Data Driven Safety Analysis (DDSA) Guidance

MDOT
Michigan Department of Transportation

June 8, 2022

Engineering Manual Preamble

This manual provides guidance to administrative, engineering, and technical staff. Engineering practice requires that professionals use a combination of technical skills and judgment in decision making. Engineering judgment is necessary to allow decisions to account for unique site-specific conditions and considerations to provide high quality products, within budget, and to protect the public health, safety, and welfare. This manual provides the general operational guidelines; however, it is understood that adaptation, adjustments, and deviations are sometimes necessary. Innovation is a key foundational element to advance the state of engineering practice and develop more effective and efficient engineering solutions and materials. As such, it is essential that our engineering manuals provide a vehicle to promote, pilot, or implement technologies or practices that provide efficiencies and quality products, while maintaining the safety, health, and welfare of the public. It is expected when making significant or impactful deviations from the technical information from these guidance materials, that reasonable consultations with experts, technical committees, and/or policy setting bodies occur prior to actions within the timeframes allowed. It is also expected that these consultations will eliminate any potential conflicts of interest, perceived or otherwise. Michigan Department of Transportation (MDOT) Leadership is committed to a culture of innovation to optimize engineering solutions.

The National Society of Professional Engineers Code of Ethics for Engineering is founded on six fundamental canons. Those canons are provided below.

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform Services only in areas of their competence.
3. Issue public statement only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, reasonably, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Data Driven Safety Analysis

As a part of the Michigan Department of Transportation's (MDOT) *Toward Zero Deaths* vision, implementing innovative traffic safety policies and procedures aimed at reducing fatalities and serious injuries is a critical focus. One area in which such policies and procedures can make a significant impact is the design development process. This includes incorporating safety analyses during the planning and scoping phases, the alternative identification and evaluation phases, and the design phases of the project development cycle. Specifically, the consideration of traffic safety impacts during the alternative design phase of the project development process can help to identify alternatives which will provide the greatest safety benefit for Michigan's road users.

Traditional crash and roadway analysis methods mostly rely on subjective or limited quantitative measures of safety performance. This makes it difficult to calculate safety impacts alongside other criteria when planning projects. Data-driven safety analysis (DDSA) employs newer, evidence-based crash models that will provide MDOT with the means to quantify safety impacts similar to the way they do other impacts such as environmental effects, traffic operations and pavement life.

Crash analyses need to provide scientifically sound, data-driven approaches to identifying high-risk roadway features and executing the most beneficial projects with limited resources to achieve fewer fatal and serious injury crashes. This effort focuses on both predictive and systemic crash analyses—two types of data-driven approaches that can be implemented individually or in combination.

Predictive analysis helps identify roadway sites with the greatest potential for improvement and quantify the expected safety performance of different project alternatives. Predictive approaches combine crash, roadway inventory, and traffic volume data to provide more reliable estimates of an existing or proposed roadway's expected safety performance. The results inform roadway safety management and project development decision-making. The data not only help MDOT make better decisions, but also inform the public as to what safety benefits they can expect from their investment.

Systemic analysis uses crash and roadway data in combination to identify high-risk roadway features that correlate with particular crash types. MDOT has traditionally relied on crash history data to identify "hot spots," or sites with high crash frequency. However, severe crashes are widely dispersed over road networks, and their location and frequency fluctuate over time. Systemic analysis identifies locations that are at risk for severe crashes, even if there is not a high crash frequency. Practitioners can then apply low-cost countermeasures to those locations. The benefit is wider, but more targeted, safety investment.

- **Targeted Investment.** Analyses used to optimize funding by selecting the most appropriate roadway features and project sites.

- **Improved Safety.** DDSA offers a scientifically sound, data-driven approach to allocating resources that results in fewer fatal and serious injury crashes on the Nation’s roadways.

Benefits of DDSA

- Ability to quantify the safety impacts of various design alternatives
- Improved decision making
- Use of effective safety countermeasures
- Integrates safety elements in the most cost-effective manner in project development process
- Improved safety with approach that allocates resources that results in fewer fatal and serious injury crashes

Areas of Application

- Project development safety analysis
- Design Exceptions/Design Variances
- Alternative analysis as part of National Environmental Policy Act (NEPA)
- Interstate Access Requests
- Performance Based Practical Design (PBPD)

DDSA Toolbox

- Highway Safety Manual (HSM)
- MDOT Highway Safety Manual Spreadsheets
- Crash Modification Factors (CMFs)
- Interactive Highway Safety Design Model (IHSDM)
- Interchange Safety Analysis Tool Enhanced (ISATe)
- Safety Crash Analysis Map

Types of Crash Analyses

Crash analyses, a key component of an overall safety analysis, are generally performed using a range of techniques, from basic traditional methods (e.g. crash rates, frequency) to more advanced predictive methods outlined in the HSM (*3*). Additionally, systemic and risk-based crash analysis methods have also been introduced which identify safety concerns not well-addressed by traditional safety analysis techniques.

Basic Crash Analysis Methods

Basic crash analysis methods include simple historical crash data evaluations or site audits of existing facilities. The application of a crash modification factor (CMF) to observed crash data or the comparison of two relative CMFs are also examples of basic analyses (*3*). A CMF represents the relative change in crash frequency due to a change in one specific condition, or an estimate of the effectiveness of a particular treatment or condition based upon prior research (*1*).

Intermediate Crash Analysis Methods

Intermediate methods include the application of volume-only safety performance functions (SPF), or a SPF in combination with a CMF adjustment (*3*). A SPF is a regression equation that estimates the average crash frequency for a specific highway facility based upon traffic volume and other site conditions (*1*). Guidance is provided in the HSM and by several FHWA guidance documents, to either calibrate the models in the HSM for local conditions or develop jurisdiction-specific models (*1, 4, 5, 6*). It is also worth noting that MDOT has recently sponsored research to develop jurisdiction specific SPFs (*7, 8*). These intermediate analyses are particularly useful for evaluating a proposed facility and unique roadway configurations which differ from common base conditions (*3*).

Advanced Crash Analysis Methods

The most advanced technique involves combining the observed crash frequency at a particular facility with the predicted crash frequency developed via the SPFs in the HSM by applying the Empirical Bayes (EB) method (*1*). The EB-method applies a weighting factor based upon the variance of the SPF to combine the observed and predicted frequencies into a weighted average. Ultimately, the EB-method provides several notable advantages when compared to traditional analysis methods, including:

- Regression-to-the-mean bias is considered as a long-term expected average crash frequency is utilized compared to short-term observed crash frequency;
- Reliance on the availability of limited crash data for one site is reduced as predicted relationships are incorporated based upon data from many similar sites;
- The method considers the fundamentally non-linear relationship between crash frequency and traffic volume; and
- The predictive models used are based upon the negative binomial distribution, which is better suited to address the variability of crash data than traditional modelling techniques (*1*).

Systemic Safety Analysis Methods

Severe crashes, particularly in rural environments and/or related to non-motorized road users, tend to be widely distributed over a roadway network (*9*). Such low densities of severe crashes are unlikely to be identified using site-specific analysis techniques which focus on identifying high-crash locations (*10*). Additionally, these severe crash types often occur on locally controlled roadways that may have less available data for performing network screening activities (*10*). To address this concern, various systemic safety analysis methods have been developed which focus on the identification of treatments and countermeasures to address these distributed crash types. It is important to note that systemic safety analysis does not replace traditional site-specific analysis methods, instead both approaches are necessary to achieve a comprehensive safety management program (*10*).

Risk-Based Analysis Methods

To address safety issues where crash data is unavailable, is low frequency and high severity, or tends to be more distributed within a transportation network, the International Road Assessment Program (iRAP) has developed an alternative approach to quantifying road safety risk (*12*). This approach focuses on screening large roadway networks and quantifying risk based on the presence or absence of traffic control and other roadway design features which are known to impact safety. Using this approach each roadway segment/intersection within a network is assigned a risk score (*12*). The risk score is then communicated using star ratings. This approach has been found to be extremely effective in analyzing pedestrian, bicycle, and motorcycle related safety issues.

Appropriate Level of Crash Analysis

Given the range of methodologies available, selecting an appropriate level of crash analysis consistent within the context of the project development process and project type is a key component of implementing DDSA within MDOT. Analysis methods should be used which will provide the necessary decision-making capability and can be performed with data typically available at the current phase of the project development process (*3*).

Appropriate Level of Crash Analysis for Project Type

Crash analyses are separated into four distinct tiers based on the "project type". Each tier increases in complexity consistent with the associated project type, providing a balance between the potential project impact and the time required to complete the evaluation. Each tier and crash analysis method will be described later in this document.

Table 1 provides a matrix to select the appropriate level of crash analysis by project type. Please note, that additional project types may exist beyond those included in **Table 1** and engineering judgement should be used to identify the appropriate tier in such situations.

Table 1. Appropriate Level of Crash Analysis by Project Type

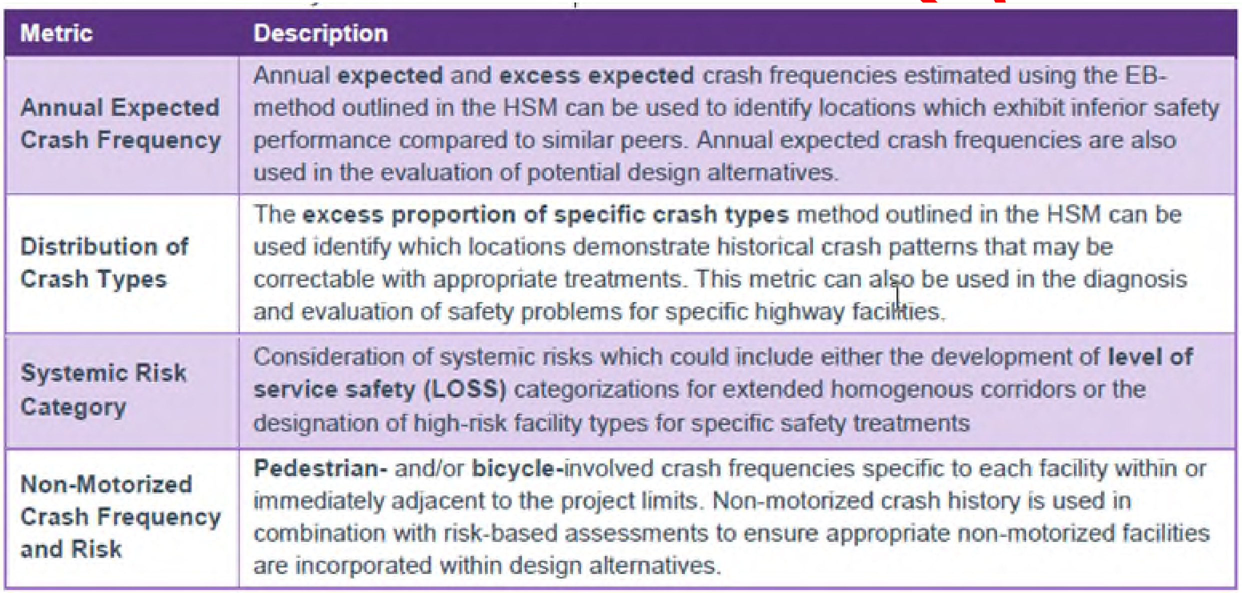
Category Type	Program/Project Type	Project Examples	Crash Analysis Tier
Roadway Maintenance	Road Capital Preventive Maintenance (CPM) • Pavement Seal • Functional Enhancement	Micro-Surfacing, Ultra-Thin Overlay Overlay, Shoulder Ribbons	Tier I*
Roadway Maintenance	Freeway Resurfacing Program (FRP)	Single or Two Course Overlay	Tier I*
Roadway Maintenance	Non-Freeway Resurfacing Program (NFRP)	HMA Overlay	Tier I*
Safety – Non-Pavement	Guardrail	Cable barrier, guardrail, median barrier	Tier I*
3R – Resurfacing, Restoration and Rehabilitation	Bridge Road – Pavement Road – Operational Road - Safety	Overlay, widen lanes, barrier/railing replacement Resurfacing, milling, concrete overlays, inlays Passing relief lanes, turn lanes, thru lanes Minor alignment improvements, roadside safety improvements, lane or shoulder widening, intersection or rail-grade crossing upgrades	Tier II
3R – Resurfacing, Restoration and Rehabilitation	Road - Major Pavement Reconstruction	Full-Depth Replacement Only	Tier III
4R – Reconstruction or Replacement	Bridge Roadway Reconstruction Roadway Operational Improvements	Bridge deck or superstructure replacement Major alignment of geometric improvements, intermittent grade modifications (over 50%) Adding lanes to increase capacity	Tier IV
New Construction	Construction of new facility	Construction of additional miles of roadway or new bridge on new alignment	Tier IV

*Overall Safety Analysis must confirm that no significant safety upgrades beyond the capability of the funding source are needed. If needed such upgrades should be addressed by other means and/or project type.

Safety Performance Metrics and Thresholds

Four data-driven safety performance metrics are to be used to identify roadway facilities which are exhibiting inferior safety performance compared to similar peers. These metrics are designed to consider a combination of site-specific ("hot spots") safety concerns, potential systemic concerns, as well as non-motorized considerations. Additionally, the metrics can assist in the diagnosis of potential safety concerns as well as the evaluation design alternatives. It should be noted that metrics are evaluated for individual roadway facilities (e.g. highway segments, intersections, freeway ramps, etc) and one project will often incorporate several facilities. **Table 2** shows the proposed safety performance metrics as well as a brief description of the associated methods and applications. Each metric is described in more detail in the proceeding subsections.

