (UDOT) uses a Safety Index as one of several metrics to identify and prioritize projects for their Long-Range Plan (LRP). The Safety Index uses crash history metrics, but it does not consider forecasts of safety conditions. This research sought to identify a process to improve long-range planning prioritization by using forecasted safety metrics in place of the existing UDOT Safety Index.

The research team for this project developed a Safety Forecast Model using Highway Safety Manual (HSM) Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs). The research team obtained existing roadway characteristics that served as inputs for the Safety Forecast Model from uPlan. The research team also collected condition data—such as forecast volumes and lanes—from the Utah Statewide Travel Model (USTM), a travel demand forecasting model. Existing crash data (obtained from UDOT) were used to assess the base-year crash predictions of the Safety Forecast Model. The model was used to compare crashes predicted based on the current 2015–2040 UDOT LRP Build scenario to crashes predicted based on the No-Build scenario.

The research team determined, through a case study of 15 LRP widening projects, that the project prioritization ranking changes if the ranking considers future safety impacts rather than relying solely on historical crash data. All else being equal, the new process examined as part of this research gives road segments that are most likely to experience an improvement in safety a higher prioritization ranking than segments that would not experience an increase in safety.

The research team also determined that the Safety Forecast Model could be used to recommend safety projects or for other applications such as systemic safety analyses. Systemic safety analysis looks at roadway and crash attributes to identify common conditions across the state (as opposed to looking at spot aggregations of crashes) that lead to fatal and serious-injury crashes. For example, the Safety Forecast Model was used to identify road segments with the highest reduction in fatal and injury (FI) crashes if lane widths and shoulder widths are improved on rural two-lane, two-way roads.

1.0 INTRODUCTION

1.1 Problem Statement

UDOT currently uses a Safety Index as one of several factors in prioritizing projects for the LRP (UDOT, 2015). The Safety Index is based on historical crash data, including crash rates, severe crash rates, and crash rates and severe crash rates normalized by mile (Allen, 2013). The Safety Index provides metrics for historical trends, but it does not account for present and future conditions. UDOT has been developing more robust statistical models to address nuanced elements of crash prediction (Shultz et al., 2013; Shultz et al., 2015; Schultz et al., 2016). However, these models currently only consider historical data to estimate current crashes.

1.2 Objectives

This research sought to identify a process to improve long-range planning prioritization by using forecasted safety metrics in place of the UDOT Safety Index.

1.3 Scope

The first step toward the research objective required creating a Safety Forecast Model to quantify crashes based on current and future roadway conditions, including forecasted volumes. The research team conducted a literature review to assess the current use of the Safety Index in the UDOT LRP process and the applicability of the more robust statistical models currently being developed by UDOT. The literature review also examined the HSM, which contains crash prediction models (The Highway Safety Manual, 2010).

The research team created a Safety Forecast Model using HSM SPFs and CMFs. The research team obtained existing roadway characteristics that served as inputs for the Safety Forecast Model from uPlan. The research team also collected condition data—such as forecast volumes and lanes—from the USTM, a travel demand forecasting model. Existing crash data (obtained from UDOT) helped the research team assess the base-year crash predictions of the Safety Forecast Model.

The second step used the output of the Safety Forecast Model to calculate a modified UDOT Safety Index based on future conditions. The model was used to compare crashes predicted based on the current 2015–2040 UDOT LRP Build scenario to the No-Build scenario.

Finally, the research team performed a case study to evaluate several UDOT LRP widening projects to determine how project rankings were affected based on future forecasted safety. The case study used a template provided by UDOT that included UDOT's LRP project-ranking process. The research team also applied the Safety Forecast Model to a systemic safety analysis of two-lane rural roads.

1.4 Outline of Report

This report is organized into the following chapters:

- Introduction
- Literature Review
- Safety Forecast Model
- Data Collection
- Safety Forecast Results
- Sample Applications
- Conclusions
- Recommendations and Implementation

2.0 LITERATURE REVIEW

2.1 Overview

Quantitative evaluation of safety and predicting crash frequency is an emerging field, with a growing body of literature and tools to support these types of analyses. Recent advances in crash data and computing power have improved the ability to quantitatively evaluate safety on roadways. This chapter describes a literature review on crash prediction methodologies that could be applied to future traffic and roadway conditions, specifically the HSM and related research, tools that use the HSM, local safety research in Utah, and the UDOT Safety Index.

2.2 Highway Safety Manual

The most significant improvement in the quantitative evaluation of safety has been the publication of the HSM in 2010 by the American Association of State Highway and Transportation Officials (AASHTO). A revised version of the First Edition, which includes additional information, was published in 2014. This research-based manual provides information regarding the influence of several factors on crash frequency and severity, and provides methods for evaluating the crash reduction benefits of various treatments. This manual helps practitioners identify crash patterns and evaluate countermeasures' effectiveness, which allows for evaluation of the safety implications of projects and their alternatives.

Variables that contribute to the SPFs in the HSM include average annual daily traffic (AADT), area type, cross-section (lane count), and segment length. Additional roadway characteristics such as lane width, shoulder width, and horizontal curves are accounted for using CMFs. A local calibration factor can also be used to adjust to local conditions. The HSM includes a project prioritization process to rank projects across different measures such as benefit to ratios.

The HSM is the most commonly used tool in the emerging field of quantitative evaluation of safety. As the HSM is a relatively new resource, a significant amount of research has involved advancing the state of this guide and better calibrating it to local conditions. For example, at the Transportation Research Board's 96th Annual meeting in January 2017, an entire session was dedicated to work evaluating and refining the HSM and CMFs (Le et al., 2017; Torbic et al., 2017; Wang et al., 2017; Zegeer et al., 2016).

2.3 Safety Analysis Tools for HSM

Several tools are available that implement HSM equations and methodologies, including Safety Analyst, Enhanced Interchange Safety Analysis Tool (ISATe), and Interactive Highway Safety Design Model (IHSDM). Safety Analyst is maintained by AASHTOWare and focuses on site-specific highway safety improvements and on enabling prioritization of projects in accordance with Highway Safety Improvement Program specifications. Safety Analyst is written in Java and uses Java Database Connectivity application programming interface to connect to several database management systems. State departments of transportation, as members of AASHTO, can license this software, which includes procedures from Part B of the HSM. ISATe and IHSDM are tools that can implement the predictive methods in Part C of the HSM.

2.4 Recent Safety Research in Utah

Research in Utah has also evaluated potential methods for analyzing roadway safety and hotspots, including the Utah Crash Prediction Model and the Utah Crash Severity Model (Schultz et al., 2013; Schultz et al., 2015). Utah has also developed tools to facilitate this analysis, including the Roadway Safety Analysis methodology (Schultz, et al. 2016). However, these methods focus on existing conditions and historical crash data and—at the time of this research—do not account for or attempt to predict future conditions.

2.5 UDOT Safety Index

The UDOT Safety Index combines four crash statistics into a single, 0–10 scale (Allen, 2013) that is used to prioritize UDOT LRP projects. According to the Region Prioritization Template Worksheet (UDOT, personal communication), the Safety Index comprises 25–30% of projects' prioritization scores depending on the type of project. However, the Safety Index is not applied to new facilities since it uses historical data.

The four components of the Safety Index are as follows (Allen, 2013):

1. Ratio of crash rate to statewide average crash rate for the facility type.
2. Number of crashes per mile.
3. Ratio of severe crash rate to statewide average severe crash rate for the facility type.
4. Number of severe crashes per mile.

Severe crashes are defined as category severity level 4 and 5, which means crashes corresponding to serious injuries and fatalities, respectively.

Each road segment is given a 0 to 5 score for each of the four categories based on the values' relationships to overall average statewide values for similar functional class and volume roads as shown in Table 2.1. All four subscores are added and divided by two to arrive at a total Safety Index value between 0 and 10 (Allen, 2013).

Table 2.1 Safety Index Subscore Criteria

Subscores	Segment Ranking
0	No crashes
1	<50th percentile
2	51st to 75th percentile
3	76th to 90th percentile
4	91st to 95th percentile
5	>95th percentile

3.0 SAFETY FORECAST MODEL

3.1 Overview

The Safety Forecast Model was created based on SPFs and CMFs contained in the HSM. The HSM methodology was chosen based on the simplicity of the model, the availability of most data required for these calculations, and the ability to account for future conditions (such as AADT). This chapter includes a discussion of the scope of the Safety Forecast Model; the process by which the highway network is segmented for analysis; detailed discussions of SPFs and CMFs, including the required data; an outline of the model format; and a discussion of the availability of the required data.

3.2 Scope of Model

This research project limited its focus to the state roads (SRs) in the rural planning areas for which the UDOT Planning Division is currently responsible. This project did not consider freeways, federal-aid routes (FARs), and intersections; the data required for these applications were beyond the scope of this project. Follow-up studies, such as corridor studies or project-level analyses, could consider freeways, FARs, and intersections if detailed data could be obtained.

3.3 Segmentation

The research team separated roadways into smaller segments to serve as the primary geographic units in the Safety Forecast Model. Accurately forecasting safety for the roadway network requires that each segment be as homogenous as possible with respect to roadway characteristics. Additional detail on the roadway network segmentation is provided in Section 4.2 . The final dataset included approximately 5,500 unique road segments.

3.4 Safety Performance Functions

The HSM provides SPFs for several types of rural, urban, and suburban facility types. As illustrated in Figure 3.1, rural facilities include two-lane two-way roads, undivided four-lane roads, and divided four-lane roads. There are no SPFs for rural facilities with six or more lanes. Urban/suburban arterial facilities include two-lane undivided arterials; three-lane arterials, including a two-way left-turn lane (TWLTL); four-lane undivided arterials; four-lane divided arterials (with a raised or depressed median); and five-lane arterials, including TWLTL. There are no SPFs for urban arterials with more than two lanes in each direction of travel.

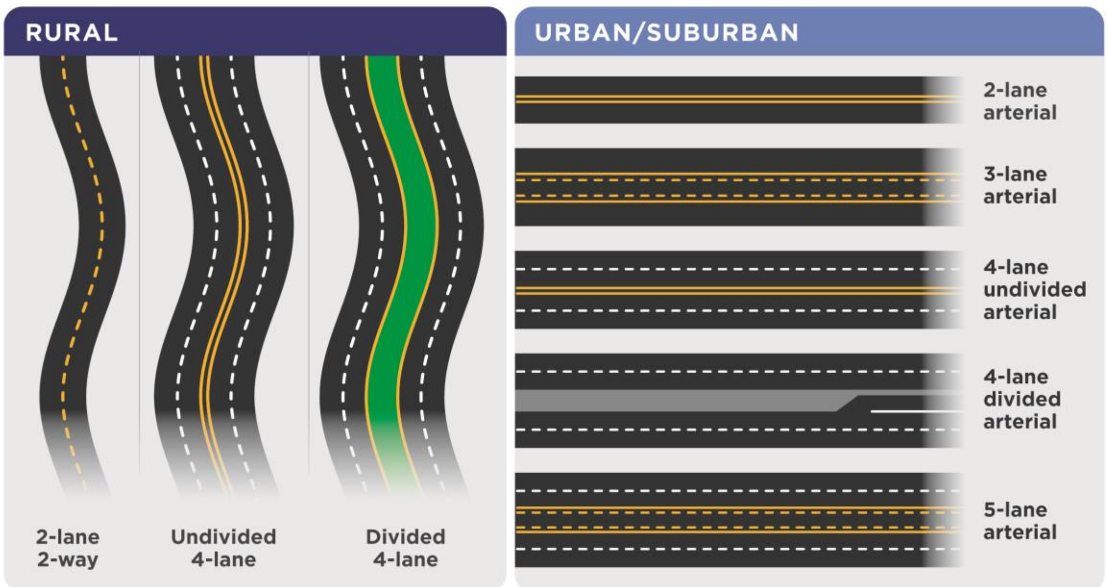

Figure 3.1 The HSM Includes SPFs for Three Rural Cross-Sections and Five Urban/Suburban Cross-Sections

No roads within the Safety Forecast Model space currently have more than two travel lanes in each direction of travel. However, the UDOT LRP does include some larger roads. The four-lane SPFs were used to model these scenarios as they represent the best available model for larger roads. SPFs for rural road segments (two-lane, two-way, and multilane highway) are a function of length and AADT. In addition to length and AADT, SPFs for urban and suburban arterials are also a function of speed limit and the number of driveways (by type).

SPFs are used to calculate FI crashes and total crashes for each road segment based on its roadway and traffic characteristics. In addition to FI crashes, total crashes also include property-damage-only (PDO) crashes. FI crashes are equivalent to UDOT severity levels 2 through 5.

UDOT identifies "severe" crashes as those with severity levels 4 and 5; therefore, FI crashes and "severe" crashes are not equivalent. However, the HSM does not have a methodology to predict severity level 4 and 5 crashes, so FI crashes are a good approximation of more severe crashes.

3.5 Crash Modification Factors

The number of crashes predicted by SPFs are adjusted (upward or downward) by CMFs to account for differences between the base conditions and site-specific conditions. CMFs are the ratio of the of the crash frequency of a site with a certain condition to the crash frequency of a site under a base condition. Therefore, a CMF greater than 1.0 represents a condition that is likely to have more crashes than the base condition, while a CMF less than 1.0 represents a condition that is likely to have fewer crashes than the base condition (The Highway Safety Manual, 2010). CMFs used for each facility type in the Safety Forecast Model are listed in Table 3.1 and Table 3.2 for rural and urban/suburban facilities, respectively. These tables also include the data sources for calculating the CMFs or the default values if no data were available.

Table 3.1 Crash Modification Factors—Rural Facilities

Facility Type	CMF	Description	Data Source	Default Value
Rural Two-Lane	CMF_{1r}	Lane Width	uPlan	--
	CMF_{2r}	Shoulder Width and Type	uPlan	--
	CMF_{3r}	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transition	uPlan*	--
	CMF_{4r}	Horizontal Curves: Superelevation	n/a	AASHTO recommended superelevation
	CMF_{5r}	Grades	uPlan	--
	CMF_{6r}	Driveway Density	uPlan*	--
	CMF_{7r}	Centerline Rumble Strips	n/a	Centerline rumble strips present
	CMF_{8r}	Passing Lanes	uPlan	--
	CMF_{9r}	Two-Way Left-Turn Lanes	uPlan	--
	CMF_{10r}	Roadside Design (Roadside hazard rating)	n/a	Roadside hazard rating: 3
	CMF_{11r}	Lighting	n/a	No lighting
	CMF_{12r}	Automated Speed Enforcement	n/a	No automated speed enforcement
Rural Multilane Undivided	CMF_{1ru}	Lane Width**	uPlan	--
	CMF_{2ru}	Shoulder Width and Shoulder Type	uPlan	--
	CMF_{3ru}	Side Slopes	n/a	1:7 or flatter
	CMF_{4ru}	Lighting	n/a	No lighting
	CMF_{5ru}	Automated Speed Enforcement	n/a	No automated speed enforcement
Rural Multilane Divided	CMF_{1rd}	Lane Width**	uPlan	--
	CMF_{2rd}	Right Shoulder Width	uPlan	--
	CMF_{3rd}	Median Width	uPlan	--
	CMF_{4rd}	Lighting	n/a	No lighting
	CMF_{5rd}	Automated Speed Enforcement	n/a	No automated speed enforcement

*These data required additional processing; details are provided in Section 4.5 .

**Lane width only available for one lane in each direction of travel, but assumed to be the same for multilane roads.

Table 3.2 Crash Modification Factors—Urban/Suburban Facilities

CMF	Description	Data Source	Assumed Default Value
CMF_{1r}	On-Street Parking	n/a	No on-street parking
CMF_{2r}	Roadside Fixed Objects	n/a	No fixed objects
CMF_{3r}	Median Width	uPlan	--
CMF_{4r}	Lighting	n/a	No lighting
CMF_{5r}	Automated Speed Enforcement	n/a	No automated speed enforcement

3.6 Model Format

The Safety Forecast Model was created using a Microsoft Excel workbook. A tab was created for each SPF and related CMFs that calculated total crashes and FI crashes. Each SPF tab references input data for each segment. A detailed discussion on the data assembled for the model is found in Chapter 4.0 . A summary tab determines the appropriate facility type for a given horizon year and then pulls the total crashes and FI crashes from the corresponding SPF tab. This determination is based on the number of lanes, median type, and the area type (rural vs. urban). Figure 3.2 illustrates the Safety Forecast Model process.

