IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Development of a Methodology to Evaluate the Highway Safety Improvement Program

RP 287

By

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16. Abstract
The goal of this research study was to provide information and develop tools that can help the Idaho Transportation Department (ITD) conduct safety effectiveness evaluation consistently across the state, provide data-driven rationale for future investments, and to help prepare the evaluation section of the Highway Safety Improvement Program (HSIP) Annual Report. A method and a geographic information system (GIS) tool were developed to evaluate the safety effectiveness of individual projects and groups of projects. The tool uses readily available data to calculate four safety performance measures: crash frequency, crash rate, annual economic cost, and severe crash proportion. The tool output includes: an Excel file with safety performance measure data; GIS files for mapping the crash data; and a report that provides tables and charts for the safety performance measures, a Google Street View image, and crash map. In the future, ITD could implement the process through a different platform, such a web application, or modify the GIS tool for future needs. A case study evaluation was done for nineteen HSIP projects that were completed between 2014 and 2016.

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Technical Advisory Committee

Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an ITD project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

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List of Abbreviations and Acronyms

23 CFR 924.15	Code of Federal Regulations, Title 23, Part 924.15
AADT	Annual Average Daily Traffic
CMF	Crash Modification Factor
DOT	Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
IDE	Integrated Development Environment
ITD	Idaho Transportation Department
LHTAC	Local Highway Technical Assistance Council
MEV	Million Entering Vehicles
OTIS	Office of Transportation Investment Systems
RTM	Regression to the Mean
SPF	Safety Performance Function
TAC	Technical Advisory Committee
TEV	Total Entering Vehicles
VMT	Vehicle Miles Traveled

Executive Summary

The Highway Safety Improvement Program (HSIP) is a core Federal-aid program to reduce fatalities and severe injuries on all public roads. Each state must submit its HSIP Annual Report to the Federal Highway Administration (FHWA) Division Administrator. The goal of this research study was to provide information and develop tools that can help the Idaho Transportation Department (ITD) conduct safety effectiveness evaluation consistently across the state, provide data-driven rationale for future investments, and to help prepare the evaluation section of the HSIP Annual Report.

A method and a geographic information system (GIS) tool were developed to evaluate the safety effectiveness of individual projects and groups of projects. The tool uses readily available data to calculate four safety performance measures: crash frequency, crash rate, annual economic cost, and severe crash proportion. The tool output includes: an Excel file with safety performance measure data; GIS files for mapping the crash data; and a report that provides tables and charts for the safety performance measures, a Google Street View image, and crash map. In the future, ITD could implement the process through a different platform, such a web application, or modify the tool for future needs.

A case study evaluation was done for nineteen HSIP projects that were completed between 2014 and 2016. Ten of the projects experienced reductions in crash frequency; eleven experienced reductions in crash rate; eight experienced reductions in annual economic cost; and ten experienced reductions in severe crash proportion. Four projects experienced reductions in all four safety measures.

Recommendations

The following recommendations are opportunities for ITD to improve the methodology. These are explained in greater detail in the final chapter of the report.

1. Create and maintain an online geodatabase of projects.
2. Create and maintain an online searchable database of countermeasures associated with project.
3. Create and maintain an online searchable database of the crash types that are targeted by each project.
4. Create and maintain an online geodatabase of estimated AADT for all public roads.
5. Improve the online crash geodatabase by adding and removing fields.
6. Improve the speed of the evaluation tool and create a web application.
7. Develop a tool to automatically create comparison groups for roadway segments and intersections.
8. Continue to improve the ITD's Safety Management Process, especially the first step of identifying candidate projects through Network Screening.

1. Introduction

Problem Statement

The Highway Safety Improvement Program (HSIP) is a core Federal-aid program to reduce fatalities and severe injuries on all public roads. Each year Idaho receives approximately $18 million in HSIP funds. To track HSIP efforts, an annual report is required to document its implementation and effectiveness under 23 CFR 924.15. States are to select and implement projects that will contribute to a reduction in fatalities and serious injuries, consistent with their Strategic Highway Safety Plan (SHSP) goals and safety performance targets. Each state must submit its HSIP Annual Report to the Federal Highway Administration (FHWA) Division Administrator no later than August 31st of each year. The Idaho Transportation Department (ITD) prepares the document, reporting on ITD and Local Highway Technical Assistance Council (LHTAC) HSIP projects. ITD's HSIP Annual Report is to include the following:

- An assessment of the effectiveness of the safety improvements; and
- A description of how the safety improvements have contributed to reducing fatalities and severe injuries on all public roads.

Currently, ITD's HSIP Annual Report only provides an overall evaluation of statewide crash statistics. ITD and LHTAC currently do not have tools available to perform post-analysis of individual projects or groups of projects, which makes it difficult to determine if implemented countermeasures have been effective.

Goal, Objectives, and Scope

The goal of this research study was to provide information and develop tools that can help ITD prepare the evaluation section of the HSIP Annual Report. To achieve this goal, the objectives of this research were to:

1) Develop a <u>method</u> to evaluate the safety effectiveness of individual HIIP projects and groups of HSIP projects.
2) Create a geographic information system (GIS) <u>tool</u> that employs the method.
3) Perform a <u>case study</u> evaluation for a group of HSIP projects.

The Technical Advisory Committee (TAC) for this research study determined that the methodology should utilize data that is readily available, the output should focus on the requirements of the HSIP Annual Report, and the process should have minimal impact on staff workload. The data sources would include ITD's project database called OTIS (Office of Transportation Investment Systems) and ITD's published data for Annual Average Daily Traffic (AADT) and crashes. Although the evaluation will be limited in scope, the TAC determined that the output could provide a starting point for identifying HSIP projects that should be analyzed further using additional data and other methods.

The following bullets describe the assumptions and scope of this research study.

- The evaluation method does not isolate specific crash types, such as “Rear-End” or “Run Off Road” crashes, because information about targeted crash types is not readily available in the OTIS database. Such information can only be assembled through an investigation of original project documentation. Furthermore, many locations in the case study experienced very few crashes, thus diminishing the potential value of evaluating a smaller subset of crashes.
- The evaluation method does not involve “comparison group" sites which requires the time-intensive task of finding other locations with comparable characteristics.
- The evaluation method does not involve Safety Performance Functions (SPF), which must be developed or calibrated using a significant amount of data. SPFs are mathematical models for predicting the number of crashes expected at an intersection or along a roadway segment.
- The tool requires the user to provide the geographic footprint for each project because the existing geodatabases maintained by ITD lack sufficient GIS data for project footprints.
- The tool uses values for AADT that were estimated as part of this research study because ITD currently (January 2023) does not maintain a geodatabase of AADT for all public roads statewide. The methodology we used to estimate AADT is described in Appendix A. (ITD is currently funding an effort to estimate statewide AADT values for all public roads. The evaluation tool should be updated to use ITD’s official “all-roads” AADT estimates when they are ready.)
- Group evaluation is only performed on projects grouped by geographic footprint type: i.e., Intersection projects or Segment projects. There is no group evaluation for other groupings. We considered grouping projects by District, by Work Category, or by countermeasure. However, such data was not available, or the groups consisted of only one project. The Work Category labels available in the OTIS database were deemed inadequate proxy for countermeasure type.

Relation to Previous ITD Research

ITD Research Report 225 describes the calibration and development of three SPFs for specific use in Idaho (Abdel-Rahim and Sipple, 2015). ITD Research Report 257 summarizes safety evaluation methods and demonstrates two methods for projects in Idaho (Loudon and Schulte, 2016). Both reports are discussed in the next chapter.

Report Organization

Chapter 2 provides background information for the proposed method and tool. Chapter 3 introduces the methodology and describes the tool output. Chapter 4 summarizes the results from a case study evaluation of nineteen HSIP projects that were completed between 2014 and 2016 (The entire case study report is provided in Appendix D). Finally, chapter 5 concludes with a discussion of the strengths and limitations of the proposed method and offers recommendations for future work.

2. Literature Review

This chapter provides background for the method and tool. The interested reader should consult *Chapter 9 Safety Effectiveness Evaluation* of the Highway Safety Manual (HSM), for additional information about safety evaluation. The HSM is the authoritative resource for safety analysis (AASHTO, 2010). Another essential resource is the *Highway Safety Improvement Program Manual* published by FHWA to provide state DOTs guidance for integrating HSM methods with their state HSIP effort (Herbel et al., 2010). A few years later, FHWA launched a series of reports called *Reliability of Safety Management Methods* to provide additional explanations and examples. The report authored by Srinivasan et al. (2016) is focused on evaluation and provides examples using simulated data.

Safety Management Process

The *Safety Management Process* is a six-step cycle presented in the HSM to help state DOTs identify and prioritize site-level safety improvement projects (AASHTO, 2010). Figure 2.1 shows the steps: Network Screening, Diagnosis, Select Countermeasures, Economic Appraisal, Prioritize Projects, and Safety Effectiveness Evaluation. The following paragraphs provide a brief description of each step.

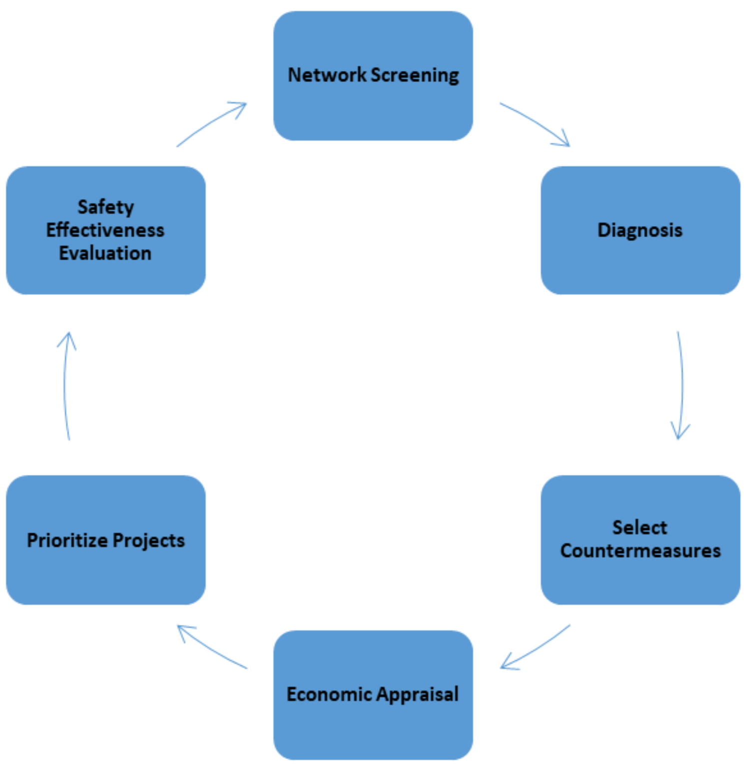


Figure 2.1 Safety Management Process (AASHTO, 2010)

The first step is *Network Screening*. This is the process of scanning segments and intersections throughout the state to rank-order locations where roadway improvements might be able to reduce crashes. Network screening is done separately for sites that are segments and sites that are intersections. Dr. Ezra Hauer, a safety expert who helped develop the HSM, emphasized that network screening is the crucial first step to identify “sites with promise” (Hauer, 1997). Sites are ranked using *safety performance measures*, such as *crash frequency* which is the average number of crashes per year over an analysis period (typically five years for Network Screening).

The second step is *Diagnosis*. This involves identifying the root cause of the crashes at the site and determining the extent of the problem. This is done through detailed investigation of crash data, including summarizing the contributing circumstances (e.g., Excessive Speed) and harmful events (Rear-End Collision) as reported by law enforcement. The outcome of the diagnosis step is a clear understanding of what went wrong and why, which is critical in developing effective solutions and preventing similar incidents from happening in the future.

The third step is *Select Countermeasures*. This involves identifying and choosing the most appropriate solutions to address identified safety risks. A countermeasure is a specific strategy taken to reduce collisions and improve road safety. This could include measures such as installing roundabouts, adding road signs and traffic signals, increasing road visibility, improving road surfaces, creating pedestrian and cyclist paths, and implementing traffic calming measures. The goal of these countermeasures is to minimize the likelihood and severity of crashes and create safer conditions for all road users. This step in the Safety Management Process requires a thorough evaluation of various options, taking into consideration their feasibility, cost-effectiveness, and their potential impact on safety. The goal is to select countermeasures that effectively mitigate the identified risks.

The fourth step is *Economic Appraisal.* This is an assessment of the costs and benefits associated with implementing countermeasures at a particular site. This step involves estimating the financial impact of potential safety measures, including both the costs of implementing the measures and the benefits that may result from reduced vehicle collisions. The goal of the Economic Appraisal step is to ensure that the most cost-effective safety measures are selected and implemented, while taking into consideration both financial and non-financial factors such as regulatory requirements and public perception. The results of the Economic Appraisal are used to inform the decision-making process and support the development of a safety management plan.

The fifth step is *Prioritize Projects*. This involves prioritizing potential safety improvement projects based on a variety of factors, including crash frequency and severity, target population, and cost-effectiveness. This step allows agencies to focus their limited resources on the projects that will have the greatest impact on reducing crashes and improving safety for all road users. The prioritization process also helps to ensure that limited funding is allocated to the most pressing safety concerns and that projects are aligned with overall transportation and safety goals.

The sixth step is *Safety Effectiveness Evaluation.* This is the evaluation of completed safety improvement projects. One approach is to compare safety performance measures, such as crash frequency, before and after project completion. For Safety Effectiveness Evaluation the before and after analysis period is typically three years. This information helps to determine the effectiveness of the implemented countermeasures, guide decision-making for future projects, and allocate resources effectively. The Safety Effectiveness Evaluation step is an ongoing process that enables agencies to continuously monitor and evaluate their safety programs to ensure they are achieving their desired outcomes and making progress towards reducing crashes and improving safety on the roadway.

Safety Performance Measures

Safety performance measures are metrics for (1) Network Screening to rank-order sites and (2) Safety Effectiveness Evaluation to determine if the implemented countermeasures improved safety. The four most used safety performance measures are *crash frequency*, *crash rate*, *annual economic cost*, and *severe crash proportion*. Each performance measure conveys a different safety aspect, so the analyst should examine all four comprehensively. The HSM recommends calculating these performance measures for a three-year analysis period, $N = 3$. (The analyst can choose to use other durations but should be aware that statistical bias increases for analysis periods less than three years and more than five years. For Safety Effectiveness Evaluation, the “before period” should be the same duration as the “after period”).

Crash frequency is calculated as follows:

$$\textit{Crash Frequency} = \frac{1}{N}\sum_{n} C_n \tag{1}$$

where C_n is the number of crashes in year n for N years. Crash frequency is expressed as *crashes/year*.

Crash Rate is the number of crashes per vehicle volume. For segments the calculation is:

$$\textit{Segment Crash Rate} = \frac{1{,}000{,}000 * \sum_n C_n}{365 \sum_n LA_n} \tag{2}$$

where C_n is the number of crashes in year n, L is the length of the segment in miles, and A_n is the Annual Average Daily Traffic (AADT) for year n. The denominator is annual Vehicle Miles Traveled (VMT), i.e. the Annual Average Daily Traffic, A_n times the length of the segment times 365. Crash Rate for a segment is expressed as *crashes/Million VMT*. When AADT varies across a segment, then A_n is a length-weighted average.

For intersections, the calculation for crash rate is:

$$Intersection\ Crash\ Rate = \frac{1{,}000{,}000 * \sum_n C_n}{365 \sum_n \sum_i d_i * A_{n,i}} \tag{3}$$

where C_n is the number of crashes in year n. is the AADT for year n on leg i. If leg i is a two-way road, then d_i = ½; if leg i is a one-way road approaching the intersection, then d_i = 1; and if leg i is one-way road leaving the intersection, then d_i = 0. For two-way roads, AADT is divided by 2 because AADT is the total volume in both directions. The denominator in Equation 3 is Total Entering Vehicles (TEV). Crash Rate for an intersection is expressed as *crashes/Million EV*.