Table 2. Data-Driven Safety Performance Metrics



Metric	Description
Annual Expected Crash Frequency	Annual **expected** and **excess expected** crash frequencies estimated using the EB-method outlined in the HSM can be used to identify locations which exhibit inferior safety performance compared to similar peers. Annual expected crash frequencies are also used in the evaluation of potential design alternatives.
Distribution of Crash Types	The **excess proportion of specific crash types** method outlined in the HSM can be used identify which locations demonstrate historical crash patterns that may be correctable with appropriate treatments. This metric can also be used in the diagnosis and evaluation of safety problems for specific highway facilities.
Systemic Risk Category	Consideration of systemic risks which could include either the development of **level of service safety (LOSS)** categorizations for extended homogenous corridors or the designation of high-risk facility types for specific safety treatments
Non-Motorized Crash Frequency and Risk	**Pedestrian-** and/or **bicycle-**involved crash frequencies specific to each facility within or immediately adjacent to the project limits. Non-motorized crash history is used in combination with risk-based assessments to ensure appropriate non-motorized facilities are incorporated within design alternatives.

Annual Expected Crash Frequency

The primary metric used to identify high-crash locations is **annual expected crash frequency** estimated via the EB-method outlined in the HSM. The EB-method combines a site's observed crash frequency with a predicted crash frequency developed using a SPF, to estimate an expected average crash frequency. This weighted expected crash frequency represents an estimation of the long-term annual average (**Figure 3**). The use of expected crash frequencies offers several advantages over simple observed crash frequencies as it considers the impact of changing traffic volumes, regression-to-the-mean bias, and other factors that potentially affect the frequency of traffic crashes. Annual expected crash frequencies represent a consistent unit which can be evaluated objectively across all facility types and land uses present within Michigan's highway network. Additionally, this metric can be disaggregated into crashes resulting in a fatality or an injury to a crash involved occupant (FI) as well as property damage only (PDO) crashes (*23*).

Ultimately, the predicted crash frequency can be subtracted from the expected crash frequency to determine the **annual excess expected crash frequency**, or the number of expected crashes above or below crash frequencies for other similar facilities (**Figure 3**). The excess expected crash metric serves as a state-of-the-art extension of the expected crash metric to determine the potential for safety improvement at specific highway facilities. <u>When the excess annual expected crash frequency is greater than zero then the expected excess threshold has been exceeded.</u>

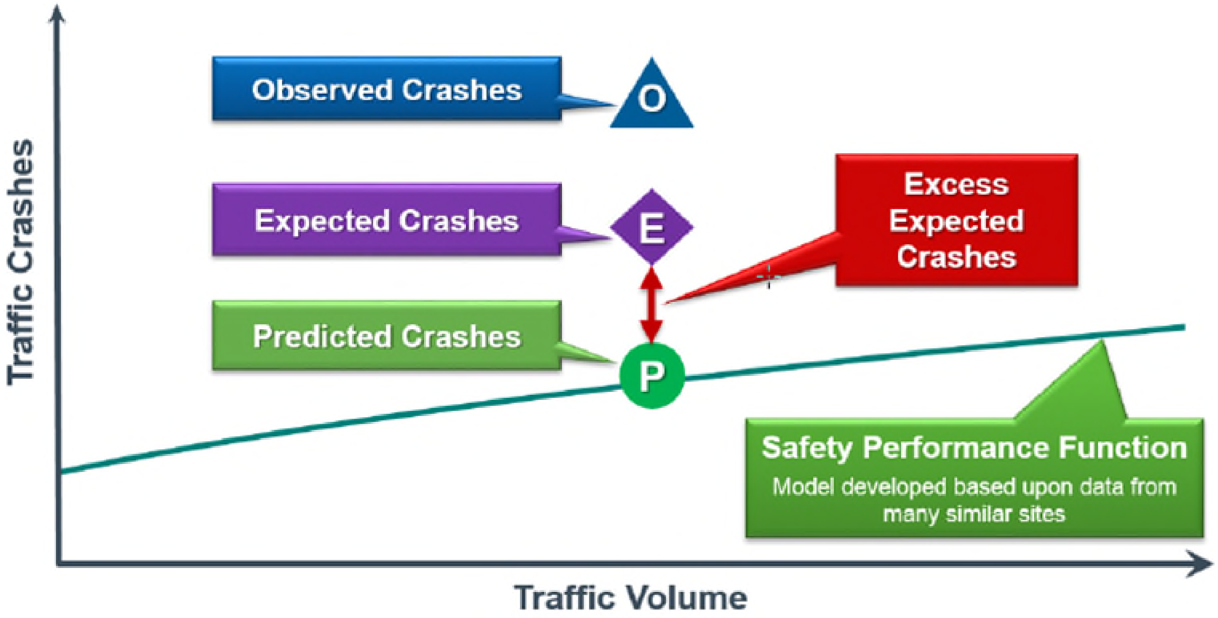


Figure 3. Observed, Expected and Predicted Crashes by Traffic Volume – EB Method Example

<u>Distribution of Crash Types</u>

In addition to the identification of high-crash locations, it is also necessary to screen for potential locations which may exhibit an increased risk for a specific crash type. Certain locations within the highway system may be operating better than similar peers from a Fatal/Injury and/or total crash perspective but may still exhibit an overrepresentation of a specific crash type. Such locations merit additional consideration as engineering treatments may be available to target overrepresented crash types. An example is shown below, where a study intersection demonstrates an overrepresentation of rear end and angle crashes compared to a sample of intersections with similar characteristics (**Figure 4**). The **excess proportions of specific crash types** methodology outlined in the HSM can be used to identify locations which exhibit increased risk for specific crash types. Additional engineering judgement should be applied as some sites may be identified for further evaluation due to a usually low frequency of non-target crash types (*1*).

The sample study intersection in **Figure 4** demonstrates an overrepresentation of rear end and angle crashes when compared with the distribution of similar intersections. This metric not only identifies additional highway locations which may exhibit an increased risk for a specific crash type, it also can be used in the diagnosis of potential safety concerns. Treatments can be identified which target the overrepresented crash types and implemented into subsequent design alternatives.

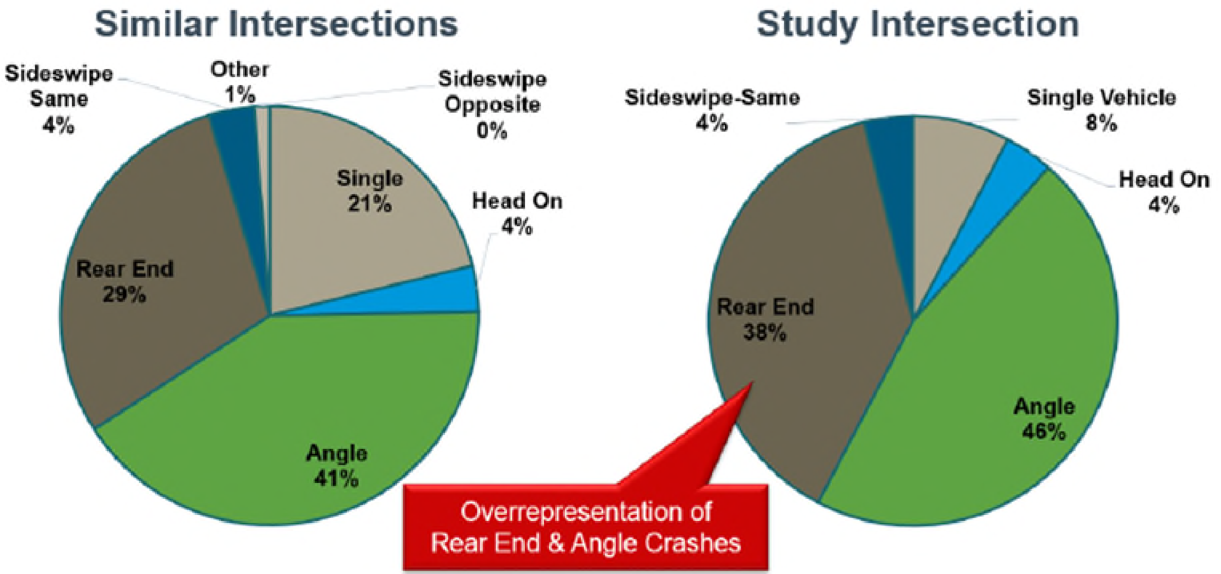


Figure 4. Crash Type Distribution – Similar Intersections compared to Sample Study Intersection

Distribution of Crash Types is not available at this time in the DDSA model.

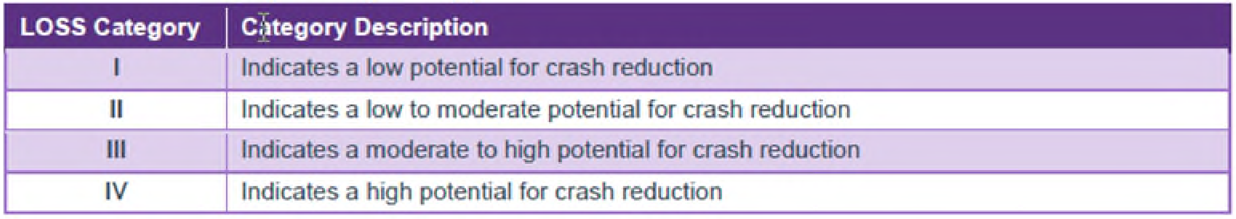
<u>Systemic Risk Category</u>

As noted by the FHWA, severe crashes, particularly in rural environments, tend to be widely distributed over a roadway network (*9*). Such low densities of severe crashes are unlikely to be identified using site-specific analysis techniques which focus on identifying high-crash locations (*10*). Therefore, additional methodology is included to identify facilities within the highway network where systemic treatments are more beneficial.

In addition to the high-crash and crash type metrics suggested earlier, the design of a systemic risk categorization process would allow for the identification of roadway facilities with an increased risk for such systemic crashes. While this could be completed by simply identifying roadway facility types which are at an increased risk for systemic crash types (e.g. high-speed two-lane highways and lane departure crashes), more targeted methods could include level of service safety (LOSS) categorizations for roadway segments aggregated into extended homogenous corridors. This would allow for the identification of systemic safety issues present along specific corridors, as opposed to the site-specific (or “hot spot”) metrics. As part of this process, each corridor within the highway system is placed into one of four distinct LOSS categories depending on the degree in which observed crash frequency is statistically different than the predicted crash frequency (*1*).

LOSS category descriptions from the HSM are provided in **Table 3** and an example of results for urban six-lane freeway facilities is shown in **Figure 5** from the original research by Kononov and Allery (*54*).

Table 3. LOSS Category Descriptions (*1*)



LOSS Category	Category Description
I	Indicates a low potential for crash reduction
II	Indicates a low to moderate potential for crash reduction
III	Indicates a moderate to high potential for crash reduction
IV	Indicates a high potential for crash reduction

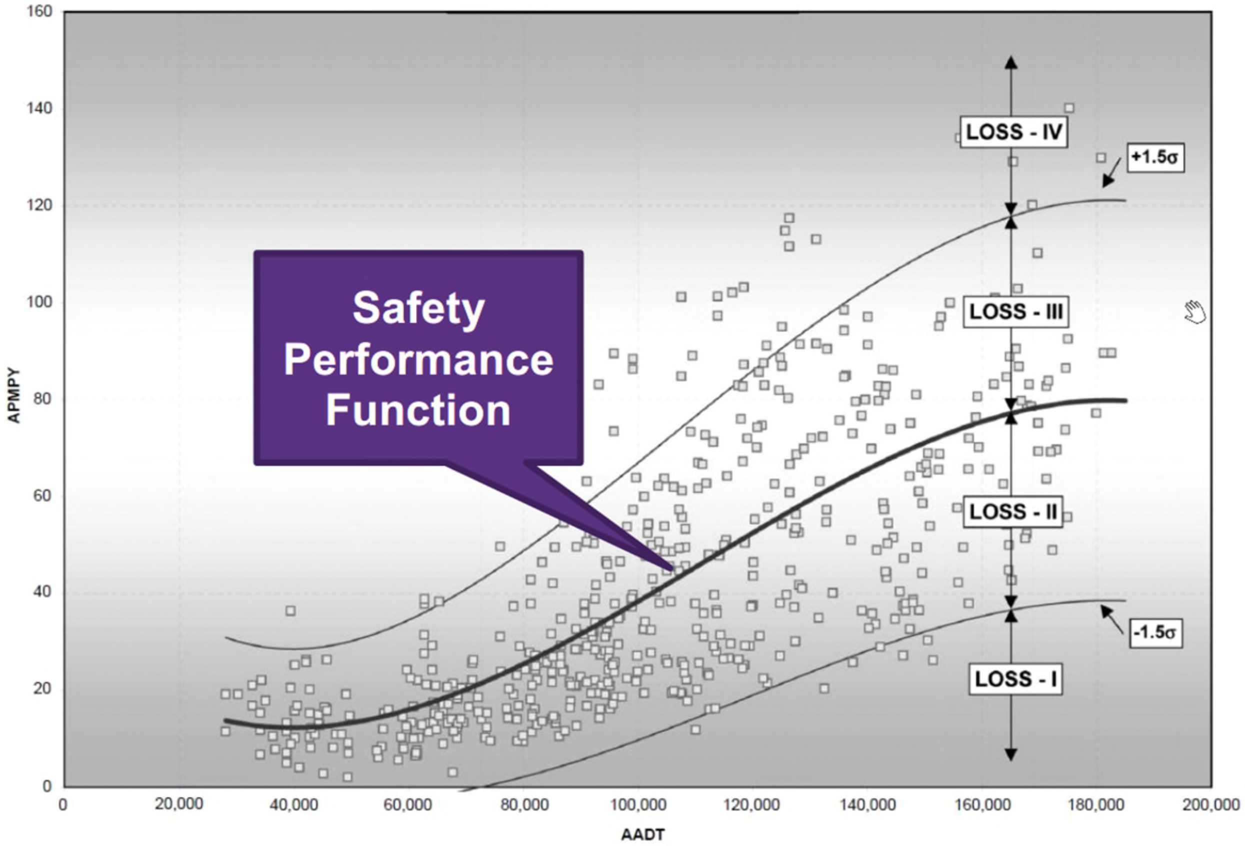


Figure 5. Level of Service Safety – SPF Graph for Urban Six-Lane Freeway from Kononov and Allery (*54*)