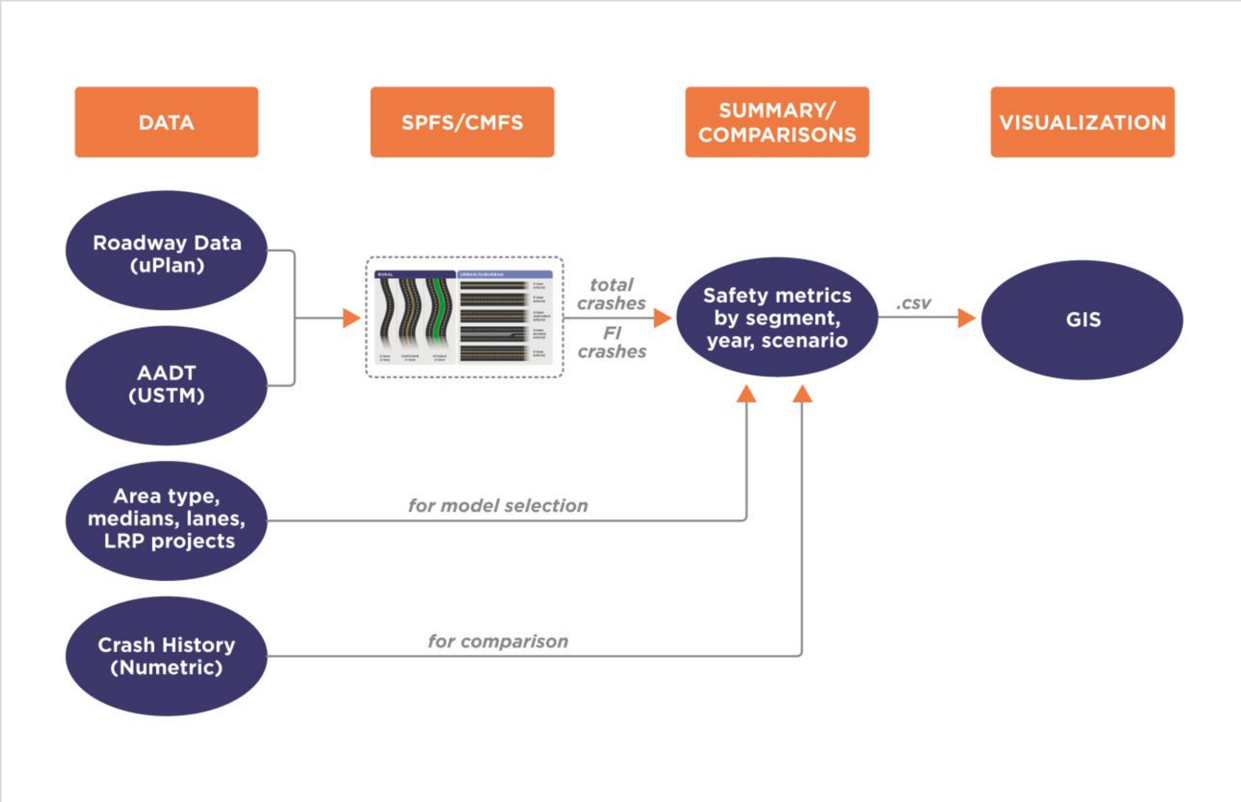

Figure 3.2 Safety Forecast Model Process

Once total and FI crashes are calculated for each segment and horizon year, other metrics can be calculated such as crashes per mile, crash rate, and Safety Index. These metrics are discussed in Chapter 5.0 . Metrics are then joined back to the segment shapefile in GIS for visualization.

3.7 Availability of Data

Primary data required for the SPF calculations includes the number of lanes and area type (for purposes of identifying the correct facility type), AADT, and length. AADT, area type, and lane count can change with each travel demand model scenario. Urban/suburban facilities also require speed limit and driveway data. These data were available from uPlan. Data required for CMFs is discussed in Table 3.1 and Table 3.2; some data were not available from uPlan. A high-level estimate of the effect of CMFs on crash prediction was prepared to determine the extent of critical data not available. CMFs for which no data were available that were estimated to have at least a 25% effect on crash prediction include the Roadside Hazard Rating (for two-lane rural roads) and On-Street Parking (for urban/suburban arterials). Obtaining the Roadside Hazard Rating is a data-intensive process, although there may be ways to estimate it based on other surrogate data. On-street parking would likewise require individually reviewing every roadway segment. Obtaining these data would improve future versions of the Safety Forecast Model. These data could also be obtained for targeted corridor- or project-level studies.

4.0 DATA COLLECTION

4.1 Overview

This chapter describes data collection efforts for the Safety Forecast Model. Collected data can be grouped into three categories: 1) roadway characteristics, which were obtained from uPlan; 2) existing and future traffic volumes, which were obtained from USTM; and 3) crash history data, which were obtained from udot.numetric.com. GIS was used to process these datasets and join them to a segmented base dataset. Some additional processing was also required to format certain datasets for use in the SPFs and CMFs.

4.2 Roadway Characteristics Data

Roadway data were collected in the form of shapefiles from the open data portal provided by UDOT's uPlan website. A base dataset was determined and created from a uPlan-sourced shapefile and used to store data from other source shapefiles and create a single roadway database. This process included downloading source data, processing the data, and merging the data into a single database.

4.2.1. Downloading Source Data

The source data for this task were collected from the UDOT's uPlan open data portal. Shapefiles collected included AADT, barriers, driveways, lanes, medians, route grade, rumble strips, shoulders, speed, and urban code.

4.2.2. Data Processing

The first step in processing the data was to determine which shapefile would be the best to use as a "base dataset." Each shapefile that was downloaded was compared by number of records within the shapefile. Each acquired shapefile uses the same projected coordinate system of NAD83 UTM Zone 12; the geometries are identical but do not share identical link segmentation. It was important to select a shapefile that did not have too many links as this could produce too many smaller links, which increases the errors when spatially joining data. It was also important to have a base dataset that did not have too few links, as this could produce information loss because segments are too large. The medians shapefile was chosen as the base dataset because it contained an optimal quantity of segments.

More processing was needed to clean up and prepare the dataset for joining data after deciding which source file to use as the base dataset. A second field, “NS_EW,” was added to identify the direction of each route. UDOT route numbering indicates the orientation of the route and was used to calculate the “NS_EW” field. A third field, “Join_ID,” was added to uniquely identify each link and to be used when joining data to the base dataset. Unused fields in the base dataset were removed. To finalize the base dataset, all roads within MPO areas and freeways were removed. This process was automated and recorded with two models created in ArcMap’s Model Builder (see Appendix A).

Further data processing was done to calculate the total number of driveways on each segment in the base dataset. Driveway source data are represented as line features within a polyline shapefile. These data were converted to points by calculating the link midpoint coordinates and creating a new point shapefile. A spatial join was executed to obtain the number of driveways that spatially joined to each link in the base dataset. This process was also recorded with Model Builder (see Appendix A). The driveway count was joined to the base dataset using the “Join_ID.”

Data processing also required determining the total number of driveways by type for each link. Driveways were grouped into eight types:

1. Gated/Utility
2. Major Commercial Driveway
3. Major Industrial/Institutional Driveway
4. Major Residential Driveway
5. Minor Commercial Driveway
6. Minor Industrial/Institutional Driveway
7. Minor Residential Driveway

8. Unknown

A separate process was employed to get this join. The process involved the development of a Python script that iterates through the driveway data shapefile, obtains a count of driveways by type, and then appends this information back to the base dataset. The script executes the following process for each driveway-type iteration (eight iterations):

1. Query driveways by type and convert to points.
2. Spatially join the driveway type points with the base dataset and output join count table.
3. Join table to base dataset using the "Join_ID" and append the count of driveways.
4. Delete intermediate data.

The final data processing step was developed using ModelBuilder. This step joins the desired data to the base dataset from the data source input to the model. The model takes three inputs: the base dataset, source shapefile containing data to join, and the field or list of fields to join from the shapefile to the base dataset. The model applies the following workflow:

1. Query base dataset by route direction and create two new files.
    a. Output N/S routes.
    b. Output E/W routes.
2. Convert output base dataset route files to points.
    a. Output N/S route points.
    b. Output E/W route points.
3. Copy input source data shapefile.
    a. Add route field and fill.
    b. Add route direction field and fill.
    c. Query by route direction and create two new files.
        i. Output N/S routes.
        ii. Output E/W routes.
4. Spatially join the source data output N/S routes and the base dataset N/S route points.

    a. Output N/S spatial join results.

5. Spatially join the source data output E/W routes and the base dataset E/W route points.
    a. Output E/W spatial join results.
6. Combine the two spatial join results into one join table.
7. Join the selected fields from the spatial join table to the original base dataset using the link unique identifier field (“Join_ID”).
8. Delete all intermediate data created by the model.

4.2.3. Final Dataset

Applying the preceding steps resulted in a single database containing all roadway characteristics appended to each roadway segment. The final database contained 5,472 records (segments) and 35 attribute fields. Table 4.1 shows the data dictionary for the final roadway safety database.

Table 4.1 Data Dictionary for GIS Dataset

Field Name	Field Type	Field Description
Join_ID	Long	Unique identifier
SEGID	Double	USTM segment ID
_Route	Long	Utah route number
NS_EW	Short	North/south or east/west oriented route
MEDIAN_TYP	Text	Description of median type
MEDIAN_WID	Long	Width of median
MEDIAN_NUM	Long	Enumerated median type
PASS_CNT	Long	Number of passing lanes
THRU_CNT	Long	Number of thru lanes
THRU_WDTH	Long	Width of thru lanes
TWOWAY_CNT	Long	Number of TWLTLs
SHOULDERWI	Long	Width of shoulder
SHLDR_MATL	Text	Type of shoulder material
EDGE_TYPE	Text	Type of road edge
Num_DrvWy	Long	Number of driveways per segment
Speed_Limi	Long	Approximate speed limit
URBAN_DESC	Text	Urban description
BEG_ELEV	Double	Beginning segment elevation
END_ELEV	Double	End segment elevation
Shape_Leng	Double	Length of segment (meters)
LEN_MI	Double	Length of segment (miles)
Grade	Double	Segment slope percent grade
X_Line_Srt	Double	X coordinate of line start (meters)
Y_Line_Srt	Double	Y coordinate of line start (meters)
X_Line_End	Double	X coordinate of line end (meters)
Y_Line_End	Double	Y coordinate of line end (meters)
Line_Dist	Double	Straight-line distance between segment start and segment end points
GateUtlDrv	Long	Gated/utility driveway type
MjrComDrv	Long	Major Commercial driveway type
MjrIndDrv	Long	Major Industrial driveway type
MjrResDrv	Long	Major Residential driveway type
MinComDrv	Long	Minor Commercial driveway type
MinIndDrv	Long	Minor Industrial driveway type
MinResDrv	Long	Minor Residential driveway type
UnkwnDrv	Long	Unknown driveway type

4.3 Travel Demand Model Data

Future travel demand forecasts were obtained from work previously conducted for the UDOT LRP using USTM. No-Build and Build volumes were available for horizon years 2024, 2034, and 2040. Traffic volumes for 2015, the base year of this analysis, were available from UDOT (Traffic on Utah Highways, 2015).

4.3.1. USTM Traffic Forecasts

UDOT applied USTM version 1.3 to produce the future volume forecasts used in the 2015 LRP development. USTM is a behaviorally based travel demand forecasting tool that forecasts travel based on the current and future locations of jobs and housing and the transportation infrastructure (UDOT Long-Range Plan, 2015). UDOT utilized USTM to generate roadway demand based on the following scenarios:

- **2011 Base-Year Run**. The 2011 (base year of the model) base-year scenario was used to assess the reasonableness of the model's forecasting ability. The model's performance was assessed by comparing the 2011 base-year model run to UDOT's 2011 traffic count data. In general, the model compared reasonably well to the observed counts and was sufficiently calibrated to perform the analysis without further modifications.

- **No-Build Runs**. The No-Build runs included the future socioeconomic data (only existing plus committed highway network). The existing plus committed highway network was defined as anything built today plus the projects programmed in the State Transportation Improvement Program. No-build scenarios were defined as follows:

    - No-Build 2024–2024 socioeconomic, 2019 highway network.
    - No-Build 2034–2034 socioeconomic, 2019 highway network.
    - No-Build 2040–2040 socioeconomic, 2019 highway network.

- **Fiscally Constrained Runs**. The results of the need scenario runs were taken to the UDOT region leadership and discussed along with the fiscal constraints identified for each horizon year of the plan, project viability, and other local input. A fiscally constrained project list that balanced all these factors was identified and became the final project list for the LRP. These projects were then coded into the highway network. The fiscally constrained scenarios were run for the following years and used to develop the final traffic forecasts for the plan:

- Build 2024–2024 socioeconomic, 2024 fiscally constrained highway network.
- Build 2034–2034 socioeconomic, 2034 fiscally constrained highway network.
- Build 2040–2040 socioeconomic, 2040 fiscally constrained highway network.

Model network loading can be inconsistent due to the coarseness of centroid connector loading. The final traffic forecasts from the USTM model output were postprocessed—or smoothed—at a segment level by calculating the distance weighted average volume for each segment. The change in average volume from each future year to the model base year was calculated and the difference in daily volume was added to the 2011 UDOT traffic counts. The research team performed reasonableness checks to ensure the future forecasts followed a reasonable growth trend compared to UDOT historical count data.

4.3.2. Segment ID

Each segment in the USTM post-processed model space includes a unique segment ID (Seg_ID). These Seg_IDs were joined to the Join_ID in the base dataset discussed in Section 4.2 so that forecasted volumes could be associated with each Safety Forecast Model segment.

4.4 Existing Crash Data

Existing crash data were obtained from the UDOT Division of Traffic and Safety for January 1, 2010 through December 31, 2015. Crash data are available through udot.numetric.com. For this research, the relevant data obtained included latitude and longitude, crash severity, and whether a crash was intersection related. Numerous other crash data characteristics were available, but these were not necessary for this research.

The crash locations were geocoded in GIS using the latitude and longitude and converted to a shapefile. A Python script was developed to summarize the crash data by all crashes and by FI crashes by year for each segment within the Safety Forecast Model network. The output from the script is a .csv summary table with a unique identifier and the total number of crashes along each segment by year. The unique identifier was used to join the crash summary table to the dataset.

4.5 Data Post-Processing

Some CMFs require data that are not available in uPlan, but these data can be estimated from uPlan data. These include horizontal curve data and driveway density.

4.5.1. Horizontal Curve Data

Detailed horizontal curve data are required for CMF_{3r}, including length, radius, and presence or absence of spiral curves. There is currently no dataset available on uPlan that inventories all horizontal curves on Utah's roads. To better estimate curve data (instead of assuming all road segments are straight), a simple method was developed to create a rough estimate of curve radiuses using the segment length and the straight-line distance between the endpoints of the segment.

For purposes of this research, all curved segments were assumed to have spiral curves (transition curves between tangent sections and horizontal curves) and curve lengths equivalent to the segment length. CMF was calculated using these assumptions and the estimated radius length.

4.5.2. Driveway Density

Because some roadway segments lengths are short, the presence of one driveway creates a high driveway density value. For the urban/suburban arterials, high driveway densities have a significant effect on crash prediction. The research team created an algorithm to estimate the driveway density over a longer period of highway. The algorithm searched through consecutive road segments in the Safety Forecast Model database and calculated a cumulative driveway density for segments until the group of consecutive segments was at least one-half-mile long. This average driveway density was then reported for all individual segments within the group. This had a dampening effect on unrealistically high driveway densities.

4.6 Summary

Roadway characteristic data, future traffic volumes, and crash history were obtained from UDOT and joined to a segmented base dataset for use in the Safety Forecast Model described in Chapter 3.0 using GIS processes.