Annual Economic Cost is based on the concept of cost "equivalence" for each severity type. Table 2.1 shows economic cost equivalent values for each severity type in 2021-dollars. The calculation for the performance measure is:

$$Annual\ Economic\ Cost = \frac{1}{N} \sum_n \sum_s C_{n,s} * E_s \tag{4}$$

where N is the number of years, $C_{n,s}$ is the number of crashes in year n for severity s and E_s is the economic cost equivalent for severity, s. Annual Economic Cost is expressed as *dollars/year*. (Sometimes this performance measure is divided by the equivalent cost associated with Property Damage Only crashes, in which case the value is a unitless index relative to PDO).

Table 2.1 Crash Severity Equivalent Economic Cost (ITD, 2022)

KABCO	Severity	Cost
K	Fatalities	$11,800,000
A	Suspected Serious Injury	$564,335
B	Suspected Minor Injury	$153,707
C	Possible Injuries	$78,488
O	No Injuries (Property Damage Only)	$3,976

Severe crash proportion is the percent of crashes that are categorized as either fatal or serious injury crashes. This calculation is:

$$\textit{Severe Crash Proportion} = \frac{\sum_n \sum_{s \in KA} C_{n,s}}{\sum_n \sum_{s \in KABCO} C_{n,s}} \tag{5}$$

where $C_{n,s}$ is the number of crashes in year *n* for severity *s*. The numerator is a summation of fatal (K) and serious injury (A) crashes. The denominator is a summation of all crashes. Severe crash proportion is expressed as a percentage.

For example, Table 2.2 shows before crash data for two intersection projects and two segment projects (these projects were selected from the case study). Table 2.3 shows after crash data. The data is for a three-year analysis period. Traffic volume is in units of million TEV for intersections and million VMT for segments. The intersection projects involved one intersection each (it is possible to have multiple intersections associated with a single HSIP project). The first segment project is one continuous segment 84 miles long. The second segment project is four segments totaling 10 miles. The segment projects have more crashes because of the long geographic distance.

Table 2.2 Example Before Crash Data

ID	Project Type	Volume	K	A	B	C	O	Total
1	Intersection	35.33	0	2	3	2	15	22
2	Intersection	11.50	0	1	4	1	5	11
3	Segment	182.69	5	8	28	43	276	360
4	Segment	36.72	0	3	10	14	48	75

Note: Volume for intersection projects is million entering vehicles (MEV) and for segment projects volume is million vehicle miles traveled (VMT).

Table 2.3 Example After Crash Data

ID	Project Type	Volume	K	A	B	C	O	Total
1	Intersection	41.85	1	1	3	6	13	24
2	Intersection	13.59	0	0	1	2	12	15
3	Segment	248.11	6	12	20	32	123	193
4	Segment	35.50	0	3	11	9	37	60

Note: Volume for intersection projects is million entering vehicles (MEV) and for segment projects volume is million vehicle miles traveled (VMT).

Table 2.4 shows the safety performance measure results. This example illustrates the value of calculating and examining all four comprehensively. For example, Project 1 exhibits an increase in crash frequency but a decrease in crash rate. This mixed result is because although the number of total crashes increased by two, the volume increased by 18%. In addition, this location showed a significant increase in annual economic cost, but this is due to the high weight given to the one fatality that occurred in the after period. Yet, the severe crash proportion (K and A crashes) dropped by nearly 1%.

Project 2 shows an increase in crash frequency and crash rate but a decrease in annual economic cost and severe crash proportion. Project 3 exhibits the opposite trend. Finally, project 4 shows improvement in the first three performance measures but not for severe crash proportion. For this set of example projects, a comprehensive examination of all four safety performance measures provides more robust insight into safety effectiveness.

Table 2.4 Example Safety Performance Measure Results

ID	Crash Frequency Before	Crash Frequency After	Crash Rate Before	Crash Rate After	Annual Economic Cost Before	Annual Economic Cost After	Severe Proportion Before	Severe Proportion After
1	7.3	8.0	0.62	0.57	$602,136	$4,449,357	9.1%	8.3%
2	3.7	5.0	0.96	1.10	$425,844	$119,465	9.1%	0.0%
3	120.0	64.3	1.97	0.78	$24,096,945	$27,882,275	3.6%	9.3%
4	25.0	20.0	2.04	1.69	$1,506,585	$1,412,429	4.0%	5.0%

One way to reduce RTM bias is to evaluate a group of projects together. Then, the analyst calculates the average value for the performance measure across the group (crash frequency, crash rate, annual economic cost, or severe crash proportion). The group evaluation reduces the chance of RTM bias because some locations would be experiencing a natural high while others are experiencing a natural low, such that the average across the group more accurately represents the before or after periods.

The analyst can define evaluation groups in a variety of ways. One necessary group distinction is geographic footprint: projects are either intersection projects (geographic points) or segment projects (geographic lines). A segment project should never be grouped with intersection projects, and vice versa. Thus, an essential group evaluation is for all intersection and segment projects.

The analyst could further stratify the groups by any number of strata, such as by District, County, Program Year, Work Category, or Countermeasure. Creating groups based on countermeasures is the most useful to a state DOT because the results from the evaluation can help determine which countermeasures should be implemented in the future. If the group size is sufficiently large (>20) or if a comparison group is available (see next section for more information about comparison groups), then a Crash Modification Factor (CMF) for the countermeasure can be calculated (Gross et al., 2010). A CMF is a multiplicative factor used to estimate the reduction in crash frequency due to a specific countermeasure.

Analysis Enhancements

The previous section described four "standard" safety performance measures: crash frequency, crash rate, annual economic cost, and severe crash proportion. These are used most frequently by state DOTs because they require the least amount of data and can effectively communicate safety issues to the public and other stakeholders (Tsapakis et al., 2019). Additional safety performance measures are described in the HSM, and researchers frequently propose new safety performance measures that are variations, enhancements, or combinations of standard safety performance measures (Venkataraman et al., 2014). The following sections describe enhancements for improving safety analysis.

Evaluating Groups of Projects

Often the public and stakeholders would like to evaluate the safety effectiveness of individual projects. However, caution is advised when examining before and after safety performance measures for individual projects. The *potential* issue is a statistical phenomenon called Regression to the Mean (RTM) bias. Figure 1 illustrates the possibility of RTM bias for crash frequency. Note that the number of crashes fluctuates from year to year. Sometimes by coincidence, a three-year analysis period will capture low or high average crash frequency.

It is possible that the fluctuation is merely due to chance. If the project was implemented after the first low period, then it would appear to a naïve analyst that the project had a harmful impact (i.e., low to high crash frequency). However, if the project was implemented after the high period, then it would appear to the naïve analyst that the project had a positive impact (i.e., high to low crash frequency) when, in fact, the project had no effect. For this reason, simple before and after evaluation of individual projects is called "naïve evaluation." RTM bias can occur for any of the four standard performance measures, i.e., crash frequency, crash rate, annual economic cost, and severe crash proportion.

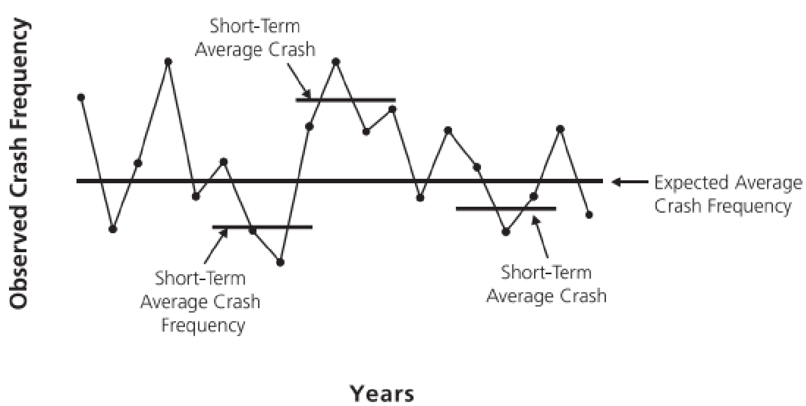


Figure 2.2 Example of RTM Bias (AASHTO, 2010)

In some cases, naïve evaluation may not suffer from RTM bias; in other words, the observed decrease (or increase) in crash frequency might indeed be due to the effectiveness of the HSIP project. The problem is that we have no way of knowing. In some circumstances, we can assume that the observed effect was *probably* due to the project. For example, if the before-crash frequency was 46.2 crashes/year and the after-crash frequency was 3.3 crashes/year, then it would be reasonable to assume that this dramatic change was due to the project's effectiveness. However, extreme caution is advised when interpreting these results if the difference is from 4.2 crashes/year to 3.9 crashes/year. Research is needed to determine in what circumstances the analyst can ignore RTM bias for naïve evaluation of individual projects. RTM bias is an essential consideration for locations with low crash numbers (spoiler alert: including all locations in the case study presented in Chapter 4).

Targeted Crash Types

One enhancement is only to include specific crash types in the calculation. For example, the analyst could calculate crash frequency only for crashes that involved "Head-On Turning." This new performance measure can be called "Head-On Turning Crash Frequency." In the context of Network Screening, the analyst will rank sites based on this "targeted" crash type. In the context of Safety Effectiveness Evaluation, this approach is specific to the crash type targeted by the countermeasure.

Imagine the following hypothetical situation. Suppose there were 20 crashes/year before a HSIP project was implemented and 20 crashes/year in the after period. At first glance, it seems the countermeasure was ineffective. However, imagine that a closer look at this hypothetical situation reveals 7 head-on turning crashes/year in the before period and 0 head-on turning crashes/year in the after period. Now the effectiveness of the countermeasure is more nuanced. In this situation, the "target crash type" was reduced dramatically, but there must have been an increase in crash frequency for some other crash type(s). For example, it has been shown that some countermeasures that target a reduction in Head-On Turning crashes, exhibit an increase in Rear-End crashes (Jensen, 2010).

In a similar way, the analyst may want to calculate one of the other safety performance measures for specific crash types, i.e., crash rate, annual economic cost, or severe crash proportion. In some situations, this enhancement can provide additional insight about safety effectiveness. However, this approach requires identifying the crash type(s) that were targeted by the HSIP project, and in the case of annual economic cost, the calculation requires additional data—cost equivalents by crash type. Sometimes isolating specific crash types provides no added value. For locations that experience low crash numbers, there is generally no added value to evaluate an even smaller subset of crashes.

Comparison Groups

Another enhancement to the standard safety performance measures is to use "comparison groups." This enhancement requires collecting data to define groups. For example, the analyst could group segments by one or many characteristics, such as the number of lanes, speed limit, vehicle volume, heavy vehicle percent, adjacent land use type, and urban/rural designation. Likewise, the analyst could group intersections by characteristics, such as traffic control type, number of legs, number of lanes, number of turn bays, vehicle volume, adjacent land use type, and urban-rural designation. In the context of Network Screening (the process of identifying hot spots), the analyst assigns all sites to a group. A safety performance measure is calculated for each site and compared to the average for the group. Sites are rank-ordered based on their relative performance to their group. The performance measure could be crash frequency, crash rate, annual economic cost, or severe crash proportion.

In the context of Safety Effectiveness Evaluation, the analyst creates a comparison group comprised of locations that do not have the countermeasure. The comparison group is called the “control group” or “without treatment group”. The average safety performance measure (e.g., crash frequency, crash rate, annual economic cost, or severe crash proportion) is calculated for the control group and compared to an individual HSIP project or, even better, compared to a group of projects to reduce RTM bias (see the discussion in the previous section). The group of HSIP projects must share the same new countermeasure. This group is the “with treatment group.” If the group sizes are large enough, the analyst can use a statistical procedure to calculate a CMF for the countermeasure (Gross et al., 2010).

Safety Performance Functions

A third enhancement is to use Safety Performance Functions (SPF) in the analysis. SPFs are mathematical models for predicting crash frequency for an intersection or along a roadway segment. For example, the following is an SPF to predict the crash frequency for a rural multilane divided highway segment (AASHTO, 2010):

$$\bar{N}_{predicted} = e^{-9.03+1.05*\ln(AADT)+\ln(L)} \tag{6}$$

Where $\overline{N}_{predicted}$ is the predicted crash frequency (crashes/year), *AADT* is the segment vehicle volume, and *L* is the length of the segment.

One way to use an SPF is to compare the observed crash frequency, $\overline{N}_{observed}$, with the predicted crash frequency. In the context of Network screening, locations can be rank ordered based on how much the predicted crash frequency is exceeded,

$$\bar{N}_{exceeded} = \bar{N}_{observed} - \bar{N}_{predicted} \tag{7}$$

In the context of Safety Effectiveness Evaluation, the change in $\overline{N}_{exceeded}$ from the before period to the after period is used to determine effectiveness.

Another way to use SPFs is through a procedure called the Empirical Bayes (EB) Method in which the observed crash frequency and predicted crash frequency are combined using a formula that produces the "expected crash frequency" (the formula is provided in Appendix A). The expected crash frequency is then used for Network Screening or for Safety Effectiveness Evaluation.

There are more than one hundred SPFs in the HSM, and researchers are frequently publishing new SPFs. They are created through a regression technique that involves collecting data for a group of locations that have similar characteristics. Therefore, using an SPF is essentially a more sophisticated version of the comparison group enhancement. An analyst can create an SPF from data they have collected for a group of locations. Alternatively, the analyst can follow a procedure in the HSM to *calibrate* an SPF that was created with data from somewhere else. For example, the SPF shown in Equation 6 was created using data from Florida. Calibration would adjust this SPF for use in Idaho (Srinivasan et al., 2013).

Abdel-Rahim and Sipple (2015) calibrated three SPFs from the HSM for use in Idaho. The SPFs are for rural highway facilities: (1) two-lane two-way highway segments, (2) three-leg stop controlled intersections, and (3) four-leg stop controlled intersections. They showed that the HSM SPFs without calibration consistently predicted crash frequency higher than the observed crash frequency. Thus, the calibration factors reduced the predicted crash frequency for the three facility types by 87%, 56%, and 62%, respectively. Furthermore, they also created Idaho-specific versions of these SPFs. They showed that Idaho-specific SPFs provided better crash predictions for the two-lane two-way highways roadway segments and the 3-leg stop controlled intersections. For the 4-leg controlled intersections, the Idaho-specific SPF did not provide significant crash prediction improvement over the HSM SPF.

Since the work of Abdel-Rahim and Sipple (2015) produced SPFs for only three facility types, the application to Safety Effectiveness Evaluation is limited (However, these SPFs could have an important role for Network Screening). Loudon and Schulte (2016) demonstrated evaluation using one of the Idaho-specific SPFs.

The study by Loudon and Schulte (2016) includes a review of the evaluation process for 26 state DOTs and found that none were using SPFs for evaluation. Tsapakis et al. (2019) completed a more recent review of HSIP reporting for all 50 state DOTs. They also discovered that SPFs and other advanced safety performance measures are rarely used for Safety Effectiveness Evaluation. Instead, most state DOTs simply report statewide crash statistic summaries, just as ITD does for the HSIP Annual Report. One relevant recommendation by Loudon and Schulte (2016) is to develop automated or semi-automated evaluation methods (One of the main objectives of the present research study).

3. Evaluation Method and Tool

This chapter describes the recommended evaluation method and a GIS tool that implements the method. In the future, ITD could implement the method through a different platform, such a web application, and/or modify the GIS tool for future needs.