The observed crash frequency for each urban six-lane freeway segment is represented along the y-axis with the annual average daily traffic (AADT) volume specific to that facility shown along the x-axis. The appropriate safety performance function (specific to urban six-lane freeways) is also shown which represents the average crash frequency for the given facility type with known traffic volumes. Sites are placed in LOSS categories based upon the degree in which observed crash frequency is statistically different than the average predicted crash frequency using the over dispersion parameter from the SPF to determine a standard deviation (σ) from the mean. The mean frequency from the SPF, as well as the frequency 1.5 standard deviations above and below the mean, are used as three thresholds to place sites into the four LOSS categories. While the LOSS approach has a variety of potential applications in the DDSA process, it is particularly suitable for determining the statistical significance of differences in site-specific safety performance relative to the mean. This concept, in combination with the development of extended homogenous highway corridors on which specific systemic safety concerns may be present, will allow for the identification of sites which may possess additional systemic risk. This varies from the **annual expected crash frequency** and **distribution of crash types** metrics which target localized site-specific safety concerns.

There are many potential corridor aggregation schemes which may be appropriate depending on the specific systemic concern. Therefore, while an example of such a systemic risk categorization approach for four corridors is shown in **Figure 6**, the ultimate selection of aggregation schemes and pertinent details of the analysis should be determined in consultation with MDOT to ensure general agreement with agency safety goals.

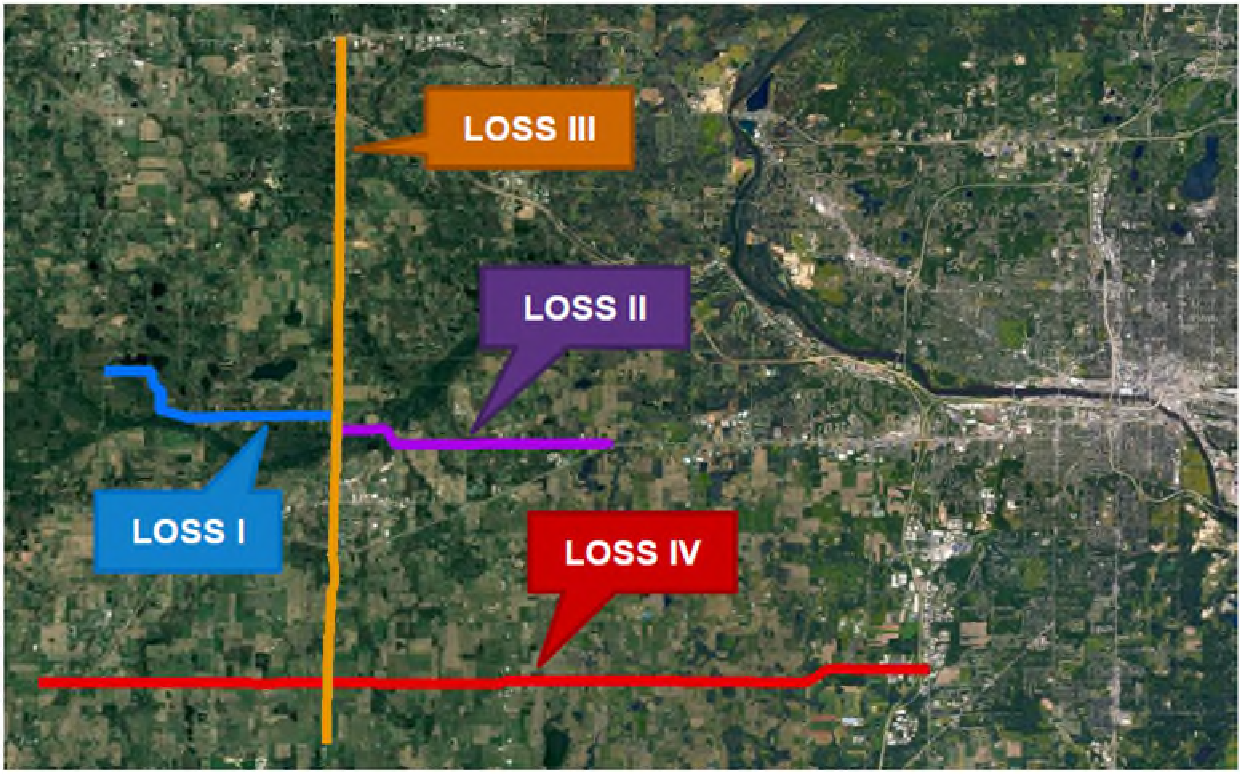


Figure 6. Example of LOSS Systemic Risk Categories Corridor Analysis – Four Example Corridors

Non-Motorized Crash Frequency and Risk

While the prior three metrics are focused on the identification of locations which exhibit an increased risk for vehicular crashes, it is also important to consider the risk of crashes involving non-motorized road users. Similar to systemic safety concerns, collisions involving pedestrians and/or bicyclists tend to be widely distributed over a highway network. Therefore, current site-specific analysis techniques which focus on identifying high-crash locations may be less suitable for this application. Even though empirical methods for evaluating non-motorized safety risks are still in development, a simple review of crash report form narratives for any collisions involving pedestrians or bicyclists may reveal patterns which can be addressed by engineering countermeasures. Crash report form narratives should be reviewed for each collision which occurred within or immediately adjacent to the project bounds that involved a non-motorized road user. Regardless of the non-motorized crash history, appropriate non-motorized road user facilities could always be implemented within design alternatives consistent with existing MDOT guidance.

System-wide vs. Site-specific Models

The four data-driven metrics outlined were selected in part because they can be evaluated at both system-wide and site-specific levels. System-wide models involve the aggregation of several large databases (such as the roadway inventory, AADT maps, and historical crash databases) into a single safety analysis database for further evaluation. Site-specific models include the development of a new model for a specific project or purpose based upon data associated with an individual roadway facility or corridor. Both applications of the data-driven metrics important roles in the safety analysis process.

System-wide Crash Model and Safety Crash Analysis Maps

The development of a system-wide crash model includes the aggregation of several databases which provide the necessary details to calculate the data-driven metrics. This would include leveraging existing state-wide databases (such as the *Michigan Geographic Framework*, the *Non-Trunkline Federal Aid Mapping Application*, and the historical crash databases compiled annually by the Michigan State Police). Data specific to each roadway facility (e.g. highway segments, intersections, freeway ramps, etc.) is aggregated and evaluated to provide a **safety crash analysis map** with the data-driven metrics within an appropriate file format (such a KMZ or SHP). The map includes data for roadway facilities where there is at least a planning-level estimate of traffic volumes available on the state trunkline and federal aid system.

See Safety Crash Analysis Map Instructions on how to determine Excess Expected Total Crashes, Excess Expected Fatal and Injury Crashes and LOSS for a specific location at the planning level and how to quantify the impacts of proposed improvements to convert to a project level analysis.

Site-Specific Crash Models and Methods

Given that a system-wide crash map is typically developed using data available at a system-wide level, not every factor considered as a part of a standard site-level EB-analysis will likely be available. Additionally, traffic crash data and/or roadway inventory data may be either out of date, erroneous, or lack adequate precision. Therefore, it may be necessary depending on the site and project conditions to develop a site-specific crash model which provides increased reliability and precision in the predictive process. This can be conducted by use of the MDOT HSM worksheet or the IHSDM software tool. In addition, other software tools may be appropriate in consultation with Safety Programs, however, it is critically important to ensure uniform methods are applied across all projects. In these cases, an analyst with prior experience developing such crash models should develop the site-specific model(s) to ensure that the model is representative of field conditions. Finally, this could also include the use of risk-based analysis tools specific to non-motorized analysis such as iRAP or other MDOT tools currently under development.

Crash Analysis Process

Guidance to complete each tier of crash analysis is provided in the following subsections. Flow charts are included which provide a general structure to approach crash analyses consistent with **Table 1**. Given that the guidance included here is generalized, site and project conditions may require modification of the proposed processes. Additionally, analytical methods beyond what is included in this report are required to complete crash analyses, particularly involving the development of site-specific models or the selection of an appropriate CMF. Analysts should refer to the appropriate resource (such as the HSM, MDOT *HSM Spreadsheet* or *CMF Clearinghouse*) for additional detail on how to complete the necessary analyses. Case studies of applied examples for each tier are provided in the appendix.

Tier I

Given that routine maintenance projects generally offer the lowest potential to impact safety performance, **Tier I** crash analyses represent a brief examination of historical safety performance to determine if additional consideration is required. A flow chart is provided in **Figure 7** which outlines the **Tier I** process.

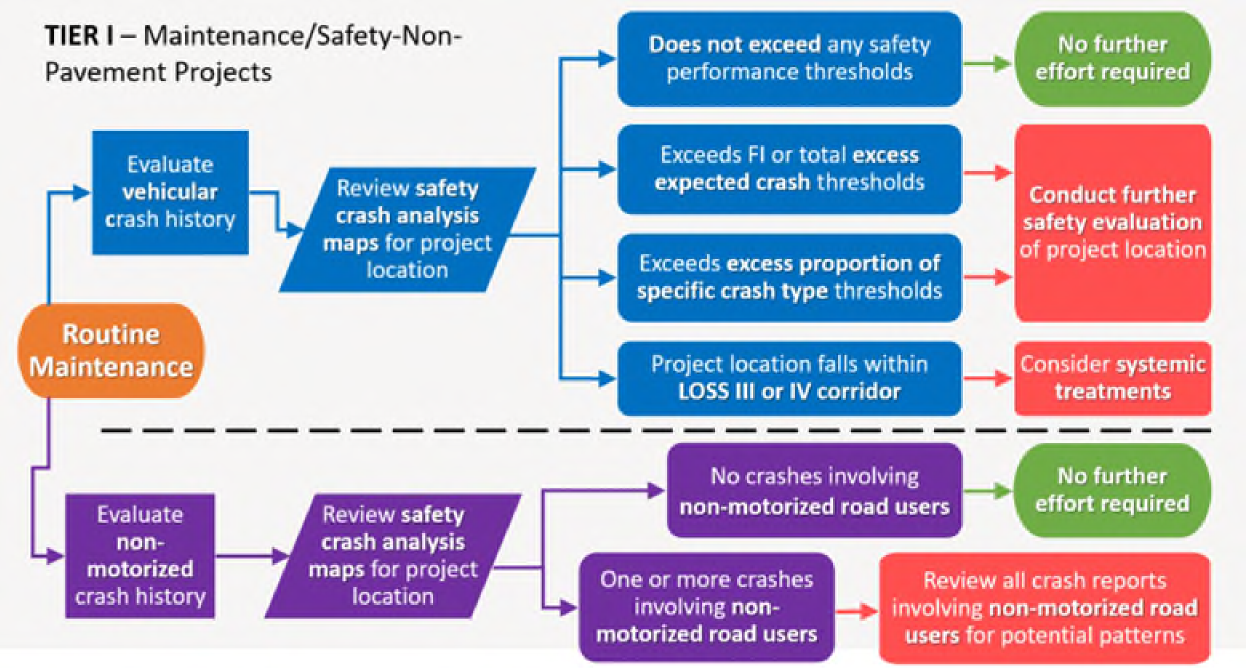


Figure 7. TIER I – Roadway Maintenance/Safety-Non-Pavement Project Crash Analysis Flowchart

The **vehicular crash history** of the roadway facilities which incorporate the proposed routine maintenance work should be reviewed via the safety crash analysis map:

In cases where none of the three potential safety metrics are exceeded (the value reported is greater than zero), no further effort is required with respect to vehicular crashes.