5.0 SAFETY FORECAST RESULTS

5.1 Overview

The research team populated the Safety Forecast Model described in Chapter 3.0 with the roadway characteristic data described in Chapter 4.0 and evaluated two scenarios, including No-Build and Build of the UDOT 2015–2040 LRP projects. Output metrics included the number of FI crashes and total crashes per segment, from which crashes per mile was calculated. A modified UDOT Safety Index was also calculated with the forecasted crashes and FI crashes per mile. This chapter compares 2015 model results to crash history records and the outputs of the Safety Forecast Model for No-Build and Build scenarios, including visualization of the results using GIS.

5.2 2015 Base-Year Comparison

The Safety Forecast Model was used to analyze base-year (2015) conditions that can be compared to recent crash data. As discussed in Section 4.4 , crash data were filtered to remove intersection crashes, MPO area crashes, and freeway crashes to provide an accurate comparison of the scope of the Safety Forecast Model. Table 5.1 shows a comparison between modeled and actual total crashes and FI crashes for the study area. Total crashes were approximately 20% higher than modeled crashes, while FI crashes were approximately 12% less than predicted.

Table 5.1 Predicted vs. Actual Crashes (2015)

	Predicted	Actual*	% Difference
Fatal/Injury Crashes	1,081	947	-12.4%
Total Crashes	3,332	3,984	19.6%

*Actual crashes are based on a six-year average (2010–2015).

Figure 5.3 and Figure 5.4 compare modeled to actual FI crashes and modeled to actual total crashes, respectively.

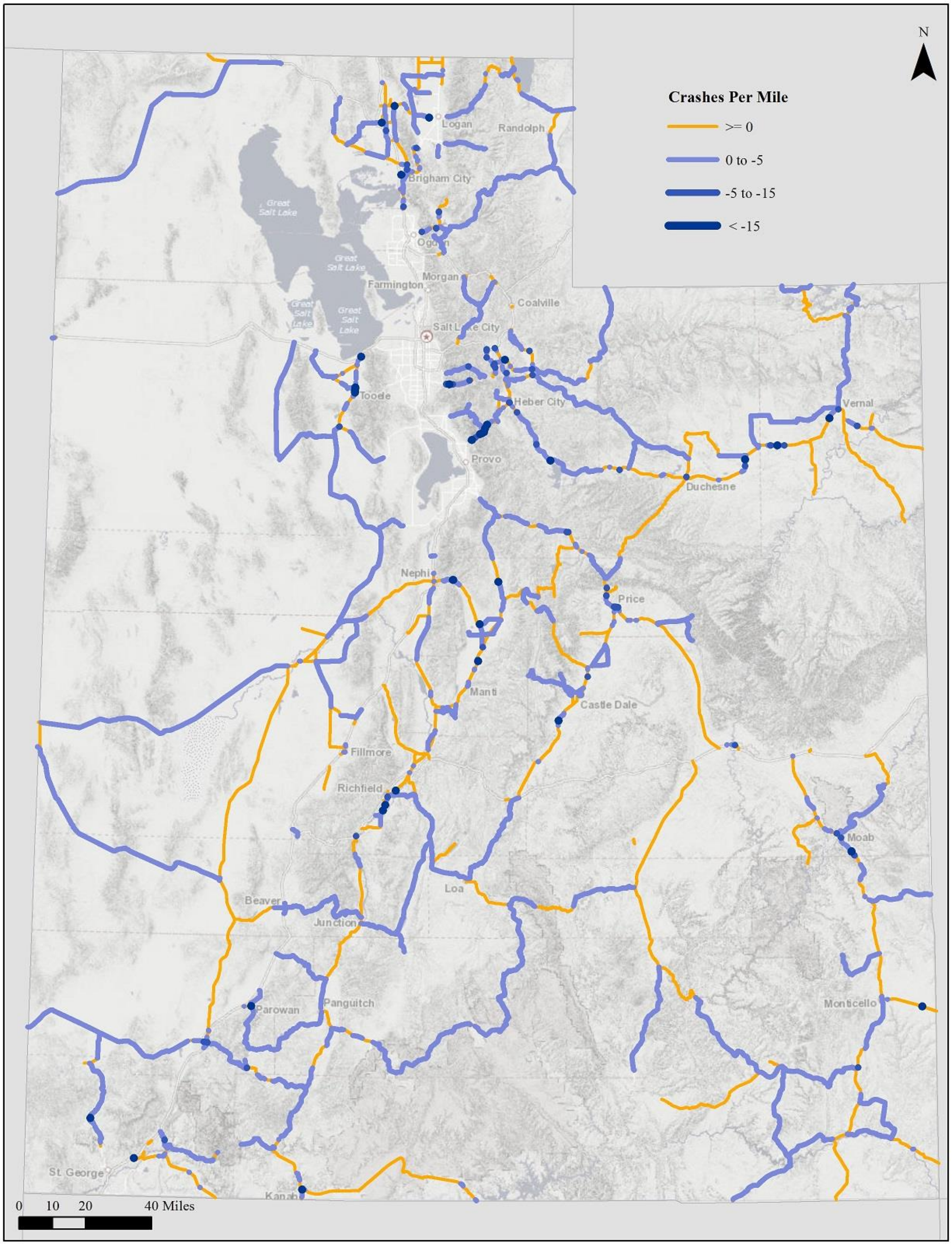

Figure 5.1 Difference Between Modeled and Actual Fatal/Injury Crashes

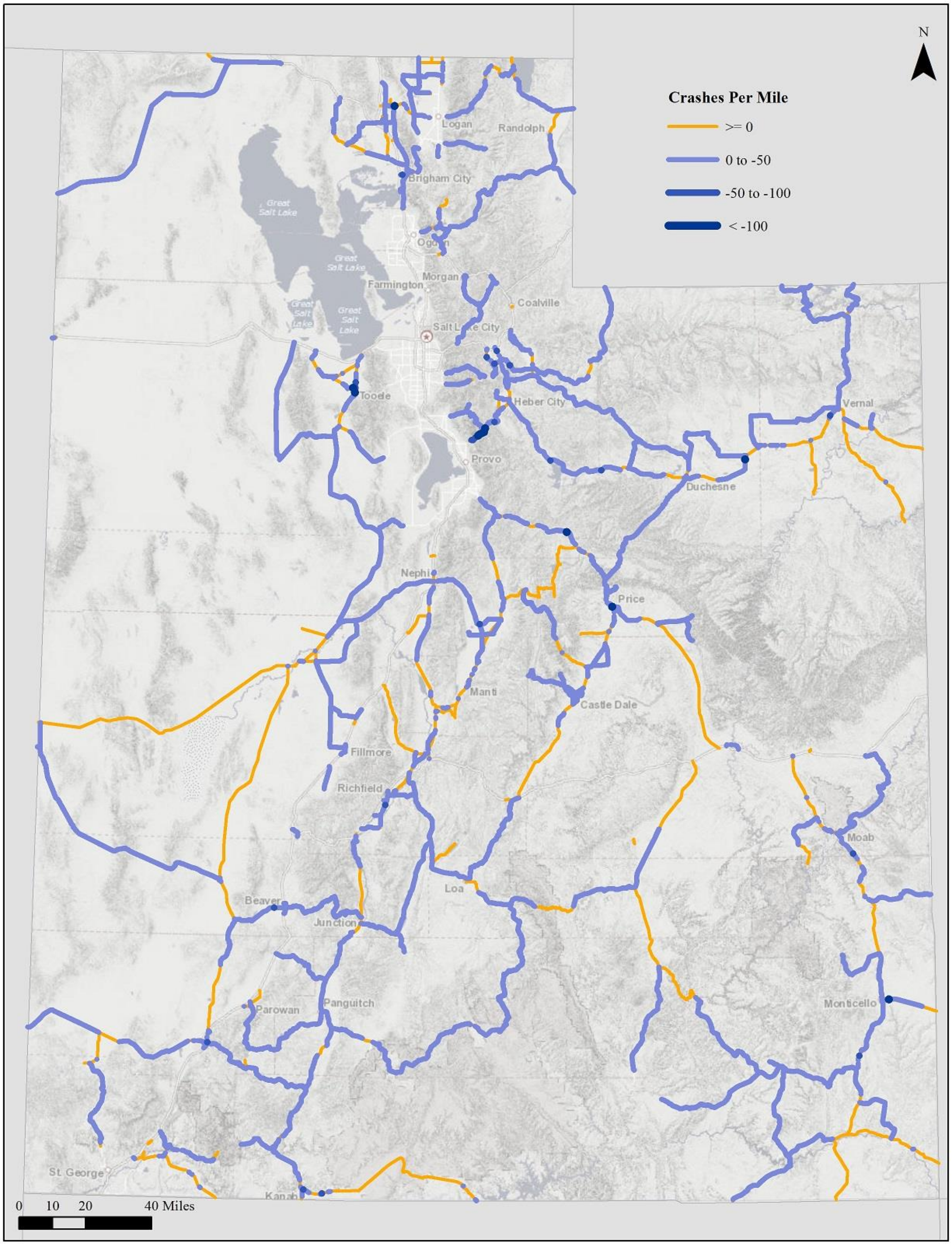

Figure 5.2 Difference Between Modeled and Actual Total Crashes

5.3 No-Build and Build Scenarios

5.3.1. No-Build Scenarios

The No-Build model scenarios assumed no changes to roadway characteristics for any of the horizon years (2024, 2034, and 2040). The research team obtained forecast traffic volumes from USTM No-Build scenarios (as described in Section 4.3). Figure 5.3 and Figure 5.4 show 2040 FI and total crashes per mile, respectively.

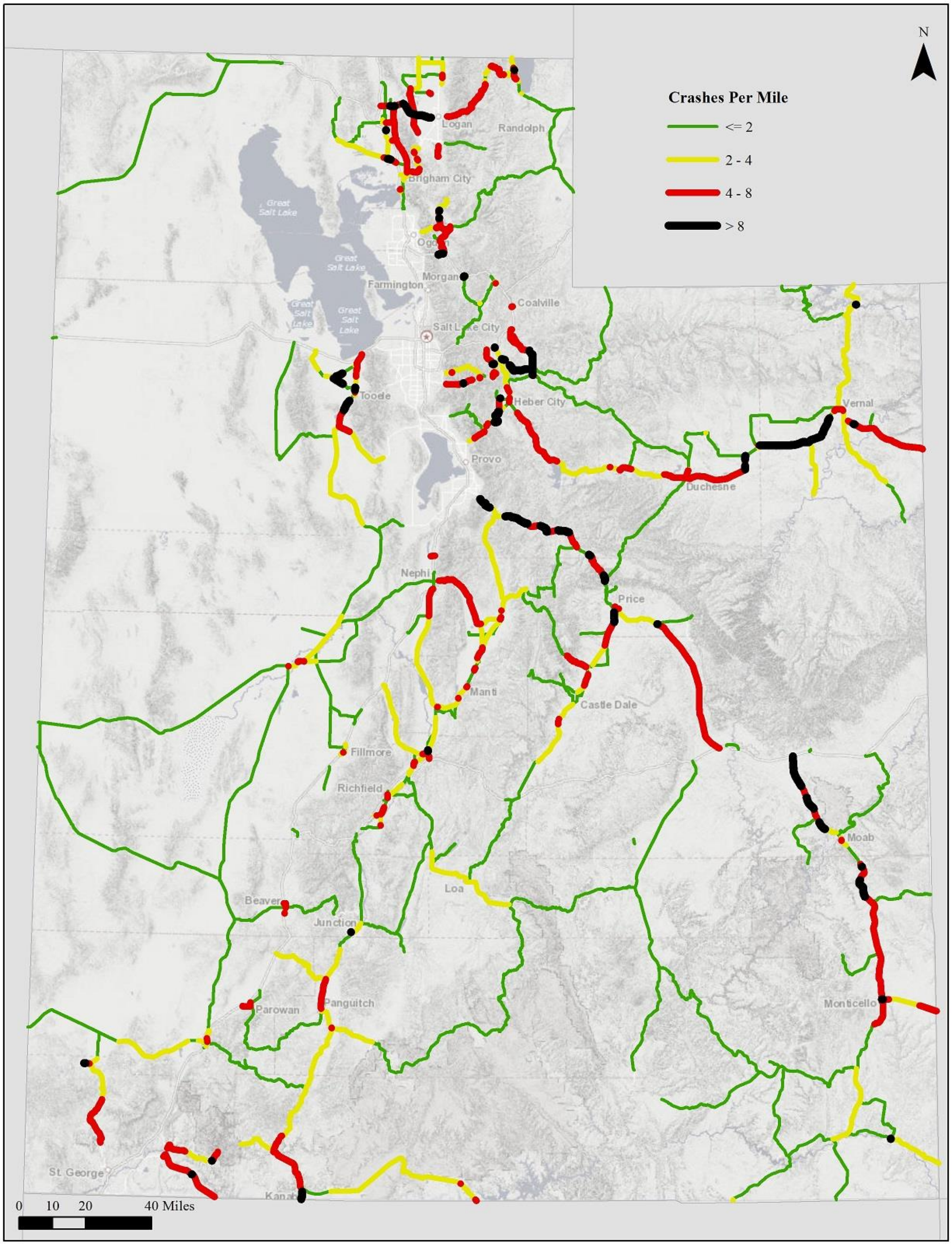

Figure 5.3 No-Build 2040 Fatal/Injury Crashes per Mile

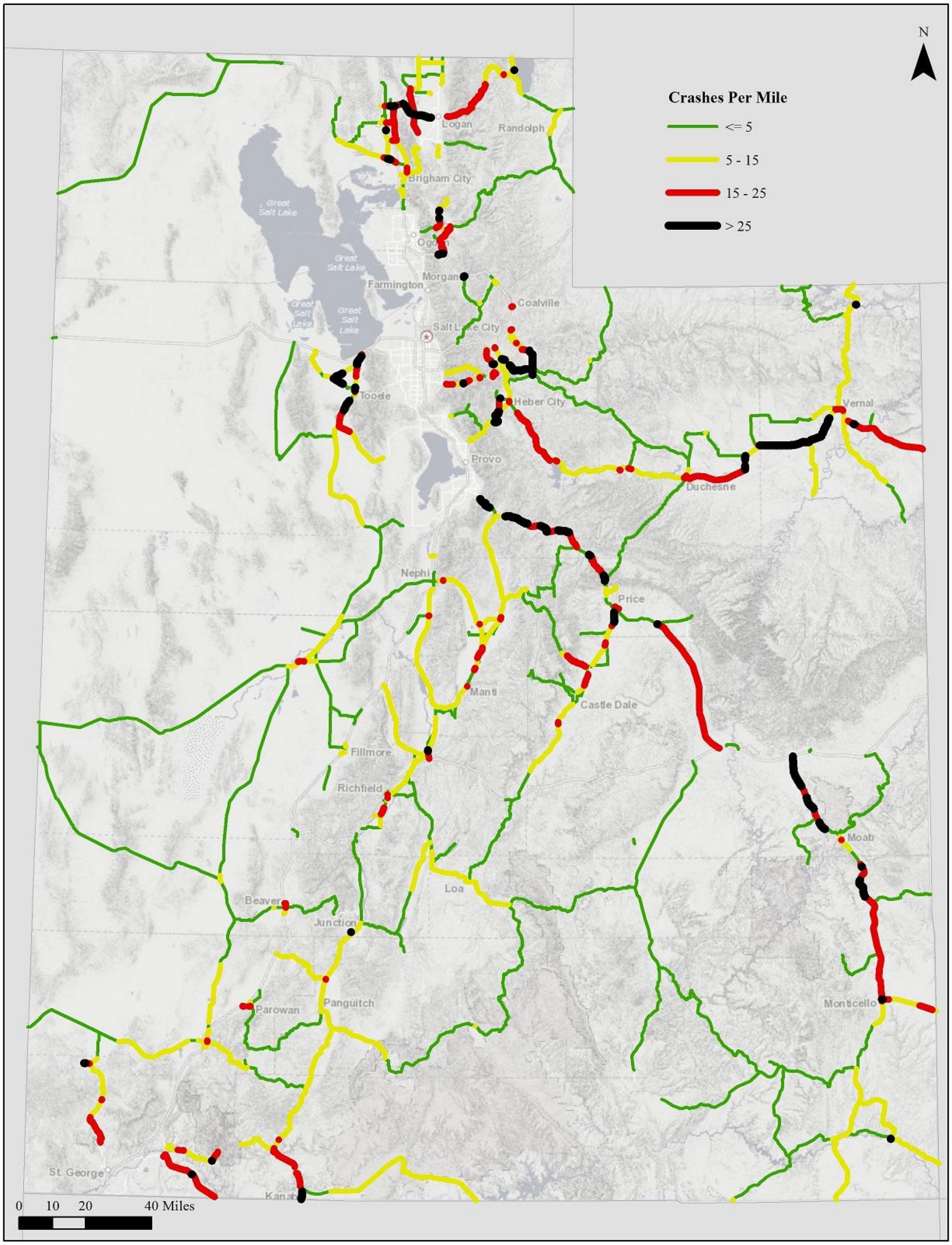

Figure 5.4 No-Build 2040 Total Crashes per Mile

5.3.2. Build Scenarios

The research team modified the Build model scenarios to include future lane counts on road segments with widening projects. The research team also assumed that some changes to roadway characteristics would likely occur with each new widening project. Other types of spot projects fell outside of the scope of the Safety Forecast Model and were not evaluated. These included at-grade intersections or interchanges as the project only sought to evaluate road segments. Operational projects were also not considered as they do not affect any of the variables in the Safety Forecast Model. New facilities and passing-lane projects could be included in the Build model; however, this was not done as it was beyond the scope of this research project. Forecast traffic volumes were obtained from USTM Build scenarios as described in Section 4.3 . Figure 5.3 and Figure 5.4 show 2040 FI and total crashes per mile, respectively.