Recommended Methodology

Table 3.1 lists the tasks the analyst should follow and the tasks that are done automatically by the tool. The first task for the analyst is to decide the length of the analysis period for calculating before and after safety performance measures. The HSM recommends an analysis period between three and five years. Less than three years increases the possibility of RTM bias (see Chapter 2 for more information about RTM bias). More than five years increases the possibility of bias from a change in the surrounding land use and traffic patterns. Five years provides more time to monitor crash conditions, which is important for many locations in Idaho with low crash occurrence compared to states with densely populated areas. However, five years involves analysis too far back in the past: Some projects are under construction for two or three years and official publication of AADT and crash data can be as much as two years behind. Consequently, for some projects a three-year analysis period means the start of the before period is 11 years in the past and for a five-year analysis period, the start of the before period can be as far back as 15 years ago. There is too much that can change in terms of driver behavior, vehicle technology, and surrounding environment. We recommend using a three-year analysis period for Safety Effectiveness Evaluation and a five-year analysis period for Network Screening.

The analyst identifies the HSIP-funded projects that are to be evaluated (Analyst Task 2). For the current version of the tool, the analyst must query the OTIS database for project information and create GIS files for project footprints (Analyst Tasks 3 and 4). ITD currently does not maintain an adequate geodatabase of project footprints, especially not for projects that occurred so long ago (the case study includes projects that began between 2013 and 2015). Consequently, the analyst must provide an Excel file with project information and GIS files for project footprints. Figure 3.1 shows the tool interface. The evaluation procedure is automatic (Tool Tasks 1 to 18).

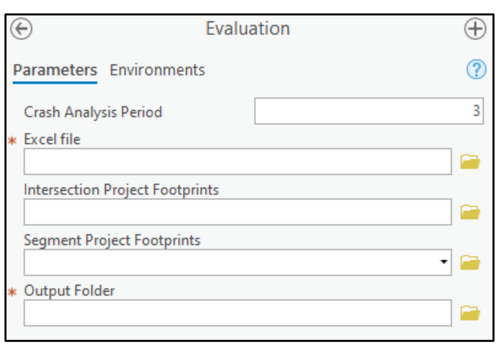


Figure 3.1 Evaluation tool interface.

Table 3.1 Recommended Methodology

Task	Description	Comment
Analyst: Task 1	Decide analysis period.	3 to 5 years. HSM recommends three-year analysis period.
Analyst: Task 2	Identify Key Numbers of HSIP-funded projects.	Completed two years plus analysis period in the past.
Analyst: Task 3	Query OTIS for project information: district, category, description.	Future tool could query online geodatabase (see Chapter 5 Recommendations).
Analyst: Task 4	Create geographic footprint for projects.	Future tool could query online geodatabase (see Chapter 5 Recommendations).
Analyst: Task 5	Open and run GIS tool.	
Tool: Task 1	Align project footprint with links and nodes of the AADT network.	Should be updated with ITD's AADT (see Chapter 5 Recommendations).
Tool: Task 2	Calculate vehicle volume for before and after analysis period.	VMT for segment projects, TEV for intersection projects.
Tool: Task 3	Buffer project footprint.	100 ft for segment projects, 300 ft for intersection projects.
Tool: Task 4	Clip crash data for before and after analysis period.	ITD's online crash data. Keep only intersection related crashes for intersection project.
Tool: Task 5	Calculate before and after crash frequency.	
Tool: Task 6	Calculate before and after crash rate.	Per million vehicles.
Tool: Task 7	Calculate before and after annual economic cost.	Uses ITD's economic cost equivalent data. (Should be updated annually).
Tool: Task 8	Calculate before and after severe crash proportion.	KA/KABCO
Tool: Task 9	Create charts for safety performance measures	Four charts.
Tool: Task 10	Create chart for prominent contributing factors.	10 most frequent contributing factors.
Tool: Task 11	Create chart for prominent harmful events.	10 most frequent harmful events.
Tool: Task 12	Calculate performance measures for group evaluation.	Segment projects and Intersection projects. Future tool could include additional groupings (see Chapter 5 Recommendations).
Tool: Task 13	Create charts for group evaluation.	Segment projects and Intersection projects.
Tool: Task 14	Create map of project footprint and crash points.	Image file exported from ArcGIS.
Tool: Task 15	Get Google Street View image.	Located at latitude, longitude starting point of first segment or first intersection centroid.
Tool: Task 16	Create output Excel file.	
Tool: Task 17	Create output GIS files.	An ArcGIS Map Project and geodatabase with project footprints and crash points.
Tool: Task 18	Create output Word and PDF report.	
Analyst: Task 6	Extract information as need for HSIP Annual Report.	From Word or Excel files.
Analyst: Task 7	Select projects for further investigation.	Optional.

The tool is an open-source Python script for ArcGIS Pro 2.9. It runs directly from a folder on a hard drive or USB storage device without the need for installation. The computer code can be edited using any integrated development environment (IDE), such as Spyder.

Tool Task 1 is to align the project footprints with a GIS file that has AADT values for all public roads in Idaho to extract the appropriate volume data. The current version of the tool uses a GIS file for AADT that we created for this research study. ITD publishes AADT data for many roads in Idaho, including roads of "statewide significance", i.e., state highways and major arterials that feed the highway system. However, ITD currently (as of January 2023) does not maintain a geodatabase of AADT for all public roads in the state, such as local streets and low-volume rural roads. ITD is currently funding an effort to estimate AADT for all public roads statewide. The evaluation tool should be updated to use ITD's official "all-roads" AADT estimates when they are ready. Our methodology to estimate AADT statewide is provided in Appendix B.

Tool Task 2 calculates vehicle volume passing through the project footprint for the analysis period. For HSIP projects that involve segments (GIS polylines), the volume calculation is VMT. A project's footprint might terminate anywhere along a roadway link (a "link" is the roadway between intersections, whereas a "segment" might span across multiple links). The calculation uses the length-weighted summation of AADT for all links or portions of links that underlie the project segment or segments (one Key Number can have multiple segments). This value is multiplied by 365 and summed for all years in the analysis period. The calculation for VMT is shown in Chapter 2 as the denominator of Equation 2.

The volume calculation for intersections (GIS points) is TEV. The calculation is the summation of entering AADT for every approach leg. AADT is divided by two for two-way roads because AADT is the total volume in both directions. This value is multiplied by 365 and summed for all years in the analysis period. The calculation for TEV is shown in Chapter 2 as the denominator of Equation 3.

Next, the tool identifies crashes within a certain distance of the project footprints (Tool Tasks 3 and 4). The search distance, or buffer distance in GIS terminology, is 100 feet for segment projects and 300 feet for intersection projects. This search distance is an example of code modification that could be done. For intersection projects, only intersection related crashes are kept.

The tool calculates safety performance measures for the before and after period (Tool Tasks 5 to 8). These four safety performance measures are crash frequency, crash rate, annual economic cost, and severe crash proportion. The equations are provided in Chapter 2. Next, charts are made for each safety performance measure (Tool Task 9). This is followed by the creation of charts for contributing factors and harmful events (Tool Tasks 10 and 11). For these charts, only the 10 most frequent items are included.

Tool Task 12 calculates the average safety performance measure for groups of projects. For the current version of the tool, group evaluation is only done for project type: segment projects and intersection projects. For the case study, we could find no other way to group projects that would produce meaningful results. We attempted grouping by District and grouping by Project Category (called

“SubClass” in the OTIS database), but there were not enough projects in some of the groups and often these groups had only one project in the “group”. Furthermore, Project Category was deemed inappropriate for grouping because it is too broad. A better grouping would be by countermeasure, but this information is not available in the OTIS database (see Chapter 5 Recommendations). Tool Task 13 creates charts for the group evaluation.

Next, the tool creates a map image for each project footprint showing the crash locations (Tool Task 14). The tool connects to Google’s online Street View database to get a representative image for each project (Tool Task 15). For segment projects, the image is taken from the latitude, longitude of the starting point of the first segment associated with that Key Number. For intersection projects, the image is taken from the latitude, longitude of the centroid of the first intersection associated with that Key Number. Finally, the tool creates the output files (Tool Tasks 16 to 18). The output includes an Excel file, GIS database, and a report in Word and PDF format. These are described in the next section.

When the tool has completed, the analyst can proceed to use the information as needed (Analyst Tasks 6 and 7). The analyst might choose to extract information from the Word document or the Excel file to include in the Annual HSIP Report (noting that this evaluation pertains to projects done in the past). The analyst may want to investigate some projects further. For example, they may want to look closer at the original project documentation to better understand the goals of the project or examine the police reports to better understand the nature of the crashes that occurred. If possible, the analyst could try to identify a comparison group to check how much the results differ compared to locations with similar characteristics (see Chapter 2).

Tool Output

The tool creates the following output:

- Excel file with safety performance measure data for each project.
- GIS files with crash data and project footprints.
- Word and PDF formatted report.

The Excel file contains all relevant information. The fields are shown in Table 3.2. The data for the first eight fields are copied from the input that the analyst uploads to the tool. The data for the remaining fields are created by the tool.

Table 3.2 Output Excel Fields

Source	Excel Field	Description
Input	Key_No	Key Number Unique identifier.
Input	Project_Type	Intersection or Segment
Input	Project_Start_Year	Program Year from OTIS
Input	Project_End_Year	Finl_Est_Year from OTIS
Input	District	District ID (1 through 6)
Input	Location	Location title from OTIS
Input	Category	SubClass category from OTIS
Input	Description	Description from OTIS
Tool	Features	Number of geographic features
Tool	Latitude	Centroid for intersection projects or starting point for segment projects
Tool	Longitude	Centroid for intersection projects or starting point for segment projects
Tool	Volume_Before	TEV for intersection projects or VMT for segment projects
Tool	Volume_After	TEV for intersection projects or VMT for segment projects
Tool	K_Before	Number of fatal crashes in before period
Tool	K_After	Number of fatal crashes in after period
Tool	A_Before	Number of suspected serious injury crashes in before period
Tool	A_After	Number of suspected serious injury crashes in after period
Tool	B_Before	Number of suspected minor injury crashes in before period
Tool	B_After	Number of suspected minor injury crashes in after period
Tool	C_Before	Number of possible injury crashes in before period
Tool	C_After	Number of possible injury crashes in after period
Tool	Pdo_Before	Number of property damage only crashes in before period
Tool	Pdo_After	Number of property damage only crashes in after period
Tool	Total_Before	Number of all reportable crashes in before period
Tool	Total_After	Number of all reportable crashes in after period
Tool	Frequency_Before	Crash frequency for before period
Tool	Frequency_After	Crash frequency for after period
Tool	Economic_Before	Annual economic cost for before period
Tool	Economic_After	Annual economic cost for after period
Tool	Rate_Before	Crash rate for before period
Tool	Rate_After	Crash rate for after period
Tool	Severe_Before	Severe crash proportion for before period
Tool	Severe_After	Severe crash proportion for after period

The GIS files are stored in a geodatabase as shown in Figure 3.2. The crash points and unit crash points (one point for each vehicle involved) are labeled with the associated Key Number and analysis period designation: before or after. The project footprints are the polygon buffer that surrounds the project centroid or centerline. Figure 3.3 shows and example project footprint and the associated crash data.

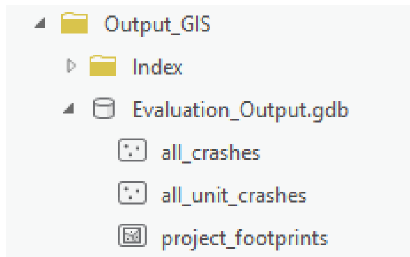


Figure 3.2 Output geodatabase.

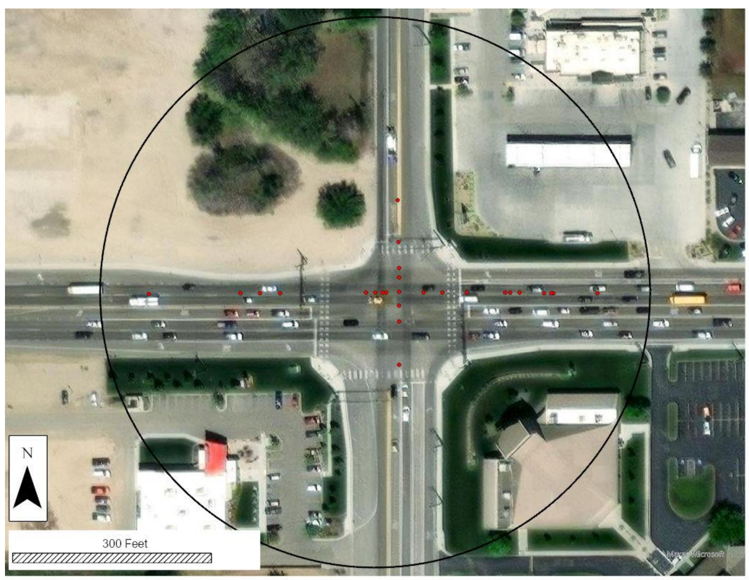
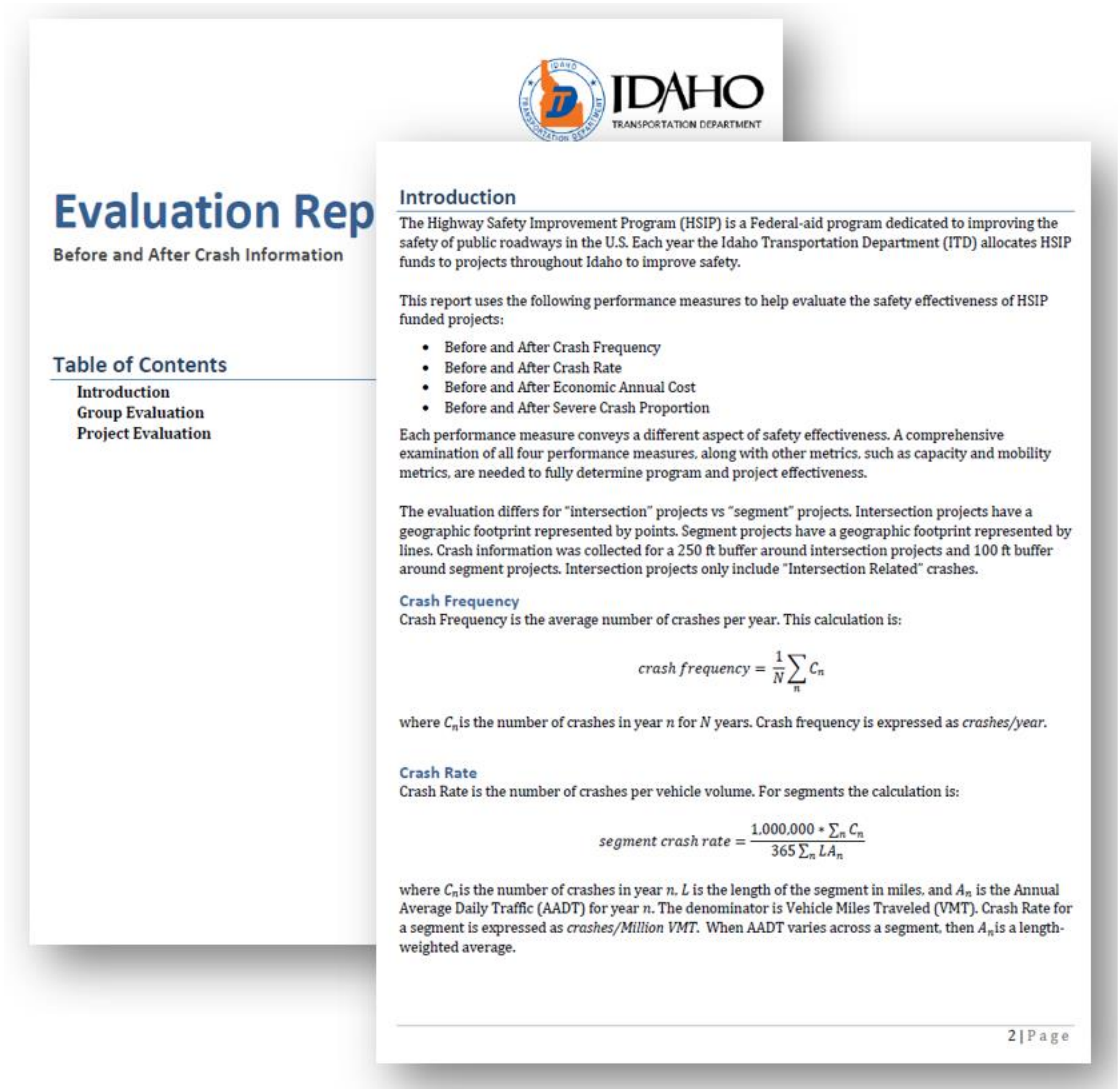


Figure 3.3 Example output project footprint and crash data.