- However, if either the excess expected crash thresholds or the crash type thresholds are exceeded, further safety evaluation of the project location should be conducted.
    - This would include a traditional review of the historical traffic crash data to determine if there are trends correctable with minor safety treatments or if the project location should be evaluated for more substantial safety treatments.
- If the project location falls within a LOSS III or LOSS IV corridor, systemic safety treatments should be considered consistent with the facility type, project scope and potential systemic concern.
    - Systemic treatments designed to address the target crash type should be identified and considered for further implementation. It should be noted that many systemic treatments may not be feasible within the existing scope and therefore additional consideration may be required.

With respect to **non-motorized crash history**, the non-motorized crash history of the roadway facilities which incorporate the proposed routine maintenance work should be reviewed via the safety crash analysis map:

- All crash report form narratives involving non-motorized road users should reviewed for potential correctable patterns which may be addressable with appropriate treatments.
- In addition, consideration should be given to immediately adjacent facilities consistent with project bounds to determine if there are non-motorized safety concerns within the potential influence area.

Tier II

Tier II crash analyses, which are appropriate for use in 3R projects, incorporate similar steps as Tier I except the end processes include the evaluation of specific safety treatments. The Tier II analysis process includes a streamlined, data-driven method to evaluate existing conditions and potential alternatives and can be applied with the use of the safety crash analysis map. A flow chart is provided in **Figure 8** which outlines the Tier II process.

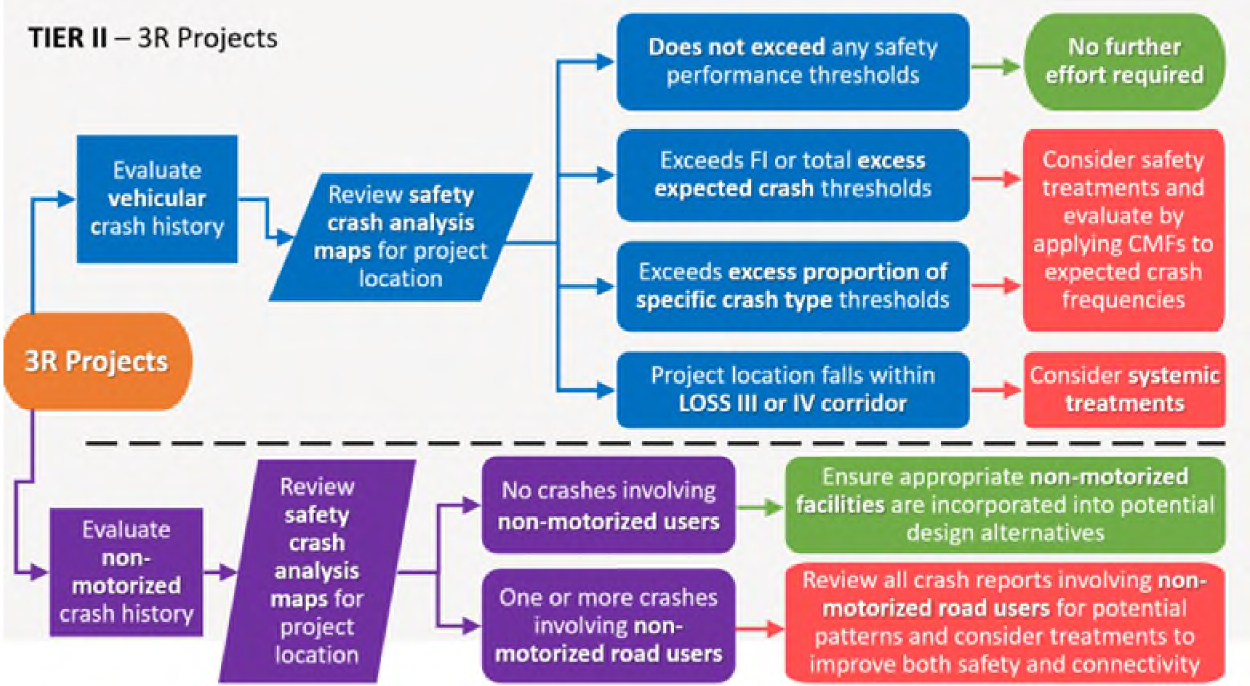


Figure 8. TIER II – 3R Project Crash Analysis Flowchart

The **vehicular crash history** of the roadway facilities which incorporate the proposed 3R project limits should be reviewed via the safety crash analysis map:

- In cases where none of the three potential safety metrics are exceeded, (the value reported is greater than zero), no further effort is required with respect to vehicular crashes.
- However, if either the excess expected crash thresholds or the crash type thresholds are exceeded, further evaluation of the project location should be conducted:
    - This would include a traditional review of the historical traffic crash data to determine potential safety treatments and/or design alternatives.
    - This would also include an evaluation of potential safety treatments by applying a CMF from either the HSM, *CMF Clearinghouse*, or another approved MDOT repository. CMFs should be applied to the expected crash values associated with the specific CMF (typically, Fatal/Injury or total

    crashes, but many CMFs are available which target specific crash types). The safety crash analysis map would provide these expected crash values.
        - Situations may exist where an appropriate CMF is not available, or a site-level model may be required to evaluate potential treatments. In these cases, complete the **Tier IV** evaluation process.
- If the project location falls within a LOSS III or LOSS IV corridor, systemic safety treatments should be considered consistent with the facility type, project scope and potential systemic concern.
    - Systemic treatments designed to address the target crash type should be identified and considered for further implementation. It should be noted that many systemic treatments may not be feasible within the existing scope and therefore additional consideration may be required.

With **respect to non-motorized crash history**, the non-motorized crash history of the roadway facilities which incorporate the proposed 3R project limits should be reviewed via the safety crash analysis map:

- All crash report form narratives involving non-motorized road users should reviewed for potential correctable patterns which may be addressable with appropriate treatments.
- In addition, consideration should be given to immediately adjacent facilities consistent with project bounds to determine if there are non-motorized safety concerns within the potential influence area.
- Ultimately, the incorporation of appropriate non-motorized facilities within project alternatives should be ensured regardless of the specific non-motorized crash history.

<u>Tier III</u>

Given that reconstruction projects typically involve the most substantial modifications to highway facilities, it is recognized that these types of projects often provide the greatest potential to improve safety performance. As such, the **Tier III** crash analysis process allows for the streamlined analysis methods outlined in **Tier II** for certain 3R projects, with the provision that many scenarios will require the most advanced analysis methods to adequately quantify existing safety performance and project alternatives. The **Tier III** process is appropriate for 3R (formally 4R) projects which initially include only limited or no planned geometric modifications. This generally includes full-depth pavement reconstruction projects along roadways which are not previously known to exhibit poor safety performance. A flow chart is provided in **Figure 9** which outlines the **Tier III** process.

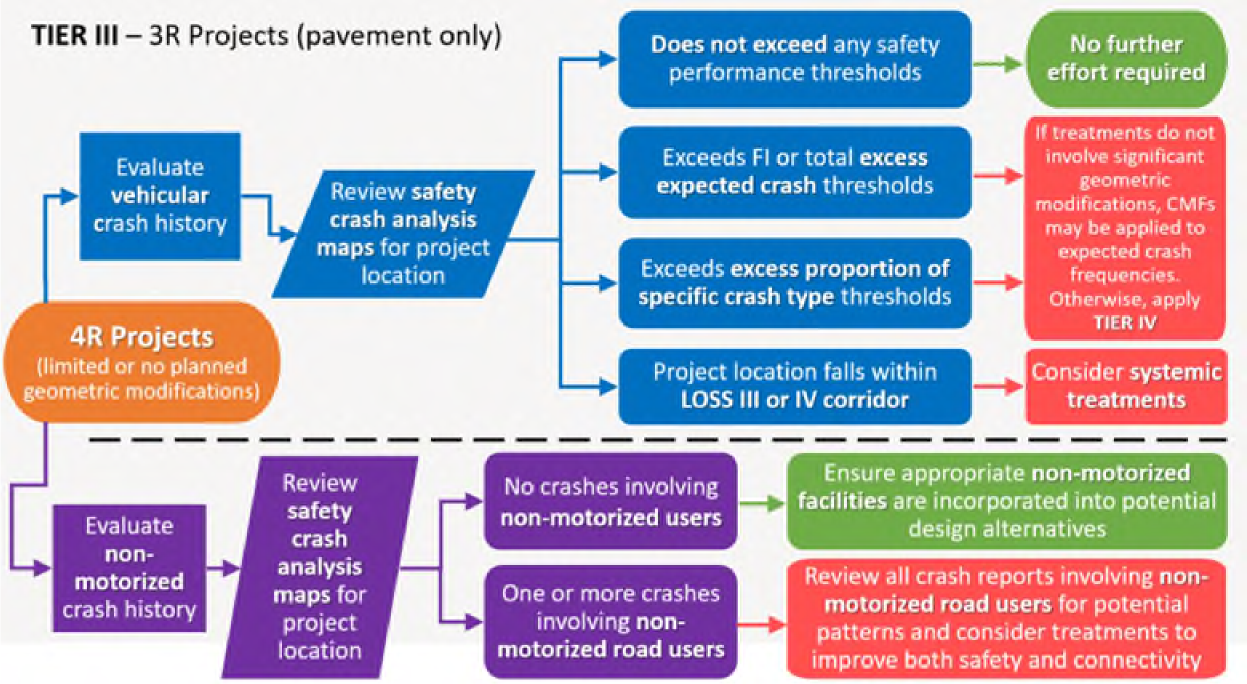


Figure 9. TIER III – 3R Projects with Full-Depth Replacement Only Crash Analysis Flowchart

The **vehicular crash history** of the roadway facilities which incorporate the proposed 4R project limits should be reviewed via the safety crash analysis map:

- In cases where none of the three potential safety metrics are exceeded, (the value reported is greater than zero), no further effort is required with respect to vehicular crashes.
- However, if either the excess expected crash thresholds or the crash type thresholds are exceeded, further evaluation of the project location should be conducted:

    - This would include a traditional review of the historical traffic crash data to determine potential safety treatments and/or design alternatives.
    - This would also include an evaluation of potential safety treatments by applying a CMF from either the HSM, *CMF Clearinghouse*, or another approved agency repository. CMFs should be applied to the expected crash values associated with the specific CMF (typically, Fatal/Injury or total crashes, but many CMFs are available which target specific crash types). The safety crash analysis map would provide these expected crash values.
        - Situations may exist where an appropriate CMF is not available, or a site-level model may be required to evaluate potential treatments. In these cases, complete the **Tier IV** evaluation process.
- If the project location falls within a LOSS III or LOSS IV corridor, systemic safety treatments should be considered consistent with the facility type, project scope and potential systemic concern.
    - Systemic treatments designed to address the target crash type should be identified and considered for further implementation. It should be noted that many systemic treatments may not be feasible within the existing scope and therefore additional consideration may be required.

With **respect to non-motorized crash history**, the non-motorized crash history of the roadway facilities which incorporate the proposed 4R project limits should be reviewed via the safety crash analysis map:

- All crash report form narratives involving non-motorized road users should reviewed for potential correctable patterns which may be addressable with appropriate treatments.
- In addition, consideration should be given to immediately adjacent facilities consistent with project bounds to determine if there are non-motorized safety concerns within the potential influence area.
- Ultimately, the incorporation of appropriate non-motorized facilities within project alternatives should be ensured regardless of the specific non-motorized crash history.

Tier IV

4R projects with planned geometric modifications, in addition to new construction projects, offer the greatest potential to impact safety performance. As such, the most advanced analytical methods are recommended to quantify existing safety performance and the relative performance of project alternatives. This includes the development of site-specific models (as opposed to use of the safety crash analysis map) using the MDOT HSM spreadsheet, IHSDM, or other Safety Programs approved analysis tool. Tier IV analyses should be conducted by safety personnel with a background in safety modelling to ensure the site-specific models are representative of field conditions. A flow chart is provided in **Figure 10** which outlines the Tier IV process.

