

Pilot Use of Telematics for Traffic Safety Analysis

Final Report

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16. Abstract This project developed and piloted a telematics-based traffic safety analysis framework. The study reviewed current practices, calibrated high-risk driving indicators using Wisconsin telematics and crash data, and developed two web-based tools: a Risk Mitigation Hotspot Tool and a Safety and Cost Mitigation Assessment Tool. The pilot results showed that telematics-derived indicators can identify site-level risk patterns and support before-after evaluation of safety improvements. The Safety and Cost Mitigation Assessment Tool demonstrated how telematics-derived risk factors can be combined with exposure, crash prediction, and crash cost information to estimate site-specific Safety Mitigation Factors and Cost Mitigation Factors. The results suggest that telematics data can provide useful supplemental evidence for safety screening and project evaluation when interpreted together with crash history, roadway context, and engineering judgment.			
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Executive Summary

Wisconsin has long been committed to improving roadway safety through data-driven planning, engineering, enforcement, and education. However, many safety risks are difficult to identify using crash records alone. Crashes are relatively rare, are observed only after harm has occurred, and often provide limited information about the driving behaviors that happened before the crash. To support a more proactive safety analysis approach, this project examined how large-scale telematics data can supplement traditional safety data by identifying driving risk patterns, supporting hotspot screening, and evaluating safety improvements before and after treatment. The project developed an integrated **telematics-based safety analysis framework** for the Wisconsin Department of Transportation (WisDOT). The framework converts raw vehicle trajectory records into interpretable driving risk factors, links those factors with roadway context, exposure, and crash records, and presents the results through web-based tools for site screening and project evaluation. The work included four major activities: reviewing the state of practice, defining and calibrating driving risk indicators, developing two analytical tools, and applying the tools to pilot roadway sites and selected Highway Safety Improvement Program (HSIP) locations.

To support practical safety analysis, the project first established a set of measurable driving risk indicators. The team examined available telematics data fields and focused on indicators that could be consistently derived from the project data, including rapid acceleration, hard braking, speeding, jerk, and turning-related behavior. Using StreetLight telematics data, WisTransPortal crash records, roadway network information, and traffic exposure data, the project evaluated candidate thresholds and tested their relationship with observed crash frequency. This process identified Wisconsin-calibrated thresholds of 0.22 g for rapid acceleration and 0.24 g for hard braking, providing a defensible basis for converting raw telematics records into crash-relevant behavioral risk factors. The project developed two complementary tools:

1. **Risk Mitigation Hotspot Tool**

This tool processes large-scale telematics trajectory data and converts them into event-level risk factor records that can be mapped, queried, and summarized. It identifies five primary risk factor types: **Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit**. Each factor can be classified by severity and grouped into sustained driving events. The web interface allows users to define a study area, select time periods and risk factor types, and review mapped results and summary counts. This tool is intended to support early screening of locations where risky driving behaviors are concentrated.

2. **Safety and Cost Mitigation Assessment Tool**

This tool extends the hotspot analysis by linking telematics-derived risk factors to crash prediction and economic evaluation. It uses site-level risk factor summaries, vehicle miles traveled, WisTransPortal crash records, and HSIP project information. The tool compares expected crashes before and after a treatment period and reports two key indicators: the **Safety Mitigation Factor (SMF)** and the **Cost**

Mitigation Factor (CMF). The SMF measures the ratio of predicted after-period crash frequency to predicted before-period crash frequency. The CMF applies the same idea to expected crash cost using severity-specific unit crash costs. For both indicators, values below 1.0 indicate estimated safety or economic improvement.

The Risk Mitigation Hotspot Tool was tested at six Wisconsin roadway sites selected in coordination with WisDOT. These sites included both urban and rural locations. Using Wejo telematics data from October 2019, the pilot showed that the tool can identify different driving risk patterns across roadway contexts. For example, some urban intersections and corridors showed more Hard Braking events, while several rural or higher-speed locations showed more Speed Above Limit events. This pilot confirmed that the tool can support map-based screening and comparison of candidate safety concern locations.

The Safety and Cost Mitigation Assessment Tool was then applied to **Wisconsin HSIP sites**. These sites covered different counties, roadway types, ownership categories, and treatment types, including rumble strips or warning devices, pavement or shoulder widening, guardrail and barrier improvements, turn-lane or channelization improvements, pedestrian and bicycle safety improvements, and signal or phasing improvements. The analysis used 2019 telematics-derived risk factors as the before period and 2024 telematics-derived risk factors as the after period.

Across all 10 HSIP sites, both the estimated **SMF and CMF were below 1.0**, indicating reductions in expected crash frequency and expected crash cost after treatment. Estimated reductions in expected monthly crash frequency ranged from **6.39% to 51.56%**, and estimated reductions in expected monthly crash cost ranged from **5.48% to 51.97%**. The results also showed reductions across crash severity categories, including fatal, suspected serious injury, suspected minor injury, possible injury, and property-damage-only crashes. Speed Above Limit and Hard Braking accounted for most detected risk factors, although their relative importance varied by roadway context.

Several key findings emerged from the project. First, telematics data can provide useful behavioral safety indicators that complement traditional crash records, especially for proactive screening and short-term monitoring. Second, local calibration is important because Wisconsin-specific thresholds provide a stronger basis for interpretation than directly adopting thresholds from other studies. Third, combining risk factor mapping, crash prediction, and cost estimation can make telematics data more useful for agency decision-making.

At the same time, telematics-based tools should be used as part of a broader safety analysis process. They can help identify risk patterns, compare candidate locations, and evaluate whether safety indicators improve after a project. However, they should not replace engineering judgment, crash diagnosis, field review, or established HSIP evaluation procedures.

The project also identified several considerations for future implementation. Telematics data coverage can vary across vendors, years, locations, and vehicle populations. Differences between Wejo and StreetLight data, as well as differences in observation periods, should be considered when interpreting before-and-after comparisons. Sampling frequency may affect acceleration, jerk, and turning measures, and some safety-related behaviors, such as distraction or lane keeping, cannot be reliably inferred from the available data. Future work should expand the

number of evaluated sites, use longer and more consistent observation periods, continue validating telematics-derived risk factors against crash outcomes, and refine models by roadway type, treatment type, and context. Aggregated reporting and protection of individual trip privacy should remain core requirements.

Overall, this project demonstrates a scalable approach for using telematics data in WisDOT safety analysis. The work produced a locally calibrated risk factor framework, two web-based tools, and pilot applications at roadway and HSIP sites. The results support the use of telematics data as a practical supplement to traditional crash-based safety analysis, particularly for project screening, treatment monitoring, and communicating expected safety and cost impacts in a consistent and data-driven way.

Table of Contents

List of Figures	viii
List of Tables	ix
1. Introduction.....	1
1.1 Study Objectives	1
1.2 Study Methods	2
2. Research Approach	5
2.1 Overall Analytical Framework	6
2.2 Data Sources	6
2.3 Literature Review and Identification of Candidate Risk Factors.....	6
2.4 High-Risk Behavior Threshold Development	7
2.4.1 Acceleration and Deceleration Derivation.....	8
2.4.2 Distribution-Based Candidate Thresholds	8
2.4.3 Crash-Linked Threshold Evaluation	9
2.5 Telematics Data Cleaning and Standardization	10
2.6 Database Organization	10
2.7 Road Matching.....	11
2.8 Risk Factor Calculation.....	12
2.8.1 Point-Level Measures	12
2.8.2 Severity Classification	12
2.8.3 Event Grouping.....	13
2.9 Risk Mitigation Hotspot Tool Development.....	13
2.10 Safety and Cost Mitigation Assessment Tool Development	14
2.10.1 Spatial, Temporal, and Exposure Alignment.....	14
2.10.2 Crash-Frequency Model.....	15
2.10.3 Safety Mitigation Factor	16
2.10.4 Crash Cost Calculation	16
2.11 Web Tool Architecture and Outputs	18
2.12 Pilot Implementation of the Risk Mitigation Hotspot Tool	20
2.13 Pilot Evaluation of the Safety and Cost Mitigation Assessment Tool.....	20
2.14 Interpretation of the Research Approach	22
3. Results and Analysis	22
3.1 High-Risk Behavior Definition and Threshold Calibration Results	22
3.2 Risk Mitigation Hotspot Tool Pilot Results.....	24
3.3 Safety and Cost Mitigation Assessment Tool Pilot Results.....	27
3.4 Crash-Severity Results.....	29
3.5 Risk-Factor Composition by Roadway Context	29

3.6 Overall Findings from the Results	30
3.7 Summary of Before-After Outcomes from the HSIP Pilot.....	31
3.8 Additional Risk Mitigation Hotspot Tool Result Figures.....	32
3.9 Additional Safety and Cost Mitigation Assessment Tool Result Figures.....	36
3.9.1 Site 1 Evaluation Output.....	37
3.9.2 Site 2 Evaluation Output.....	38
3.9.3 Site 3 Evaluation Output.....	39
3.9.4 Site 4 Evaluation Output.....	40
3.9.5 Site 5 Evaluation Output.....	41
3.9.6 Site 6 Evaluation Output.....	42
3.9.7 Site 7 Evaluation Output.....	43
3.9.8 Site 8 Evaluation Output.....	44
3.9.9 Site 9 Evaluation Output.....	45
3.9.10 Site 10 Evaluation Output.....	46
3.10 Interpretation of the Additional Result Figures	46
4. Conclusions and Implementable Recommendations	47
4.1 Conclusions.....	47
4.2 Implementable Recommendations.....	48
4.3 Suggested Implementation Pathway	49
4.4 Limitations and Future Improvements.....	50
4.5 Closing Statement	51
References.....	51
Appendix A. Supplementary Materials.....	liii