The report is produced in Word and PDF formats. The PDF for the case study is provided in Appendix D. Figure 4.4 shows the cover page and an introduction page. There three sections in the report. The Introduction describes the safety performance measures and provides the equations. The next section is Group Evaluation. For the current version of the tool, group evaluation is only done for project type: segment projects and intersection projects. The group evaluation includes group averages for each safety performance measure. An example of group evaluation is provided in the next chapter.



IDAHO
TRANSPORTATION DEPARTMENT

Evaluation Rep

Before and After Crash Information

Table of Contents

Introduction

The Highway Safety Improvement Program (HSIP) is a Federal-aid program dedicated to improving the safety of public roadways in the U.S. Each year the Idaho Transportation Department (ITD) allocates HSIP funds to projects throughout Idaho to improve safety.

This report uses the following performance measures to help evaluate the safety effectiveness of HSIP funded projects:

- Before and After Crash Frequency
- Before and After Crash Rate
- Before and After Economic Annual Cost
- Before and After Severe Crash Proportion

Each performance measure conveys a different aspect of safety effectiveness. A comprehensive examination of all four performance measures, along with other metrics, such as capacity and mobility metrics, are needed to fully determine program and project effectiveness.

The evaluation differs for "intersection" projects vs "segment" projects. Intersection projects have a geographic footprint represented by points. Segment projects have a geographic footprint represented by lines. Crash information was collected for a 250 ft buffer around intersection projects and 100 ft buffer around segment projects. Intersection projects only include "Intersection Related" crashes.

Crash Frequency

Crash Frequency is the average number of crashes per year. This calculation is:

$$crash\ frequency = \frac{1}{N}\sum_{n} C_n$$

where C_n is the number of crashes in year n for N years. Crash frequency is expressed as *crashes/year*.

Crash Rate

Crash Rate is the number of crashes per vehicle volume. For segments the calculation is:

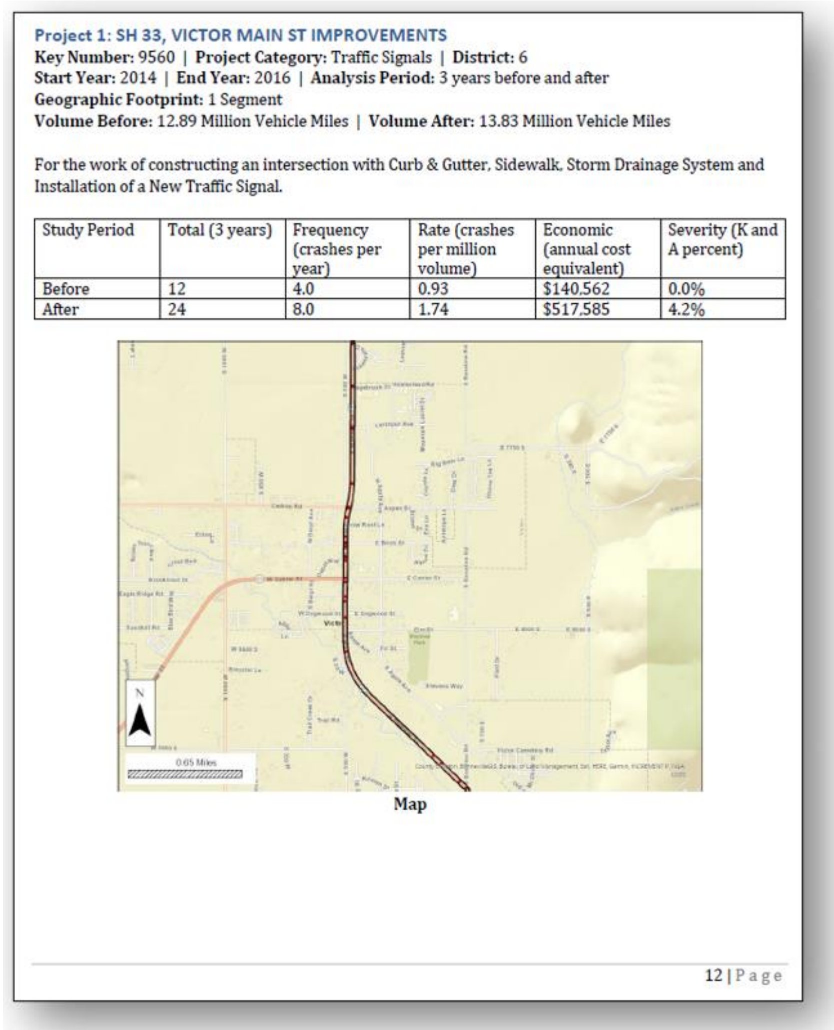
$$segment\ crash\ rate = \frac{1{,}000{,}000 * \sum_n C_n}{365 \sum_n LA_n}$$

where C_n is the number of crashes in year n, L is the length of the segment in miles, and A_n is the Annual Average Daily Traffic (AADT) for year n. The denominator is Vehicle Miles Traveled (VMT). Crash Rate for a segment is expressed as *crashes/Million VMT*. When AADT varies across a segment, then A_n is a length-weighted average.

2 | Page

Figure 3.4 Cover and Introduction pages of the report created by the evaluation tool.

The final section of the report provides individual project evaluation for all the projects. There are three pages for each project. Figure 3.4. shows an example first page for a project. At the top is general information about the project, including the project category, years of construction, and before and after vehicle volume. Next is a table showing the four performance measures. This page also provides a map of the project location.



Project 1: SH 33, VICTOR MAIN ST IMPROVEMENTS
Key Number: 9560 | **Project Category:** Traffic Signals | **District:** 6
Start Year: 2014 | **End Year:** 2016 | **Analysis Period:** 3 years before and after
Geographic Footprint: 1 Segment
Volume Before: 12.89 Million Vehicle Miles | **Volume After:** 13.83 Million Vehicle Miles

For the work of constructing an intersection with Curb & Gutter, Sidewalk, Storm Drainage System and Installation of a New Traffic Signal.

Study Period	Total (3 years)	Frequency (crashes per year)	Rate (crashes per million volume)	Economic (annual cost equivalent)	Severity (K and A percent)
Before	12	4.0	0.93	$140,562	0.0%
After	24	8.0	1.74	$517,585	4.2%

Map

12 | Page

Figure 3.5 Example first page of project evaluation.

Figure 3.6 shows an example of the second page for a project. For each project there is one image of from Google Street View. For intersection projects, the image is taken at the latitude, longitude of the first intersection. For the segment projects, the image is taken at the latitude, longitude of the start of the first segment. Next, there are charts for each safety performance measure. The chart axis scale is automatically adjusted for each project (i.e., the axis scales are different for each project). The red bars are the before period and the blue bars are for the after period. Figure 3.7 shows and example of the third page for a project. There are two charts: harmful events and contributing circumstances. The red bars are the before period and the blue bars are for the after period.

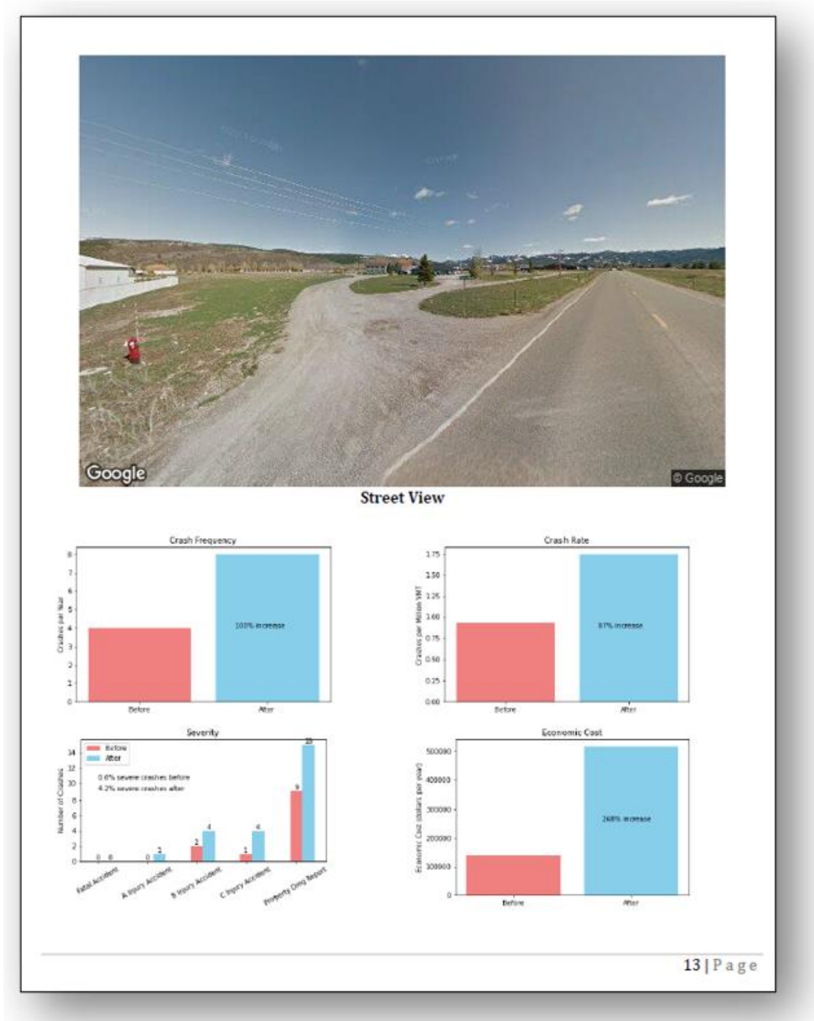


Figure 3.6 Example second page of project evaluation.

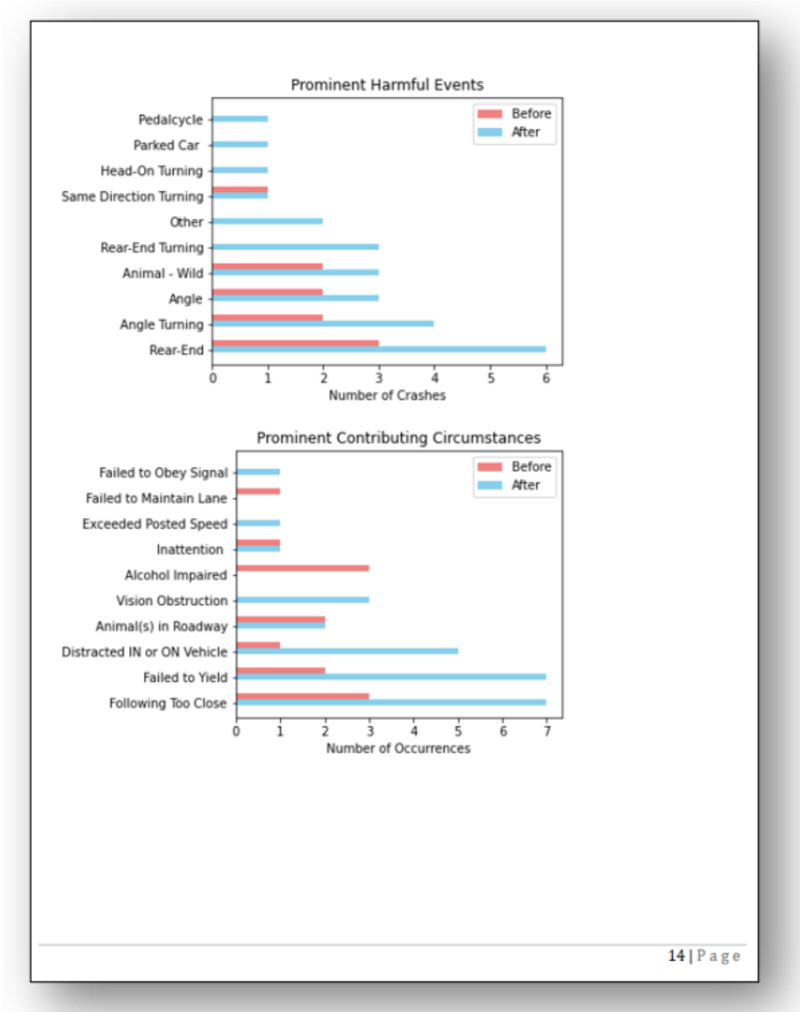


Figure 3.7 Example third page of project evaluation.

4. Case Study Evaluation

This chapter provides a summary of the case study evaluation. The detailed report that is produced automatically by the tool is provided in Appendix D.

Case Study Data

It took significant effort to identify a list of projects for evaluation. The first challenge was dealing with the long timelines inherent to project planning, programming, construction, and evaluation. For example, official AADT and crash data can be up to two years behind, the after period is another three years, and construction can last three more. Consequently, the case study focused on HSIP projects that began between 2013 and 2015 and were completed by 2016. Furthermore, the programming process can take as much as five to seven years from the initial proposal to construction. This lengthy timeline means any evaluation is for projects conceived as much as fifteen to twenty years ago!

ITD, like most state DOTs, did not begin using a data-driven decision-making process until about 2015. As a result, projects selected back then are now being constructed. In other words, the projects in this case study were not selected for implementation through a process like Network Screening which identifies “sites with promise” (Hauer, 1997). Indeed, most state DOTs only recently began to implement the Safety Management Process.

The next challenge was to ascertain project completion dates. It is our understanding that there is no definitive and reliable project completion field in OTIS because of the prolonged nature of signing off on projects and ending construction contracts. Safety effectiveness evaluation ideally takes into consideration an acclimation period after project completion in which the public is becoming familiar with the new roadway. The HSM does not provide a definitive acclimation timeframe but suggests this period might last one month to a year (AASHTO, 2010). The challenge is compounded by the fact that projects are completed at any time during the year. Consequently, we recommend, for evaluation purposes, that ITD ignore partial year analysis and acclimation periods. This approach significantly simplifies the calculations of safety performance measures by associating AADT data and crash occurrence within the calendar year.

Another difficult challenge was obtaining geographic data for each project. Currently, ITD does not maintain a geodatabase of project footprints, especially not for projects that occurred so long ago. Consequently, ITD had to create GIS files specifically for this research study. This task is difficult because project documentation often lacks detailed spatial information. For example, a project that involved installing guardrails would ideally have data for the precise mile markers where the guardrails were installed. Specific spatial data makes it possible for the project to be represented with multiple line features rather than one single line feature that encompasses the entire project length.

Furthermore, creating GIS data is difficult because it requires deciding if the project is a segment project or intersection project. If it is a segment project, then it should be represented in GIS with lines. If it is an intersection project, then it should be represented in GIS with points. For example, a project that upgrades stop signs along a corridor should be a series of geographic points at each intersection rather than a line for the corridor.

Table 4.1 presents the case study projects. There are ten segment projects and nine intersection projects. These projects began between 2013 and 2015 and were completed by 2016. Additional projects from that timeframe are listed in Appendix C. These projects were not included either because we were not provided the GIS data, crash evaluation is not applicable (e.g., planning studies), or there were less than four crashes in the before period. The information in Table 4.1 was the input we uploaded to the evaluation tool. We used a three-year analysis period.