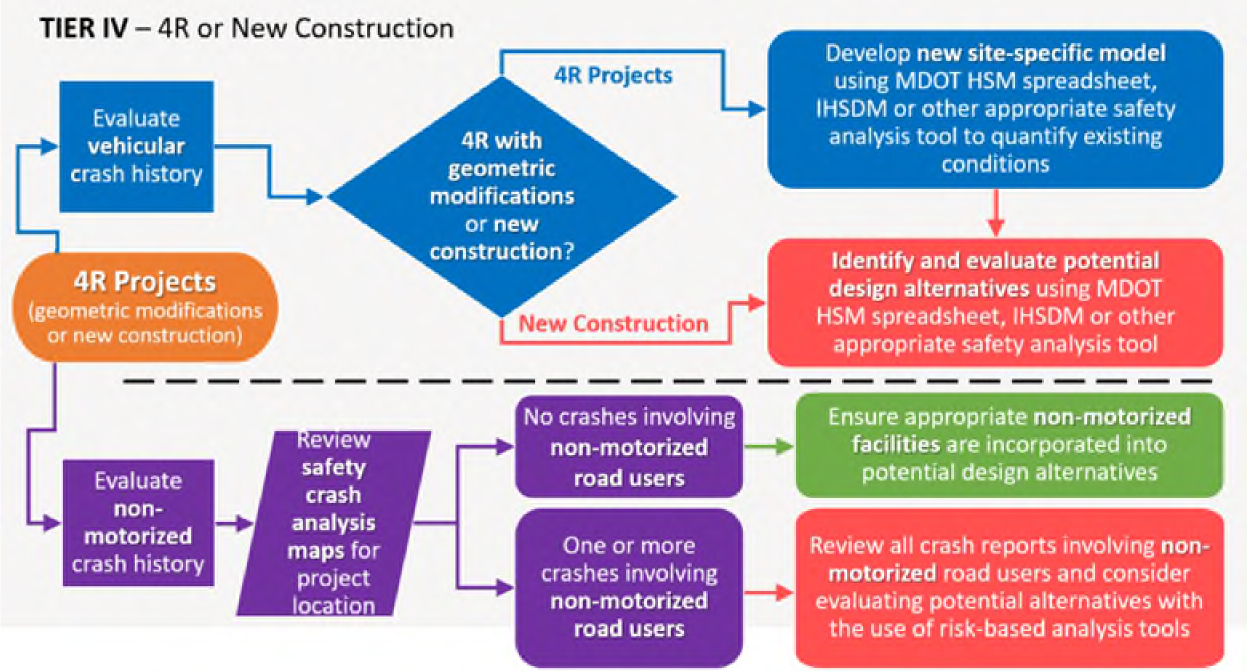


Figure 10. TIER IV – 4R Projects with Significant Geometric Modifications Crash Analysis Flowchart

The evaluation of **vehicular crash history** should include the development of a site-specific model using the MDOT HSM spreadsheet, IHSDM or another Safety Programs approved safety analysis tool to adequately evaluate the existing conditions:

- These results, in combination with a traditional review of the historical traffic crash data should be used to determine potential safety treatments and/or design alternatives for the project location.
- Each alternative should be modelled using similar techniques as the evaluation of the existing condition. In the cases where a new facility is being constructed, only the alternatives step can be performed. The difference between expected crash frequencies in the existing condition (4R projects only) and the project alternatives (both 4R projects and new construction) represents the most advanced data-driven method to quantify changes in objective safety performance.

    - Analysts should refer to the HSM or other appropriate resource for detailed methodology on developing site-specific models and alternatives analysis methods.

With respect to **non-motorized crash history**, the non-motorized crash history of the roadway facilities which incorporate the proposed 4R project limits should be reviewed via the safety crash analysis map:

- All crash report form narratives involving non-motorized road users should reviewed for potential correctable patterns which may be addressable with appropriate treatments.
- In addition, consideration should be given to immediately adjacent facilities consistent with project bounds to determine if there are non-motorized safety concerns within the potential influence area.
- The application of risk-based analysis tools, such as iRAP or other tools currently under development by MDOT are useful for evaluating the relative safety performance impact of both the existing condition (4R projects) as well as potential design alternatives (both 4R projects and new construction). This represents the most advanced data-driven method to quantify changes in objective safety performance with respect to non-motorized road users.
- Ultimately, the incorporation of appropriate non-motorized facilities within project alternatives should be ensured regardless of the specific non-motorized crash history and risk-based analysis methodology.

Design Exception/Design Variance Process

Design exceptions, subject to approval of the FHWA, are required for projects occurring on the NHS when any of the ten controlling criteria are not met (*16*). In these instances, application of DDSA techniques can help to quantify how design alternatives impact the expected safety performance, required in FHWA documentation. The **design exception process**, shown in **Figure 11**, incorporates similar elements as the **Tier IV** analysis to estimate the potential impacts of design exceptions as well as mitigation strategies designed to reduce their expected safety impact. It should be noted that the process outlined in **Figure 11** should be implemented consistent with the ***design exception/design variance process*** specified in ***MDOT Road Design Manual (52)***.

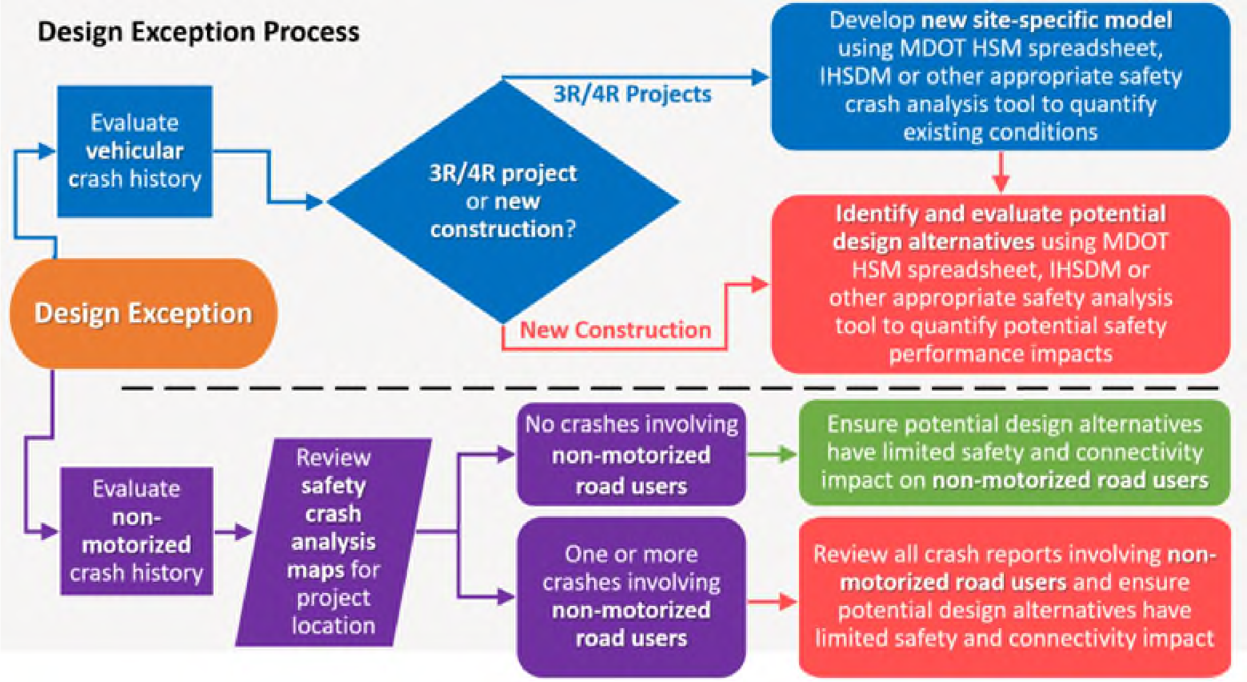


Figure 11. Design Exception Process - Crash Analysis Flowchart

The evaluation of **vehicular crash history** should include the development of a site-specific model using the MDOT HSM spreadsheet, IHSDM or another Safety Programs approved safety analysis tool to adequately evaluate the existing conditions:

- These results, in combination with a traditional review of the historical traffic crash data should be used to determine potential mitigation measures and/or design alternatives (including scenarios which involve the implementation of the design exception) for further evaluation.
- Each scenario would ultimately be modelled using similar techniques as the existing condition to quantify differences in objective safety performance.
    - While this process should generally be performed using site-specific models, there may be cases where expected crash output from the safety crash analysis map and the use of CMFs can adequately quantify potential

    alternatives. This would generally be limited to very low-impact design variances involving scenarios where the application of a high-reliability CMF can appropriately represent changes in condition.
    - Analysts should refer to the HSM or other appropriate resource for detailed methodology on developing site-specific models and alternatives analysis methods.

With respect to non-motorized crash history, the non-motorized crash history of the roadway facilities which incorporate the proposed project limits should be reviewed via the safety crash analysis map:

- All crash report form narratives involving non-motorized road users should reviewed for potential correctable patterns which may be addressable with appropriate treatments.
- In addition, consideration should be given to immediately adjacent facilities consistent with project bounds to determine if there are non-motorized safety concerns within the potential influence area.
- The application of risk-based analysis tools, such as iRAP or other tools currently under development by MDOT are useful for evaluating the relative safety performance impact of both the existing condition and potential design scenarios. This represents the most advanced data-driven method to quantify changes in objective safety performance with respect to non-motorized road users.
- Ultimately, the incorporation of appropriate non-motorized facilities within project alternatives should be ensured regardless of the specific non-motorized crash history and risk-based analysis methodology.

Alternatives Analysis Considerations and CMFs

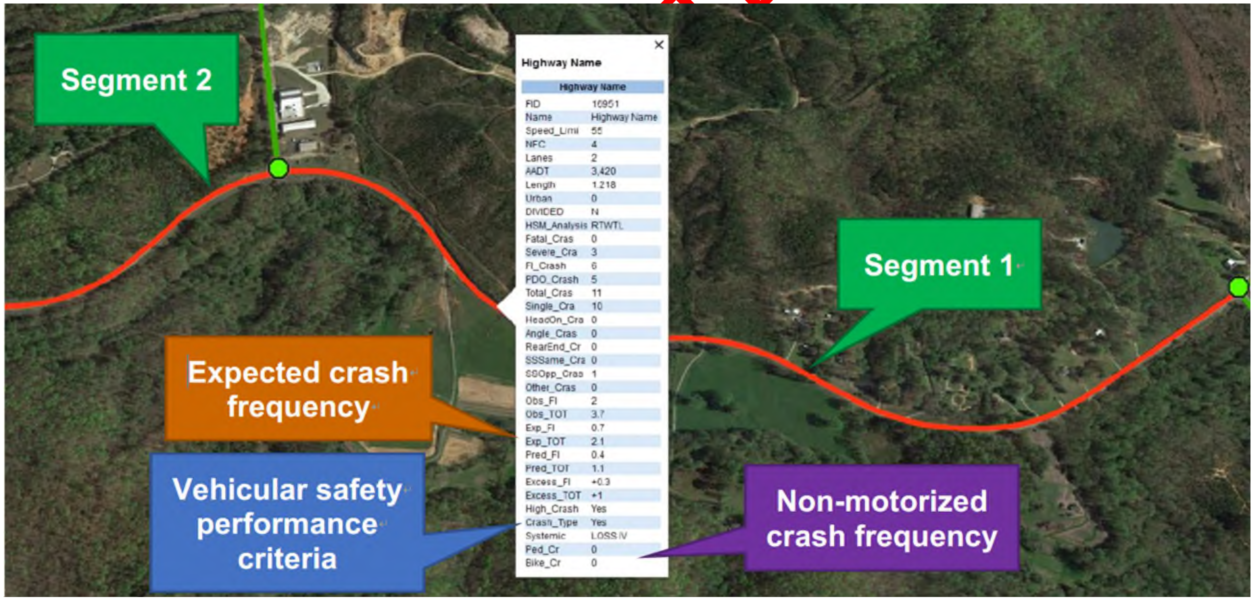
There are several additional considerations within the alternatives analysis process that are important to consider ensuring consistent DDSA implementation throughout MDOT. It is recommended that alternatives analyses be conducted using expected crashes per year (and expected Fatal/Injury crashes per year) as the standard unit for comparing multiple design scenarios. Expected crashes represent a consistent unit which can be evaluated objectively across all facility types and land uses present within Michigan's highway network. Additionally, changes in expected crashes can be easily quantified in an economic analysis using the methods included in MDOT's TOR form which employ the National Safety Council's average economic crash costs (*55*). This economic analysis can be used as a part of a larger evaluation (in conjunction with operational, environmental, and other analyses) to help select the most beneficial outcome for Michigan's road users.

Case Studies

Case study examples for each tier of crash analysis is included to provide additional guidance towards applying the processes outlined. It should be noted that these case studies are intended to demonstrate the DDSA process and the methods for calculating expected and predicted crash frequencies can be found in other published resources, including the HSM as well as recent SPF research in Michigan (1, 7, 8). While screen shots from an example safety crash analysis map are included for each scenario, there are several ways in which such a safety crash analysis map could be segmented, aggregated or color-coded. The examples provided are intended to offer an overview of the safety analysis process and there are several analytical decisions which should be made in consultation with MDOT.

Roadway Maintenance Example

The two-lane, two-way high-speed rural highway shown in **Figure 12** is scheduled to undergo a thin asphalt overlay as a part of the CPM program. Given that this activity is considered a routine maintenance project in **Table 1**, the Tier I crash analysis process should be applied outlined. The first step in this process is to refer to the safety crash analysis map to obtain the appropriate safety performance data, also shown in **Figure 12**.