List of Figures

Figure 1 Temporal coverage and relative scale of available telematics data sources.....	3
Figure 2 Overall workflow for telematics-based traffic safety analysis.	5
Figure 3 PostgreSQL/PostGIS database schema used for telematics processing.	11
Figure 4 Risk Mitigation Hotspot Tool web interface.	14
Figure 5 Example API response or web output for factor-level risk records.	19
Figure 6 Example output from the Safety and Cost Mitigation Assessment Tool.	19
Figure 7 Threshold-sweep results for acceleration and deceleration.	23
Figure 8 Risk-factor maps for the six Risk Mitigation Hotspot Tool pilot sites.....	26
Figure 9 Aggregated expected crash counts by severity for the 10 pilot HSIP sites, before and after treatment.	29
Figure 10 Aggregated risk-factor composition by roadway context and analysis period.....	30
Figure 11 Risk Mitigation Hotspot Tool factor-layer and severity-threshold controls.	33
Figure 12 Example mapped risk-factor output from the Risk Mitigation Hotspot Tool.	34
Figure 13 Example summary output from the Risk Mitigation Hotspot Tool.....	34
Figure 14 Detailed Tool 1 map outputs for two urban pilot sites.	35
Figure 15 Detailed Tool 1 map outputs for two rural pilot sites.....	35
Figure 16 Risk-factor marker legend used in the Safety and Cost Mitigation Assessment Tool pilot maps.	36
Figure 17 Safety and Cost Mitigation Assessment Tool output for Site 1: St. Croix: CTH U to Mackin Rd.	37
Figure 18 Safety and Cost Mitigation Assessment Tool output for Site 2: Grant: Platteville Business 151 corridor.....	38
Figure 19 Safety and Cost Mitigation Assessment Tool output for Site 3: Portage: US 51 / WI 66 interchange area.	39
Figure 20 Safety and Cost Mitigation Assessment Tool output for Site 4: Outagamie: STH 47 corridor.	40
Figure 21 Safety and Cost Mitigation Assessment Tool output for Site 5: Portage: Elk Road to Division Street.	41
Figure 22 Safety and Cost Mitigation Assessment Tool output for Site 6: Milwaukee: W. Lincoln Avenue intersections.....	42
Figure 23 Safety and Cost Mitigation Assessment Tool output for Site 7: Green: STH 81 corridor.....	43
Figure 24 Safety and Cost Mitigation Assessment Tool output for Site 8: Milwaukee: Lake Drive corridor.....	44
Figure 25 . Safety and Cost Mitigation Assessment Tool output for Site 9: Green: STH 11 Monroe-Brodhead corridor.	45
Figure 26 Safety and Cost Mitigation Assessment Tool output for Site 10: La Crosse: STH 16 intersection.	46

List of Tables

Table 1 Major data sources used in the study	3
Table 2 Summary of project tools and pilot applications	4
Table 3 Risk factors used in the project.....	7
Table 4 Database organization.....	11
Table 5 Crash unit costs used for safety and cost evaluation	16
Table 6 Comparison-site groups and adjustment factors used in the Safety and Cost Mitigation Assessment Tool	18
Table 7 Main outputs from the two project tools.....	18
Table 8 Pilot sites for the Risk Mitigation Hotspot Tool.....	20
Table 9 HSIP sites used for pilot evaluation.....	21
Table 10 Locally calibrated harsh-driving thresholds used in the project	23
Table 11 Summary of Risk Mitigation Hotspot Tool pilot results	24
Table 12 HSIP pilot factor changes and mitigation factors	27
Table 13 Expected monthly crash frequency and crash cost changes at HSIP pilot sites	28
Table 14 Aggregated before-after outcomes from the HSIP pilot evaluation	32
Table 15 Suggested implementation pathway for telematics-based safety analysis.....	50
Table 16 Supplementary materials provided with the final report	liii

1. Introduction

Traffic safety remains a major priority for the Wisconsin Department of Transportation (WisDOT).

Traditional safety analysis relies heavily on police-reported crash records, roadway inventory data, traffic exposure information, and engineering judgment. These sources remain essential for safety management; however, crash records are retrospective by nature and often require several years of observations before reliable patterns can be established. Because crashes are relatively rare events, crash-based analysis alone may provide limited ability to identify emerging safety concerns, monitor short-term behavioral changes, or evaluate the early effects of roadway safety improvements.

Vehicle telematics data provide a complementary source of information for traffic safety analysis. These data capture high-volume observations of real-world vehicle movement, including vehicle location, timestamp, speed, heading, and derived movement characteristics such as acceleration, deceleration, jerk, lateral movement, and speeding. When processed and aggregated appropriately, telematics data can reveal patterns of risky driving behavior before crashes occur. These behavioral indicators can support proactive hotspot screening, site-level risk assessment, and before-after evaluation of safety improvements.

Recent studies have used telematics and connected-vehicle data to identify harsh braking, rapid acceleration, speeding, phone use, near-crash events, and other surrogate safety measures [1-9]. However, the literature also shows several challenges. Definitions of high-risk driving behavior vary across studies, and thresholds for harsh events are not standardized [3, 6-8]. Data sources differ in sampling frequency, spatial accuracy, vehicle coverage, available attributes, and privacy restrictions. In addition, telematics-derived indicators must be interpreted together with roadway context, exposure, and crash history before they can support agency decision-making. These challenges motivated the development of a Wisconsin-specific telematics safety analysis framework.

The purpose of this project was to develop and pilot a practical, scalable, and implementation-oriented framework for using telematics data in traffic safety analysis. The framework was designed to convert large-scale vehicle trajectory data into interpretable risk factors, connect those factors with roadway and crash data, and present the results through web-based tools that can support both hotspot screening and project-level safety evaluation. The project focused on two complementary applications: identifying locations where risky driving behaviors are concentrated and evaluating whether safety improvements are associated with reductions in expected crash frequency and crash cost.

1.1 Study Objectives

The overall objective of this study was to determine how telematics data can be used to supplement traditional safety analysis practices in Wisconsin. The project was designed to support practical use by

WisDOT analysts, planners, and safety practitioners rather than to develop a stand-alone academic model. The specific objectives were to:

1. Review current practices and research on the use of telematics data for transportation safety analysis, including high-risk behavior identification, hotspot detection, crash-data integration, and safety project evaluation.
2. Develop a consistent set of high-risk driving behavior definitions that can be derived from available telematics data and interpreted in relation to Wisconsin crash records and roadway conditions.
3. Establish data-processing procedures for cleaning, standardizing, road-matching, and aggregating telematics trajectory data from multiple vendors.
4. Develop a Risk Mitigation Hotspot Tool that allows users to query, map, and summarize telematics-derived driving risk factors by location, time period, factor type, and severity level.
5. Develop a Safety and Cost Mitigation Assessment Tool that links telematics-derived risk factors with crash prediction and economic evaluation to estimate Safety Mitigation Factors (SMFs) and Cost Mitigation Factors (CMFs).
6. Pilot the Risk Mitigation Hotspot Tool at selected Wisconsin roadway sites and pilot the Safety and Cost Mitigation Assessment Tool at selected Highway Safety Improvement Program (HSIP) locations.
7. Identify implementation considerations, limitations, and future improvements for using telematics data as a supplement to WisDOT's existing traffic safety analysis and project evaluation practices.

1.2 Study Methods

The study began with a review of national and international literature on the use of telematics data for traffic safety analysis [1-9]. The review focused on the types of telematics data used in previous studies, definitions of high-risk driving behavior, approaches for linking telematics data with crash records, spatial methods for hotspot detection, and privacy considerations. The review showed that geolocation, speed, acceleration, deceleration, and speeding are among the most used telematics indicators for safety analysis. It also found that harsh-event thresholds vary substantially across studies, which supported the need for local calibration before applying telematics indicators in Wisconsin.

The project then developed a data-driven approach for defining high-risk driving behavior. StreetLight telematics data, roadway and traffic information, and WisTransPortal crash records were integrated to examine acceleration and deceleration patterns on Wisconsin roadways. Candidate thresholds were evaluated using distribution-based methods and crash-frequency modeling. This analysis identified

Wisconsin-calibrated thresholds of 0.22 g for rapid acceleration and 0.24 g for hard braking. These thresholds provided a local, crash-linked basis for converting raw telematics observations into safety-relevant behavioral indicators.

The study used multiple data sources, including telematics trajectory data, crash records, roadway network information, traffic exposure measures, and HSIP project records [12, 13]. Table 1 summarizes the major datasets used in the project and their roles in the analysis.

Table 1 Major data sources used in the study

Data source	Main contents	Role in the study
Wejo telematics data	Journey ID, timestamp, latitude, longitude, speed, heading, ignition status, and vehicle-related fields	Used as the primary 2019 telematics source for pilot hotspot analysis and before-period comparison
StreetLight telematics data	Journey ID, captured time, ignition status, latitude, longitude, heading, elevation, and speed	Used for Wisconsin threshold development and 2024 after-period comparison
WisTransPortal crash records	Police-reported crash records with location, date, severity, and crash attributes	Used to link telematics-derived risk factors with observed crash outcomes and crash severity categories
Roadway network data	OpenStreetMap roadway geometry and roadway attributes, supplemented where available with traffic and roadway information	Used for road matching, roadway context, segment identification, and spatial aggregation
Traffic exposure data	Vehicle miles traveled, journey counts, AADT, and related exposure measures	Used to normalize risk factor counts and support crash-frequency modeling
HSIP project data	Project location, county, implementation year, roadway type, ownership, and treatment type	Used for before-after evaluation of selected safety improvement projects

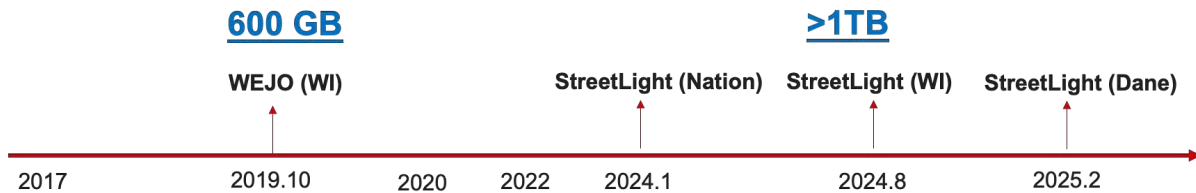


Figure 1 Temporal coverage and relative scale of available telematics data sources.

The analytical workflow converted raw telematics records into site-level safety information through several processing steps. First, raw data were spatially filtered to retain only observations within selected study areas. Second, vendor-specific data fields were standardized into a common format. Third, telematics points were matched to roadway segments using a PostgreSQL/PostGIS database environment

and roadway network reference layers. Fourth, vehicle movement measures were calculated and grouped into event-level risk factors. These factors included Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit. Each risk factor was classified by severity level and summarized with temporal, spatial, roadway, and intensity information.

The project developed two web-based tools from this workflow. The Risk Mitigation Hotspot Tool was designed for screening and visualization. Users can define a study area and time range, select risk factor types, adjust severity thresholds, and review mapped factor records and summary counts. The Safety and Cost Mitigation Assessment Tool was designed for before-after evaluation. It uses telematics-derived factor summaries, exposure measures, crash records, and severity-specific crash costs to estimate changes in expected crash frequency and expected crash cost.