Assumed changes include median and shoulder improvements. All rural road segments with widening projects were assumed to have medians at least 12 feet wide and shoulders at least 6 feet wide. Shoulder width is not a CMF for urban/suburban roads. Median width only has a CMF of 1.0 for medians at least 15 feet wide, which is wider than a typical median; therefore, the effects of widening the median to 12 or 14 feet would have been negligible. No other universal changes to roadway characteristics on widening projects seemed appropriate for this research project; however, more detailed changes could be considered in a corridor plan or more detailed safety evaluation of a project.

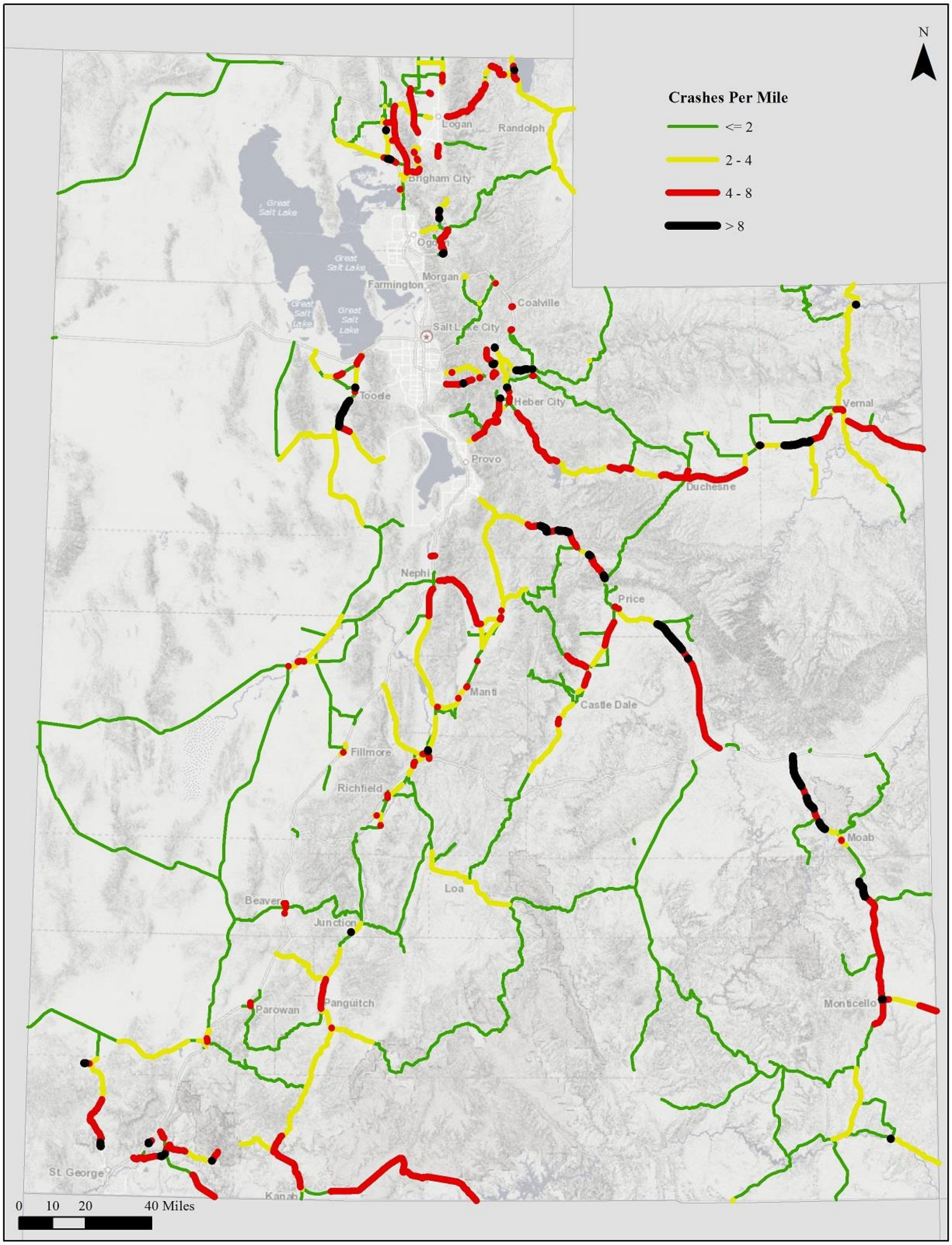

Figure 5.5 Build 2040 Fatal/Injury Crashes per Mile

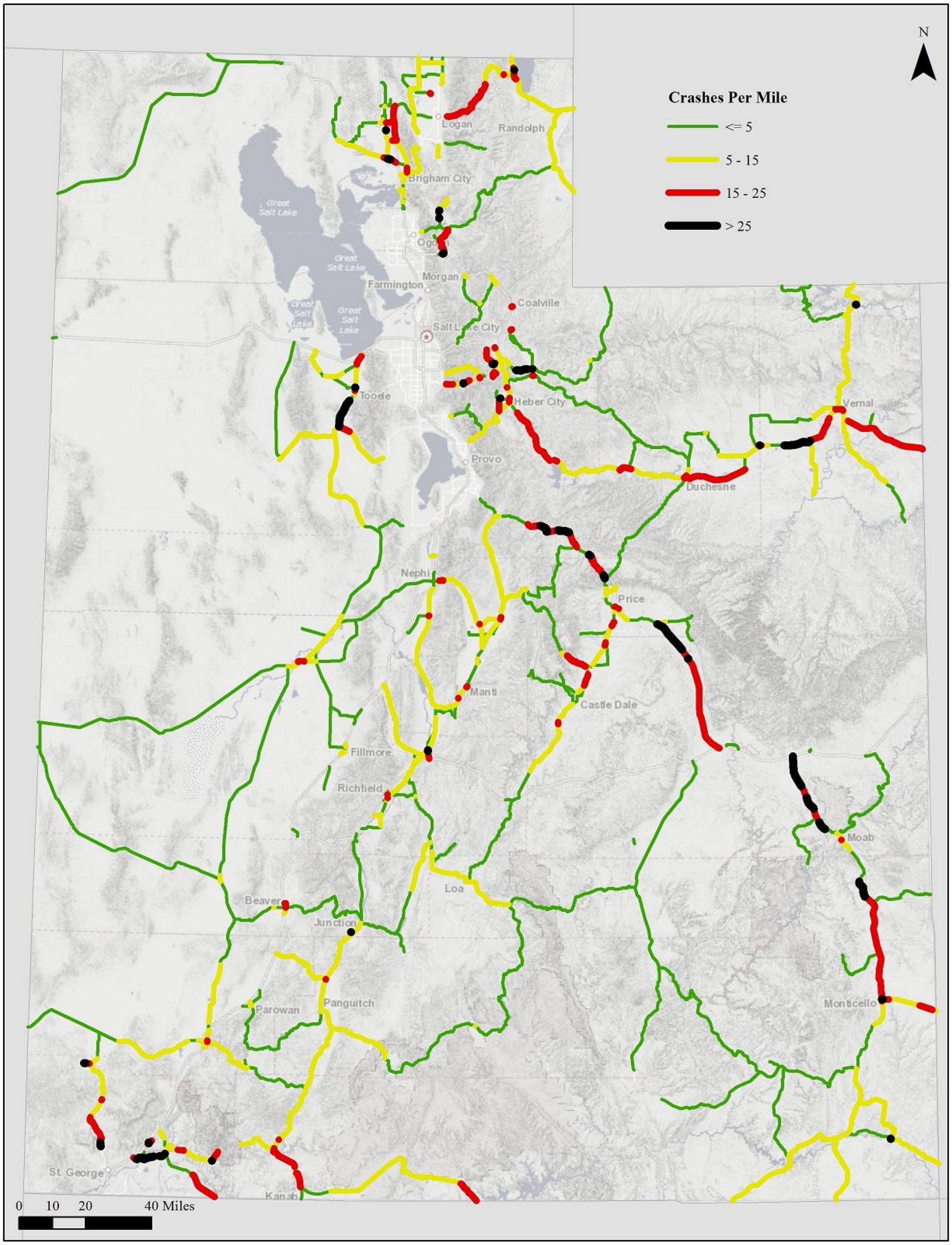

Figure 5.6 Build 2040 Total Crashes per Mile

5.3.3. No Build Versus Build

For the 2040 horizon year, FI crashes and total crashes were compared between the No-Build and Build scenarios for all road segments where no widening was assumed to have occurred and where widening was assumed to occur (based on the UDOT LRP). Figure 5.7 uses a box-and-whisker plot to illustrate the change in FI crashes per mile between No-Build and Build scenarios. Roads without widening projects experience minor change in No Build versus Build scenarios. Approximately 75% of road segments with widening projects are anticipated to experience a reduction in crashes. Figure 5.8 shows the same changes in total crashes per mile, with similar patterns. Figure 5.9 shows the changes in 2040 FI crashes per mile for all widening projects in the UDOT LRP.

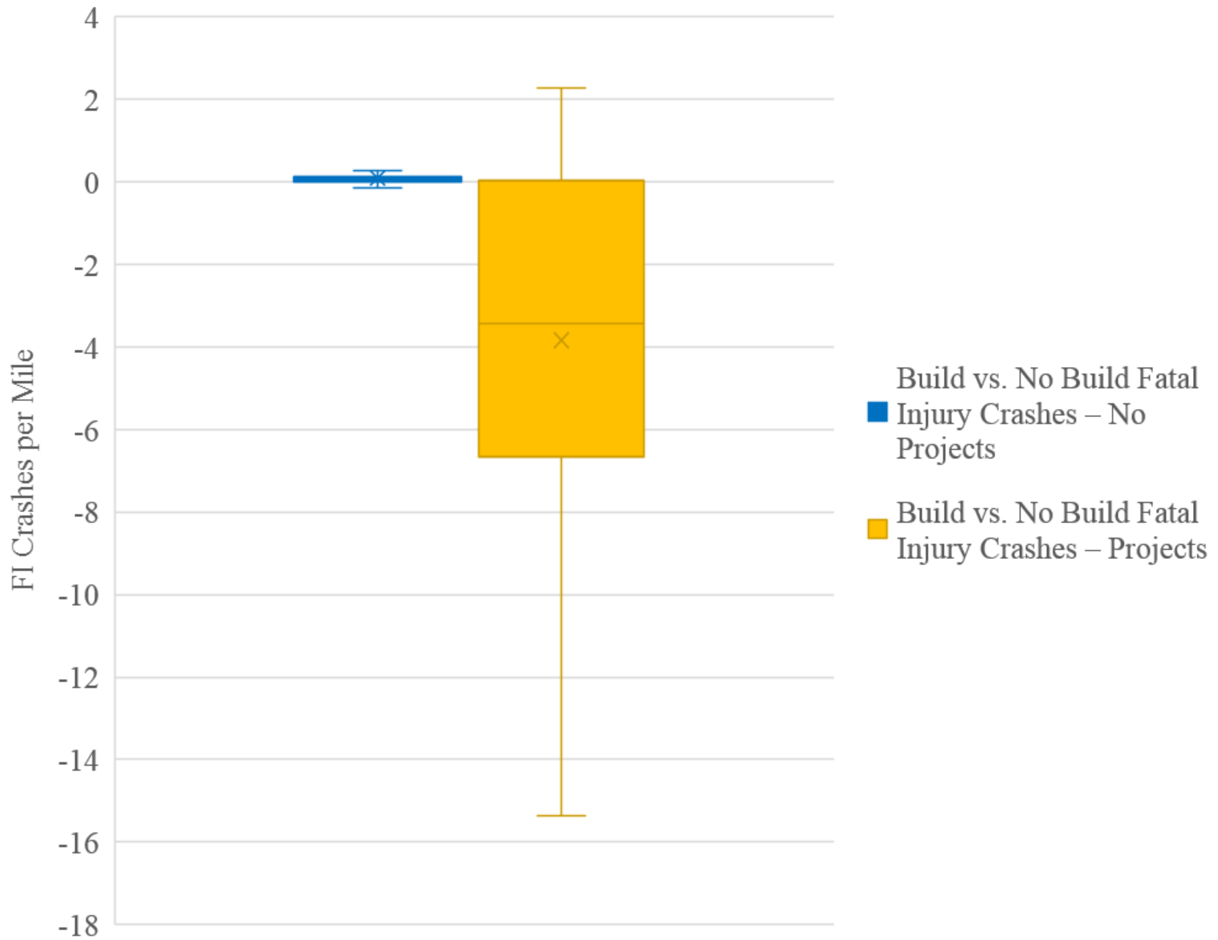

Figure 5.7 Change in FI Crashes Between No-Build and Build Scenarios for Roads Without and with Projects

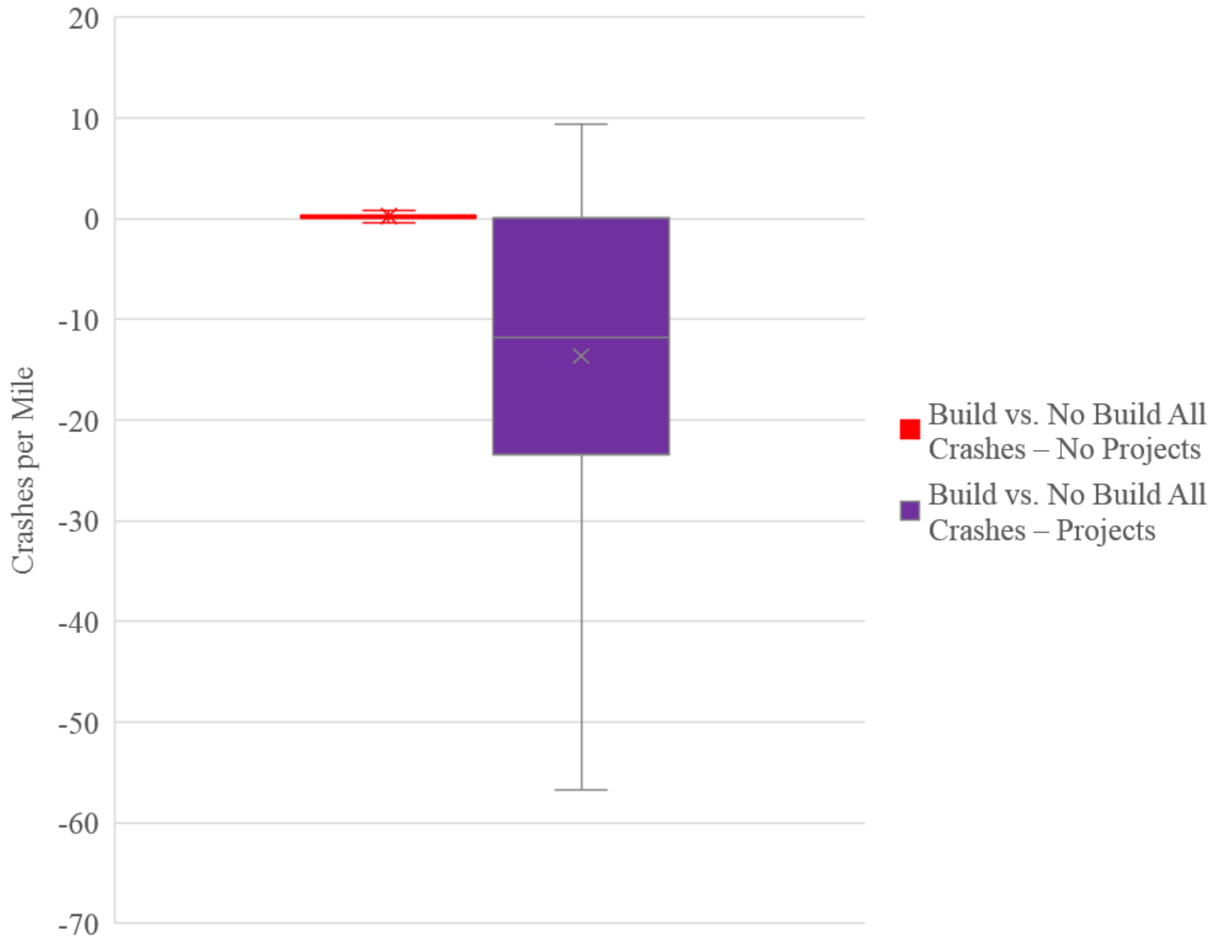

Figure 5.8 Change in Total Crashes Between No-Build and Build Scenarios for Roads Without and with Projects