Table 4.1 Case Study Projects

Key	Start	End	Project Type	District	Location	Project Category
09560	2014	2016	Segment	6	SH 33, VICTOR MAIN ST IMPROVEMENTS	Traffic Signals
11570	2013	2014	Segment	3	STATE, FY13 D3 SIGN UPGRADES	Signing Improvements
11668	2013	2014	Segment	6	SUNNYSIDE RD TO LOMAX, IDAHO FALLS, BONNEVILLE COUNTY.	Pavement Rehabilitation & Resurfacing
12046	2014	2016	Intersection	3	SH 55, INT KARCHER & MIDDLETON RDS, NAMPA	Intersection Improvement
12398	2014	2015	Intersection	4	US 26, JCT SH 46 TRAFFIC SIGNAL, GOODING	Traffic Signals
12401	2013	2014	Intersection	4	SH 50, INT 3800 E RD, TWIN FALLS CO	Intersection Improvement
12428	2014	2016	Intersection	5	US 91, YELLOWSTONE AVE & PEARL ST, POCATELLO	Traffic Signals
13022	2015	2015	Segment	3	STATE, FY15 D3 GUARDRAIL UPGRADE	Metal Guard Rail
13131	2013	2013	Segment	6	I 15, FY13 D6 CONTROLLED ACCESS FENCING	Miscellaneous Improvements
13413	2013	2015	Segment	1	I 90B, NORTHWEST BLVD SIGNAL UPGRADES, CDA	Traffic Signals
13418	2014	2015	Segment	1	LOCAL, UPRIVER & W RIVER DR SFTY UPGRADES	Signing Improvements
13420	2014	2015	Intersection	1	LOCAL, INT IMPR FLASHING BEACONS, POST FALLS HD	Intersection Improvement
13446	2014	2015	Intersection	2	LOCAL, INT FLASHING ARROW SIGNALS, LEWISTON	Intersection Improvement
13502	2014	2016	Intersection	3	STP-8213, INT MIDDLETON RD & FLAMINGO AVE, NAMPA	Traffic Signals
13543	2014	2014	Segment	4	STC-2752, 3900 N ROADWAY IMPR, TWIN FALLS HD	Signing Improvements
13574	2014	2016	Intersection	6	STATE, I 15 AND US 20 RAMP IMPROVEMENTS	Safety Improvement
13599	2014	2015	Intersection	6	SMA-7276, 1ST & AMMON SIGNALIZATION, IDAHO FALLS	Traffic Signals
13993	2015	2015	Segment	4	STC-2755, 200 N RD; 500 W TO US 93, JEROME CO	Signing Improvements
13995	2015	2015	Segment	4	STC-2713, 3700 N RD INTERSECTIONS; US 93 TO KIMBERLY	Signing Improvements

Results

The group evaluation produced inconclusive results. Table 4.2 shows that crash frequency and crash rate decreased for segment projects. However, annual economic cost and severe crash proportion increased. For the intersection projects, crash rate and severe crash proportion decreased. The mixed results demonstrate the need to group projects in other ways. A more meaningful way to group projects is by countermeasures or similar roadway characteristics (See Chapter 2).

Figures 4.1 and 4.2 show the ten most prominent harmful events and contributing factors for segment projects. Figures 4.3 and 4.4 show the ten most prominent harmful events and contributing factors for intersection projects. It still needs to be determined why there is such a dramatic change in the harmful events and contributing factors between the before and after periods.

Table 4.2 Group Evaluation Results

	Crash Frequency		Crash Rate		Annual Economic Cost		Severe Proportion	
Group	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Segment Projects	413.3	350	1.61	1.08	$68,255,490	$89,292,413	6.00%	7.50%
Intersection Projects	65	68	0.64	0.60	$4,953,222	$16,187,183	6.70%	5.90%

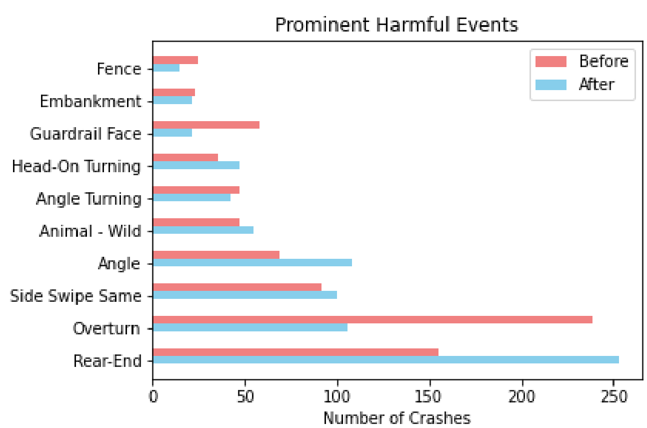


Figure 4.1 Prominent harmful events for the group of segment projects.

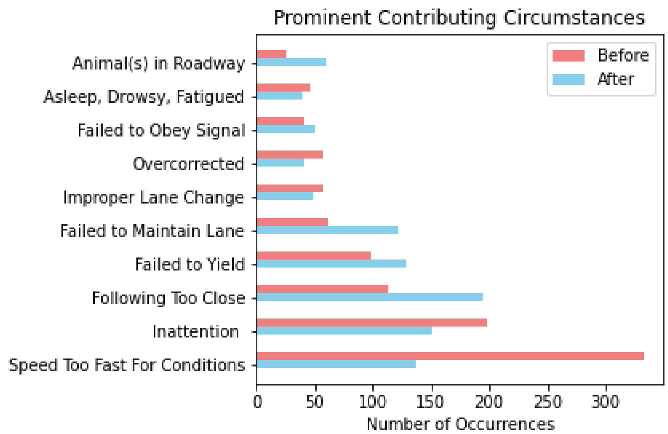


Figure 4.2 Prominent contributing circumstances for the group of segment projects.

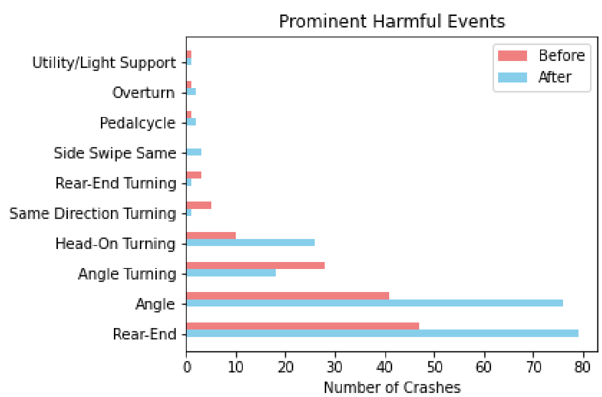


Figure 4.3 Prominent harmful events for the group of intersection projects.

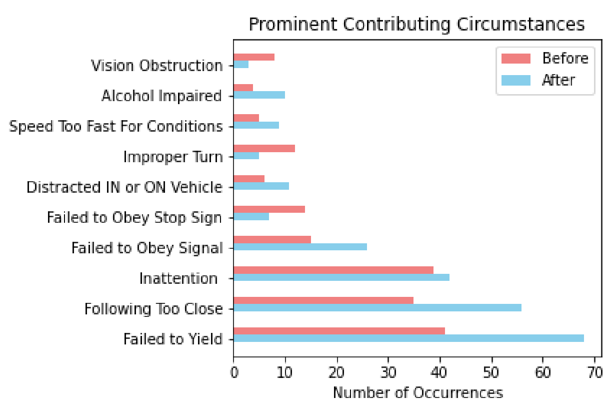


Figure 4.4 Prominent contributing circumstances for the group of intersection projects.

Figure 4.5 provides information for the individual projects. The figure shows the total number of crashes during the before and after periods (white columns). The following four columns show the percent change in crash frequency, crash rate, annual economic cost, and severe crash proportion. The results are colored on a scale from green to red, representing a decrease in the safety performance measure or an increase in the safety performance measure, respectively. A positive percent (reddish hues) indicates the safety performance measure was worse in the after period. Conversely, a negative percent (greenish hues) indicates the safety performance measure improved in the after period.

The final column tallies how many of the safety performance measures showed improvement. Zero indicates none of the safety performance measures improved, while four indicates all four safety performance measures showed improvement. Four case study projects showed improvement in every safety performance measure (green). However, there were also four projects with worse safety performance measures in the after period (red). The bottom row of the figure provides a tally of how many projects improved for each safety performance measure. There was improvement for roughly half of the projects for each performance measure.

Table 4.3 and Table 4.4 describe the evaluation results for the segment and intersection projects, respectively.

Key Number	Before	After	Frequency	Rate	Economic	Severe	Improved
9560	12	24	100%	87%	268%	4%	0
11570	431	379	-12%	-33%	-15%	-1%	4
11668	51	46	-10%	-14%	520%	2%	2
12046	22	24	10%	-8%	639%	-1%	2
12398	10	6	-39%	-44%	-56%	0%	4
12401	9	13	43%	30%	537%	-10%	1
12428	9	9	0%	-9%	-22%	0%	4
13022	22	30	37%	13%	86%	-4%	1
13131	360	193	-46%	-60%	16%	6%	2
13413	142	161	14%	9%	-8%	-2%	2
13418	75	60	-20%	-17%	-6%	1%	3
13420	29	38	31%	18%	398%	0%	0
13446	80	76	-5%	-9%	0%	-1%	3
13502	11	15	35%	15%	-72%	-9%	2
13543	44	40	-10%	-27%	-71%	1%	3
13574	19	13	-32%	-44%	-63%	-5%	4
13599	6	10	65%	55%	137%	10%	0
13993	25	20	-19%	-25%	1201%	7%	2
13995	78	97	24%	14%	681%	5%	0
		Improved:	**10**	**11**	**8**	**10**	

Figure 4.5 Safety Performance Measures for individual projects.

Table 4.3 Evaluation Description for Segment Projects

Key Number	Evaluation Description
9560	This project was a major improvement to an intersection, including a new traffic signal. A project of this magnitude would be expected to exhibit significant safety benefits. However, it was worse in all performance measures. This project should be investigated further to understand the reason for this poor performance.
11570	This project improved in all performance measures.
11668	Crash frequency and crash rate declined, but a fatality in the after period caused a huge increase in annual economic cost. This project was primarily for pavement rehabilitation, so significant safety improvements are not expected.
13022	Improvement was only seen in severe crash proportion. While there were less failures to maintain lane after construction, there was a great increase of instances of inattention contributing to crashes.
13131	This project involved installing a fence along various highway segments, protecting the traveling public from livestock. While the crash frequency and rate indicate an improvement in safety, the performance measures weighted by severity (severe crash proportion and economic cost) indicate otherwise. There was a large decrease in instances of overturning, jackknifing, and speeding in the crashes along this section of road, but it is difficult to say with the given information if the repair of the fence contributed to this occurrence. Crashes only involved with livestock obstruction or other things meant to be kept behind the fence line should be analyzed for this project.
13413	This project was worse crash frequency and crash rate, but there was decline in annual economic cost and severe crash proportion. This project involved for upgrading 6 signalized intersections. It was evaluated as segment project along the corridor. Additional evaluation should be done as an intersection project.
13418	This project was for the installation of traffic control devices (signs/chevrons) and shoulder line markings. Safety improvements were seen all but severe proportion, which experienced a slight increase.
13543	Description was not found in ProjectWise. Economic Cost showed improvement after construction for this location, but only slightly so in terms of crash rate and severe crash proportion. Crash frequency increased slightly after construction. For some reason, not many contributing circumstances in the “after” period were reported.
13993	This project was for more advance warning signs, larger stops signs, and more speed limit signs along a road segment. No improvement was observed in any of the recorded performance measures except severe crash proportion.
13995	This project was for adding speed limit signs, stop bars, short lane markings, and larger stop signs along a road segment. No improvement was observed in any of the recorded performance measures. However, crashes caused by inattention and failure to yield noticeably decreased after construction. The segment is very long and perhaps would be better evaluated in smaller sections, or with a sliding window technique.

Table 4.4 Evaluation Description for Intersection Projects

Key Number	Evaluation Description
12046	Improved crash rate and severe proportion. Worse crash frequency and economic cost. This project was a major improvement to an intersection, including a new traffic signal. This project should be investigated further to understand the reason for this poor performance.
12398	This project was for the signalization of Jct of SH-46/US26. All the safety performance measures indicate a discernible improvement in safety at this location.
12401	This project involved adding a 12' acceleration lane to the roadway. While a project of this sort is expected to exhibit safety improvements, no discernible improvement was observed. All performance measures showed significant lack of improvement after construction except severe crash proportion. Prominent contributing circumstances after construction included failure to yield, failure to obey stop sign, alcohol impairment, and inattention. This project should be investigated further.
12428	This project was related to pedestrian improvements, such updating to ADA compliance. An evaluation focused on pedestrians should be done. Angle-turning crashes likely caused by failures to yield, and improper turns have gone down, but the number of rear-end crashes caused by speeding, inattention, and tailgating has increased at this site.
13420	This project was for the installment of new flashing beacons and stop signs at various intersections. No improvement was observed in any of the performance measures used. This project should be investigated further to understand the reason for this poor performance.
13446	This project improved in all performance measures.
13502	This project involved the design and installation of a traffic signal at an intersection. Crash frequency and rate did not improve at this location, but economic cost and severe crash proportion showed improvement. This was likely due to one less A-Injury crash in the period after construction.
13574	This project was for improving the safety of the on-ramp at an interchange. Improvement was observed in all performance measures, but the collection of data in this case might have been flawed. First, there looks to be data from crashes that occur nearby the intersection (such as on the neighboring freeway or at the adjacent off-ramp), but not at the location of interest.
13599	This project was for the installation of a signal and ADA improvements to an intersection. No improvement was observed in any of the recorded performance measures. This project should be investigated further to understand the reason for this poor performance.

Case Study Limitations

The case study projects were implemented between 2013 and 2015 and were selected to receive funding five to seven years earlier. ITD, like most state DOTs, did not begin using a data-driven project selection process, like Network Screening, until about 2015. Consequently, it is not surprising that the evaluation results are weak. Furthermore, several projects were not included in the evaluation (see Appendix C).

HSIP Reporting

The goal of this research study was to provide information that can help ITD prepare the evaluation section of the HSIP Annual Report. Evaluation always pertains to projects done in the past (while other sections of the HSIP Annual Report concern projects programmed in the year of the report). Some states with large numbers of HSIP projects could report year-to-year evaluations for projects that were completed in a particular year, e.g., 2016-completed projects could be in the 2021 annual report, then 2017-completed projects could be in the 2022 annual report, and so forth. For Idaho, reporting should cover a rolling three-year window. The case study was for projects completed from 2014 to 2016. The subsequent evaluation should be for projects completed from 2015 to 2017.

The HSIP Annual Report has many purposes, including providing a means for federal oversight, compliance verification, record keeping, and monitoring progress. FHWA is interested in state DOTs demonstrating substantiative effort toward continual progress and improvement. For example, consider the following question in the evaluation section of the HSIP Annual Report:

> *Has the State completed any countermeasure effectiveness evaluations during the reporting period?*

That question might be answered as follows:

> *We evaluated nineteen HSIP projects that were completed between 2014 and 2016. We used a three-year analysis period to evaluate the before and after change in four safety performance measures: 1) crash frequency, 2) crash rate, 3) annual economic cost, and 4) severe crash proportion.*
>
> *Ten of the projects experienced reductions in crash frequency; eleven experienced reductions in crash rate; eight experienced reductions in annual economic cost; and ten experienced reductions in severe crash proportion. Four projects experienced reductions in all four safety measures.*
>
> *A few projects showed reduced crash frequency and crash rate but increased annual economic cost and severe crash proportion. We plan to investigate these projects further to determine possible reasons for the rise in KA crashes.*
>
> *Our evaluation did not include group evaluation by countermeasure. We are working to improve our methodology for group evaluation.*

5. Conclusions and Recommendations

This chapter presents the strengths and limitations of the methodology, followed by recommended actions ITD could complete to improve Safety Effectiveness Evaluation.