Table 2 Summary of project tools and pilot applications

Tool	Primary purpose	Main outputs	Pilot application
Risk Mitigation Hotspot Tool	Identify and visualize locations where telematics-derived driving risk factors are concentrated	Mapped risk factor records, factor counts, severity summaries, exposure-normalized factor rates, and affected-journey shares	Applied to six Wisconsin roadway sites, including three urban and three rural locations
Safety and Cost Mitigation Assessment Tool	Evaluate safety and economic changes before and after roadway safety improvements	Predicted crash frequency, predicted crash cost, Safety Mitigation Factor, and Cost Mitigation Factor	Applied to 10 selected Wisconsin HSIP sites using 2019 as the before period and 2024 as the after period

The Risk Mitigation Hotspot Tool was piloted at six selected Wisconsin roadway locations. These sites included urban intersections, urban corridor or interchange areas, rural intersections, and rural highway locations. The pilot used Wejo telematics data from October 2019 and demonstrated that the tool could distinguish different risk patterns across roadway contexts. Some sites were dominated by Hard Braking events, while others were dominated by Speed Above Limit events. The pilot confirmed that telematics-derived factors can be mapped, summarized, and reviewed at the site level to support exploratory screening of candidate safety concern locations.

The Safety and Cost Mitigation Assessment Tool was piloted at 10 selected HSIP locations in Wisconsin. These sites represented different counties, roadway types, ownership categories, and treatment types, including rumble strips or warning devices, pavement or shoulder widening, guardrail and barrier improvements, turn-lane or channelization improvements, pedestrian and bicycle safety improvements, and signal or phasing improvements. The pilot used 2019 telematics-derived risk factors as the before period and 2024 telematics-derived risk factors as the after period. For each site, the tool generated factor

summaries, exposure-normalized measures, expected crash frequency, expected crash cost, SMF, and CMF.

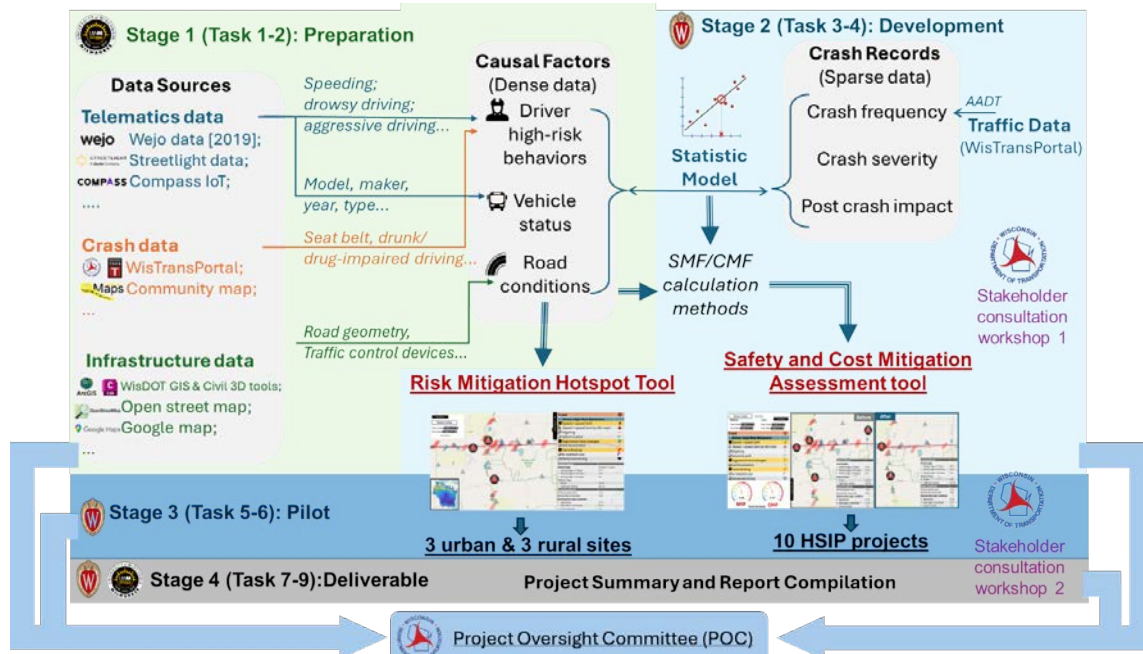


Figure 2 Overall workflow for telematics-based traffic safety analysis.

Overall, the project developed a practical framework for using telematics data as a supplement to Wisconsin's existing traffic safety analysis process. The tools and pilot results show that telematics-derived indicators can provide useful behavioral information for hotspot screening and before-after evaluation. At the same time, the project recognizes that telematics-based analysis should not replace established crash analysis, field review, or engineering judgment. Instead, telematics data should be used as an additional source of evidence to support proactive safety monitoring, project evaluation, and data-driven decision-making.

2. Research Approach

This project used a multi-stage research approach to develop, implement, and pilot a telematics-based traffic safety analysis framework for Wisconsin. The approach was designed to transform large-scale vehicle trajectory records into interpretable safety indicators, integrate those indicators with roadway context and crash records, and provide web-based tools for practical safety screening and before-after project evaluation.

The overall methodology included six major components: literature review and metric identification, high-risk behavior definition, telematics data processing, risk factor event generation, crash and cost

modeling, and pilot implementation. These components were integrated into two practical tools: the Risk Mitigation Hotspot Tool and the Safety and Cost Mitigation Assessment Tool.

2.1 Overall Analytical Framework

The central idea of the project was to use telematics-derived driving behavior as a supplemental safety data source. Instead of relying only on historical crash occurrence, the project identified measurable driving risk factors from vehicle trajectory data and then used those factors in two ways. First, risk factors were mapped and summarized to support hotspot screening. Second, risk factor summaries were linked with crash records, exposure, and crash costs to support before-after safety and cost evaluation.

The framework was designed around the following logic:

1. Raw telematics trajectory data contain information about how vehicles move through the roadway network.
2. After cleaning, standardization, and road matching, trajectory records can be converted into interpretable point-level measures such as acceleration, deceleration, speed exceedance, jerk, and lateral movement.
3. Point-level exceedances can be grouped into event-level risk factors, such as Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit.
4. These risk factor events can be summarized by location, time period, factor type, severity level, exposure, and journey count.
5. Risk factor summaries can be used directly for map-based screening or incorporated into statistical models that estimate crash frequency and crash cost.
6. Before-after changes in predicted crash frequency and predicted crash cost can be summarized through Safety Mitigation Factors and Cost Mitigation Factors.

This framework was implemented in a PostgreSQL/PostGIS data environment, exposed through a REST API, and visualized through browser-based web interfaces.

2.2 Data Sources

The project used several complementary datasets. Telematics data provided high-resolution movement observations. Roadway and map data provided spatial context and speed-limit information. Crash records provided safety outcomes. HSIP project records provided the basis for before-after evaluation. The primary datasets and their roles are summarized in Table 1.

2.3 Literature Review and Identification of Candidate Risk Factors

The research began with a literature review on the use of telematics data for traffic safety analysis. The review focused on how previous studies used vehicle trajectory, connected-vehicle, and mobile telematics

data to identify high-risk driving behaviors, detect near-crashes, conduct spatial hotspot analysis, and evaluate safety countermeasures.

The review showed that most prior telematics safety studies relied on some combination of location, speed, acceleration, deceleration, and roadway context [1-9]. Commonly used risk indicators included harsh braking, harsh acceleration, speeding, cornering or lateral movement, jerk, phone use, and safety-system activation. However, the review also showed that threshold values varied substantially across studies. For example, reported hard-braking and hard-acceleration thresholds were not standardized and were often selected based on prior studies, vendor defaults, or descriptive statistics rather than local crash correlation [3, 6-8].

Based on the literature review and the available project datasets, the project focused on risk factors that could be consistently derived from the available telematics records. These included the five factor types summarized in Table 3.

Table 3 Risk factors used in the project

Risk factor	Description	Primary telematics basis
Rapid Acceleration	A period of unusually high positive longitudinal acceleration	Speed change over time
Hard Braking	A period of unusually high negative longitudinal acceleration or deceleration	Speed change over time
High Jerk	Abrupt change in acceleration	Change in acceleration over time
Sharp Turning / Lane Change	Elevated lateral movement or turning-related behavior	Speed, heading, and roadway context
Speed Above Limit	Vehicle speed exceeding the posted speed limit by a defined margin	Vehicle speed and roadway speed limit

Because the available telematics data did not consistently include driver distraction, lane-keeping, phone movement, ABS activation, ESC activation, or other high-frequency vehicle-system variables, those indicators were not used as primary factors in the final framework.

2.4 High-Risk Behavior Threshold Development

A key methodological need was to define which observed vehicle movements should be classified as high-risk behavior. The project used a two-part approach. First, literature-based thresholds were reviewed to identify a reasonable candidate range. Second, Wisconsin telematics data were combined with Wisconsin crash records to empirically evaluate acceleration and deceleration thresholds.

The data-driven threshold analysis used StreetLight telematics data from September 15-19, 2024, roadway and traffic data, and WisTransPortal crash records [11, 14]. The analysis focused primarily on acceleration, deceleration, and speeding because these variables could be robustly derived from the available data. Jerk and lateral movement were included in the later tool framework, but acceleration and deceleration were the main focus of local crash-linked threshold calibration.

2.4.1 Acceleration and Deceleration Derivation

For each journey, telematics observations were sorted by timestamp. Speed was converted into consistent units and then differentiated over time to estimate longitudinal acceleration. If speed was recorded in miles per hour, the conversion was:

$$v_i^{\text{ft/s}} = 1.4667 v_i^{\text{mph}}$$

If speed was recorded in kilometers per hour, the conversion was:

$$v_i^{\text{ft/s}} = 0.9113 v_i^{\text{km/h}}$$

Longitudinal acceleration was calculated as:

$$a_i = \frac{v_i - v_{i-1}}{t_i - t_{i-1}}$$

where a is longitudinal acceleration, v is vehicle speed, the previous observation is represented by the prior time step, and the denominator is the time difference between consecutive observations. Acceleration was also converted into g-units:

$$a_i^g = \frac{a_i}{32.174}$$

Positive acceleration was used to evaluate rapid acceleration. Negative acceleration was converted into a positive braking intensity measure:

$$b_i = \max(0, -a_i)$$

2.4.2 Distribution-Based Candidate Thresholds

The first threshold-screening step used distributional analysis. Near-zero acceleration values were removed to reduce the influence of idling, coasting, and steady cruising. The remaining acceleration and

deceleration distributions were evaluated using percentile-based thresholds, standard-deviation thresholds, and interquartile-range thresholds.