Highway Name

Highway Name	
FID	10951
Name	Highway Name
Speed_Limi	55
NFC	4
Lanes	2
AADT	3,420
Length	1.218
Urban	0
DIVIDED	N
HSM_Analysis	RTWTL
Fatal_Cras	0
Severe_Cra	3
FI_Crash	6
PDO_Crash	5
Total_Cras	11
Single_Cra	10
HeadOn_Cra	0
Angle_Cras	0
RearEnd_Cr	0
SSSame_Cra	0
SSOpp_Cras	1
Other_Cras	0
Obs_FI	2
Obs_TOT	3.7
Exp_FI	0.7
Exp_TOT	2.1
Pred_FI	0.4
Pred_TOT	1.1
Excess_FI	+0.3
Excess_TOT	+1
High_Crash	Yes
Crash_Type	Yes
Systemic	LOSS IV
Ped_Cr	0
Bike_Cr	0

Figure 12. Two-Lane, Two-Way Highway scheduled for Asphalt Overlay

Highway Name

Highway Name	
FID	16951
Name	Highway Name
Speed_Limi	55
NFC	4
Lanes	2
AADT	3,420
Length	1.218
Urban	0
DIVIDED	N
HSM_Analysis	RTWTL
Fatal_Cras	0
Severe_Cra	3
FI_Crash	6
PDO_Crash	5
Total_Cras	11
Single_Cra	10
HeadOn_Cra	0
Angle_Cras	0
RearEnd_Cr	0
SSSame_Cra	0
SSOpp_Cras	1
Other_Cras	0
Obs_FI	2
Obs_TOT	3.7
Exp_FI	0.7
Exp_TOT	2.1
Pred_FI	0.4
Pred_TOT	1.1
Excess_FI	+0.3
Excess_TOT	+1
High_Crash	Yes
Crash_Type	Yes
Systemic	LOSS IV
Ped_Cr	0
Bike_Cr	0

The highway segment shown in **Figure 12** (as well as the adjacent segment which is also included within the project bounds) exhibits a modest number of annual excess expected crashes, **Excess_TOT** +1 (row 6 from bottom), including at least one crash type which is significantly overrepresented. Further inspection of the crash data included in the map suggest that this segment is experiencing a considerable number of single vehicle crashes, **Single_Cra** (row 16) (10 out of 11), as well as one sideswipe-opposite collision, **SSOpp_Cras** (row 21). The segment also falls within a LOSS IV corridor, suggesting a high potential for crash reduction. After reviewing the crash data, it was determined that the majority of collisions were the result of a lane departure event.

Despite the presence of adequate pavement width, centerline and shoulder rumble strips are currently not included. A proposed treatment for this location could include implementing rumble strips along the study corridor. It should be noted that implementing rumble strips may not fall within the initial scope and additional consideration could be required to determine feasibility. This countermeasure is especially appropriate for this scenario given that it not only treats the excess expected crashes and the excess crash type, but it also addresses the systemic concern identified by the LOSS IV categorization. It should be noted that zero collisions occurred involving non- motorized road users along these segments, and therefore no additional evaluation is required with respect to pedestrians or bicyclists.

While many CMFs for these treatments are available from the CMF Clearinghouse, a CMF of 0.828 which applies to total crashes was selected as it was derived from a study performed in Michigan specific to this treatment scenario. The CMF was multiplied by the annual expected crash frequency, **Exp_TOT** (row 10 from bottom), without treatment obtained from the safety crash analysis map for all segments along the study corridor (**Figure 12** shows Segment 1’s data - 2.1 annual expected crashes). **Table 4** shows the expected crash totals with and without treatment, as well as the expected crash reduction on an annual basis. Calculations to determine the annual expected crash frequencies with treatment (**Equation 1**) and the reduction in annual expected crashes (**Equation 2**) are provided for Segment 1.

$$Exp_{With\ Treatment} = (Exp_{Without\ Treatment}) * (CMF_{Treatment}) \qquad (1)$$

$$1.7 = 2.1 * 0.828$$

$$Exp_{Reduction} = (Exp_{Without\ Treatment}) - (Exp_{With\ Treatment}) \qquad (2)$$

$$0.4 = 2.1 - 1.7$$

Table 4. Annual Expected Crashes – Centerline and Shoulder Rumble Strips for Study Corridor

Location	Annual Expected Crashes without CLRS and SRS Treatment	Annual Expected Crashes with CLRS and SRS Treatment	Annual Expected Crash Reduction
Segment 1	2.1	1.7	0.4
Segment 2	1.6	1.3	0.3
Corridor Total	**3.7**	**3.0**	**0.7**

3R Rehabilitation Example

The four-legged signalized intersection shown in **Figure 13** has been selected for a traffic signal modernization. The Tier II analysis outlined prior in documents was applied given the project type, consistent with **Table 1**. The first step in this process is to refer to the safety crash analysis map to obtain the appropriate safety performance data, also shown in **Figure 13**.

Major Road at Minor Road

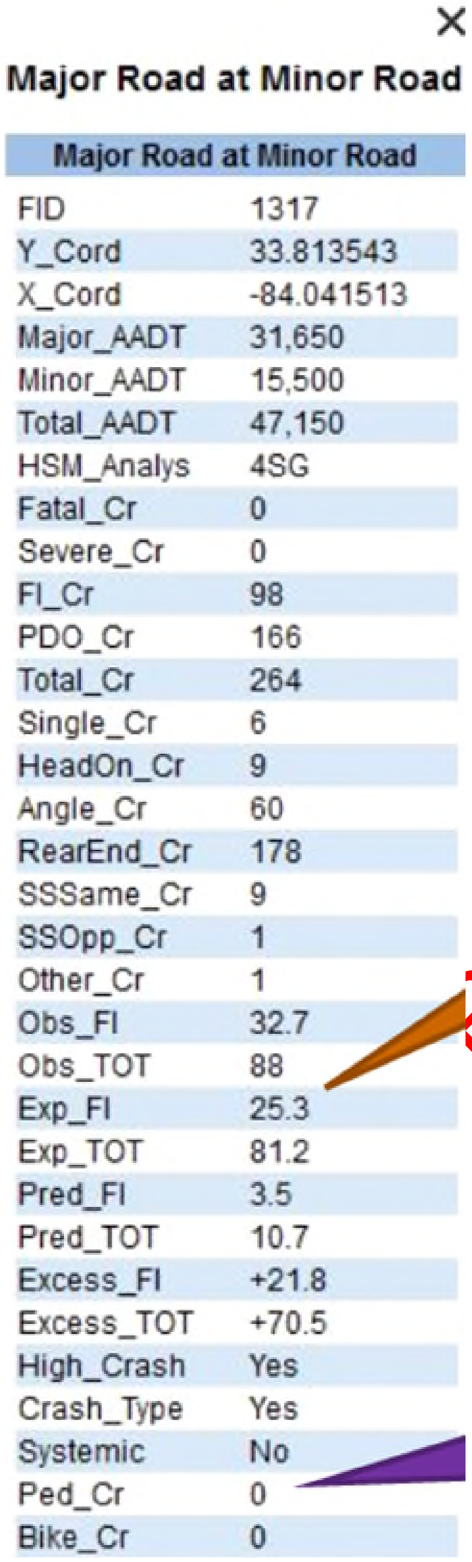
Major Road at Minor Road	
FID	1317
Y_Cord	33.813543
X_Cord	-84.041513
Major_AADT	31,650
Minor_AADT	15,500
Total_AADT	47,150
HSM_Analys	4SG
Fatal_Cr	0
Severe_Cr	0
FI_Cr	98
PDO_Cr	166
Total_Cr	264
Single_Cr	6
HeadOn_Cr	9
Angle_Cr	60
RearEnd_Cr	178
SSSame_Cr	9
SSOpp_Cr	1
Other_Cr	1
Obs_FI	32.7
Obs_TOT	88
Exp_FI	25.3
Exp_TOT	81.2
Pred_FI	3.5
Pred_TOT	10.7
Excess_FI	+21.8
Excess_TOT	+70.5
High_Crash	Yes
Crash_Type	Yes
Systemic	No
Ped_Cr	0
Bike_Cr	0

Expected crash frequency

Vehicular safety performance criteria

Non-motorized crash frequency

Figure 13. Four-Legged Signalized Intersection Selected for Traffic Signal Modernization



Major Road at Minor Road

Major Road at Minor Road	
FID	1317
Y_Cord	33.813543
X_Cord	-84.041513
Major_AADT	31,650
Minor_AADT	15,500
Total_AADT	47,150
HSM_Analys	4SG
Fatal_Cr	0
Severe_Cr	0
FI_Cr	98
PDO_Cr	166
Total_Cr	264
Single_Cr	6
HeadOn_Cr	9
Angle_Cr	60
RearEnd_Cr	178
SSSame_Cr	9
SSOpp_Cr	1
Other_Cr	1
Obs_FI	32.7
Obs_TOT	88
Exp_FI	25.3
Exp_TOT	81.2
Pred_FI	3.5
Pred_TOT	10.7
Excess_FI	+21.8
Excess_TOT	+70.5
High_Crash	Yes
Crash_Type	Yes
Systemic	No
Ped_Cr	0
Bike_Cr	0

The intersection shown in **Figure 13** experienced an annual average of 88.0 total crashes, **Obs_TOT** (row 21), during a five-year analysis period, including 32.7 crashes resulting in an injury to a crash-involved occupant, **Obs_FI** (row 20). After combining the observed frequencies with the predicted estimates via the EB-method process, the intersection is expected to experience approximately 81.2 total crashes, **Exp_TOT** (row 23), including 25.3 FI crashes, **Exp_FI** (row 22), in any given year. As a result, the intersection is experiencing an annual excess of approximately 70.5 total crashes, **Excess_TOT** (row 27), including 21.8 FI crashes, **Excess_FI** (row 26). The intersection is intuitively on the high-crash location list, and additionally experiences an excess proportion of angle collisions. A point map of crashes occurring during the five-year study period was also evaluated to ensure the safety crash analysis map was representative of actual conditions (**Figure 14**).

Figure 14. Traffic Crashes occurring at Study Intersection – Five Year Analysis Period

As a part of the traffic signal modernization project, the installation of reflectorized backplates was considered to treat the excess annual crashes occurring at this location. It should be noted that given the crash patterns observed in **Figure 14**, many additional treatments could also be considered in combination with the reflectorized backplates. A CMF of 0.85 which applies to total crashes was selected from the CMF Clearinghouse specific to this treatment. The CMF was multiplied by the annual expected crash frequency, **Exp_TOT**, without treatment obtained from the safety analysis map for the study intersection (**Figure 13** shows Intersection 1's data - 81.2 annual expected crashes). **Table 5** shows the expected crash totals with and without treatment, as well as the expected crash reduction on an annual basis. Calculations to determine the annual expected crash frequencies with treatment (**Equation 3**) and the reduction in annual expected crashes (**Equation 4**) are provided the study intersection.

$$Exp_{With\ Treatment} = (Exp_{Without\ Treatment}) * (CMF_{Treatment}) \qquad (3)$$

$$69.0 = 81.2 * 0.85$$

$$Exp_{Reduction} = (Exp_{Without\ Treatment}) - (Exp_{With\ Treatment}) \qquad (4)$$

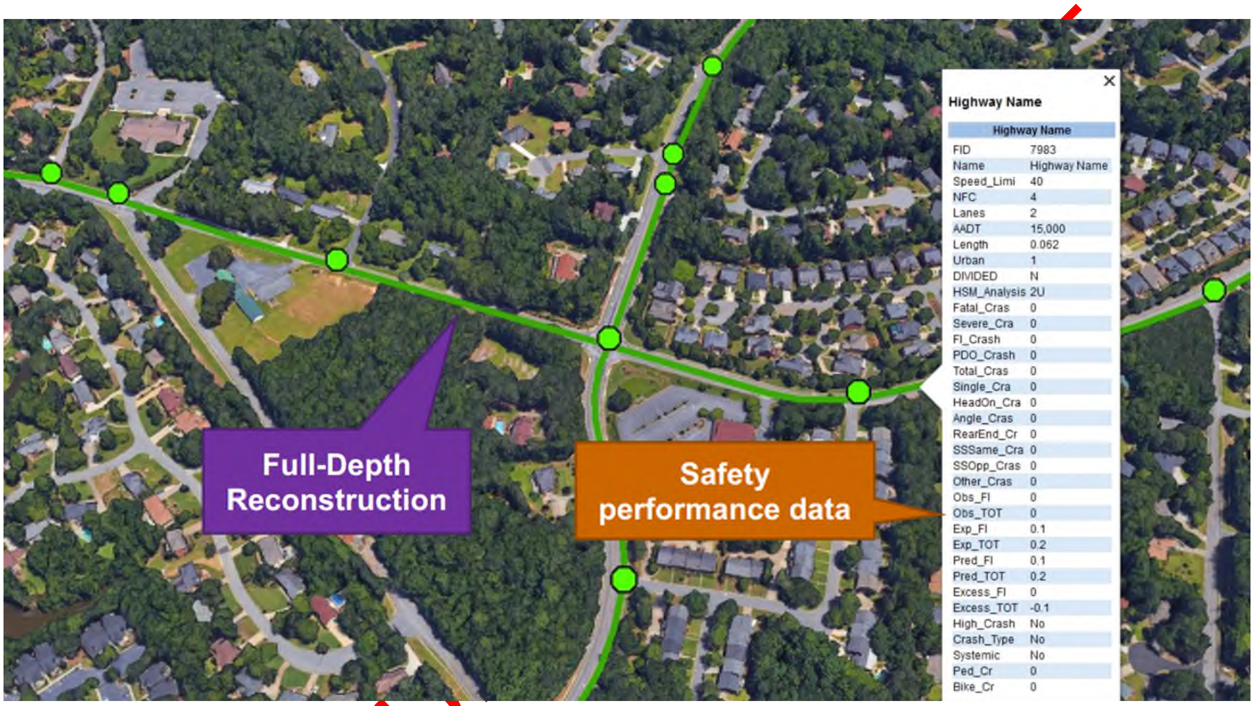
$$12.2 = 81.2 - 69.0$$

Table 5. Annual Expected Crashes – With and Without Signal Treatment

Location	Expected Crashes without Signal Treatment	Expected Crashes with Signal Treatment	Expected Crash Reduction
Intersection 1	81.2	69.0	12.2

3R Full-Depth Pavement Reconstruction Example

A two-lane two-way highway shown in **Figure 15** is scheduled to undergo a full-depth pavement reconstruction. The study corridor is not currently known to exhibit any specific safety performance concerns, and the project is not expected to incorporate significant geometric modifications. Given that this activity is considered a 3R (formally 4R) project with limited or no planned geometric modifications in **Table 1**, the Tier III crash analysis process should be applied as outlined prior in the document. The first step in this process is to refer to the safety crash analysis map to obtain the appropriate safety performance data, also shown in **Figure 15**.