Strengths of the Evaluation Method and Tool

There are several strengths of the methodology developed for this research study. First, the methodology uses data that is readily available. There are three data sources:

- ITD's project database called OTIS.
- ITD's published data for AADT.
- ITD's published data for crashes.

Second, the tool automatically queries the AADT and crash data without the analyst interacting with those data sources. For the current tool version, the analyst must only collect project data; they are to query OTIS and create GIS footprints. However, even those tasks could be automated in a future version of the tool (see Recommendations for Future Work).

Third, since the tool focuses on the requirements of the HSIP Annual Report, the process is streamlined and has minimal impact on staff workload. The output provides sufficient information for reporting requirements and provides a starting point for identifying HSIP projects that should be analyzed further using additional data and other methods.

Finally, the methodology provides a framework that can be easily adapted, expanded, or implemented using a different tool. Note that our recommended methodology includes all aspects of the evaluation prescribed in this research report. This includes the recommended length of the analysis period, how to deal with project start and end dates, which safety performance measures to use and how to calculate them, how to represent projects in GIS, how to summarize contributing circumstances and harmful events, which output to provide, and recommendations for conducting group evaluation in the future.

Limitations of the Evaluation Method and Tool

The methodology has limitations, some of which can be mitigated through the recommendations provided in the next section.

- The tool cannot evaluate projects that are aimed at system-level safety improvements, for example education campaigns and public service announcements. Instead, the tool is intended site-level evaluation, i.e., for projects that have specific geographic locations, such as an intersection or roadway. In the future the tool could be modified to evaluate system-level projects by using GIS polygons to represent the area of impact (rather than points and lines). For example, imagine a project aimed at reducing distracted driving that is implemented for a specific county, then the same four safety performance measures could be calculated for the area under a polygon for that county. Crash rate would be calculated for county-wide VMT. The same approach could be used for any geographic area, such as city boundaries or the entire state.

- The tool ignores the acclimation period and partial year impacts.

- The current version of the tool requires the user to provide the geographic footprint for each project because the existing geodatabases maintained by ITD lack sufficient GIS data for project footprints (See Recommendations for Future Work).

- Group evaluation is only performed on projects grouped by geographic footprint type: i.e., Intersection projects or Segment projects. There is no group evaluation for other groupings. We considered grouping projects by District or by Work Category, but many of these groups consisted of only one project. Furthermore, the Work Category labels available in the OTIS database were deemed inadequate for Safety Effectiveness Evaluation. A meaningful way to group projects is by countermeasures or similar roadway characteristics

- The evaluation method does not isolate specific crash types, such as “Rear-End” or “Ran Off Road” crashes, because information about targeted crash types is not readily available in the OTIS database.

- The evaluation method does not involve “comparison group” locations which requires the time-intensive task of finding other locations with comparable characteristics. Likewise, the evaluation method does not involve SPFs which must be developed or calibrated using a significant amount of data.

- The tool uses values for AADT that were estimated as part of this research study because ITD currently (January 2023) does not maintain a geodatabase of AADT for all public roads statewide. ITD is presently funding an effort to estimate statewide AADT values for all public roads. Upon completion, the evaluation tool should be updated to use ITD’s official AADT “all public roads” estimates. Furthermore, we identified a few limitations with ITD’s published AADT data: 1) numerous links are missing in the 2015 data for the layer that includes all years, 2.) data is not available for 2020, 3.) the layer naming convention changed in 2016, and 4.) the field names changed in 2017.

- The tool runs slower than anticipated. The case study takes 30 minutes to execute, which seems long compared to other GIS tools we have developed. Most of the execution time is dedicated to calculating VMT and TEV. Additional work could be done in the future to optimize performance.

Recommendations for Future Work

The following recommendations are opportunities for ITD to improve the methodology.

1. **Create and maintain an online geodatabase of projects.** ITD staff and contractors currently generate various spatial data associated with a project, including CAD drawings, milepost descriptions, and GIS files. The data are organized and stored in disparate locations. ITD should establish a standard schema (i.e., database organization and structure) and implement a statewide geodatabase for projects.

   Creating and maintaining a geodatabase can be a complex process. First, there are organizational and schematic challenges, including deciding the desired accuracy level, attribute requirements, and appropriate spatial representation (i.e., representing features with points, lines, or polygons). These decisions depend on the intended purpose of the data.

   For safety evaluation, determining whether to represent a project with points or lines is critical. If the project is intended to impact only an intersection or intersections (rather than the whole corridor between intersections), then it should be represented with points. The points should be the centroids of the intersections. On the other hand, if a project is expected to impact the whole corridor, then it should be represented with a line (or lines). The evaluation for intersection projects only includes crashes that are intersection-related. Moreover, intersection crash rate is calculated using TEV in the denominator. For segment projects, all crashes are included in the evaluation, and crash rate is calculated using VMT in the denominator.

   As another example, the analyst should represent a project that involves installing guardrails along multiple sections of a road with multiple short line features rather than just one line feature that spans the whole project. The geographic features should represent the impact footprint.

   Sometimes the geographic representation of a project is different than one might expect. Consider, for example, the installation of signs for Sharp Curve Ahead. Rather than using geographic points for each sign, the analyst should represent this project's linear area of impact.

   Moreover, the analyst may want to represent some aspects of a project with points and other elements with lines. Or, in some situations, the analyst may want to evaluate the intersections of a project and the whole corridor as a line.

   As seen from these examples, the geodatabase for safety evaluation may need to be distinct from other geodatabases intended for other purposes.

   Once ITD begins maintaining an online geodatabase, the evaluation tool should be modified to query the geodatabase automatically.

   This will significantly reduce the analyst's workload and improve the tool's functionality.

2. **Create and maintain an online searchable database of countermeasures associated with each project.** Currently, the analyst can find countermeasure information in project documentation using ProjectWise, ITD's file management system. We recommend adding countermeasure information to OTIS, ITD's online project management system, or another searchable database. For example, countermeasure types could be tagged to a project Key Number and stored one-to-many. Another option is to include countermeasure information with the proposed project geodatabase (see recommendation #1), in which case countermeasures could be tagged to specific geographic features.

   This will provide the opportunity to evaluate projects by countermeasure, and if there are multiple projects with the same countermeasure, then this will provide the opportunity for group evaluation (See Advanced Safety Performance Measures in Chapter 2).

3. **Create and maintain an online searchable database of the crash types that are targeted by each project.** Like countermeasure information, the analyst can find which crash types were targeted for each project using ProjectWise, but ITD should archive this information in a searchable database by project Key Number. Alternatively, ITD could establish a table that cross-references crash types and countermeasures. Crash types can be defined in a variety of ways, including based on contributing circumstance (e.g., Exceeded Posted Speed), harmful event (e.g., Rear-End), severity, or any other crash data element such as light condition and weather. ITD should develop a list of crash-type definitions in conjunction with countermeasure definitions.

   This will provide the opportunity to evaluate projects by targeted crash types (See *Advanced Safety Performance Measures* in Chapter 2).

4. **Create and maintain an online geodatabase of estimated AADT for all public roads.** ITD publishes AADT data for many roads in Idaho, including roads of "statewide significance", i.e., state highways and major arterials that feed the highway system. However, ITD currently (as of January 2023) does not maintain a geodatabase of AADT for all public roads in the state, such as local streets and low-volume rural roads. ITD is currently funding an effort to estimate AADT for all public roads statewide. The evaluation tool should be updated to use ITD's official "all public roads" AADT estimates when they are ready.

   This will provide the opportunity to evaluate projects anywhere in the state, including on local roads.

5. **Improve the online crash geodatabase by adding and removing fields.** ITD maintains a REST API that provides online access to crash data. The data is organized in the usual three datasets: by crash, by unit (vehicle), and by person. We recommend adding weather, light condition, work zone, functional class, roadway class, and type of intersection to the crash dataset. Furthermore, we recommend removing any field that is not specific to a particular dataset. For example, the following fields should only be associated with the crash dataset: severity, number of fatalities, and number of injuries. Likewise, fields for contributing circumstances and harmful events should only be associated with the unit dataset. Finally, age, gender, injury type, and protective device should only be associated with the person dataset.

   This will ensure correct data analysis. For example, an analyst might overcount severity crashes because severity is currently associated with the person dataset. In addition, an analyst can easily link datasets via serial numbers.

6. **Improve the speed of the evaluation tool and create a web application.** The tool could be enhanced in a variety of ways. For example, the computer code could be optimized to reduce execution time by incorporating Python accelerators or multiprocessing. In addition, the method could be transferred to another platform, such as a web application. ITD, like many state DOTs, has a subscription to Numetric, an online platform for safety analysis. Numetric provides several tools, including a tool for Network Screening; however, they still need to develop a tool for Safety Effectiveness Evaluation. The Numetric team might be willing to work with ITD to create a custom tool that implements the methodology developed for this research study (Numetric, 2022).

   This will provide quicker completion time, make the tool more accessible for staff unfamiliar with GIS, and increase the efficiency of the process.

7. **Develop a tool to automatically create comparison groups for roadway segments and intersections.** ITD should sponsor a research study to develop a tool to automatically create groups of roadway segments and intersections. The tool could scan ITD's existing GIS data to create groups based on characteristics such the number of lanes, speed limit, vehicle volume, heavy vehicle percent, adjacent land use type, and urban/rural designation.

   This will provide the opportunity for comparison group evaluation and may provide the opportunity to create and apply SPFs (See Advanced Safety Performance Measures in Chapter 2) more easily.

8. **Continue to improve the state's Safety Management Process, especially the first step of identifying candidate projects through Network Screening.** Using a data-driven approach in selecting safety improvement projects is crucial as it provides a solid foundation for decision-making. Network Screening provides a means to identify "sites with promise" where safety improvements are more likely to reduce crashes (Hauer, 1997). The Safety Management Process leads to more informed and targeted investment in safety measures, which ultimately leads to a reduction in collisions and their associated costs. A data-driven approach also helps ITD to measure the effectiveness of their safety improvement efforts, allowing them to adjust their approach and continuously improve. In short, a data-driven approach ensures that safety improvement resources are allocated where they will have the greatest impact.

   This will increase the likelihood of seeing positive results from Safety Effectiveness Evaluation.

6. Cited Works

AASHTO, 2010. *Highway Safety Manual*. American Association of State Highway and Transportation Officials: Washington, DC, USA, 19192.

Abdel-Rahim, A. and Sipple, M.C., 2015. *Calibration and development of safety performance functions for rural highway facilities in Idaho* (No. FHWA-ID-15-225). Idaho. Transportation Department.

Carter, D., Gelinne, D., Kirley, B., Sundstrom, C., Srinivasan, R. and Palcher-Silliman, J., 2017. *Road Safety Fundamentals: Concepts, Strategies, and Practices that Reduce Fatalities and Injuries on the Road* (No. FHWA-SA-18-003). United States. Federal Highway Administration. Office of Safety.

ESRI, 2021. 2021 *US Business Locations & Summary data: Esri Methodology Statement*. Accessed November 14, 2022. https://storymaps.arcgis.com/stories/cef7e34fb9f646c091d532eb19d86cff

Gross, F., Persaud, B.N. and Lyon, C., 2010. *A guide to developing quality crash modification factors* (No. FHWA-SA-10-032). United States. Federal Highway Administration. Office of Safety.

Hauer, E., 1997. *Observational before/after studies in road safety. Estimating the effect of highway and traffic engineering measures on road safety*.

Herbel, S., Laing, L. and McGovern, C., 2010. *Highway Safety Improvement Program Manual: The focus is results* (No. FHWA-SA-09-029). United States. Federal Highway Administration. Office of Safety. Accessed November 14, 2022. https://safety.fhwa.dot.gov/hsip/resources/fhwasa09029/

Iacono, M., Krizek, K. and El-Geneidy, A.M., 2008. Access to destinations: How close is close enough? Estimating accurate distance decay functions for multiple modes and different purposes.

ITD, 2022. Idaho Traffic Crashes 2021, Idaho Transportation Department, Office of Highway Safety. Accessed November 14, 2022. https://apps.itd.idaho.gov/Apps/OHS/Crash/21/Analysis.pdf

Jensen, S., 2010. Safety effects of intersection signalization: A before-after study. In TRB 89th Annual Meeting Compendium of Papers CD-ROM. Washington, DC.

Loudon, W. and Schulte, R.J., 2016. *Evaluating Performance of Highway Safety Projects* (No. FHWA-ID-16-257). Idaho. Transportation Department.

Lowry, M. 2014. “Spatial interpolation of traffic counts based on origin-destination centrality” Journal of Transport Geography, 36, pp. 98-105.

Numetric, 2022. *About Numetric*. Accessed November 14, 2022. https://www.numetric.com/numetric-company-info/

Srinivasan, R., Carter, D. and Bauer, K.M., 2013. *Safety performance function decision guide: SPF calibration vs SPF development* (No. FHWA-SA-14-004). United States. Federal Highway Administration. Office of Safety.

Srinivasan, R., Gross, F.B. and Bahar, G.B., 2016. *Reliability of Safety Management Methods: Safety Effectiveness Evaluation* (No. FHWA-SA-16-040). United States. Federal Highway Administration. Office of Safety.

Tsapakis, I., Sharma, S., Dadashova, B., Geedipally, S., Sanchez, A., Le, M., Cornejo, L., Das, S. and Dixon, K.K., 2019. *Evaluation of Highway Safety Improvement Projects and Countermeasures: Technical Report* (No. FHWA/TX-19/0-6961-R1). Texas A&M Transportation Institute.

Venkataraman, N.S., Ulfarsson, G.F. and Shankar, V.N., 2014. Extending the Highway Safety Manual (HSM) framework for traffic safety performance evaluation. Safety science, 64, pp.146-154.

U.S. Census Bureau, 2022. American community survey (ACS). The United States Census Bureau Accessed November 14, 2022. https://www.census.gov/programs-surveys/acs

Appendix A. Empirical Bayes Method

An important safety performance measure is *crash frequency*, the average number of crashes over an analysis period. For Safety Effectiveness Evaluation it is common to use a three-year analysis period before and after the construction of a safety improvement project. However, the natural fluctuation of crashes can misconstrue the interpretation of the evaluation. This phenomenon is called Regression to the Mean (RTM) bias and is illustrated with a figure in Chapter 2.

One approach to mitigate RTM bias is to combine the observed crash frequency with a predicted crash frequency obtained from a Safety Performance Function (SPF). For demonstration, consider the SPF to predict crash frequency for a rural multilane divided highway segment. This equation was shown in Chapter 2 and is provided again here:

$$\overline{N}_{predicted} = e^{-9.03+1.05*\ln(AADT)+\ln(L)} \tag{A1}$$

where $\overline{N}_{predicted}$ is the predicted crash frequency (crashes/year), *AADT* is the segment vehicle volume, and *L* is the length of the segment (AASHTO, 2010).

SPFs are created using a statistical technique called negative binomial regression and crash data from dozens of sites that have similar characteristics (number of lanes, vehicle volumes, speed limits, etc.). The model will be reliable since it is based on data from so many similar sites. However, we don't know what is more reliable: the observed frequency (which might be suffering from RTM bias) or the predicted frequency (which is inherently imperfect because it is only a model). The famous statistician Thomas Bayes developed a whole branch of statistics that combines observed information (which has flaws) with model predictions (which also have flaws) to produce a result that is more reliable than the observation or prediction alone.