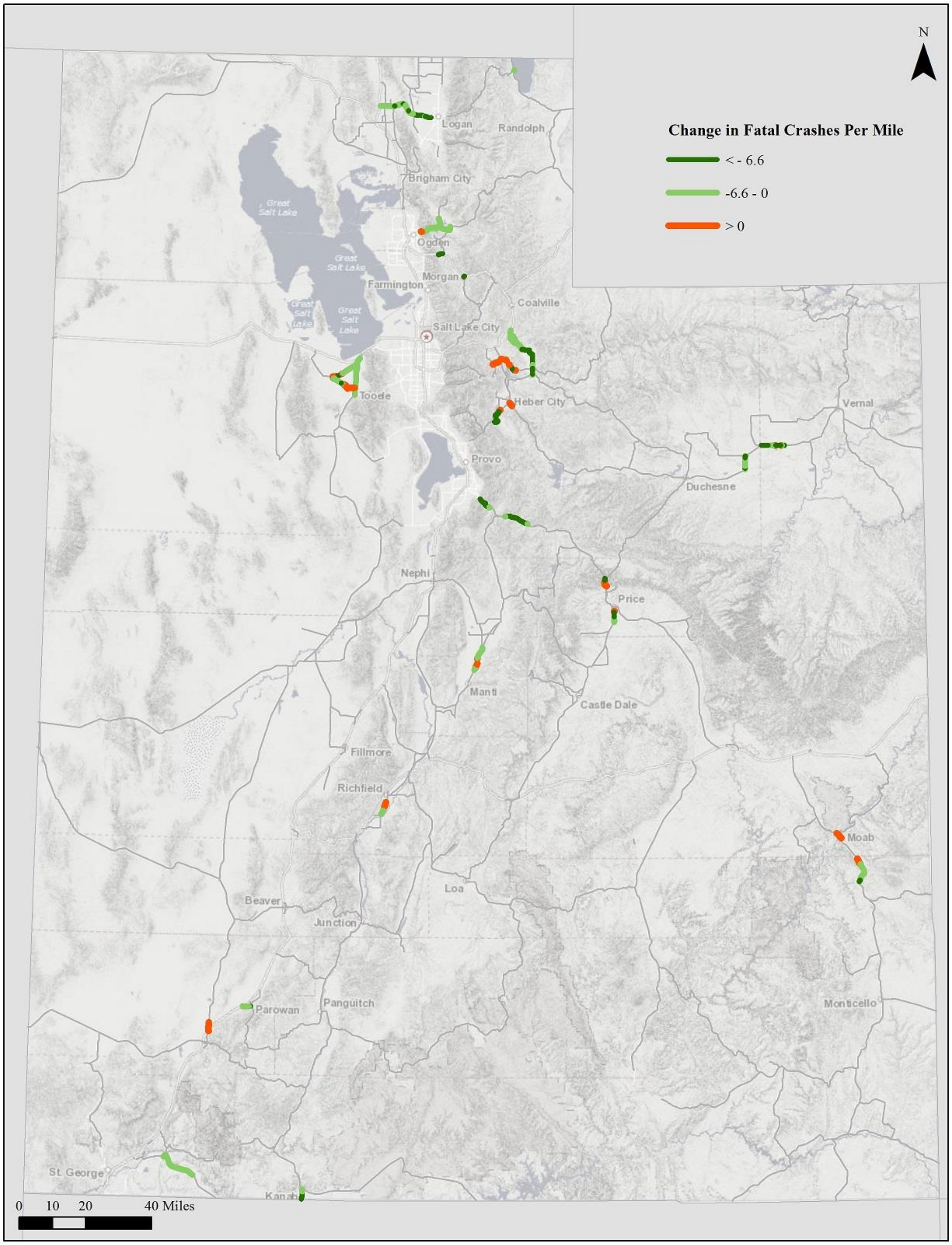

Figure 5.9 Change in 2040 FI Crashes for Segments with UDOT LRP Projects

5.4 Safety Index

The research team calculated a modified version of the UDOT Safety Index (discussed in Section 2.5) for each segment. Modifications were required for two aspects:

1. The UDOT Safety Index covers all SRs in Utah, so segments are being compared and indexed against all SRs. The scope of the Safety Forecast Model covers only a portion of the state; therefore, segments could have lower or higher index values as compared to the UDOT Safety Index.

2. Severe crashes in the UDOT Safety Index calculation only include severity levels 4 and 5 crashes. However, the FI crashes from the Safety Forecast Model include severity levels 2 through 5.

The modified Safety Index was calculated for both the No-Build and Build scenarios. Figure 5.10 and Figure 5.11 show the No-Build and Build UDOT Safety Index for 2040 conditions, respectively.

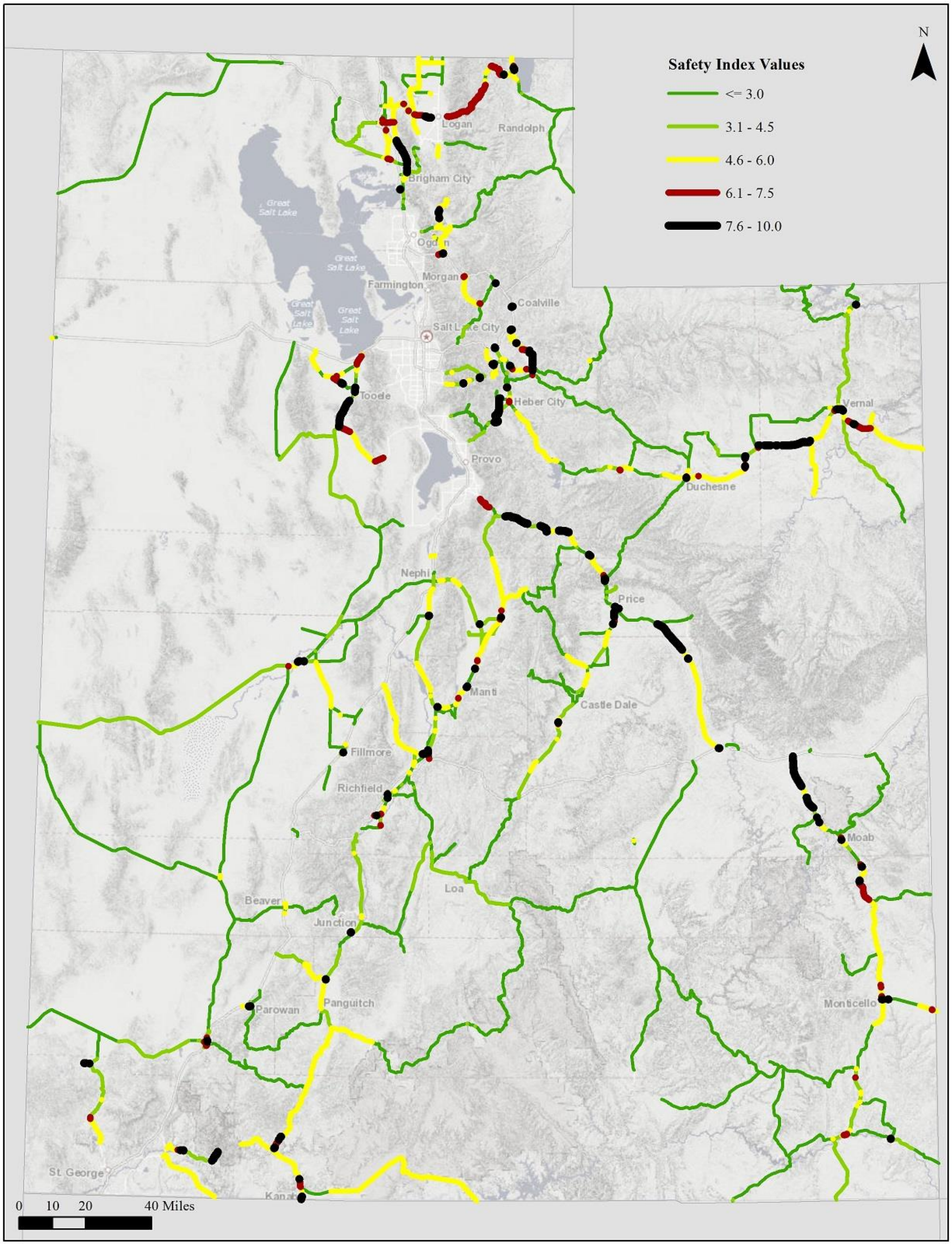

Figure 5.10 Safety Index Based on LRP No-Build Scenario (2040)

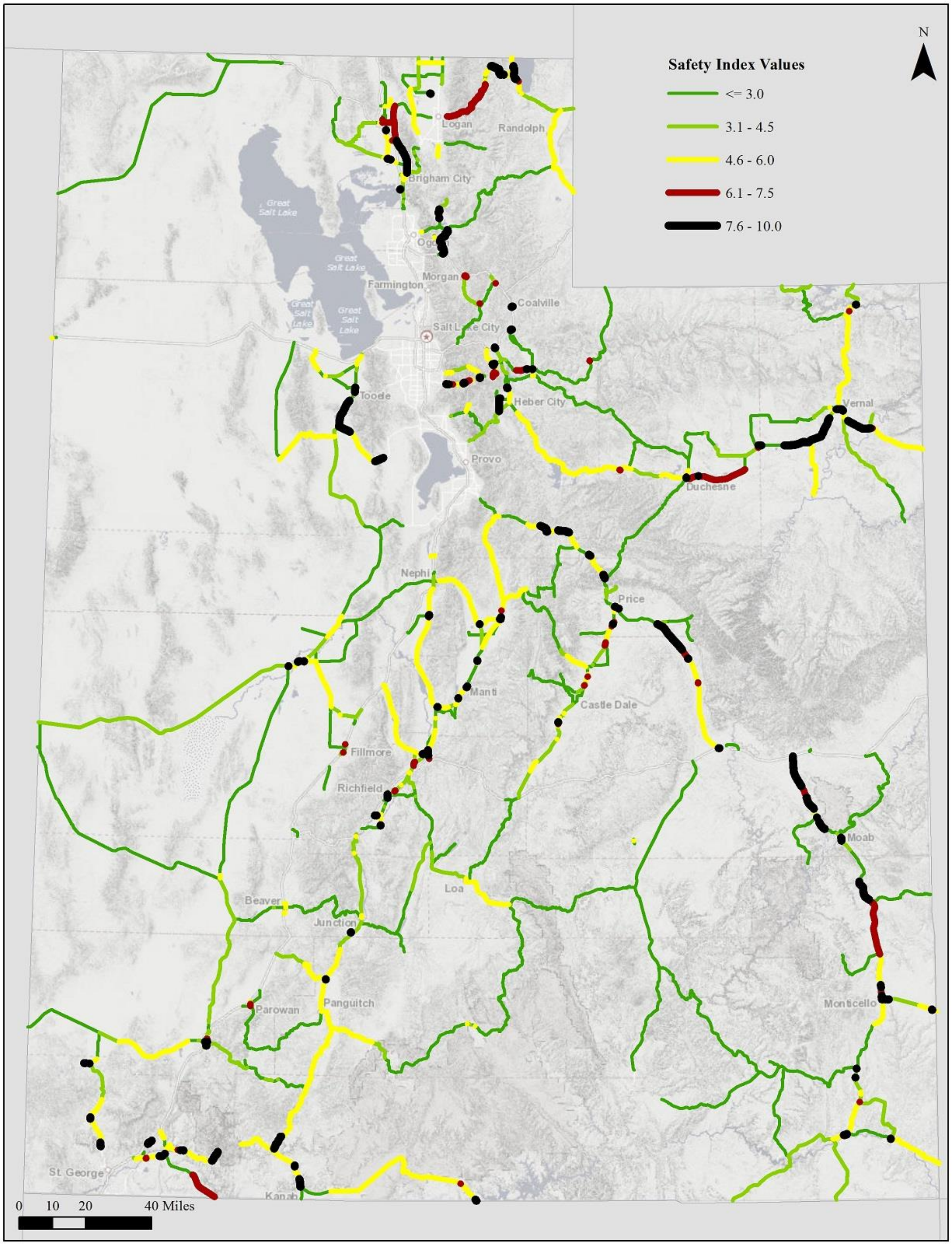

Figure 5.11 Safety Index Based on LRP Build Scenario (2040)

Most road segments with projects have a decrease in Safety Index in the Build scenario with respect to the No-Build scenario. This is similar to FI crashes and total crashes. However, since the Safety Index is indexed to all road segments, there is an increase in Safety Index values for roads without projects. Figure 5.12 shows the change in segments with no projects compared to segments with projects.

Figure 5.13 compares 2040 calculated Safety Index for segments with LRP projects.