Highway Name	
FID	7983
Name	Highway Name
Speed_Limi	40
NFC	4
Lanes	2
AADT	15,000
Length	0.062
Urban	1
DIVIDED	N
HSM_Analysis	2U
Fatal_Cras	0
Severe_Cra	0
FI_Crash	0
PDO_Crash	0
Total_Cras	0
Single_Cra	0
HeadOn_Cra	0
Angle_Cras	0
RearEnd_Cr	0
SSSame_Cra	0
SSOpp_Cras	0
Other_Cras	0
Obs_FI	0
Obs_TOT	0
Exp_FI	0.1
Exp_TOT	0.2
Pred_FI	0.1
Pred_TOT	0.2
Excess_FI	0
Excess_TOT	-0.1
High_Crash	No
Crash_Type	No
Systemic	No
Ped_Cr	0
Bike_Cr	0

Figure 15. Two-Lane, Two-Way Highway Scheduled for Full-Depth Reconstruction

The inspection of the safety analysis map reveals that the study corridor is performing better than the predicted estimates for all segments and intersections along its length. Therefore, no additional effort is required with respect to vehicular safety performance. It may still be advisable to perform a cursory review the crash data along the corridor to ensure no obvious trends are present. Similarly, there were no pedestrian or bicycle involved crashes occurring within or adjacent to the study corridor. As such, the only requirement with respect to non-motorized road users is to ensure that adequate facilities are provided as a part of the selected alternative.

Design Exception Process Example

Suppose the cross-section of the two-lane roadway shown in **Figure 15** currently included a limited three-foot paved shoulder. As a part of the project development process, a design exception (or variance) may be requested to maintain the limited three-foot paved shoulder, as opposed to a full eight-foot shoulder. The MDOT HSM Worksheet was used to estimate the annual expected crash frequencies with a full eight-foot paved shoulder, as opposed to the limited three-foot paved shoulder, consistent as discussed before. **Table 6** shows the annual expected crash counts for segments within the project bounds, as well as the expected crash impact if the three-foot-wide shoulder is maintained. Calculations to determine the annual expected crash impact of the limited three-foot shoulders relative to the full eight-foot shoulders are provided in **Equation 5** for Segment 1.

$$Exp_{Impact} = (Exp_{3'Shoulders}) - (Exp_{8'Shoulders}) \qquad \textbf{(5)}$$

$$0.03 = 0.14 - 0.11$$

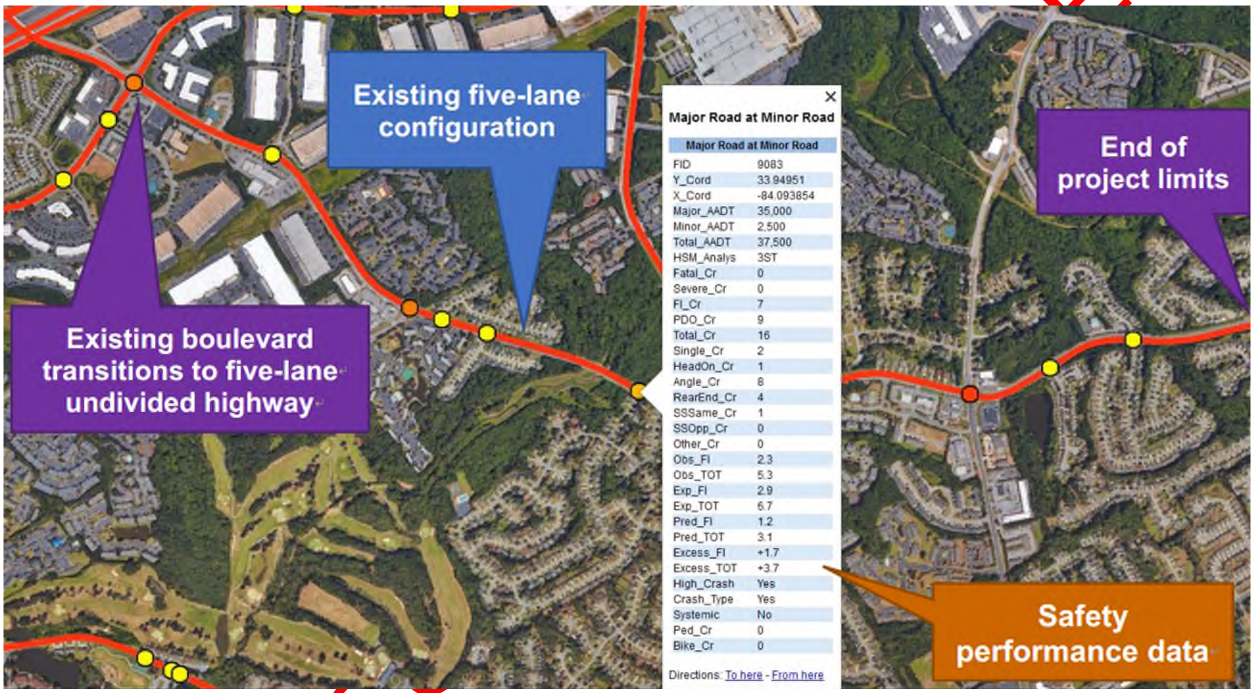
Table 6. Annual Expected Crashes – 8' vs 3' Paved Shoulder Scenarios

Location	Expected Crashes with Full 8' Shoulders	Expected Crashes with Limited 3' Shoulders	Expected Crash Impact
Segment 1	0.11	0.14	0.03
Segment 2	0.23	0.25	0.02
Segment 3	0.17	0.22	0.05
Segment 4	0.29	0.33	0.04
Segment 5	0.14	0.16	0.02
Segment 6	0.07	0.11	0.04
Corridor Total	**1.01**	**1.21**	**0.20**

Segments within the project bounds are expected to experience a total of 1.01 crashes annually with the eight- foot paved shoulder, compared to 1.21 crashes annually with the limited three-foot paved shoulder. This represents an annual increase of approximately 0.20 total crashes over all six segments in the project bounds. It should be noted that similar calculations could be provided with respect to FI crashes for additional context. These data could be provided to FHWA as a part of the documentation requesting the design exception (or variance) to show a relatively modest safety impact of maintaining the limited three-foot shoulder width.

4R with Geometric Modifications Example

The five-lane highway shown in **Figure 16** is located within a growing community, experiencing continually rising traffic volumes which have contributed to both congestion and safety concerns. This section of five-lane highway is located just east of a segment of highway which was converted to a six-lane boulevard during a previous project. As a part of the current project development process, converting the existing five-lane undivided highway to a six- lane boulevard has been identified as a potential alternative. Given that this activity would be considered a 4R project with geometric modifications in **Table 1**, the Tier IV crash analysis process should be applied as outlined prior in the document.



Major Road at Minor Road

Major Road at Minor Road	
FID	9083
Y_Cord	33.94951
X_Cord	-84.093854
Major_AADT	35,000
Minor_AADT	2,500
Total_AADT	37,500
HSM_Analys	3ST
Fatal_Cr	0
Severe_Cr	0
FI_Cr	7
PDO_Cr	9
Total_Cr	16
Single_Cr	2
HeadOn_Cr	1
Angle_Cr	8
RearEnd_Cr	4
SSSame_Cr	1
SSOpp_Cr	0
Other_Cr	0
Obs_FI	2.3
Obs_TOT	5.3
Exp_FI	2.9
Exp_TOT	6.7
Pred_FI	1.2
Pred_TOT	3.1
Excess_FI	+1.7
Excess_TOT	+3.7
High_Crash	Yes
Crash_Type	Yes
Systemic	No
Ped_Cr	0
Bike_Cr	0

Directions: To here - From here

Figure 16. Five-Lane Highway to be Converted to Six-Lane Boulevard

An evaluation was conducted using the MDOT HSM Worksheet to estimate the potential safety benefit of converting the existing five-lane configuration to a six-lane boulevard within the project bounds. **Table 7** shows the analysis results in terms of expected annual crash frequency, including both without treatment (maintaining the existing five-lane configuration) and with treatment (converting to a six-lane boulevard). Calculations to determine the annual expected crash frequencies with treatment (**Equation 1**) and the reduction in annual expected crashes (**Equation 6**) are provided for Segment 1.

$$Exp_{Reduction} = (Exp_{Five-Lane\ Undiv.}) - (Exp_{Six\ Lane\ Blvd.}) \qquad \textbf{(6)}$$

$$0.85 = 2.41 - 1.56$$

Table 7. Annual Expected Crashes – Five-Lane Undivided Highway vs Six-Lane Boulevard

Location	Expected Crashes without Treatment (Five Lane Undivided)	Expected Crashes with Treatment (Six-Lane Boulevard)	Expected Crash Reduction with Treatment
Segment 1	2.41	1.56	0.85
Segment 2	2.23	1.49	0.74
Segment 3	0.31	0.24	0.07
Segment 4	0.71	0.57	0.14
Segment 5	1.14	1.01	0.13
Segment 6	0.87	0.81	0.06
Segment 7	0.42	0.31	0.11
Segment 8	0.43	0.29	0.14
Segment 9	0.74	0.52	0.22
Intersection 1	2.31	1.94	0.37
Intersection 2	3.74	3.00	0.74
Intersection 3	1.29	1.02	0.27
Intersection 4	0.91	0.71	0.2
Intersection 5	5.69	4.21	1.48
Intersection 6	4.21	3.56	0.65
Intersection 7	1.98	1.24	0.74
Intersection 8	2.14	1.79	0.35
Corridor Total	**31.53**	**24.27**	**7.26**

In total, more than 31 crashes are expected annually along the project corridor (including both highway segments and intersections) given the existing five-lane undivided configuration. Implementation of a six-lane boulevard along the study corridor is expected to result in approximately 24.3 traffic crashes annually, representing a reduction of approximately 7.3 crashes per year with treatment. This result could be compared to other alternatives considered as a part of the project development process, consistent with prior discussions. Additionally, this crash reduction could also be used to quantify the expected economic impact of the treatment for the purposes of value engineering. It should be noted that additional evaluation of non-motorized crashes occurring along or adjacent to the study corridor could also be reviewed as a part of this process. This could also include utilizing risk-based analysis tools to further quantify the potential impacts on non-motorized road users.

New Construction Example

A city located in the center of a predominantly rural county, shown in **Figure 17**, is experiencing continual population and economic growth. The associated increases in traffic volume, particularly with respect to commercial vehicles, has resulted in congestion and potential safety concerns along the existing arterials which access the city from the north and from the east. Further, commercial vehicles navigating through the central business district have also resulted in conflicts with non-motorized road users, representing a notable safety concern. The construction of a bypass located on the northeast corner of the city has been proposed to divert traffic from entering the central business district, providing a high-speed connection for vehicles around the city center. While several options have been considered as a part of the project development process, the construction of either a five-lane undivided highway or a four-lane boulevard have been identified as the two most feasible configurations from an operational and environmental perspective. Given that this activity would be considered a new construction project in **Table 1**, the Tier IV crash analysis process should be applied as outlined in the document.

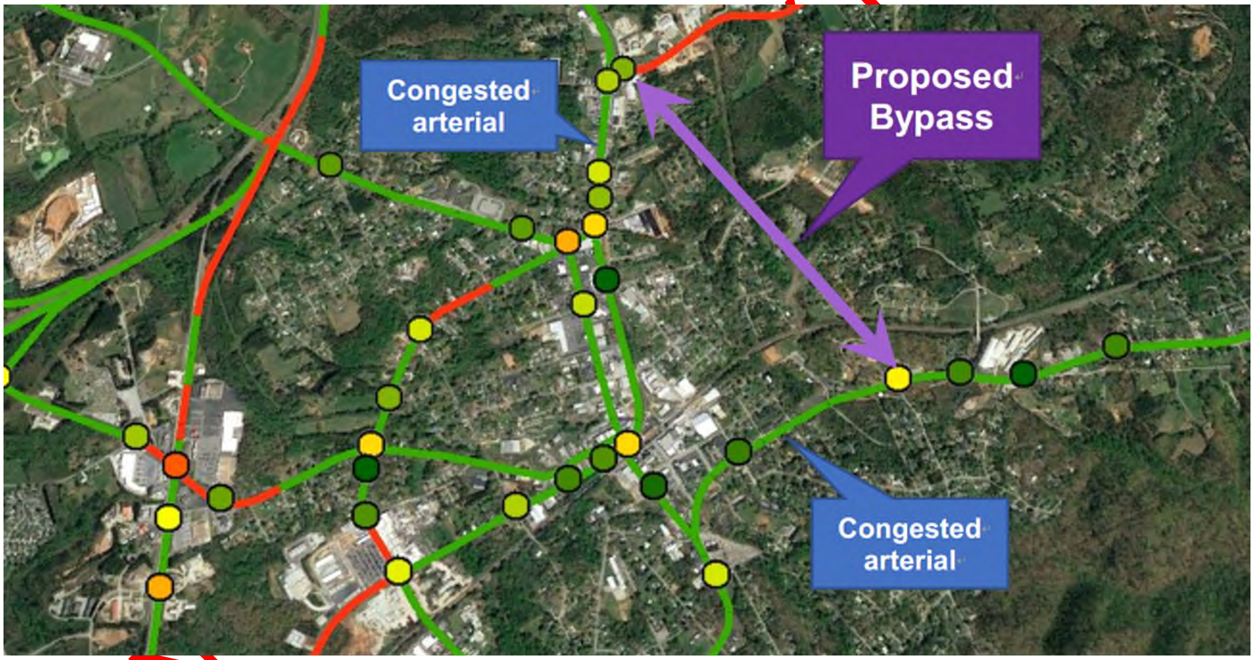


Figure 17. Proposed Bypass to be Constructed

An evaluation was conducted using the MDOT HSM Worksheet to estimate the expected crash frequency for a five-lane undivided and four-lane divided configuration. **Table 8** shows the analysis results in terms of expected annual crash frequency. It should be noted that because no historical crash data exists for the proposed bypass, predicted crash frequencies (obtained from the MDOT HSM Worksheet or other appropriate analysis tool) represent the best estimation of expected annual crash totals.