The Empirical Bayes (EB) Method combines observed crash frequency with predicted crash frequency using a formula to produce the "expected crash frequency". Figure A.1 illustrates the EB method. Suppose at location there is an observed crash frequency, $\overline{N}_{observed}$. The SPF model predicts a lower crash frequency for that location, $\overline{N}_{predicted}$. (By the way, the curve in the figure is showing that as traffic volume increases the predicted crash frequency increases along the curve). In this example, the observed crash frequency is much greater than predicted. We don't know if that is because the location is indeed worse than the dozens of locations that were used to create the model or if it is because there is RTM bias causing the observed crash frequency to appear higher than the comparison group. The EB method identifies a compromising value, that is, statistically speaking, more reliable than the observed and predicted values. This is the expected crash frequency, $\overline{N}_{expected}$.

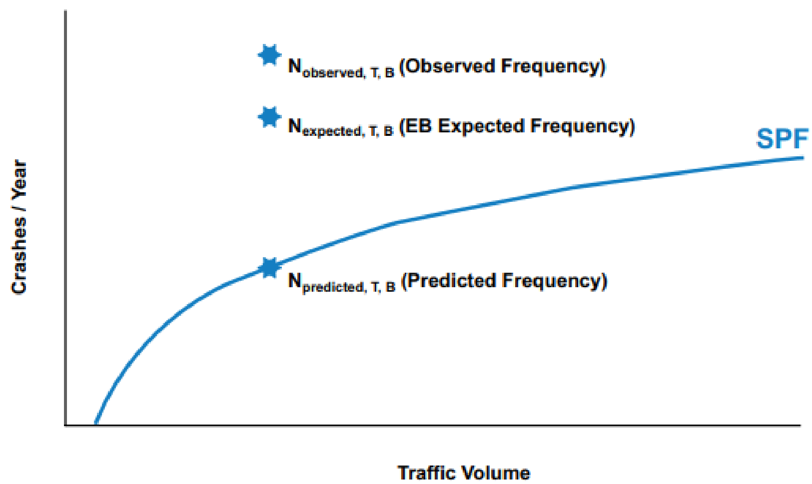


Figure A.1 Estimated crash frequency using EB method. (Gross, 2010)

Key to the EB method is deciding how much weight to give to the observed value and how much weight to give to the predicted model to determine the right compromise value. The answer comes from a statistic that indicates the reliability of the SPF called the overdispersion parameter, *k*. For example, the HSM provides the SPF shown above and equation A2 to calculate the overdispersion parameter:

$$k = \frac{1}{e^{1.55 * \ln(L)}}$$

(A2)

The overdispersion parameter is than used to calculate the weight that should be given to the model, as follows:

$$w = \frac{1}{1 + k * N_{predicted}}$$

(A3)

The weight, *w*, is a number between 0 and 1. This weight and its complement (*1* - *w*) are used to combine predicted and observed as follows:

$$\bar{N}_{expected} = w * \bar{N}_{predicted} + (1 - w) * \bar{N}_{observed}$$

(A4)

Figure A.2 shows an example calculation for a roadway with *AADT* = 30,000 *vpd*, and length = 1.4 miles. The location has an observed crash frequency of 10.0 crashes/year. The predicted crash frequency, 8.4 crashes/year, is lower than observed. The EB Method produces an expected crash frequency of 9.7 crashes/year. This example is like Figure A.1 has an observed crash frequency greater than predicted.

The opposite can also occur, i.e. observed crash frequency lower than predicted. Either way the EB method is a statistical adjustment that finds a compromise value to help overcome RTM bias.

$$\overline{N}_{observed} = 10.0$$

$$\overline{N}_{predicted} = e^{-9.03+1.05*\ln(30{,}000)+\ln(1.4)} = 8.4$$

$$k = \frac{1}{e^{1.55*\ln(1.4)}} = 0.59$$

$$w = \frac{1}{1+(0.59)(8.4)} = 0.17$$

$$\overline{N}_{expected} = 0.17 * 8.4 + (1-0.17) * 10.0 = \mathbf{9.7}\ \boldsymbol{crashes/year}$$

Figure A.2 Example EB Method Calculation.

Appendix B. Volume Estimation Methods and Tools

This appendix describes the methods that were developed for this research study to estimate vehicle volumes for segments and intersections.

Statewide AADT Estimation

Each year ITD publishes AADT data for many roads in Idaho, including every road of "statewide significance", i.e., state highways and major arterials that feed the highway system. However, ITD currently (as of January 2023) does not maintain a geodatabase of AADT for all public roads in the state. ITD does not publish AADT estimates for most local streets and low-volume rural roads. ITD is currently funding an effort to estimate AADT for all public roads statewide. Furthermore, we identified a few limitations with ITD's published AADT data: 1) numerous links are missing in the 2015 data for the layer that includes all years, 2.) data is not available for 2020, 3.) the layer naming convention changed in 2016, and 4.) the field names changed in 2017. In the future, when ITD has completed that effort, the evaluation tool should be updated to use ITD's data. In the meantime, the tool uses AADT data that was developed for this research study.

Figure B.1 shows the AADT data that ITD maintains statewide, with an inset showing the Boise area with greater detail. Figure B.2 shows roads in black color that do not have AADT estimates for the Boise area.

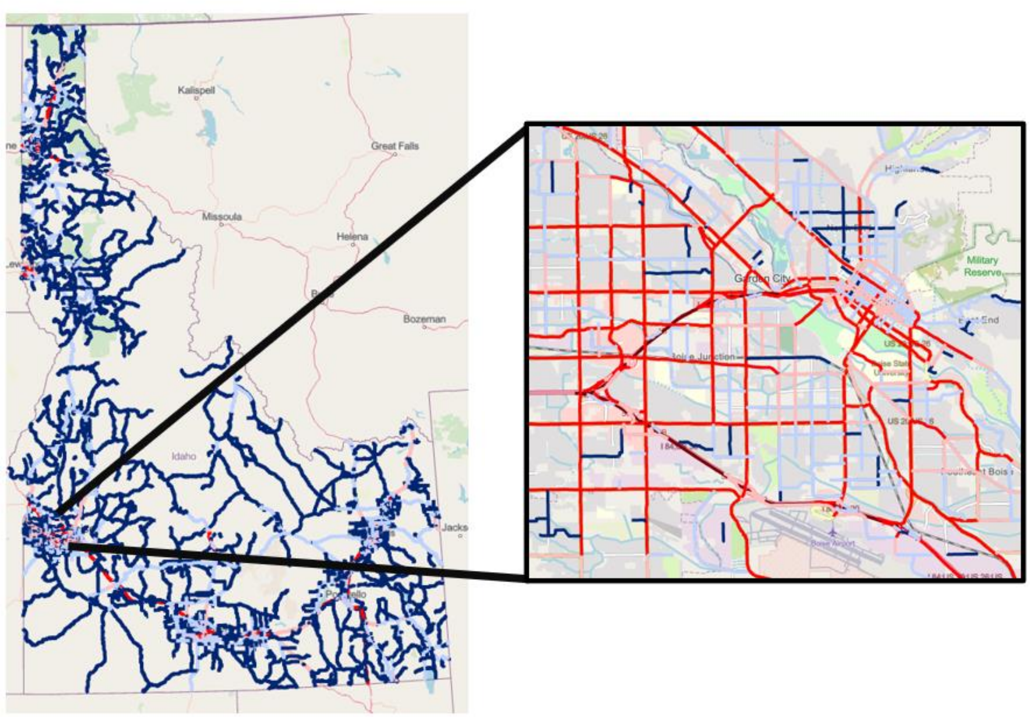


Figure B.1 ITD's AADT data and inset showing Boise.

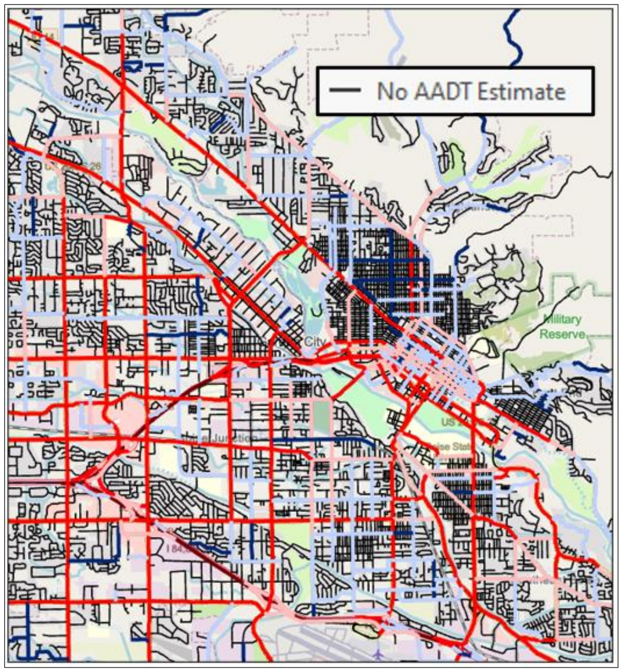


Figure B.2 Roads in black color do not have AADT estimates.

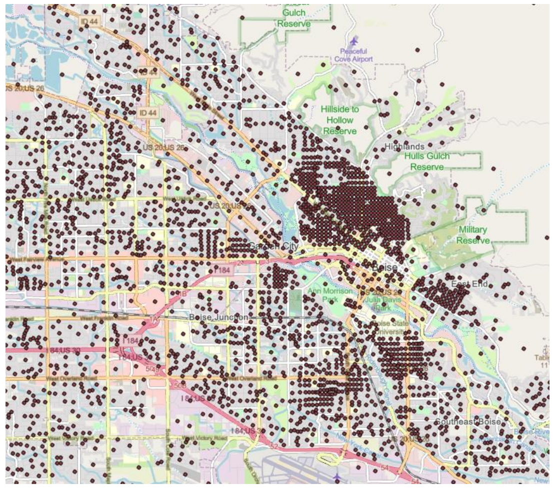
The method to estimate statewide AADT that was developed for this research study is an improvement to a method developed by Lowry (2014) to estimate city-wide AADT. There are two general types of models for estimating AADT: direct-demand models and behavior demand models. Direct demand models estimate AADT for roadway links through a regression technique that uses explanatory variables that are assumed to be predictors of AADT. The explanatory variables represent the defining characteristics of a roadway link. For example, common explanatory variables are functional class, number of lanes, speed limit, adjacent land use, etc. The general form of a direct demand model is:

$$A = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n \tag{B1}$$

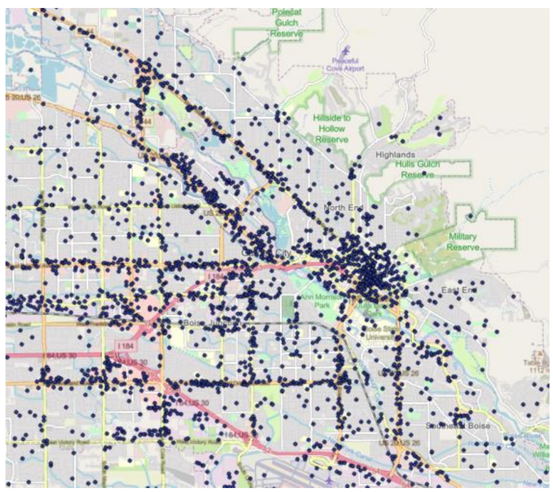
where A is the estimated AADT for the link and β_0, β_1… β_n are regression coefficients for the explanatory variables $x_1 \ldots x_n$.

Direct demand models are advantageous because they are quick and easy to implement. However, they are less accurate over a large scale because they ignore origin and destination traffic flow (i.e., traffic patterns across a network). Behavior demand models are more accurate for large scale application because they specifically incorporate origin and destination traffic flow. The most common general form of behavior demand model is the 4-Step model, which attempts to predict all aspects of travel behavior. The four steps are trip generation, trip distribution, mode split, and route assignment. The disadvantage of behavior demand models is that they are extremely complicated and require large amounts of data.

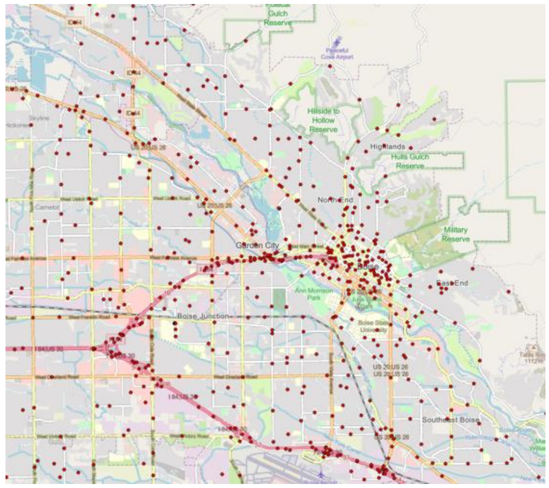
The method we developed for this research project incorporates a simple behavior demand model to create "traffic flow variables" which are then used in a direct demand model. The traffic flow variables are derived by routing traffic between points. The three types of points are shown in Figure B.3



(a) US Census Block Population points



(b) ESRI Business Number of Employees points



(c) AADT points

Figure B.3 Traffic flow origin-destination points shown separately.

The population points were created using the American Community Survey (ACS) “5-year estimate” data that is published every year since 2009 (U.S. Census Bureau, 2022). For each year 2009 to 2020, we created a GIS file. The files have one point for every Census Block in Idaho (there are 46,134 points for the year 2020). Each point includes the population for the Census Block.

The business points were obtained from ESRI Business Listing Data Axel (ESRI, 2021). One GIS file was created for business in Idaho. The file was created in 2022 and contains 50,849 points. Each point includes the number of employees associated with the business.

The AADT points were created from the midpoint of ITD’s AADT segments. There are 8,177 AADT points. Each point has ITD’s AADT value for the years 2009 to 2020 (if available).

Figure B.4 shows the points together on one map. For each year 2009 to 2020, theoretical “traffic flow” was calculated between these points. Three traffic flows were calculated:

- Population points to AADT points
- AADT points to Business points
- AADT points to AADT points

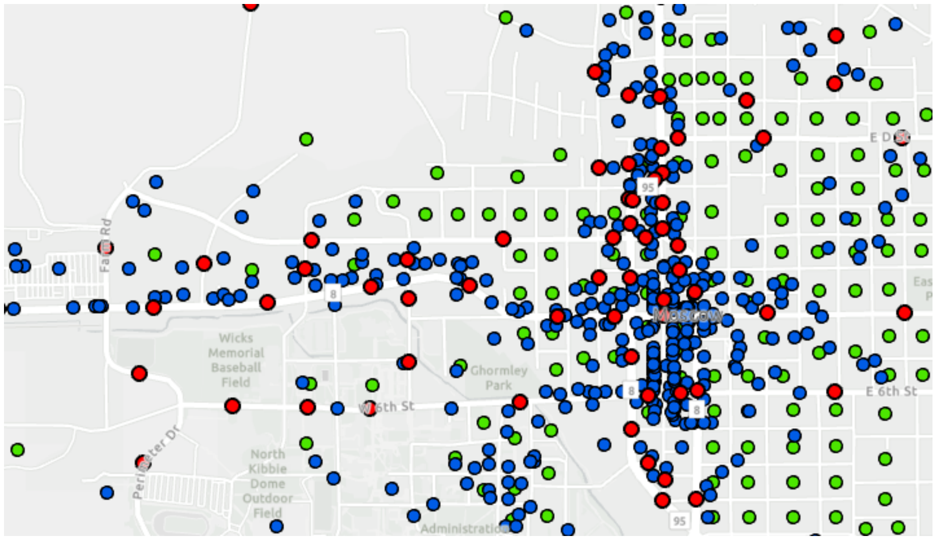


Figure B.4 Traffic flow origin-destination points shown together.

The traffic flow between two points is equal to the “multiplier” of the two points. The multiplier for population points is the population for the year of analysis. The multiplier of the business points is number of employees (does not change). The multiplier of the AADT points is ITD’s AADT value for that year. The amount of flow is distributed between points using a gravity model and distance decay function (Iacono et. al., 2008).