For percentile-based thresholds:

$$\theta_{acc,p} = Q_p(a_i \mid a_i > 0), \quad \theta_{brake,p} = |Q_{1-p}(a_i \mid a_i < 0)|$$

where the first threshold is the candidate acceleration threshold at percentile p, the second threshold is the candidate braking threshold at percentile 1-p, and Q represents the percentile operator for the relevant distribution.

For standard-deviation thresholds:

$$\theta_{acc,n} = \mu + n\sigma, \quad \theta_{brake,n} = |\mu - n\sigma|$$

where the mean and standard deviation describe the cleaned acceleration distribution, and n is the standard-deviation multiplier. For the interquartile-range method:

$$IQR = Q_3 - Q_1, \quad \theta_{acc,IQR} = Q_3 + 1.5IQR, \quad \theta_{brake,IQR} = |Q_1 - 1.5IQR|$$

These methods provided candidate threshold ranges for identifying unusually high acceleration and braking behavior. However, distributional methods alone do not show whether a threshold is related to crash occurrence. Therefore, the project further evaluated candidate thresholds using crash-frequency modeling.

2.4.3 Crash-Linked Threshold Evaluation

To determine which thresholds were most strongly associated with crash occurrence, the project used a Zero-Inflated Negative Binomial modeling approach. This model structure was selected because crash counts are discrete, often over-dispersed, and contain many zero-crash observations.

For a roadway segment i, the crash count Y_i was modeled as a mixture:

$$Y_i = 0 \text{ with probability } \pi_i, \quad Y_i \sim NB(\mu_i, \kappa) \text{ with probability } 1 - \pi_i$$

where the observed crash count for a segment is modeled as a mixture of a structural-zero state and a negative-binomial count state. The zero-inflation probability represents the probability that a segment

belongs to the structural-zero state, the expected crash count is used in the negative-binomial component, and the dispersion parameter accounts for over-dispersion.

The expected crash count was modeled using a log link:

$$\log(\mu_i) = \beta_0 + \beta_1 \text{Episodes}_i + \beta_2 \log(\text{AADT}_i) + \beta_3 \text{SpeedLimit}_i + \beta_4 \text{SpeedingRate}_i + \beta_5 \text{Lanes}_i$$

Candidate acceleration and deceleration thresholds were swept from 0.10 g to 0.50 g. For each threshold, harsh-driving episodes were reconstructed and aggregated at the roadway-segment level. A model was then fitted and evaluated using pseudo-R². The thresholds with the strongest model performance were selected as the locally calibrated Wisconsin thresholds.

The final selected thresholds were 0.22 g for rapid acceleration and 0.24 g for hard braking. These thresholds provided a locally validated basis for defining acceleration- and braking-related high-risk events in the project.

2.5 Telematics Data Cleaning and Standardization

After the risk factor framework was defined, raw telematics data were processed into a standardized analytical format. Because the project used data from more than one telematics vendor, the first step was to standardize field names, coordinate formats, timestamps, and speed units.

The data cleaning process included three primary steps. First, raw telematics records were spatially filtered to retain observations within the defined study areas. For statewide or large-volume vendor data, this step substantially reduced the data volume and produced site-specific datasets. Second, vendor-specific schemas were converted into a common format. The standardized fields used for downstream processing included `journey_id`, `capture_time`, `latitude`, `longitude`, `ignition_status`, `speed`, `heading` where available, and a location-quality indicator where available. Third, original telematics inputs were merged into consolidated site-level datasets. Because the original data were provided as large numbers of files, site-level filtering and merging were necessary to support repeatable processing and efficient tool execution.

2.6 Database Organization

All major telematics processing and analysis were conducted in a PostgreSQL/PostGIS environment. This spatial database structure allowed the project team to store large trajectory datasets, roadway reference layers, intermediate processing outputs, and final risk factor records in a repeatable and traceable manner.

List of schemas	
Name	Owner
public	postgres
telematics	teledb_user
telematics_raw_data	teledb_user
telematics_raw_data_wejo	teledb_user
telematics_results	teledb_user
telematics_risk	teledb_user
telematics_road_info	teledb_user

Figure 3 PostgreSQL/PostGIS database schema used for telematics processing.

The database organization separated raw vendor data, roadway reference data, risk parameter definitions, site-specific processing outputs, and consolidated results. The main database components are summarized in Table 4.

Table 4 Database organization

Schema or data component	Purpose
telematics_raw_data	Stores raw StreetLight data before site-level filtering and processing
telematics_raw_data_wejo	Stores raw Wejo data before site-level filtering and processing
telematics_road_info	Stores roadway network reference data derived from OpenStreetMap and supporting roadway layers
telematics_risk	Stores risk factor definitions, severity thresholds, and shared risk-related reference information
telematics_results	Stores consolidated analytical outputs, exported factor tables, and reporting-ready results
telematics_site_XX	Stores site-specific intermediate tables and risk factor outputs for individual study locations

This organization allowed each pilot site to be processed independently while maintaining a common structure for cross-site comparison.

2.7 Road Matching

Road matching was used to assign each telematics point to the most plausible roadway segment. This step was necessary because raw GPS observations do not always fall exactly on a roadway centerline and may contain spatial noise. Road matching also provided roadway context for speed-limit comparison, intersection identification, and downstream aggregation.

The road-matching process included five steps. First, candidate road segments were selected within the study boundary and a small spatial buffer around each telematics point. Second, each telematics point was projected to the nearest plausible road geometry. Third, the vehicle heading was compared with the local roadway bearing where heading information was available. Fourth, intersection zones were identified by checking whether matched points were located near roadway nodes or intersection areas. Fifth, a match confidence score was calculated based on spatial proximity and directional consistency. Points closer to the roadway centerline and more consistent with the roadway bearing received higher confidence scores. The matched point output included the original point location, projected road location, road identifier, road name, intersection indicator, and match confidence score. These attributes were used in risk factor calculation and map-based visualization.

2.8 Risk Factor Calculation

Risk factors were calculated from cleaned and road-matched telematics trajectories. The calculation process converted point-level vehicle movement measures into event-level records. This was necessary because a single risky maneuver may contain several consecutive telematics points. Treating each point as a separate event would over-count sustained maneuvers. Therefore, the project grouped temporally adjacent exceedances within the same journey into single risk factor events.

2.8.1 Point-Level Measures

The project used the following point-level measures. Longitudinal acceleration and braking intensity followed the equations introduced in Section 2.4. Speed exceedance was calculated as:

$$e_i = \max(0, v_i - SL_i)$$

where speed exceedance is the positive difference between vehicle speed and the posted speed limit at the matched roadway location. Jerk was calculated as:

$$j_i = \frac{a_i - a_{i-1}}{t_i - t_{i-1}}$$

Turning or lateral movement was represented using elevated lateral movement or heading-change-related behavior where the required heading and movement information was available. These measures were used to identify Sharp Turning / Lane Change factors.

2.8.2 Severity Classification

Each point-level measure was classified into a severity level based on factor-specific thresholds. The tool supports user-configurable thresholds. When no user-defined thresholds are provided, the default tool thresholds are applied.

For each risk factor, the point-level value was compared with factor-specific low-, medium-, and high-severity thresholds. The severity level was assigned as follows:

$$\text{severity}_{i,f} = \begin{cases} \text{None}, & x_{i,f} < \tau_{f,L} \\ \text{Low}, & \tau_{f,L} \leq x_{i,f} < \tau_{f,M} \\ \text{Medium}, & \tau_{f,M} \leq x_{i,f} < \tau_{f,H} \\ \text{High}, & x_{i,f} \geq \tau_{f,H} \end{cases}$$

Only observations classified as Low, Medium, or High were retained for event grouping.

2.8.3 Event Grouping

Point-level exceedances were grouped into event-level risk factors by journey and time continuity.

Consecutive exceedances from the same journey were treated as part of the same event if the time gap between points was less than or equal to the factor-specific grouping threshold.

For acceleration, braking, jerk, and turning-related factors, the grouping threshold was 15 seconds. For speed-above-limit factors, the grouping threshold was 20 seconds, reflecting the longer duration typically associated with sustained speeding. For two consecutive exceedance points $i-1$ and i in the same journey, the grouping rule was:

$$\text{same event if } t_i - t_{i-1} \leq \delta_f, \quad \text{new event if } t_i - t_{i-1} > \delta_f$$

Each event-level record stored the event ID, journey ID, risk factor type, severity level, start time, end time, start location, end location, associated roadway, intersection indicator, maximum factor value, average factor value, and number of contributing telematics points. This event-level design produced a compact and interpretable representation of risky driving behavior.

2.9 Risk Mitigation Hotspot Tool Development

The Risk Mitigation Hotspot Tool was developed to support site-level screening and visualization of telematics-derived risk factors. The tool connects the backend factor-generation workflow with a browser-based map interface.

The backend system exposes risk factor results through a REST API. Users can query the API by specifying a spatial bounding box and time range. The API returns matching factor-level records, including factor type, severity level, time span, geographic location, associated roadway information, and summary statistics.

The frontend was implemented as a browser-based interface using HTML, CSS, JavaScript, and Leaflet for map visualization. The tool allows users to define a query area, define a query time window, select risk factor layers, and review mapped outputs.

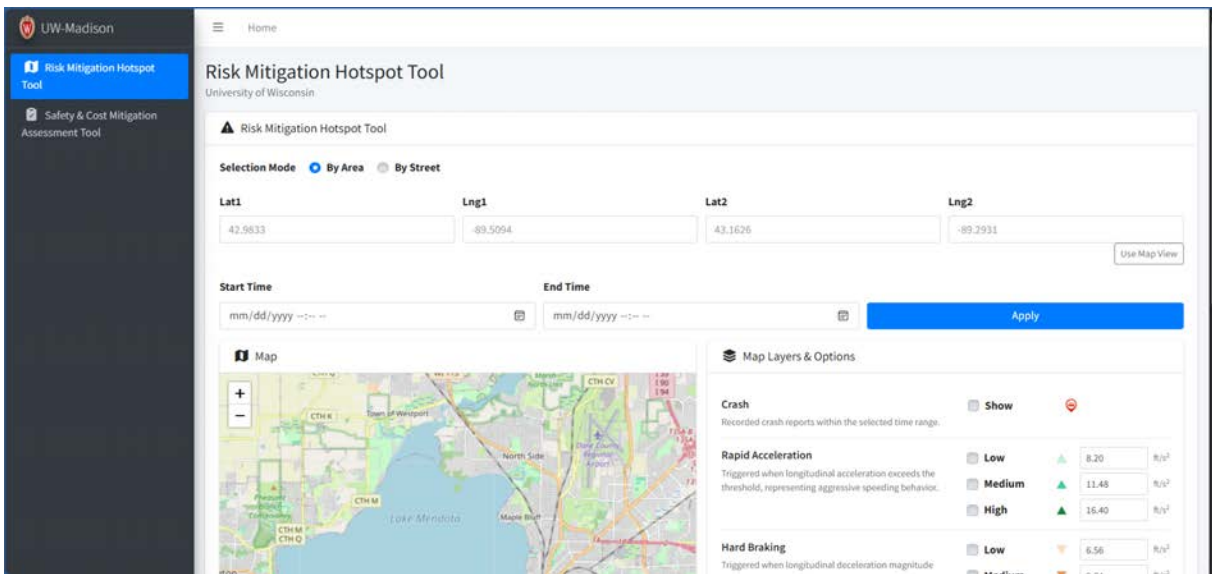


Figure 4 Risk Mitigation Hotspot Tool web interface.