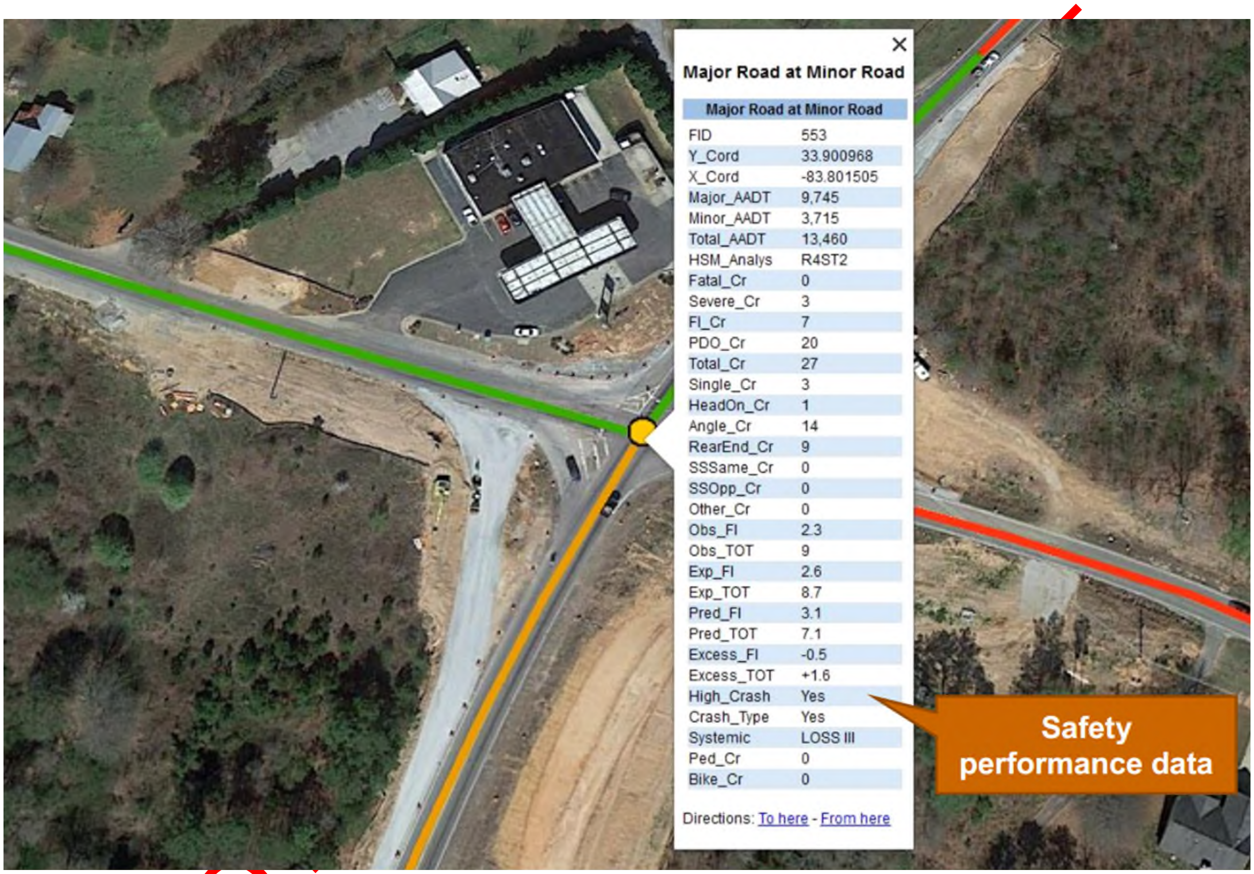
Table 8. Annual Predicted Crashes – Five-Lane Undivided Highway vs Four-Lane Boulevard

Location	Predicted Crashes with Five Lane Undivided Configuration	Predicted Crashes with Four-Lane Divided Configuration
Segment 1	1.64	1.31
Segment 2	1.94	1.61
Segment 3	0.84	0.59
Segment 4	2.98	2.14
Segment 5	0.43	0.22
Segment 6	1.31	1.01
Intersection 1	3.01	2.13
Intersection 2	0.84	0.39
Intersection 3	0.34	0.24
Intersection 4	0.21	0.15
Intersection 5	2.43	2.10
Corridor Total	**15.97**	**11.89**

Construction of the five-lane boulevard alternative is predicted to result in approximately 16 crashes annually, whereas the four-lane divided configuration is predicted to result in just less than 12 traffic crashes annually. While the results presented in **Table 8** suggest that the four-lane divided alternative represents an approximately 25 percent lower annual crash total, additional considerations (such as construction costs or environmental impacts) could also be considered to select the best option for Michigan's road users.

Alternatives Analysis Example

An unsignalized intersection (shown in **Figure 18**) located in a suburban area has been experiencing considerable queueing along the minor stop-controlled approaches due to increases in traffic volume. After a signal warrant study was performed, it was determined that the intersection would benefit from a change in traffic control. During the project development process, it was determined that either the implementation of a traffic signal or the conversion to a single-lane roundabout would be desirable from an operational perspective over the existing condition. Current safety performance data can be obtained from the safety analysis map, as shown in **Figure 18**.



Major Road at Minor Road

Major Road at Minor Road	
FID	553
Y_Cord	33.900968
X_Cord	-83.801505
Major_AADT	9,745
Minor_AADT	3,715
Total_AADT	13,460
HSM_Analys	R4ST2
Fatal_Cr	0
Severe_Cr	3
FI_Cr	7
PDO_Cr	20
Total_Cr	27
Single_Cr	3
HeadOn_Cr	1
Angle_Cr	14
RearEnd_Cr	9
SSSame_Cr	0
SSOpp_Cr	0
Other_Cr	0
Obs_FI	2.3
Obs_TOT	9
Exp_FI	2.6
Exp_TOT	8.7
Pred_FI	3.1
Pred_TOT	7.1
Excess_FI	-0.5
Excess_TOT	+1.6
High_Crash	Yes
Crash_Type	Yes
Systemic	LOSS III
Ped_Cr	0
Bike_Cr	0

Directions: To here - From here

Figure 18. Four-Legged Unsignalized Intersection Identified for Traffic Control Modification

Inspection of the existing safety performance data suggests that the intersection is observing a modest annual excess (1.6 total crashes). The intersection is intuitively on the high-crash location list, and additionally experiences an excess proportion of angle collisions. Consistent with prior discussions, the annual expected crash frequencies for both treatment scenarios were determined by multiplying an appropriate CMF collected from the CMF Clearinghouse (0.64 for signalization, 0.56 for the roundabout conversion). **Table 9** shows the annual expected crash totals for the no treatment, signalization, and roundabout conversion scenarios. Calculations to determine the annual expected crash frequencies with signalization (**Equation 7**) and annual expected crashes with a roundabout conversion (**Equation 8**) are provided for the study intersection.

$$Exp_{Signalization} = (Exp_{Without\ Treatment}) * (CMF_{Signalization}) \qquad \textbf{(7)}$$

$$5.7 = 8.7 * 0.64$$

$$Exp_{Roundabout} = (Exp_{Without\ Treatment}) * (CMF_{Roundabout}) \qquad \textbf{(8)}$$

$$4.9 = 8.7 * 0.56$$

Table 9. Annual Expected Crashes – No Treatment vs Signalization vs Roundabout Conversion

Location	Expected Crashes without Treatment	Expected Crashes with Signalization	Expected Crashes with Roundabout Conversion
Intersection 1	8.7	5.7	4.9

Glossary

Crash Modification Factor (CMF) – a factor estimating the potential changes in crash frequency or crash severity due to installing a particular treatment. As an example, a 0.70 CMF corresponds to a 30 percent reduction in crashes. A 1.2 CMF correspond to a 20 percent increase in crashes.

Data Driven Safety Analysis (DDSA) - the application of the latest Highway Safety Manual (HSM) evidence-based tools and approaches to safety analysis which provides reliable estimates of an existing or proposed roadway's expected safety performance. DDSA helps agencies quantify the safety impacts of transportation decisions, similar to the way agencies quantify: Traffic growth, Environmental impacts, Traffic operations, Pavement life and Construction costs.

Observed Crashes – a historical count of crashes that have occurred at a particular site

Empirical Bayes (EB) methodology – a method used to combine observed data for a given site with predicted crash data from many similar sites to estimate the site's expected crashes.

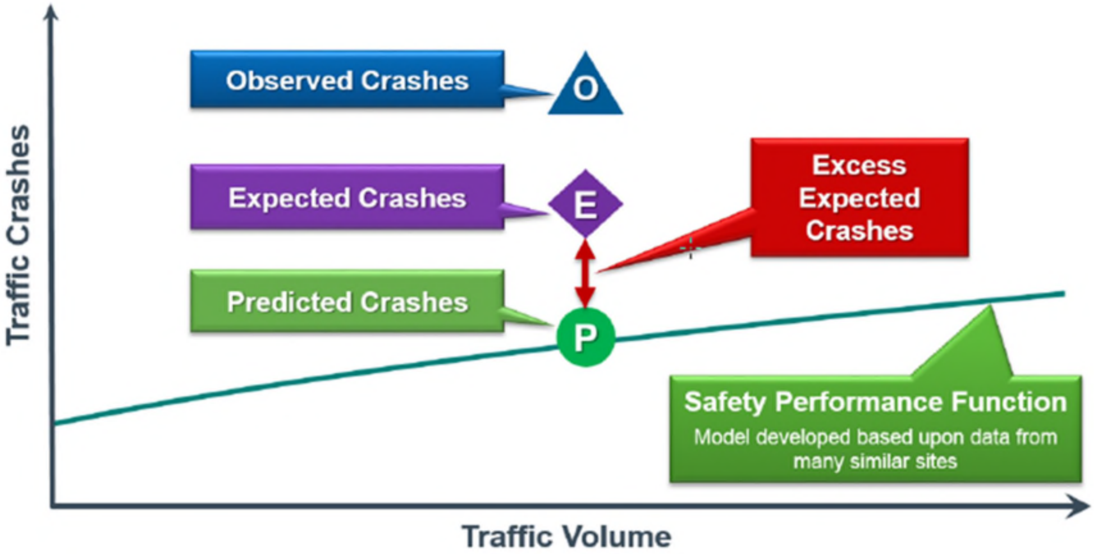
Expected Crashes – an estimate of crashes for a particular type of roadway or intersection. Using the Empirical Bayes (EB) method this value is calculated by the weighted average of observed and predicted crashes.

Excess Expected Crashes – The difference between the expected (EB method in Part C) and predicted (Part C of the HSM) crashes. Sites with a high excess value are most likely to respond to safety improvements because they are theoretically experiencing more crashes than other similar sites.

Highway Safety Manual (HSM) - the Highway Safety Manual (HSM) provides practitioners with information and tools to consider safety when making decisions related to design and operation of roadways. The HSM assists practitioners in selecting countermeasures and prioritizing projects, comparing alternatives, and quantifying and predicting the safety performance of roadway elements considered in planning, design, construction, maintenance, and operation. Prior to the HSM, there was no widely accepted tool available to quantitatively assess the impact of infrastructure decisions on safety.

Level of Service Safety – the ranking of sites according to the observed and expected crash frequency for the entire population where the degree of deviation is then labeled in to four classes of level of service. The mean frequency from the SPF, as well as the frequency 1.5 standard deviations above and below the mean, are used as three thresholds to place sites into the four LOSS categories. LOSS I and II are below the mean while II and IV are above.

Predicted Crashes – an estimate of crashes based upon roadway characteristics such as geometric conditions, traffic volumes and period of time using a regression model, known as Safety Performance Functions (SPF). The SPF is used in combination with CMFs and calibration factors to adjust the model to site-specific and local conditions.



Regression to the Mean - the natural variation in crash data. If regression to the mean is not accounted for, a site might be selected for study when the crashes are at randomly high fluctuation or overlooked form study when the site is at a randomly low fluctuation.

Safety Performance Function – a regression model or equation that estimates expected average crash frequency as a function of traffic volume and roadway characteristics.

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