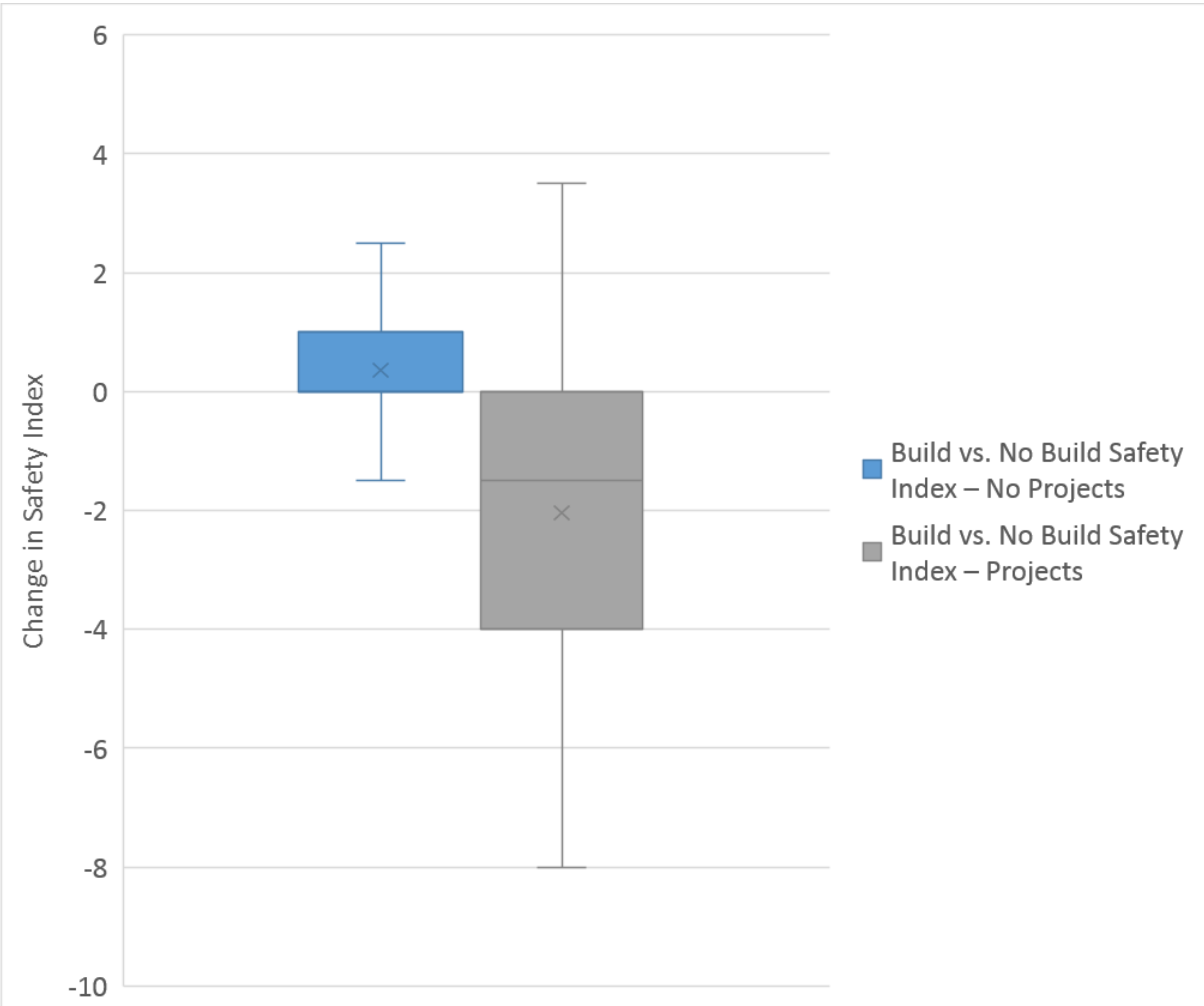

Figure 5.12 Change in Safety Index Between No-Build and Build Scenarios for Roads Without and with Projects

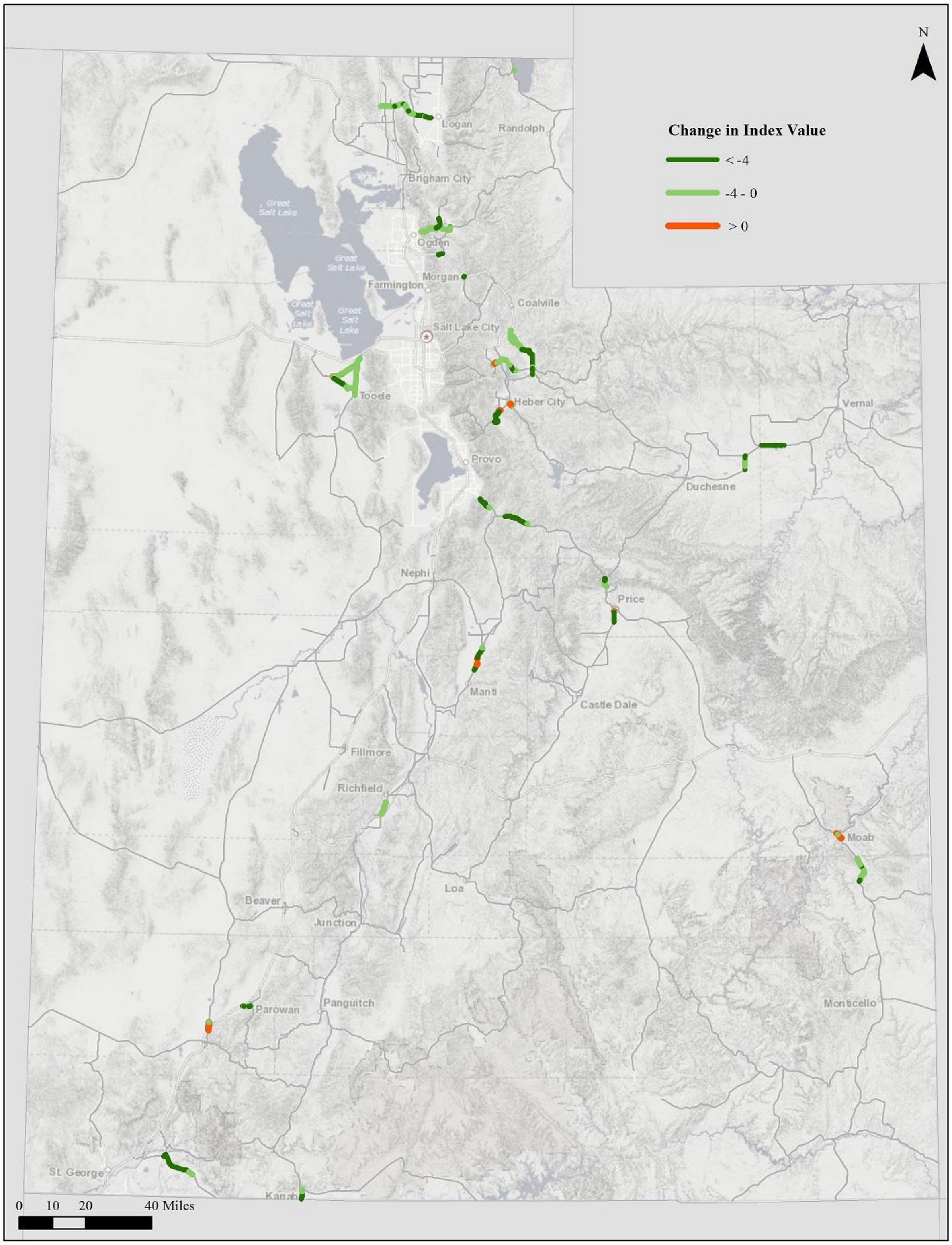

Figure 5.13 Change in Safety Index Between No Build and Build for LRP Project Locations

6.0 SAMPLE APPLICATIONS

6.1 Overview

The model was tested for use in safety analyses and planning tasks after creating a working Safety Forecast Model based on SPFs and CMFs in the HSM. This chapter discusses two of these applications. Project prioritization was tested using the Safety Forecast Model by evaluating the difference between the No-Build and Build projected crashes. The Safety Forecast Model was also used to perform a systemic safety analysis of two characteristics of rural two-lane roads, including lane width and shoulder width.

6.2 LRP Prioritization Process Case Study

As discussed in Section 2.5, 25–30% of a project's prioritization score is based on its Safety Index. Because the Safety Index is based on historical crash data, a project's ranking is significantly affected by its current and past conditions, and not by what is anticipated to occur in the future. There is also no consideration given to the potential for crashes to be reduced by a capacity project.

Several LRP projects were selected to perform a case study. The case study examined how the ranking of projects might be affected by the following modifications to the prioritization process:

- Utilize the Safety Index based on 2040 projected crashes.
- Utilize the difference between the 2040 No-Build and Build Safety Indices.

Fifteen LRP widening projects were selected, including six Phase I projects, six Phase II projects, and three Phase III projects (only three widening projects are contained in the UDOT LRP for Phase III). Ranking criteria for all categories were available for all 15 projects on uPlan (UDOT LRP 2015–2040). Table 6.1 shows scores for each LRP project.

Table 6.1 LRP Prioritization Rankings

LRP Phase	Project ID	Route	Prioritization Subscores						Total Score	Rank
			AADT	Truck AADT	Func. Class	v/c	Growth	Safety Index		
1	2015025	SR-248	4	2	4	17.5	9	13.75	50.25	1
	2015058	US-189	2	2	3	6.25	6	15	34.25	2
	2015028	SR-36	4	4	4	1.25	3	17.5	33.75	3
	2015029	SR-36	4	7	4	2.5	3	11.25	31.75	4
	2015027	SR-248	2	1	2	7.5	9	6.25	27.75	5
	2015059	US-6	2	2	3	0	6	11.25	24.25	6
2	2015035	SR-138	2	1	2	15	15	8.75	43.75	1
	2015038	SR-248	2	1	2	2.5	12	11.25	30.75	2
	2015036	SR-36	4	4	4	0	6	11.25	29.25	3
	2015037	SR-36	4	2	4	0	3	15	28	4
	2015209	US-6	2	2	4	1.25	6	11.25	26.5	5
	2015068	US-6	2	2	3	0	6	12.5	25.5	6
3	2015069	US-6	2	2	3	5	2	11.25	29.25	1
	2015047	SR-112	2	1	4	0	2	11.25	27.25	2
	2015015	SR-167	2	1	0	10	2	3.75	19.75	3

Source: uPlan, UDOT LRP 2015–2040.

The following sections discuss how the LRP rankings could be modified based on the modified safety metric (using the 2040 Safety Index and using the difference between the No-Build and Build 2040 Safety Indexes).

6.2.1. 2040 Safety Index as the Metric

The research team updated the safety subscores for each of the 15 LRP projects to calculate a revised project ranking. Table 6.2 shows the updated ranking based on the 2040 Safety Index. As shown in Table 6.2, 11 of the 15 case study projects are ranked differently when the 2040 metrics are used. Projects that received a different ranking are shaded.

Table 6.2 LRP Prioritization Rankings with 2040 Safety Index

LRP Phase	Project ID	Route	Prioritization Subscores: AADT, Truck AADT, Functional Class, v/c, and Growth	Prioritization Subscores: 2040 Safety Index	Total Score (2040 SI Method)	Updated Rank (2040 SI Method)	Original Rank
1	2015025	SR-248	See Table 6.1	12.25	48.75	1	1
	2015058	US-189		5.75	25	6	2
	2015028	SR-36		9.25	25.5	5	3
	2015029	SR-36		12	32.5	2	4
	2015027	SR-248		6.5	28	3	5
	2015059	US-6		13.25	26.25	4	6
2	2015035	SR-138	See Table 6.1	13.75	48.75	1	1
	2015038	SR-248		13	32.5	2	2
	2015036	SR-36		8.25	26.25	5	3
	2015037	SR-36		10.25	23.25	6	4
	2015209	US-6		14.75	30	3	5
	2015068	US-6		16.25	29.25	4	6
3	2015069	US-6	See Table 6.1	15	33	1	1
	2015047	SR-112		9.25	25.25	3	2
	2015015	SR-167		17	33	1	3

6.2.2. Change in No-Build Versus Build Safety Index as the Metric

For this scenario, the 2040 Safety Index was calculated based on No-Build and Build conditions. The decreases in Safety Indexes between No-Build and Build were converted to a safety subscore (0–25 scale) using a linear conversion as shown in Figure 6.1. All road segments that showed an increase in Safety Index were given a 0 score; a change in Safety Index of 5 was given the maximum score as all case study segments had a reduction of 5 or less.

The safety subscores were updated for each of the 15 LRP projects to calculate a revised project ranking based on the decrease in Safety Index. Table 6.3 shows the updated ranking based on the 2040 Safety Index. As shown in Table 6.3, 11 of the 15 case study projects change rankings using the 2040 metrics.

One Phase I project that experienced a notable change in ranking was US-6, which changed from a last-place ranking to a second-place ranking. This project is on US-6, approximately 10 miles east of US-89 in Spanish Fork Canyon (MP 195 to 197), and would widen the existing two/three-lane cross-section to match the five-lane cross-sections to the west and east. The anticipated safety benefit (i.e., reduction in Safety Index based on 2040 crash prediction) is significant enough to rank this project higher than four other Phase I widening projects. Other significant increases and decreases in project rankings are also shown in Table 6.3. Projects that received a different ranking are shaded.

All else being equal, this method gives road segments that are most likely to experience an improvement in safety a higher prioritization ranking than segments that would not experience an increase in safety.

Figure 6.1 Conversion of Decrease in Safety Index to Safety Subscore

Table 6.3 LRP Prioritization Rankings with 2040 Safety Index

LRP Phase	Project ID	Route	Prioritization Subscores: AADT, Truck AADT, Functional Class, v/c, and Growth	Prioritization Subscores: No-Build to Build Safety Index Score	Total Score (No-Build to Build Method)	Updated Rank (No-Build to Build Method)	Original Rank
1	2015025	SR-248	See Table 6.1	0	36.5	1	1
	2015058	US-189		0	19.25	5	2
	2015028	SR-36		1.5	17.75	6	3
	2015029	SR-36		4.5	25	3	4
	2015027	SR-248		0	21.5	4	5
	2015059	US-6		14	27	2	6
2	2015035	SR-138	See Table 6.1	10	45	1	1
	2015038	SR-248		13.5	33	3	2
	2015036	SR-36		2.5	20.5	5	3
	2015037	SR-36		1.5	14.5	6	4
	2015209	US-6		18	33.25	2	5
	2015068	US-6		20	33	3	6
3	2015069	US-6	See Table 6.1	15	33	2	1
	2015047	SR-112		8.5	24.5	3	2
	2015015	SR-167		24	40	1	3

6.2.3. Case Study Summary

Figure 6.2, Figure 6.3, and Figure 6.4 show the rankings using the three methodologies for the case study projects in Phase I, Phase II, and Phase III, respectively.

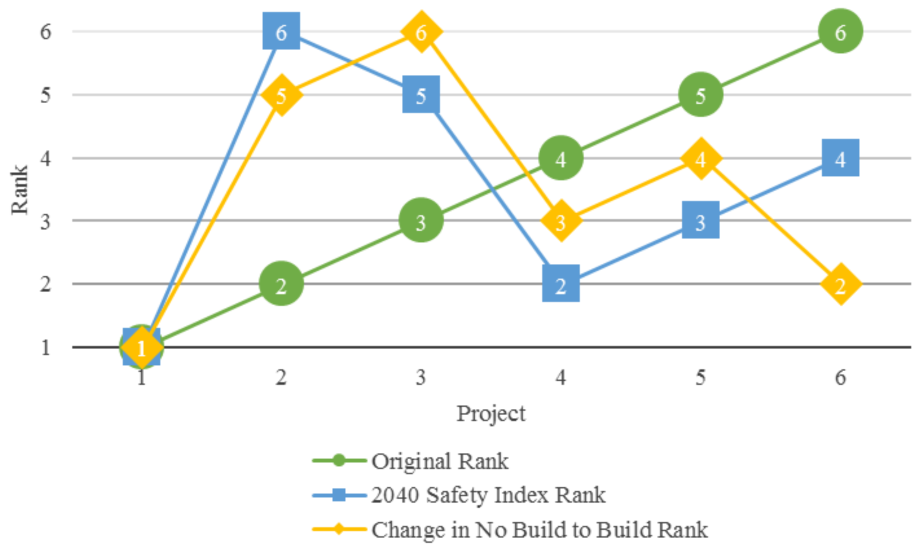

Figure 6.2 Phase I Project-Ranking Comparison

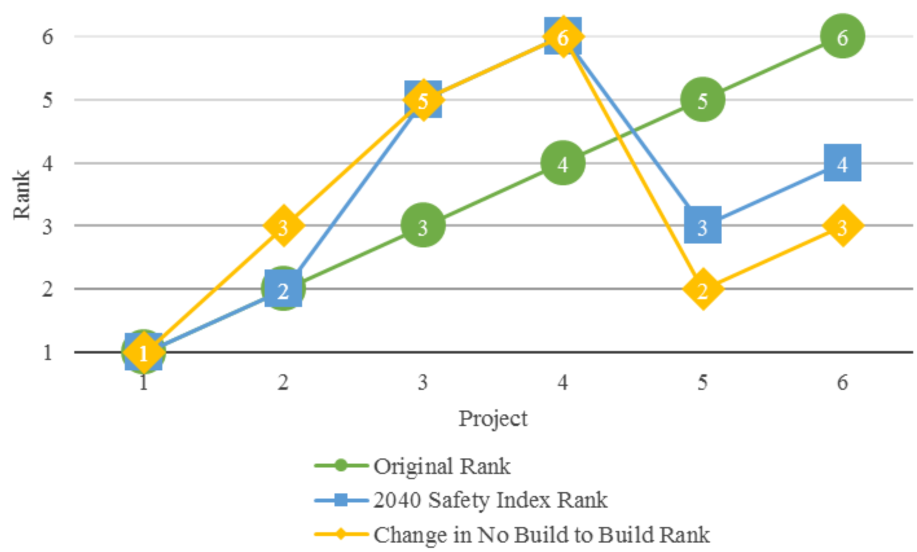

Figure 6.3 Phase II Project-Ranking Comparison

Figure 6.4 Phase III Project-Ranking Comparison

6.3 Systemic Crash Analysis

UDOT is increasingly turning to systemic safety analysis to identify future projects (UDOT LRP). Systemic analysis methods look at roadway and crash attributes to identify common conditions across the state (as opposed to looking at spot aggregations of crashes) that lead to fatal and serious-injury crashes (UDOT LRP). Two characteristics of rural two-lane, two-way roads that affect crash prediction as a function of future AADT are lane width and shoulder width. The larger the AADT, the more negative effect a narrow lane or shoulder has on forecasted crashes. The Safety Forecast Model was used to identify road segments that are more likely to see a positive benefit of a lane or shoulder widening project based on future volumes. This type of analysis could assist UDOT in prioritizing locations to obtain funding for this type of work.