The tool supports three methods for defining the spatial query area: direct coordinate entry using two latitude-longitude coordinate pairs, map-view extent where the visible map boundary is used as the query boundary, and mouse selection where the user draws a rectangular area directly on the map. After the spatial and temporal filters are applied, the user can select which factors to display. The web interface displays the selected factor records on the map and provides a summary of the number and type of detected factors.

2.10 Safety and Cost Mitigation Assessment Tool Development

The Safety and Cost Mitigation Assessment Tool extended the hotspot framework by adding crash-frequency modeling, crash-cost estimation, and before-after evaluation. The tool was designed to evaluate whether observed changes in telematics-derived risk factors were associated with estimated reductions in crash frequency and crash cost.

The tool used site-level risk factor summaries, vehicle miles traveled, crash records, and crash costs. The primary outputs were predicted crash frequency, predicted crash frequency by severity, predicted crash cost, Safety Mitigation Factor, and Cost Mitigation Factor.

2.10.1 Spatial, Temporal, and Exposure Alignment

Before modeling, risk factor records and crash records were aligned spatially, temporally, and by exposure. Spatial alignment ensured that telematics-derived factors and crash records referred to the same study boundary. Temporal alignment ensured that risk factor summaries and crash counts were

aggregated over comparable before and after periods. Exposure adjustment accounted for differences in traffic volume and observed vehicle activity. Vehicle miles traveled was used as the primary exposure measure.

Risk factor rates were computed as:

$$Rate_{i,f} = \frac{N_{i,f}}{VMT_i}, \quad Rate_{i,f}^{1000} = 1000 \times \frac{N_{i,f}}{VMT_i}$$

where the numerator is the number of risk factor events of a given type for the site-time observation and the denominator is vehicle miles traveled. Affected-journey share was computed as:

$$AffectedJourneyShare_i = \frac{J_i^{factor}}{J_i^{total}}$$

where the numerator is the number of unique journeys with at least one detected factor and the denominator is the total number of observed journeys.

2.10.2 Crash-Frequency Model

Crash frequency was modeled using a generalized linear modeling framework with a log link function. Because crash counts are discrete and typically over-dispersed, a Negative Binomial specification was adopted.

Let each observation represent a site-time unit, with crash severity categories and risk factor types indexed in the model. The observed crash count, expected crash count, vehicle miles traveled, exposure-normalized risk-factor values, severity-specific intercepts, and severity-specific factor coefficients are defined through the following equations.

The expected crash frequency was modeled as:

$$Y_{i,k} \sim NB(\mu_{i,k}, \kappa_k)$$

$$\log(\mu_{i,k}) = \log(VMT_i) + \alpha_k + \sum_f \beta_{k,f} X_{i,f}$$

where the logarithm of VMT is included as an exposure offset, the dispersion parameter is severity-specific, and the summation term represents the combined contribution of telematics-derived risk factors. The fitted model was used to predict expected crash counts under before-period and after-period risk factor conditions.

2.10.3 Safety Mitigation Factor

For each observation i and severity level k , the predicted crash frequency was:

$$\hat{\mu}_{i,k} = \exp \left[\log(VMT_i) + \hat{\alpha}_k + \sum_f \hat{\beta}_{k,f} X_{i,f} \right]$$

Total predicted crashes for observation i were computed as:

$$\hat{N}_i = \sum_k \hat{\mu}_{i,k}$$

Let the before period be represented by B and the after period by A . Total predicted crashes in the before period and after period were calculated as:

$$\hat{N}_{\text{before}} = \sum_{i \in B} \sum_k \hat{\mu}_{i,k}$$

$$\hat{N}_{\text{after}} = \sum_{i \in A} \sum_k \hat{\mu}_{i,k}$$

The Safety Mitigation Factor was calculated as:

$$SMF = \frac{\hat{N}_{\text{after}}}{\hat{N}_{\text{before}}}$$

An SMF value below 1.0 indicates an estimated reduction in expected crash frequency after treatment.

The percent reduction in expected crash frequency was calculated as:

$$\text{Percent Reduction in Crashes} = (1 - SMF) \times 100\%$$

2.10.4 Crash Cost Calculation

Crash cost was calculated using severity-specific unit crash costs. The crash severity categories followed the KABCO system used in Wisconsin crash reporting[10]. Table 5 lists the crash unit costs used for the pilot safety and cost evaluation.

Table 5 Crash unit costs used for safety and cost evaluation

Crash severity	KABCO abbreviation	HSM terminology	Unit crash cost
Fatal	K	Fatal	\$15,801,026

Crash severity	KABCO abbreviation	HSM terminology	Unit crash cost
Suspected Serious Injury	A	Serious Injury or Disabling	\$805,357
Suspected Minor Injury	B	Evident Injury or Non-disabling	\$261,834
Possible Injury	C	Possible Injury	\$156,357
Property Damage Only	O	No Injury	\$19,091

Let the unit crash cost vary by crash severity. The expected crash cost for each observation was calculated as:

$$\hat{C}_i = \sum_k c_k \hat{\mu}_{i,k}$$

The aggregated expected crash cost in the before period and after period was:

$$\hat{C}_{\text{before}} = \sum_{i \in B} \sum_k c_k \hat{\mu}_{i,k}$$

$$\hat{C}_{\text{after}} = \sum_{i \in A} \sum_k c_k \hat{\mu}_{i,k}$$

The Cost Mitigation Factor was calculated as:

$$CMF = \frac{\hat{C}_{\text{after}}}{\hat{C}_{\text{before}}}$$

A CMF value below 1.0 indicates an estimated reduction in expected crash-related cost after treatment.

The percent reduction in expected crash cost was calculated as:

$$\text{Percent Reduction in Crash Cost} = (1 - CMF) \times 100\%$$

2.10.5 Comparison-Site Adjustment

To account for background changes not directly caused by a treatment, the Safety and Cost Mitigation Assessment Tool includes a comparison-site adjustment. HSIP sites are grouped by exposure and

operating speed using VMT and median speed. Each site is assigned to a comparison group with similar VMT and speed characteristics.

The adjusted values are calculated as: Adjusted SMF = Site SMF / Control SMF Factor, and Adjusted CMF = Site CMF / Control CMF Factor. This adjustment helps distinguish site-specific treatment effects from broader changes in travel behavior, data coverage, or traffic conditions.

The current tool uses the following four comparison groups which are summarized in the following Table. The low-VMT/high-speed group is more sensitive because it is based on a smaller amount of exposure. In the current dataset, that group is represented by one candidate location, County Highway PB, with relatively low VMT. Since no current demonstration site falls into this group, we keep the factor as a candidate value rather than an applied adjustment factor.

Table 6 Comparison-site groups and adjustment factors used in the Safety and Cost Mitigation Assessment Tool

Control Group	Representative Control Location	SMF Factor	CMF Factor
High VMT / High Speed	I-39/I-90 corridor	0.936	0.917
High VMT / Low Speed	West Beltline / John Nolen Drive	0.812	0.812
Low VMT / High Speed	County Highway PB area	0.562	0.599
Low VMT / Low Speed	West Johnson Street	0.840	0.824

2.11 Web Tool Architecture and Outputs

Both tools were developed using a modular web-based structure. The frontend provided user interaction and map visualization. The backend provided factor generation, spatial querying, and analytical outputs. The API layer allowed the tools to retrieve factor-level and summary-level results without requiring users to interact directly with the database.

The Risk Mitigation Hotspot Tool returned factor-level records and summary counts. The Safety and Cost Mitigation Assessment Tool returned both factor-level records and aggregate before-after evaluation outputs. Table 6 summarizes the main inputs and outputs.

Table 7 Main outputs from the two project tools

Tool	Main user inputs	Main outputs
Risk Mitigation Hotspot Tool	Location boundary, time range, selected risk factor types, severity thresholds	Map of factor events, factor counts, severity distribution, roadway context, and summary statistics
Safety and Cost Mitigation Assessment Tool	Before-period boundary and time, after-period boundary and time, selected risk factors, crash cost values	Before-after factor maps, exposure-normalized factor rates, affected-journey shares, predicted crash frequency,

Tool	Main user inputs	Main outputs
		predicted crash cost, SMF, and CMF

The screenshot shows a web browser interface with a curl command in the top bar and a JSON response in the main area. The curl command is a POST request to `http://localhost:8001/api/v1/factors/search` with headers `Accept: application/json` and `Content-Type: application/json`. The request body is a JSON object containing a bounding box, time range, and other parameters. The response is a 200 status code with a JSON body containing a list of risk records. The first record in the list is expanded to show details like event ID, journey ID, metric name, risk level, start/end times, location, road name, and values.

```
curl -X 'POST' \
  'http://localhost:8001/api/v1/factors/search' \
  -H 'accept: application/json' \
  -H 'Content-Type: application/json' \
  -d '{
    "bbox": {
      "lat1": 42.9986,
      "lng1": -89.5362,
      "lat2": 43.1779,
      "lng2": -89.289
    },
    "time_range": {
      "start": "2019-10-12 00:00:00",
      "end": "2019-10-15 00:00:00"
    }
  }'
```

```
{
  "matched_rows": 47,
  "data": [
    {
      "event_id": "wejo_3",
      "journey_id": "586ac3f912734a55b27c9e73243ba70bd8e83583",
      "metric_name": "Rapid Acceleration",
      "risk_level": "medium",
      "start_ts": "2019-10-12 00:39:56-05",
      "end_ts": "2019-10-12 00:39:56-05",
      "start_lat": 43.116784,
      "start_lon": -89.325812,
      "end_lat": 43.116784,
      "end_lon": -89.325812,
      "road_id": 38197429,
      "road_name": "East Washington Avenue",
      "max_value": 4.693518518518517,
      "avg_value": 4.693518518518517,
      "point_count": 1,
      "start_dt": "2019-10-12T00:39:56",
      "end_dt": "2019-10-12T00:39:56"
    },
    {
      "event_id": "wejo_14",
      ...
    }
  ]
}
```

```
content-length: 22382
content-type: application/json
date: Thu, 29 Jan 2026 03:34:57 GMT
server: uvicorn
```

Figure 5 Example API response or web output for factor-level risk records.