The three traffic flows and additional explanatory variables were regressed against the observed AADT to estimate AADT for each year 2009 to 2020. The regression results for the 2020 AADT model are shown in Table B.1. The explanatory variables are statistically significant and the R-squared is very good. Similar results were obtained for other years. Figure B.5 shows 2020 AADT estimates for roads in the Boise area.

Table B.1 Regression Results to Estimate 2020 AADT.

Variable	Coefficient	p-value
Constant	-349.669	0.56
Flow_Pop_to_AADT	-0.804	0.01*
Flow_AADT_to_Business	0.025	0.00*
Flow_AADT_to_AADT	0.102	0.00*
Speed Limit	58.792	0.01*
Collector	-803.239	0.03*
Minor_Arterial	-434.691	0.29
Principal_Arterial	1680.234	0.01*

* statistically significant for 95% confidence. R^2 = 0.82

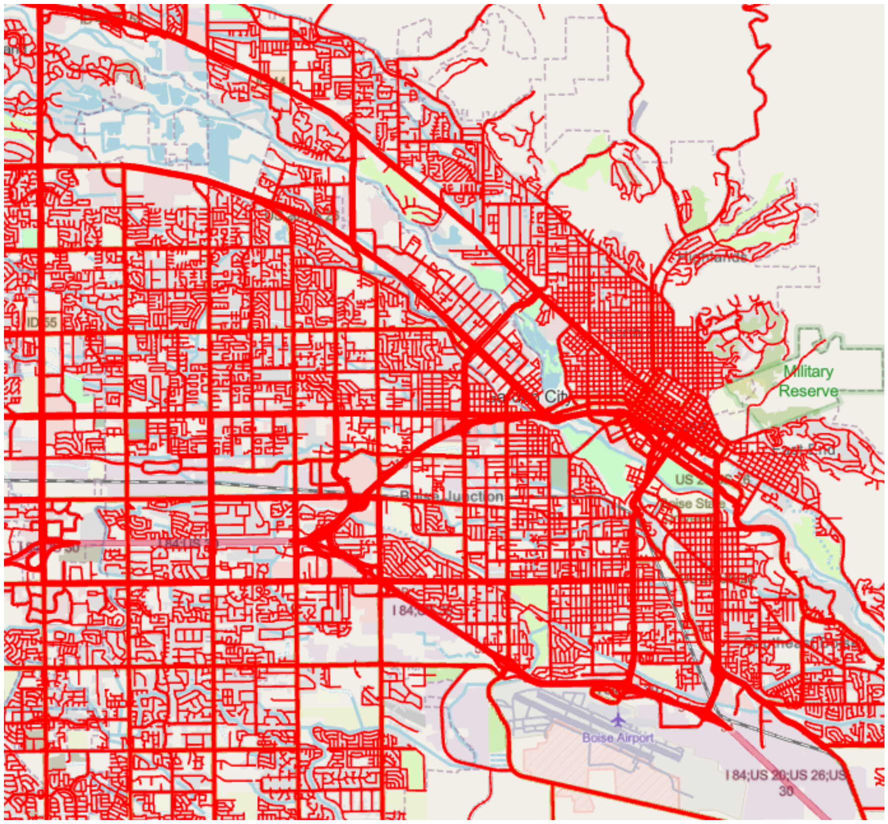


Figure B.5 Example AADT estimate for all public roads.

VMT and TEV Extraction

We created a standalone, separate toolbox to extract VMT and TEV from the AADT GIS file. The toolbox is shown in Figure B.6. The tool introduced in Chapter 3 automatically uses this toolbox. The current version of this toolbox uses the AADT file that was created for this research study. A future version of this toolbox should be updated with ITD's "all public roads" AADT data when it becomes available.

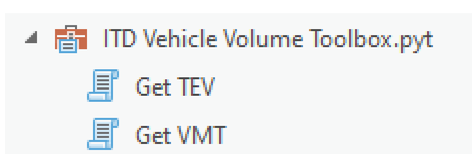


Figure B.6 Toolbox for extracting VMT and TEV.

The interface for the VMT tool is shown in Figure B.7. The analyst provides a polyline feature class of roadway segments, the time range, and the name for the time period. The tool calculates the length weighted AADT for all links or portions of links that underlie the segments. This value is multiplied by 365. This is repeated for each year and summed across years. This tool can be used for any time period between 2009 and 2020.

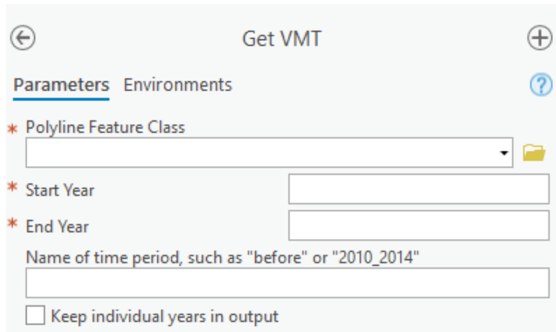


Figure B.7 Get VMT tool interface.

The calculation of VMT is:

$$VMT = 365 \sum_{n} \sum_{i} L_i A_{n,i} \tag{B2}$$

Where L_i is the link length (or portion of a link) that underlies the segment and $A_{n,i}$ is the AADT for the link for year n. This is summed across all links and all years, and then multiplied by 365.

The interface for the TEV tool is shown in Figure B.8. The analyst provides a point feature class of intersections, the time range, and the name for the time period. TEV is the summation of AADT entering an intersection. For two-way roads, this is equal to one half the AADT of the link. For one-way roads approaching an intersection this is equal to AADT. For one-way roads leaving an intersection the AADT is does not contribute to TEV. To reduce geoprocessing time, this tool references a cached point file with TEV for every intersection in Idaho. Figure B.9 shows the intersection points for the state and an insert for the Boise area. There are 128,883 intersection in Idaho. Each point has TEV for years 2009 to 2020. The tool finds the intersection closest to the user-provided point feature class.

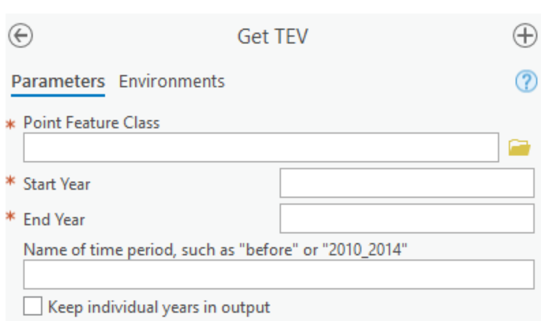


Figure B.8 Get TEV tool interface.

The calculation for TEV is:

$$TEV = 365 \sum_{n} \sum_{i} d_i * A_{n,i} \tag{B3}$$

where $A_{n,i}$ is the AADT for year n on leg i If leg i is a two-way road, then d_i = ½; if leg i is a one-way road approaching the intersection, then d_i = 1; and if leg i is one-way road leaving the intersection, then d_i = 0. For two-way roads, AADT is divided by 2 because AADT is the total volume in both directions.

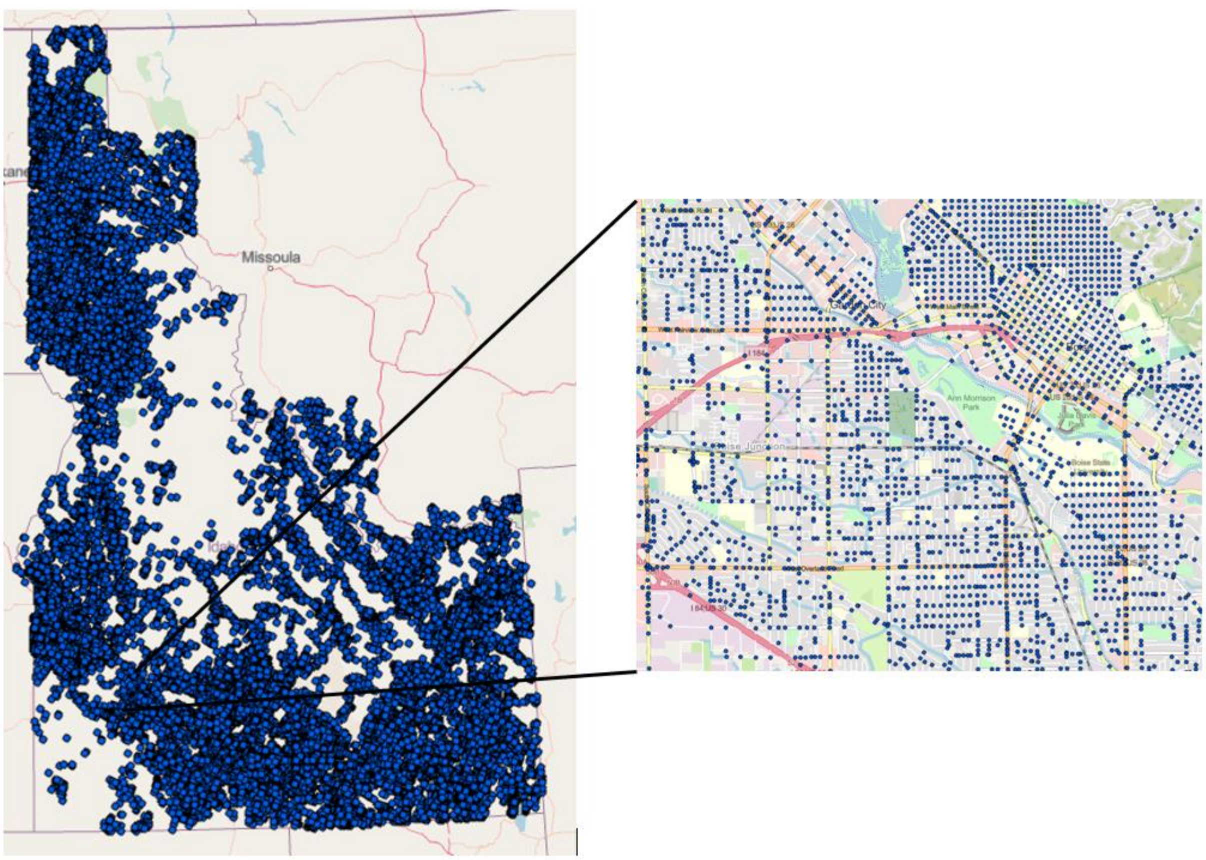


Figure B.9 Intersections with estimated TEV data.

Appendix C. Projects Not Included in Case Study

The case study focused on HSIP projects that began between 2013 and 2015 and were completed by 2016. This appendix lists projects from that timeframe excluded from the case study evaluation. Table C.1 provides the Key Number, location, project category, and reason it was not included in the case study. The reasons are either: Less than 4 crashes in the before period, GIS data not provided, or Evaluation not applicable.

Table C.1 Projects Not Included in Case Study

Key_No	Location	Project Category	Reason
11617	STATE, FY13 D4 DISTWIDE GUARDRAIL UPGRADES	Metal Guard Rail	Less than 4 crashes.
11619	STATE, FY13 D4 SIGN UPGRADES	Signing Improvements	GIS data not provided.
12025	I 84, FY13 D3 PAVEMENT STRIPING	Pavement Markings	GIS data not provided.
12120	FY 13 DISTRICT 6 PAVEMENT MARKING	Pavement Markings	GIS data not provided.
12343	FY15 D3 Pavement Striping	Pavement Markings	GIS data not provided.
12346	STATE, FY14 D3 SIGN UPGRADES	Signing Improvements	GIS data not provided.
12351	STATE, FY13 D3 SIGNAL EQUIPMENT UPGRADE	Traffic Signal replacement	Evaluation not applicable.
12397	FY15 D4 Pavement Striping	Pavement Markings	GIS data not provided.
12400	US 30, 3400 E RD TURN LANE, TWIN FALLS CO	Turn Bay	GIS data not provided.
12402	STATE, FY15 D4 GUARDRAIL UPGRADE	Metal Guard Rail	Less than 4 crashes.
12430	FY15 D5 FENCE REPAIR, BINGHAM COUNTY	Safety Improvement	GIS data not provided.
12447	STATE, FY13/14 D5 & D6 PAVEMENT STRIPING	Pavement Markings	GIS data not provided.
12449	FY15 D5 PAVEMENT STRIPING	Pavement Markings	GIS data not provided.
12454	STATE, FY15 D6 GUARDRAIL UPGRADES	Metal Guard Rail	Less than 4 crashes.
12462	FY 14 D6 SIGN UPGRADES	Signing Improvements	GIS data not provided.
12465	I 15, FY15/16 D6 PAVEMENT STRIPING	Pavement Markings	GIS data not provided.
12930	US 95, FREEZE RD & BEPLATE RD TURN BAYS, LATAH CO	Turn Bay	Less than 4 crashes.
12970	STATE, FY14, D1 DISTWIDE BROOMING	Safety Improvement	GIS data not provided.
13059	SH 44, LINDER RD TO BALLANTYNE, EAGLE	Intersection Improvement	GIS data not provided.

13085	STATE, FY16 D4 GUARDRAIL	Metal Guard Rail	Less than 4 crashes.
13087	FY14 D4 DISTWIDE GUARDRAIL UPGRADE	Metal Guard Rail	GIS data not provided.
13092	I 84, COTTERELL REST AREA RAMPS	Rest area improvement	Evaluation not applicable.
13093	SH 75, STANLEY TO CLAYTON, GUARDRAIL STUDY	Preliminary Engineering Study	Evaluation not applicable.
13133	Citywide ADA and Concrete Sidewalk Improvements	Safety Improvement	GIS data not provided.
13367	American Falls Downtown Streets	Bicycle/Pedestrian/Equestrian	Evaluation not applicable.
13424	SMA-7535, UPRIVER DR & W RIVER VIEW SAFETY AUDIT	Road Safety Audit	Evaluation not applicable.
13516	US-95, POLLOCK ROAD TURNBAY, IDAHO COUNTY	Turn Bay	GIS data not provided.
13519	FY14 D4 Signal Upgrades	Traffic Signals	GIS data not provided.
13522	US-95, LAKE RD & GREENCREEK RD TURNBAYS, IDAHO COUNTY	Turn Bay	GIS data not provided.
13542	STC-2752, 3900 N INT IMPR, TWIN FALLS HD	Signing Improvements	Less than 4 crashes.
13545	LOCAL, POLELINE RD & EASTLAND DR, TWIN FALLS	Illumination	Less than 4 crashes.
13869	STC-5790, BOTTLE BAY RD SAFETY AUDIT, BONNER CO	Road Safety Audit	Evaluation not applicable.
13892	OFFSYS, WEBB RIDGE RD; WEBB RD TO FLAT IRON RD	Minor Widening	GIS data not provided.
13991	SMA 36, US 30 & 3900N FLASHING BEACONS, TWIN FALLS CO	Signing Improvements	Less than 4 crashes.
13992	STC-2810, GANNETT PICABO RD SAFETY AUDIT, BLAINE CO	Road Safety Audit	Evaluation not applicable.
14017	OFFSYS, OLD HWY 191; UTAH LN TO DEVIL CR, ONEIDA CO	Pavement Markings	Less than 4 crashes.
14053	SMA-7406, 17TH ST SAFETY AUDIT, IDAHO FALLS	Road Safety Audit	Evaluation not applicable.
14055	OFFSYS, S BATES RD WARNING SIGNS	Signing Improvements	Less than 4 crashes.
18931	US 20, FY16 39 ADA RAMPS, IDAHO FALLS	Curb & Gutter	GIS data not provided.
18994	STATE, I90 HUETTER POE WEIGH IN MOTION	Concrete Pavement	GIS data not provided.
19151	SH 41, FY16 24 ADA RAMPS, SPIRIT LAKE	Curb & Gutter	GIS data not provided.

Appendix D. Tool Output for the Case Study

The following is the output report for the case study. This output is automatically created by the tool. The tool also generates an Excel file and GIS files, which can be provided upon request from the authors.