6.3.1. Lane Width Improvements

The CMF for lane widths on rural two-lane, two-way roads varies from 1 to 1.5 depending on the AADT and the width of the lanes. The research team adjusted the 2040 No-Build Safety Forecast Model so that all lanes were 12 feet wide. Figure 6.5 shows the magnitude of changes in FI crashes per mile. As shown in Figure 6.5, some road segments see a reduction by approximately 2 FI crashes per mile.

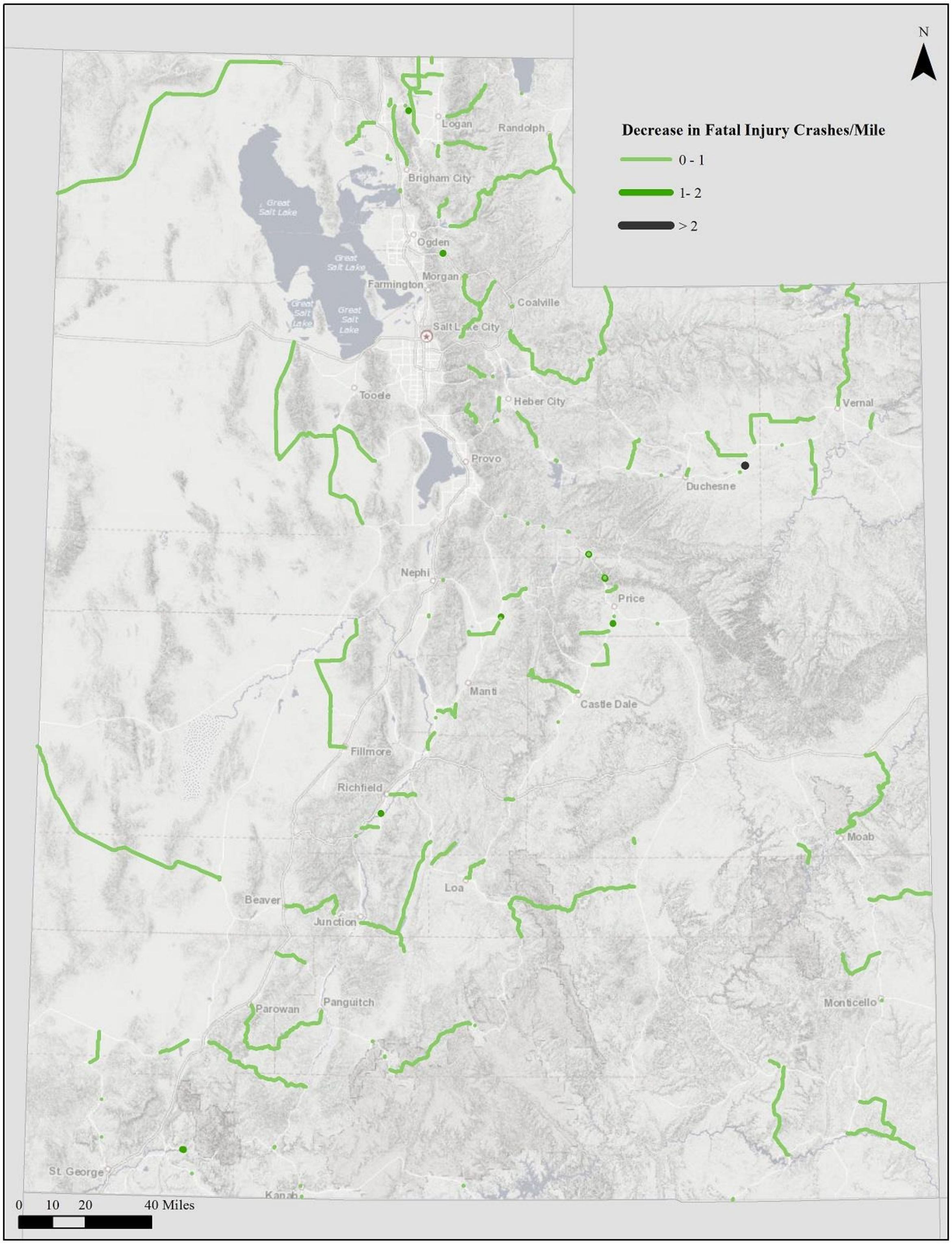

Figure 6.5 Reduction in 2040 FI Crashes Assuming All Rural Two-Lane Road Lanes are Improved to 12 Feet Wide

6.3.2. Shoulder Width Improvements

The CMF for shoulder widths on rural two-lane, two-way roads varies from 0.87 to 1.5 depending on the AADT and the shoulder width (shoulders greater than 6 feet wide have a CMF of less than 1.0). The 2040 No-Build Safety Forecast Model was adjusted so that all shoulders were at least 6 feet wide (shoulders already greater than 6 feet wide were not changed). Figure 6.6 shows the magnitude of changes in FI crashes per mile. As shown in Figure 6.6, some road segments experience a reduction of greater than 4 FI crashes per mile.

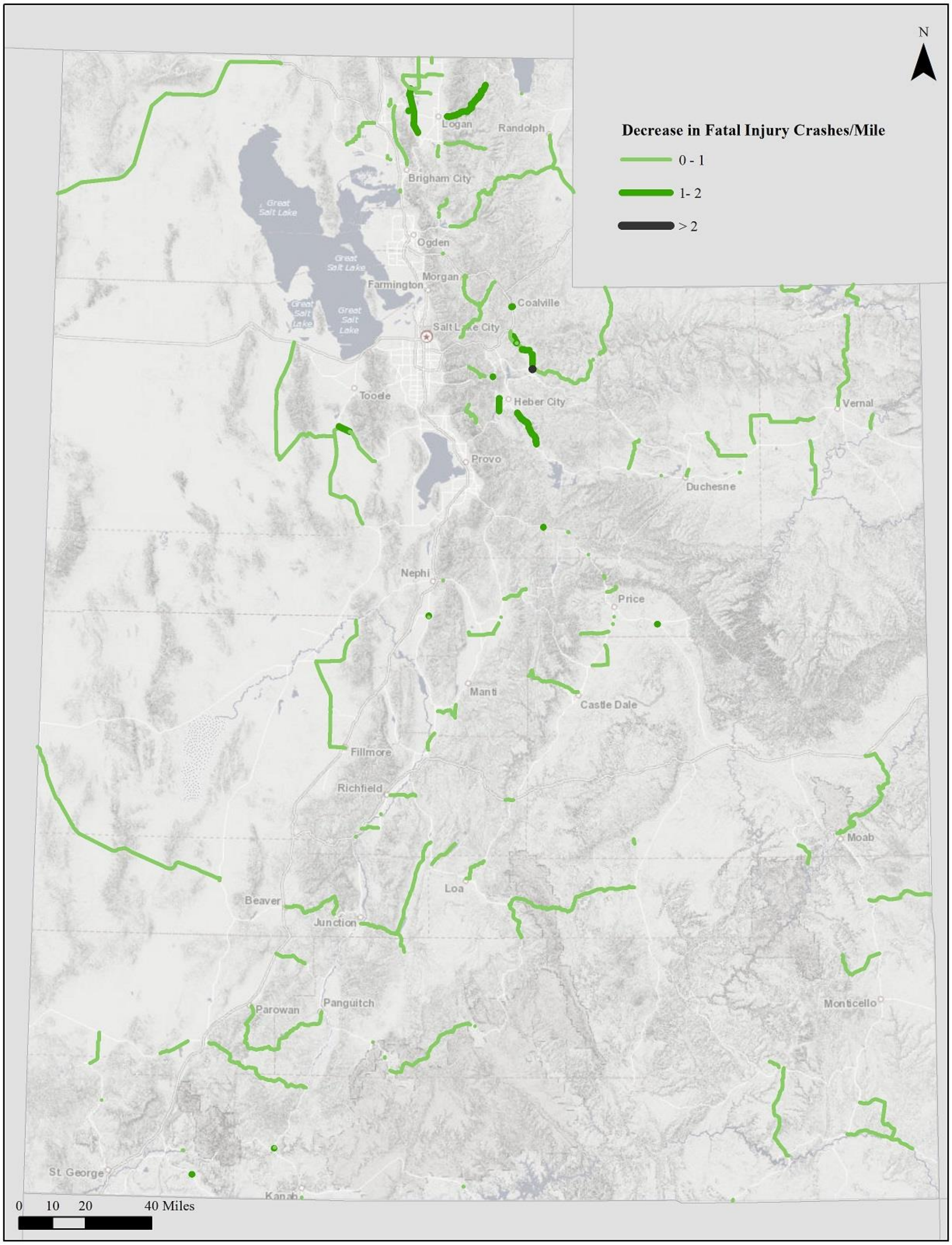

Figure 6.6 Reduction in 2040 FI Crashes Assuming All Rural Two-Lane Road Shoulders are Improved to 6 Feet Wide

6.4 Summary

This chapter discussed two ways that the Safety Forecast Model could be used for safety analyses and planning work. The Safety Forecast Model could be used for project prioritization by evaluating the difference between the No-Build and Build projected crashes. The Safety Forecast Model could also be used for systemic safety analyses by identifying road segments with the largest reduction in FI crashes (assuming that lane widths and shoulder widths are improved on rural two-lane, two-way roads).

7.0 CONCLUSIONS

7.1 Summary

UDOT currently prioritizes future projects based on historical crash data using the UDOT Safety Index. This research sought to identify a process to improve long-range planning prioritization by using forecasted safety metrics based on anticipated future conditions (such as future AADT and roadway characteristics). The primary objective was to create a functioning Safety Forecast Model, including assembling the required data to forecast future crashes. The output of the Safety Forecast Model was then used to calculate a modified Safety Index based on future conditions. A case study evaluated several UDOT LRP widening projects to determine how the rankings of these projects were affected based on forecasted safety instead of historical crash data.

7.2 Safety Forecast Model

7.2.1. Safety Forecast Model Framework

The Safety Forecast Model was created based on SPFs and CMFs contained in the HSM. Data were obtained from readily available UDOT sources, including uPlan (for roadway characteristic data) and USTM (for future forecast traffic volumes). The Safety Forecast Model includes all rural and urban/suburban state route segments within the UDOT Planning space (i.e., outside of the four Utah MPOs).

7.2.2. Safety Forecast Model Scope

The Safety Forecast Model does not include intersections, non-state routes, and freeway segments. Follow-up studies such as corridor studies or project-level analyses could consider freeways, FARs, and intersections as detailed data would be easier to acquire for smaller study areas.

7.2.3. Using Other Forecast Models

The safety analysis tool utilized—in this case, SPFs and CMFs from the HSM—is less important than having a tool that accounts for future safety. Alternative safety forecast models could be used to perform similar functions.

7.3 Safety Forecast Model Applications

7.3.1. Some Projects Increase Crashes

Most road segments (75%) with projects are anticipated to experience a reduction in crashes, but 25% of road segments with projects are anticipated to experience an increase in crashes. UDOT project development staff should consider how to mitigate safety issues associated with projects that are anticipated to experience an increase in crashes when designing and constructing these projects.

7.3.2. Prioritization Based on Future Crashes

Project prioritization ranking changes if future crash forecasts are used instead of historical crash rates found in the UDOT Safety Index.

7.3.3. Prioritization Based on Changes in Future Crashes

Project prioritization ranking changes if projects are prioritized based on the magnitude of the decrease in future crashes due to the proposed LRP project. All else being equal, this method gives road segments that are most likely to see an improvement in safety a higher prioritization ranking than segments that would not experience as significant of an increase in safety.

7.3.4. Systemic Analysis

The Safety Forecast Model can also be used for systemic safety analysis—methods that look at roadway and crash attributes to identify common conditions across the state (as opposed to looking at spot aggregations of crashes) that lead to FI crashes. For example, the Safety

Forecast Model was used to identify road segments with the highest reduction in FI crashes—assuming that lane widths and shoulder widths are improved on rural two-lane, two-way roads.

7.4 Limitations and Challenges

The scope of this research only included non-freeway road segments (excluding intersections and FARs) in the rural portions of the state (outside of the four MPOs). However, the methodologies outlined in this report could be applied to other road facilities in the state not included in this research. Some data were not available for the Safety Forecast Model, and expanding the scope would require more data that may not readily be available. Accuracy of the Safety Forecast Model could be increased with additional data, and new data sources would also be required if the scope of the model were to increase.

8.0 RECOMMENDATIONS AND IMPLEMENTATION

8.1 Recommendations

This research has demonstrated that future safety forecasts can be included in the prioritization process by using the Safety Forecast Model created and HSM methodologies described in this report. UDOT should consider future safety in subsequent updates to the UDOT LRP project identification and prioritization process. UDOT Division of Traffic and Safety and Region staff can also utilize the Safety Forecast Model to identify road segments that warrant additional safety analyses as new projects are considered.

8.2 Implementation Plan

This research was a successful proof of concept application. UDOT could implement these findings and increase the scope of the Safety Forecast Model to include freeways, FARs, intersections, and roadway networks within Utah's MPOs. Automation steps could also be investigated to update the model with new data more efficiently as these data become available.

REFERENCES

Allen, C. *Safety Index Calculation Methodology*. Wasatch Front Regional Council, 2013. http://www.wfrc.org/publications/RTP-publications/appendices/Appendix%20F%20-%20Safety%20Index%20Calculation.pdf. Accessed March 26, 2017.

Le, T. Q., F. Gross, and T. Harmon. Safety Effects of Low-Cost Systemic Safety Improvements at Signalized and Stop-Controlled Intersections. Presented at 96th Annual Meeting of the Transportation Research Board, Washington, D.C., 2017.

Schultz, G. G., D. R. Bassett, M. Saito, and C. S. Reese. *Use of Roadway Attributes in Hot Spot Identification and Analysis*. Report No. UT-15.10. Utah Department of Transportation Traffic & Safety, Research Divisions, 2015.

Schultz, G. G., J. S. Farnsworth, R. Roundy, M. Saito, C. S. Reese, and T. Briggs. *Hot Spot Identification & Analysis Methodology*. Report No. UT-13.15. Utah Department of Transportation Traffic & Safety, Research Divisions, 2013.

Schultz, G. G., S. T. Mineer, M. Saito, J. D. Gibbons, S. A. Siegel, and P. D. MacArthur. *Roadway Safety Analysis Methodology for Utah*. Report No. UT-16.13. Utah Department of Transportation Traffic & Safety, Research Divisions, 2016.

The Highway Safety Manual. AASHTO, Washington, D.C., 2010.

Torbic, D. J., D. W. Harwood, and K. M. Bauer. Application of the HSM Ramp Crash Prediction Method to Loop and Diamond Ramps. Presented at 96th Annual Meeting of the Transportation Research Board, Washington, D.C., 2017.

Traffic on Utah Highways 2015. Utah Department of Transportation Program Development Division Traffic Analysis Section. In cooperation with FHWA, U.S. Department of Transportation, 2015.

UDOT 2015–2040 Long-Range Transportation Plan: Transportation in Utah's Rural Areas. Utah Department of Transportation, 2015.