The screenshot shows a web browser interface displaying the output of the Safety and Cost Mitigation Assessment Tool. The output is a JSON object with fields for 'results', 'smf', 'cmf', 'vmt_miles', and 'predicted_crashes'. The 'predicted_crashes' field is expanded to show 'before' and 'after' scenarios for various factors (K, A, B, C, O, KABCO) with their respective values.

```
{
  "results": {
    "smf": 0.6408590491666425,
    "cmf": 0.7539508233275383,
    "vmt_miles": {
      "before": 40345.46938588286,
      "after": 35906.82541554062
    },
    "predicted_crashes": {
      "before": {
        "K": 0.009504630682916987,
        "A": 0.021181572540403207,
        "B": 0.21593493036553496,
        "C": 0.539122104438205,
        "O": 1.6378061696308015,
        "KABCO": 2.4235494076578616
      },
      "after": {
        "K": 0.007966646540296359,
        "A": 0.01708278926768601,
        "B": 0.15593400360701862,
        "C": 0.3583155864418098,
        "O": 1.013854543143186,
        "KABCO": 1.553153568999997
      }
    }
  }
}
```

Figure 6 Example output from the Safety and Cost Mitigation Assessment Tool.

2.12 Pilot Implementation of the Risk Mitigation Hotspot Tool

The Risk Mitigation Hotspot Tool was piloted at six Wisconsin roadway sites selected in coordination with WisDOT. The pilot used Wejo telematics data from October 2019 and applied the tool to sites representing both urban and rural roadway contexts. For each pilot site, a predefined rectangular spatial extent was used as the query boundary. The tool was run for the selected time period, and all available factor types were selected for review. The resulting factor records were visualized on the map, and summary counts were recorded for comparison across sites.

Table 8 Pilot sites for the Risk Mitigation Hotspot Tool

Number	Location	Intersection?	AADT	Rural / Urban
1	US-151 (E. Washington) & Mendota St, Madison	Yes	35,600	Urban
2	County Hwy MM (Rimrock Road) at US-18, Madison	No	12,800	Urban
3	W Johnson St & N Park St, Madison	Yes	19,200	Urban
4	I-90 at County Rd A, Cambridge	No	57,800	Rural
5	County Hwy PB & Red Stone Lane, Verona	Yes	9,300	Rural
6	WI-19 & WI-78, Black Earth	Yes	4,400	Rural

The purpose of this pilot was not to create a final statewide safety ranking, but to test whether the tool could produce interpretable site-level outputs across different roadway settings. The pilot evaluated whether risk factor events could be queried, mapped, summarized, and compared across sites.

2.13 Pilot Evaluation of the Safety and Cost Mitigation Assessment Tool

The Safety and Cost Mitigation Assessment Tool was piloted at 10 selected HSIP sites. These sites were selected to represent different roadway types, counties, ownership categories, and treatment types. The evaluation used a before-after framework. The before period used 2019 Wejo telematics-derived factor results, and the after period used 2024 StreetLight telematics-derived factor results.

For the pilot evaluation, 10 demonstration sites were selected from the broader set of 18 HSIP sites to keep the report concise while still covering a range of roadway contexts and treatment types. Each demonstration

site was assigned to a comparison group based on its observed VMT and median speed, allowing the before-after results to be interpreted relative to similar untreated corridors rather than relying only on the raw before-after change at the project site.

For each site, the tool generated total risk factor counts, risk factor counts by type, risk factor counts by severity, VMT-normalized factor rates, factors per 100 journeys, affected-journey share, predicted monthly crash frequency, predicted monthly crash frequency by severity, predicted monthly crash cost, SMF, and CMF.

Table 9 HSIP sites used for pilot evaluation

ID	County	Road name / location	Road type	Road owner
1	St. Croix	CTH U to Mackin Rd.	Major Collector	Local
2	Grant	C Platteville, Business 151	Minor Arterial	Local
3	Portage	Stevens Point-Waupaca / Southbound I-39 Ramp-Wildwood Drive and Country Club Drive Intersection	Other Freeways and Expressways	State
4	Outagamie	STH 47, Appleton-Black Creek, CTH JJ-CTH B	Principal Arterial Other	State
5	Portage	Elk Road to Division Street	Other Freeways and Expressways	State
6	Milwaukee	W. Lincoln Avenue intersections with S. 84th Street, S. 76th Street, and S. 71st Street	Minor Arterial	Local
7	Green	Argyle-Monroe; West Junction Old Wis 81 to Pleasant View	No Functional Classification	State
8	Milwaukee	Lake Drive corridor and selected curve/intersection locations	Principal Arterial Other	State
9	Green	Monroe-Brodhead; Hiltbrand Lane to C Brodhead Limits	Principal Arterial Other	State
10	La Crosse	City of La Crosse intersection improvements at USH 14, STH 16, and STH 33	Minor Arterial	State

The pilot evaluation was intended to test whether the tool could support practical before-after review across diverse HSIP sites. The analysis compared changes in telematics-derived factor burden with changes in expected crash frequency and expected crash cost. The results were summarized at the site level and across all pilot sites.

2.14 Interpretation of the Research Approach

The approach used in this project was designed to support practical agency use. The project did not treat telematics data as a replacement for crash records, field diagnosis, or engineering judgment. Instead, the research approach used telematics data as an additional behavioral safety layer.

This approach has three main advantages. First, it allows safety analysts to observe driving behavior at locations where crashes may be too sparse to support short-term analysis. Second, it provides a consistent way to compare before and after periods using exposure-normalized risk factor summaries. Third, it connects behavioral indicators with crash-frequency and crash-cost models, allowing safety and economic impacts to be summarized through SMF and CMF values.

At the same time, the approach requires careful interpretation. Telematics data coverage can vary by vendor, year, location, vehicle population, and sampling frequency. Differences between Wejo and StreetLight data should be considered when interpreting before-after results. The results should therefore be used as screening and evaluation support rather than as the sole basis for project-level conclusions.

3. Results and Analysis

This section summarizes the main results generated from the literature review, threshold calibration, web-tool development, and pilot applications. The results are organized around three project outcomes: locally calibrated telematics risk-factor definitions, pilot implementation of the Risk Mitigation Hotspot Tool, and pilot evaluation of the Safety and Cost Mitigation Assessment Tool. Together, these results show how raw vehicle trajectory data can be translated into site-level behavioral indicators and then connected to crash-frequency and crash-cost outcomes for safety analysis.

3.1 High-Risk Behavior Definition and Threshold Calibration Results

The literature review showed that telematics-based safety studies most commonly rely on speed, longitudinal acceleration, deceleration, and location-derived movement measures. However, prior studies used different thresholds for harsh braking, harsh acceleration, speeding, cornering, and jerk. Reported acceleration and braking thresholds varied widely, which made it necessary to calibrate the project thresholds using Wisconsin data rather than directly adopting values from other studies.

The threshold calibration used StreetLight telematics data, roadway information, traffic exposure measures, and Wisconsin crash records. The analysis first examined acceleration and deceleration

distributions and then tested candidate thresholds using Zero-Inflated Negative Binomial regression. Candidate thresholds from 0.10 g to 0.50 g were evaluated, and model performance was compared using pseudo-R-squared values. The selected thresholds were the values that provided the strongest association with crash frequency while remaining within the empirically plausible range of observed driving behavior.

Table 10 Locally calibrated harsh-driving thresholds used in the project

Behavior indicator	Selected threshold	Equivalent value	Model support	Interpretation
Rapid Acceleration	0.22 g	7.08 ft/s ²	Pseudo-R ² = 0.204	Best-performing acceleration threshold in the threshold-sweep regression analysis
Hard Braking / Deceleration	0.24 g	7.73 ft/s ²	Pseudo-R ² = 0.158	Best-performing braking threshold in the threshold-sweep regression analysis

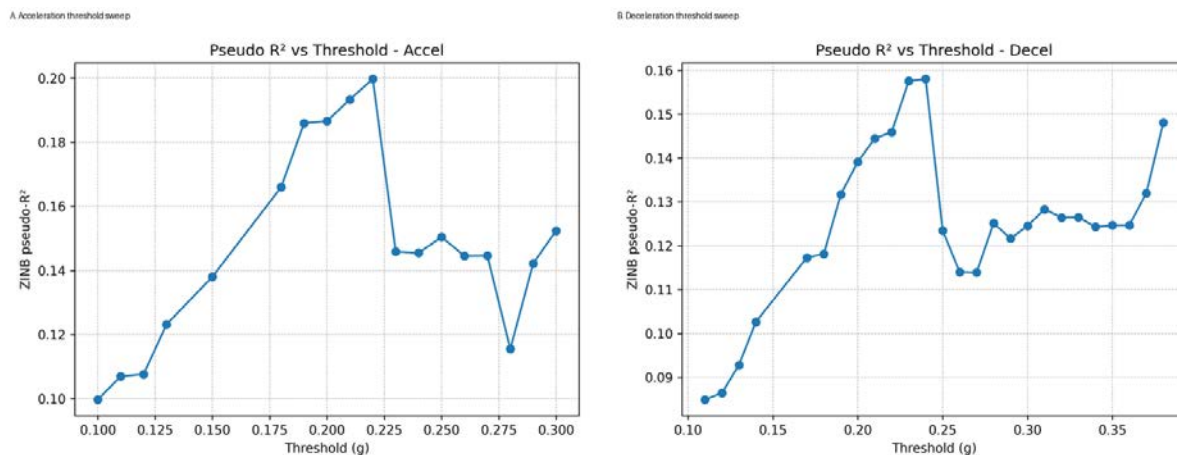


Figure 7 Threshold-sweep results for acceleration and deceleration.

The results indicate that the Wisconsin-calibrated acceleration and braking thresholds are asymmetric. The optimal threshold for rapid acceleration was 0.22 g, while the optimal threshold for hard braking was 0.24 g. Both values fall within the lower end of the range reported in the literature, but they are supported by a crash-linked local calibration process. The regression results also showed that harsh-driving episode frequency and log(AADT) were among the strongest predictors of crash occurrence. This finding supports the use of telematics-derived harsh events as crash-relevant behavioral indicators when they are interpreted together with exposure and roadway context.

The calibrated thresholds were then used as the foundation for downstream factor generation. In the web tools, acceleration and braking events could be classified into severity levels and grouped into sustained event records. This conversion from point-level trajectory measurements to event-level risk factors was

essential for reducing noise, avoiding repeated counting of the same maneuver, and producing outputs that could be interpreted by analysts.

3.2 Risk Mitigation Hotspot Tool Pilot Results

The Risk Mitigation Hotspot Tool was piloted at six Wisconsin roadway sites using Wejo telematics data from October 2019. The sites included three urban locations and three rural locations. For each site, all available factor types were selected: Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit. The tool produced event-level factor records, mapped the records within the selected site boundary, and generated summary measures such as total factor counts, factors per VMT, factors per journey, and affected-journey share.

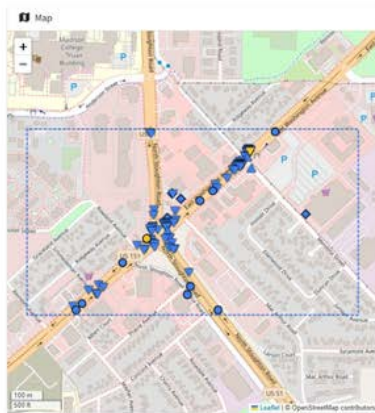
The six pilot sites showed distinct risk-factor patterns. Urban Site 1 and Urban Site 3 were dominated by Hard Braking events, which is consistent with intersection and approach-related stop-and-go operations. Urban Site 2 showed a stronger Speed Above Limit component along with substantial Hard Braking activity, reflecting its interchange and corridor context. Rural Site 1 showed a mixed speeding and braking pattern. Rural Site 2 was overwhelmingly dominated by Speed Above Limit events, while Rural Site 3 was again braking-dominant with additional High Jerk and Rapid Acceleration activity.

Table 11 Summary of Risk Mitigation Hotspot Tool pilot results

Pilot site	Context	Total factors	Factors per 1,000 VMT	Factors per 100 journeys	Affected-journey share	Dominant factor pattern
Urban Site 1: US-151 (E. Washington) & Mendota St	Urban intersection/corridor	116	20.7	0.89	0.85%	Hard Braking: 95 events (81.9%)
Urban Site 2: County Hwy MM / US-18	Urban interchange/corridor	511	38.9	2.16	2.06%	Speed Above Limit: 354 events (69.3%); Hard Braking: 143 events (28.0%)
Urban Site 3: W Johnson St & N Park St	Urban intersection	23	44.8	0.93	0.89%	Hard Braking: 19 events (82.6%)
Rural Site 1: I-90 at County Rd A	Rural highway location	44	1.88	0.20	0.20%	Mixed pattern: Speed Above Limit 24 events (54.5%) and Hard Braking 19 events (43.2%)

Pilot site	Context	Total factors	Factors per 1,000 VMT	Factors per 100 journeys	Affected-journey share	Dominant factor pattern
Rural Site 2: County Hwy PB & Red Stone Lane	Rural intersection/corridor	349	261.6	8.36	8.36%	Speed Above Limit: 346 events (99.1%)
Rural Site 3: WI-19 & WI-78	Rural intersection	47	11.9	0.80	0.70%	Hard Braking: 29 events (61.7%); High Jerk: 9 events (19.1%)

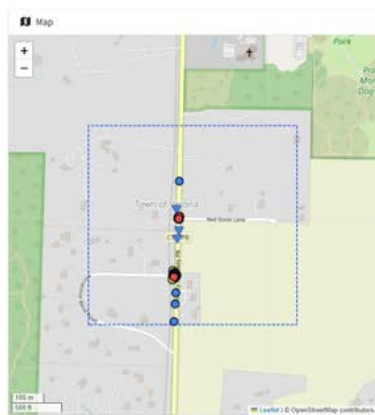
Urban Site 1: E Washington & Mendota



Urban Site 3: W Johnson & N Park



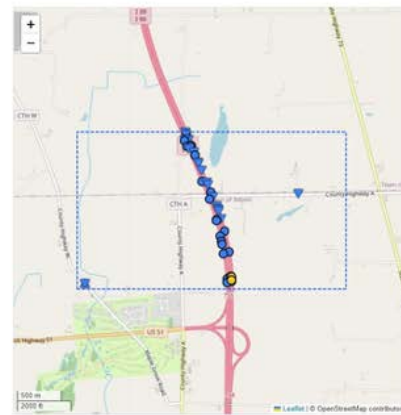
Rural Site 2: County Hwy PB / Red Stone



Urban Site 2: Rimrock Road / US-18



Rural Site 1: I-90 / County Rd A



Rural Site 3: WI-19 / WI-78

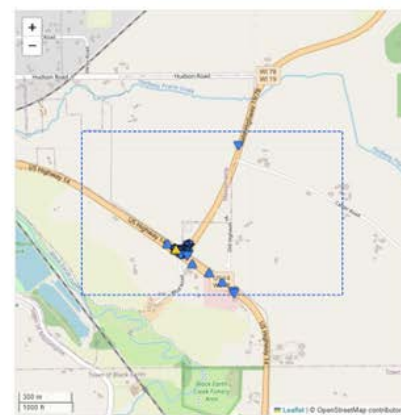


Figure 8 Risk-factor maps for the six Risk Mitigation Hotspot Tool pilot sites.

Several findings are evident from the pilot. First, the tool successfully distinguished site-specific behavioral patterns rather than producing the same factor profile at every location. This is important because different roadway contexts produce different safety concerns. Braking-dominant patterns can suggest locations where drivers are responding to intersections, congestion, turning movements, or

changing traffic-control conditions. Speeding-dominant patterns can suggest higher-speed corridors or areas where observed speeds frequently exceed the posted limit.

Second, total factor counts alone did not fully describe site risk. Rural Site 2 had 349 factors, fewer than Urban Site 2, but it had the highest normalized factor burden, with 261.6 factors per 1,000 VMT and 8.36 factors per 100 journeys. This illustrates the value of normalizing factor counts by exposure. Without exposure normalization, high-volume locations could appear riskier simply because more vehicles were observed. The pilot therefore supports reporting both raw factor counts and exposure-normalized measures.

Third, most detected factors were low-severity events. This does not mean the results are unimportant; rather, it indicates that the tool is more useful as a screening and pattern-recognition tool than as a direct crash classifier. Locations with repeated low- and medium-severity behavioral indicators may still warrant review, particularly when factors are spatially concentrated or when they occur in locations with known crash histories or recent safety projects.

3.3 Safety and Cost Mitigation Assessment Tool Pilot Results

The Safety and Cost Mitigation Assessment Tool was piloted at 10 selected HSIP sites, consistent with established before-after safety evaluation practice [15-17]. The pilot used a before-after comparison framework, with 2019 Wejo-derived risk factor outputs representing the before period and 2024 StreetLight-derived risk factor outputs representing the after period. For each site, the tool summarized telematics-derived factors, exposure-normalized measures, affected-journey shares, expected monthly crash frequency, expected monthly crash cost, SMF, and CMF.

Across the 10 HSIP sites, the crash-based evaluation results were favorable. Both the estimated SMF and CMF were below 1.0 for all sites, indicating reductions in expected crash frequency and expected crash cost after treatment. The estimated reductions in expected monthly crash frequency ranged from 6.39% to 51.56%, while estimated reductions in expected monthly crash cost ranged from 5.48% to 51.97%.

Table 12 HSIP pilot factor changes and mitigation factors

Site	Location / corridor	Before factors	After factors	Change in factors	SMF	CMF
1	St. Croix: CTH U to Mackin Rd.	2,196	1,720	-21.7%	0.94	0.95
2	Grant: Business 151 corridor	77	32	-58.4%	0.73	0.59
3	Portage: US 51 / WI 66 interchange area	1,694	802	-52.7%	0.61	0.60
4	Outagamie: STH 47 corridor	5,982	2,741	-54.2%	0.67	0.70
5	Portage: Elk Road-Division St.	30	22	-26.7%	0.62	0.60

Site	Location / corridor	Before factors	After factors	Change in factors	SMF	CMF
6	Milwaukee: W. Lincoln Ave. intersections	46	15	-67.4%	0.53	0.61
7	Green: STH 81 corridor	171	38	-77.8%	0.55	0.59
8	Milwaukee: Lake Drive corridor	39	29	-25.6%	0.73	0.71
9	Green: STH 11 Monroe-Brodhead corridor	380	129	-66.1%	0.66	0.66
10	La Crosse: STH 16 intersection	17	9	-47.1%	0.48	0.48

Table 13 Expected monthly crash frequency and crash cost changes at HSIP pilot sites

Site	Before expected crashes	After expected crashes	Crash reduction	Before expected cost	After expected cost	Cost reduction
1	2.97	2.78	-6.39%	\$491,082.70	\$464,195.42	-5.48%
2	0.36	0.26	-27.35%	\$59,175.95	\$35,177.04	-40.56%
3	0.63	0.38	-38.64%	\$74,331.46	\$44,732.30	-39.82%
4	3.77	2.51	-33.45%	\$630,388.09	\$442,551.82	-29.80%
5	0.40	0.24	-38.40%	\$87,558.23	\$52,558.73	-39.97%
6	0.07	0.04	-46.83%	\$10,188.13	\$6,247.58	-38.68%
7	0.52	0.29	-45.05%	\$100,006.26	\$58,896.25	-41.11%
8	0.31	0.22	-27.31%	\$49,256.55	\$34,835.81	-29.28%
9	1.25	0.83	-33.73%	\$229,894.71	\$152,394.28	-33.71%
10	0.09	0.05	-51.56%	\$16,004.02	\$7,686.54	-51.97%

The site-level results show several important patterns. Site 1 had the smallest estimated improvement, with an SMF of 0.94 and CMF of 0.95, but the result still indicated improvement in both expected crash frequency and cost. Site 10 had the largest proportional improvement, with both SMF and CMF equal to 0.48. Several sites, including Sites 3, 4, 6, 7, and 9, also showed substantial reductions in telematics-derived factor burden as well as favorable crash- and cost-based outputs.