UDOT. *UDOT LRP 2015-2040*. uPlan. http://uplan.maps.arcgis.com/apps/Viewer/index.html?appid=8465e972c4ae42e18cc775149f79edcf&extent=-114.6897,37.0761,-107.471,41.9088. Accessed March 26, 2017.

Wang, J., M. A. Abdel-Aty, and J. Lee. Evaluation of Safety Performance Functions Based on Experimental Design Using a Cross-Validation Method. Presented at 96th Annual Meeting of the Transportation Research Board, Washington, D.C., 2017.

Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. J. Thirsk, J. Zegeer, C. Lyon, E. Ferguson, and R. Van Houten. *Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments.* Pre-publication draft of NCHRP Research Report 841. Transportation Research Board, Washington, D.C., 2016.

APPENDIX A: MODEL BUILDER

Appendix A includes screenshots of ArcMap Model Builder used to process data from uPlan.

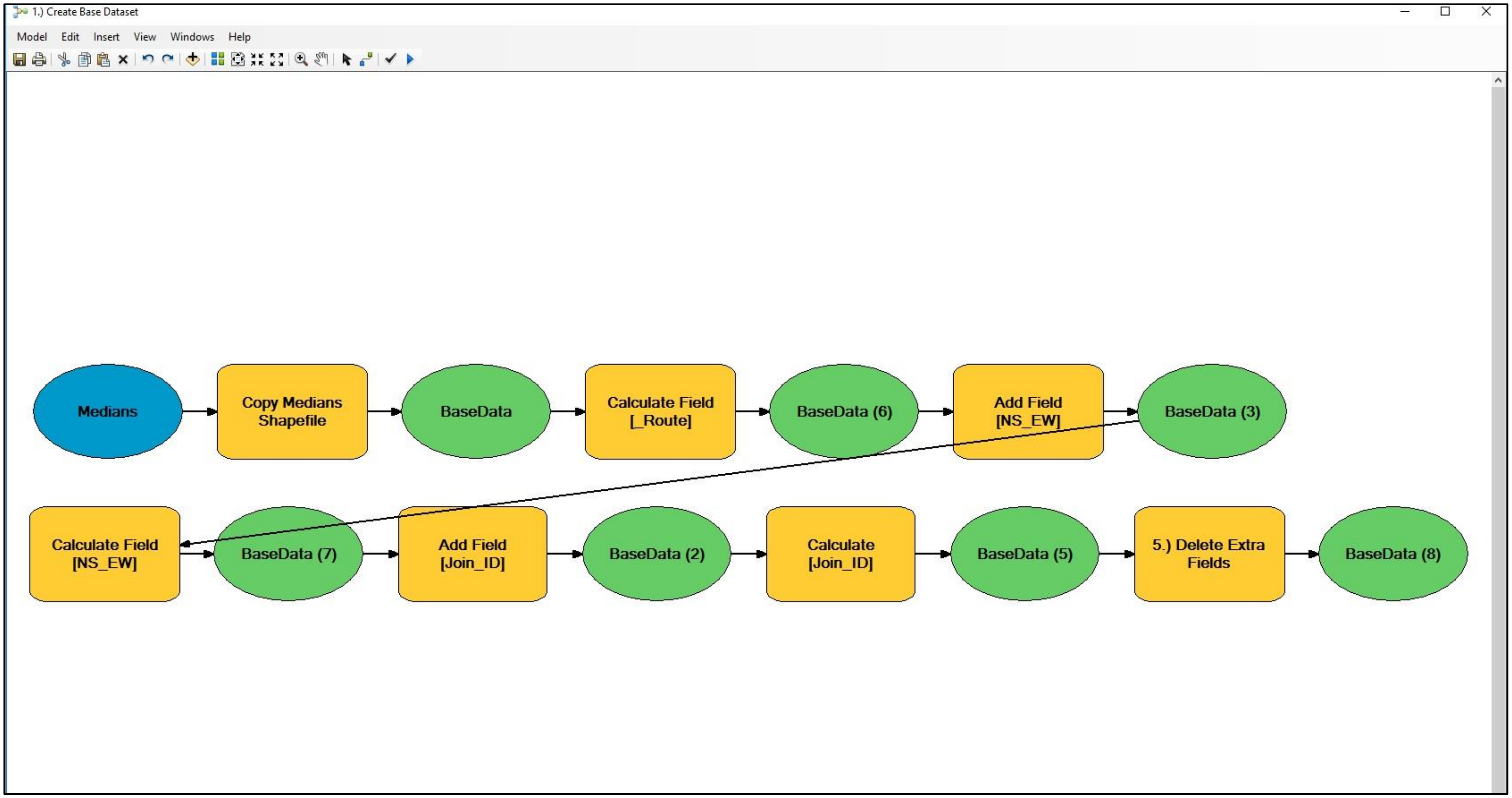

Figure A.1 Model Builder: Create Base Dataset

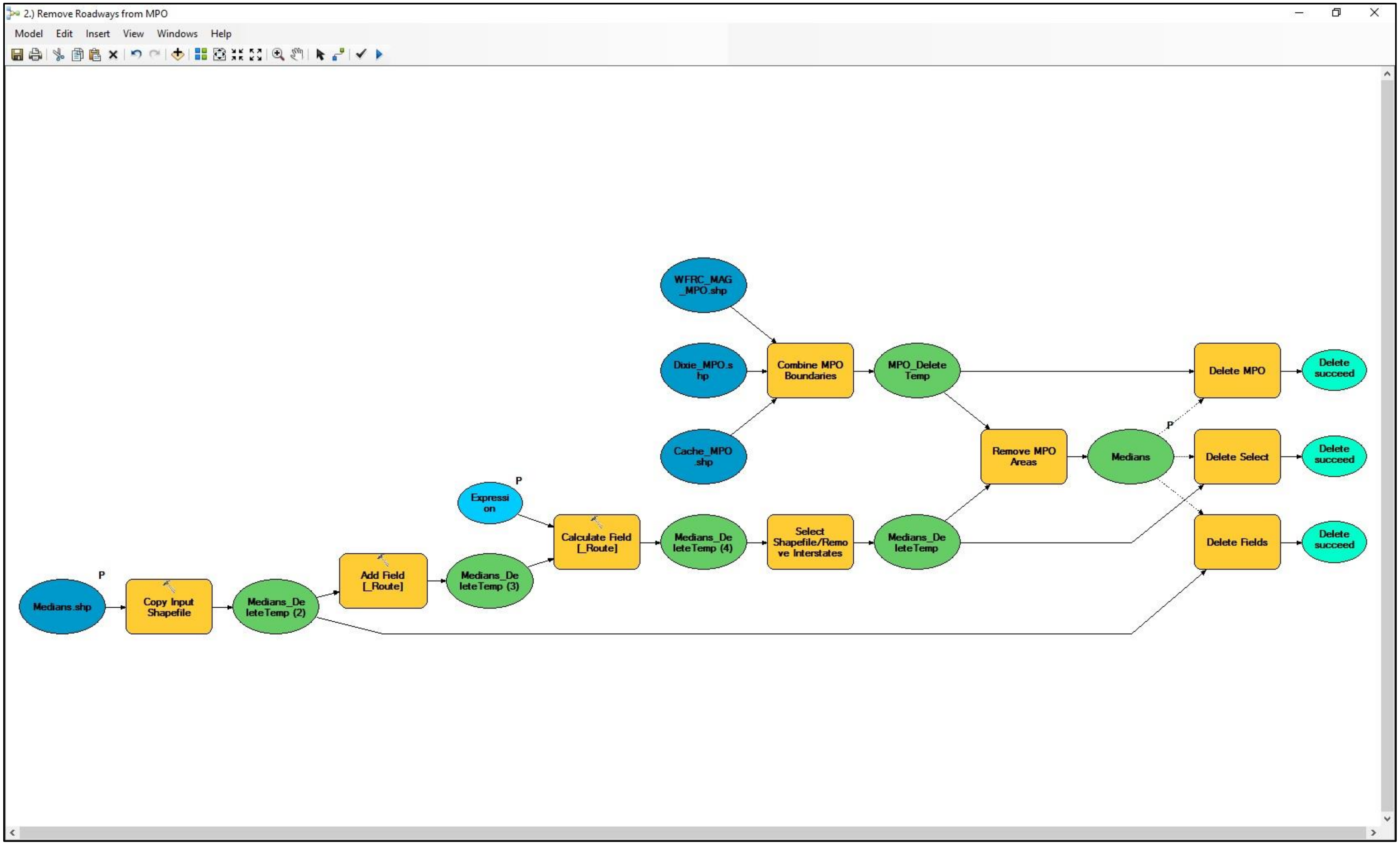

Figure A.2 Model Builder: Remove Roadways from MPO

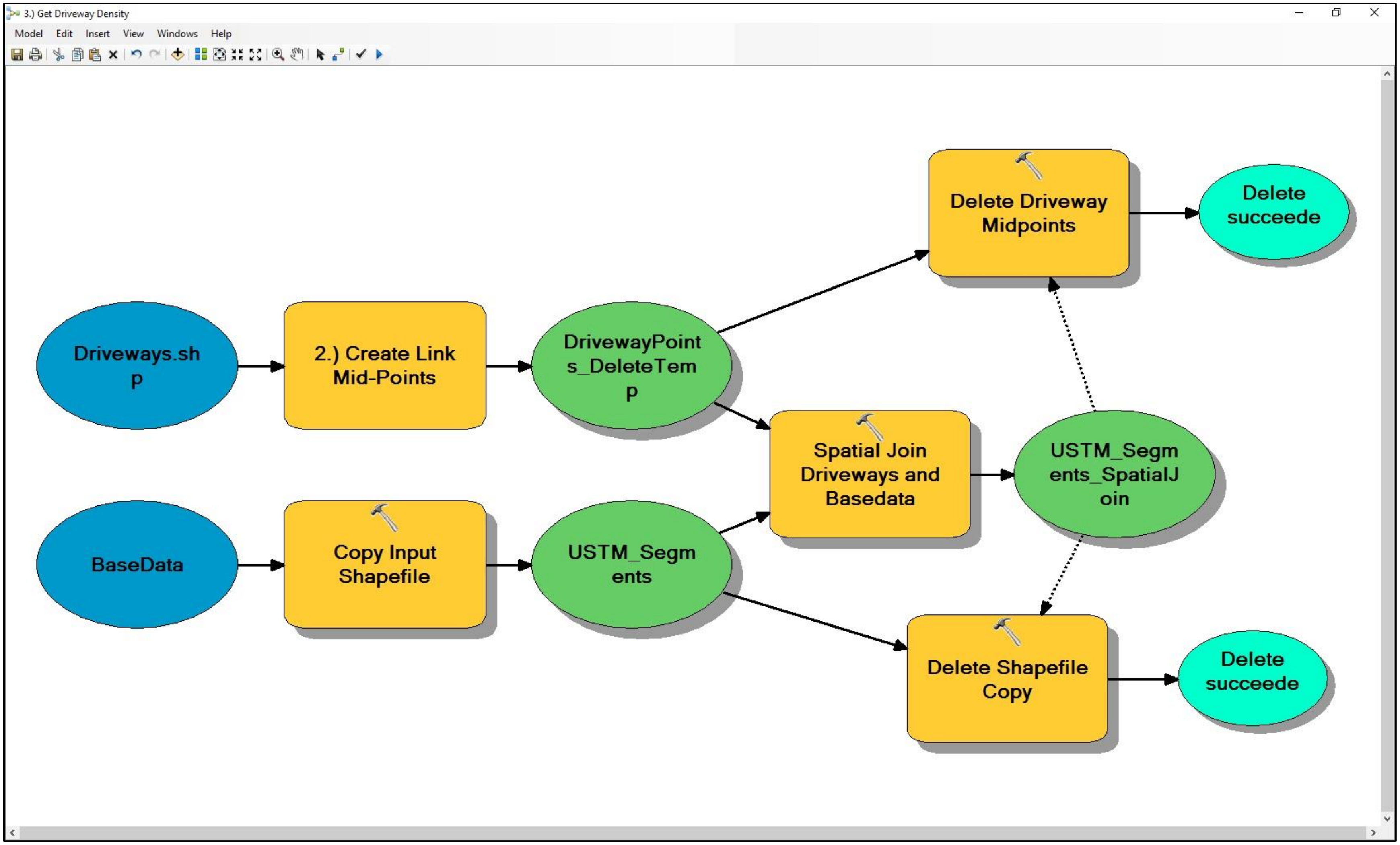

Figure A.3 Model Builder: Get Driveway Density

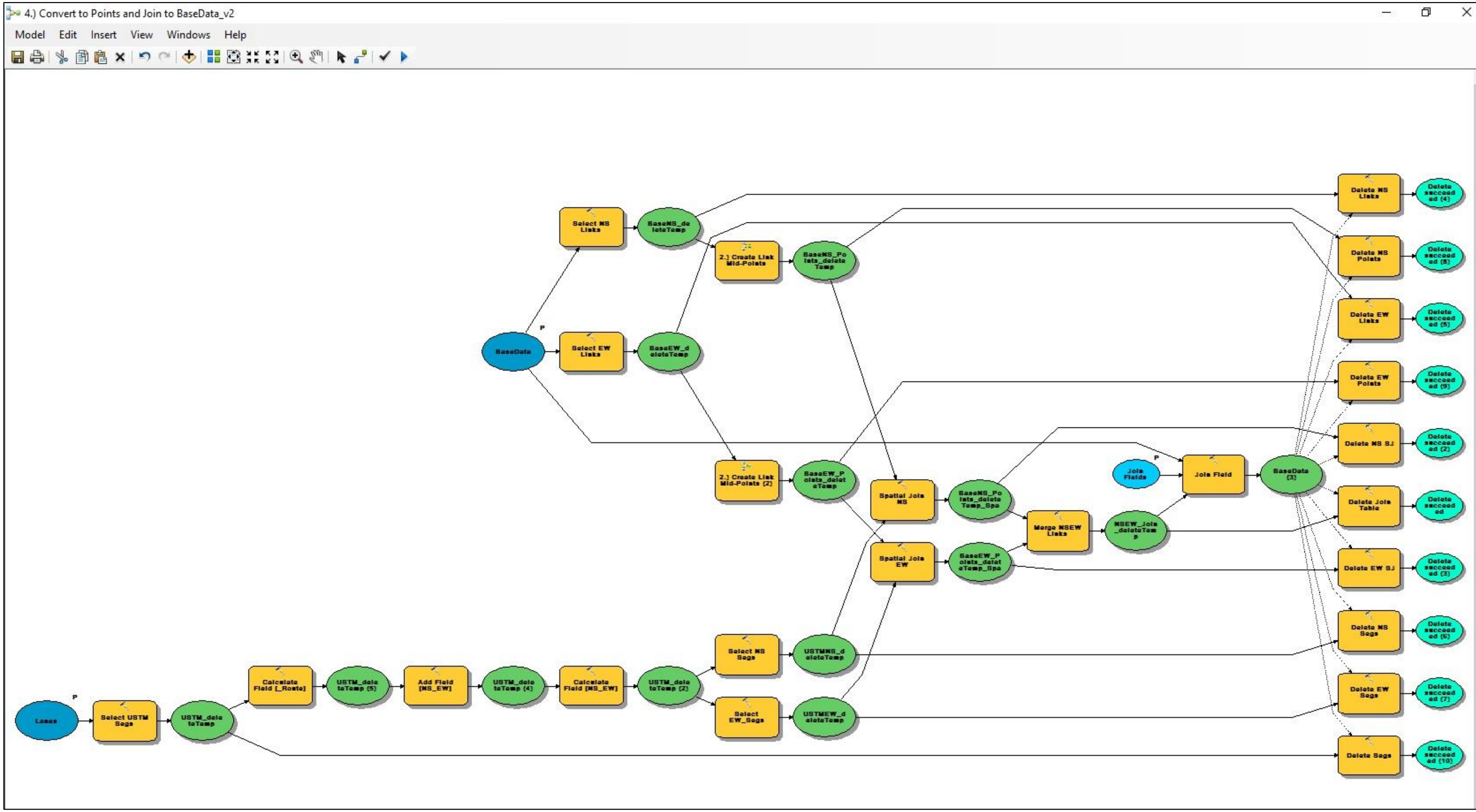

Figure A.4 Model Builder: Convert to Points and Join to Base Data