The telematics-derived factor changes and crash-based outputs were generally consistent, but not perfectly identical. For example, Sites 8 and 10 had sparse factor counts and limited change after exposure normalization, yet the crash-based mitigation outputs still indicated expected safety and cost improvements. This suggests that the tool should be interpreted as an integrated evaluation framework

rather than as a simple factor-count comparison. Factor maps, normalized factor rates, affected-journey shares, crash predictions, and cost estimates should be reviewed together.

3.4 Crash-Severity Results

The mitigation assessment also produced severity-specific expected crash estimates. Aggregating the 10 pilot HSIP sites showed reductions across all crash severity categories. The total expected crash frequency decreased from 10.37 before treatment to 7.58 after treatment, a reduction of approximately 26.9% across the aggregated two-week comparison. Reductions were observed for property-damage-only crashes, possible-injury crashes, evident-injury crashes, disabling-injury crashes, and fatal crashes.

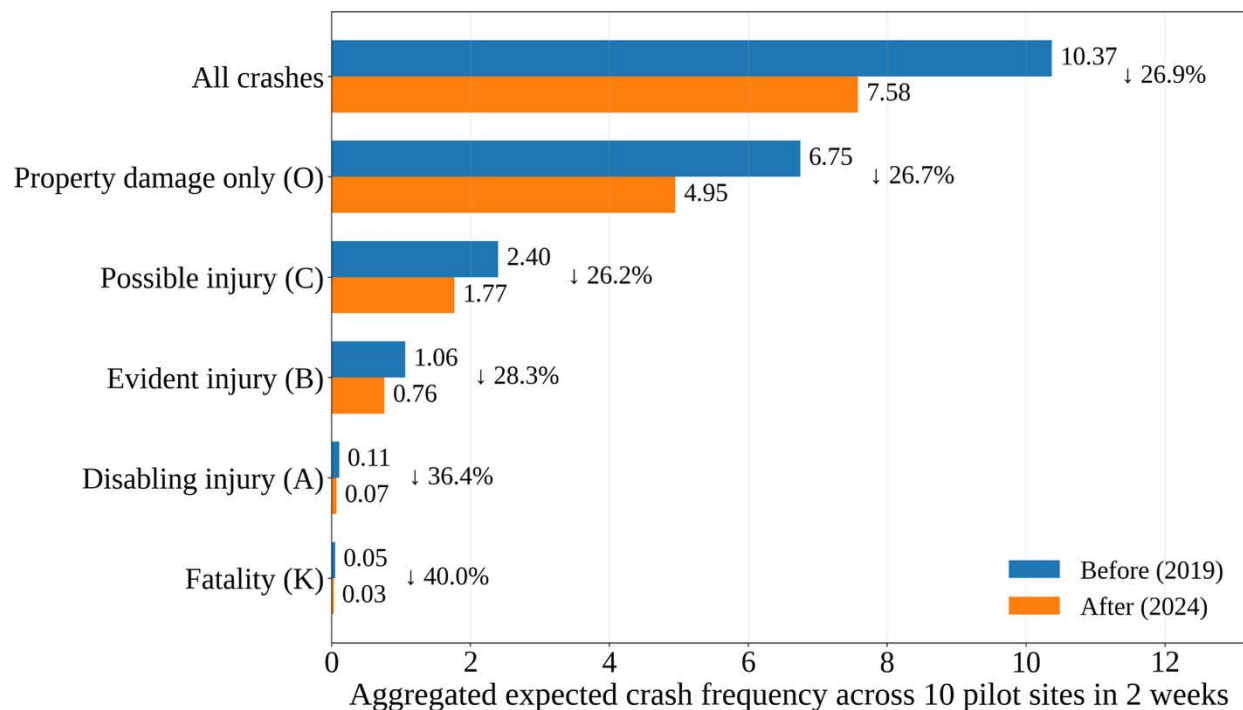


Figure 9 Aggregated expected crash counts by severity for the 10 pilot HSIP sites, before and after treatment.

The largest absolute reduction occurred for property-damage-only crashes because this was the most common severity category. However, the more severe categories also showed consistent proportional reductions. Expected fatal crashes decreased from 0.05 to 0.03, and expected disabling-injury crashes decreased from 0.11 to 0.07. These reductions should be interpreted cautiously because severe crashes are rare and the expected values are small, but the directional consistency across all severity categories supports the overall finding that the selected HSIP sites improved in the after period.

3.5 Risk-Factor Composition by Roadway Context

The pilot results also showed that the composition of risk factors varied by roadway context. Across both rural and urban groups, Speed Above Limit and Hard Braking accounted for most detected factors. Other

factors, including Rapid Acceleration, High Jerk, and Sharp Turning / Lane Change, were present but represented a smaller share of the aggregated factor counts. This pattern is important for implementation because it suggests that the tool can identify both speed-related and maneuver-related risk patterns, while also showing which factors dominate in a given site context.

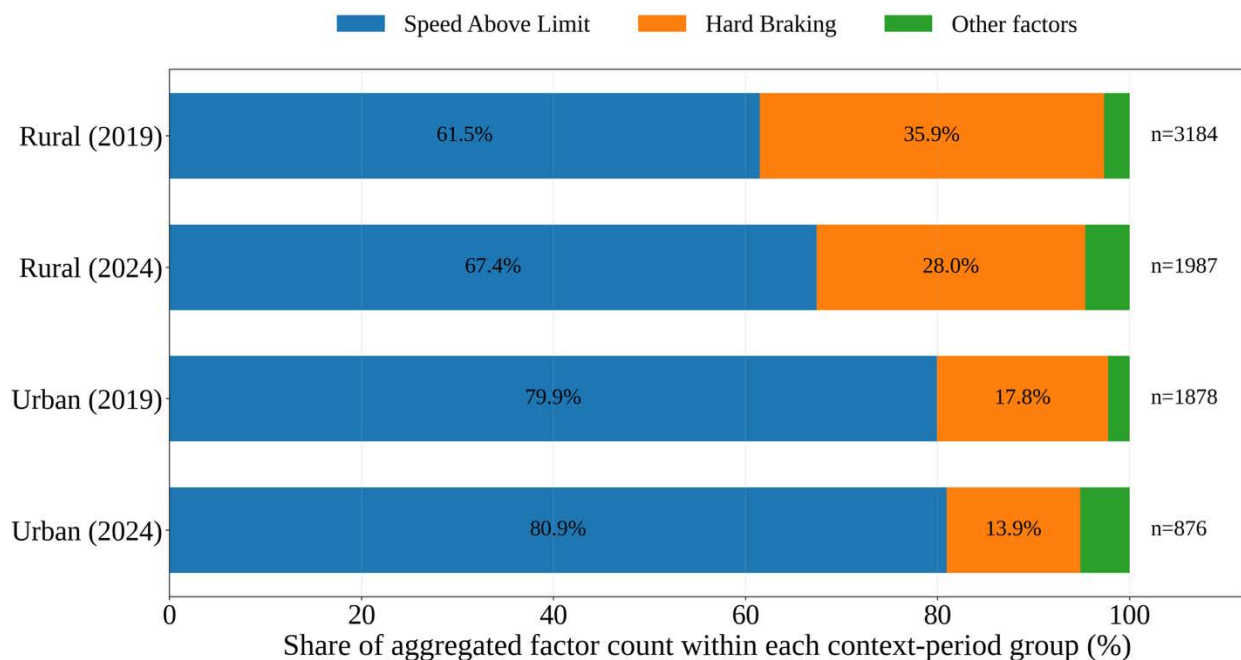


Figure 10 Aggregated risk-factor composition by roadway context and analysis period.

In the rural HSIP pilot group, Speed Above Limit accounted for 61.5% of aggregated factors in 2019 and 67.4% in 2024. Hard Braking accounted for 35.9% in 2019 and 28.0% in 2024. In the urban group, Speed Above Limit accounted for 79.9% of aggregated factors in 2019 and 80.9% in 2024, while Hard Braking accounted for 17.8% and 13.9%, respectively. These results indicate that speeding-related behavior remained the dominant factor category in both roadway contexts, but the relative share of braking events was higher in rural sites than in urban sites for the HSIP pilot set.

The interpretation of factor composition should consider site geometry, roadway class, speed environment, and treatment type. A high Speed Above Limit share may indicate a corridor-level operating-speed issue, while a high Hard Braking share may indicate locations where drivers encounter unexpected slowing, turning traffic, queues, signal changes, or complex intersection operations. The ability to distinguish these patterns is one of the main practical benefits of the telematics-based approach.

3.6 Overall Findings from the Results

The combined results from the threshold calibration, hotspot pilot, and HSIP pilot support four overall findings.

- First, telematics-derived risk factors can be calibrated using local crash data. The acceleration and braking thresholds selected for this project were not only distributionally reasonable but also showed the strongest association with Wisconsin crash occurrence in the threshold-sweep analysis.
- Second, the Risk Mitigation Hotspot Tool can identify meaningful differences in driving-risk patterns across roadway contexts. The six pilot sites showed different dominant factors, different normalized factor rates, and different spatial concentrations of events.
- Third, the Safety and Cost Mitigation Assessment Tool can combine behavioral factor summaries with crash-frequency and crash-cost outputs. Across the 10 HSIP pilot sites, all SMF and CMF values were below 1.0, indicating estimated improvement after treatment.
- Fourth, telematics-based outputs should be interpreted as supplemental evidence. The results are most useful when combined with crash history, roadway context, treatment information, exposure, field review, and engineering judgment.

Overall, the results demonstrate that telematics data can provide a practical behavioral layer for Wisconsin safety analysis. The tools developed in this project can support proactive hotspot screening, before-after project review, and communication of expected safety and cost changes. At the same time, the results should not be interpreted as a replacement for established WisDOT crash analysis or HSIP evaluation procedures. Instead, the telematics-based framework should be used to expand the evidence base available to safety practitioners.

3.7 Summary of Before-After Outcomes from the HSIP Pilot

Because the Safety and Cost Mitigation Assessment Tool was developed specifically to support project-level before-after review, the HSIP pilot provides one of the clearest demonstrations of the value of the framework. The before-after analysis should be interpreted as a pilot evaluation rather than a final causal assessment. Nevertheless, the results show that the tool can combine telematics-derived factor changes, exposure-normalized measures, predicted crash frequency, and predicted crash cost into a consistent site-level review.

Across the 10 HSIP pilot sites, the total number of detected telematics risk factors decreased from 10,632 in the 2019 before period to 5,537 in the 2024 after period, a reduction of approximately 47.9%. The expected monthly crash frequency decreased from approximately 10.37 to 7.58 crashes, and the expected monthly crash cost decreased from approximately \$1.75 million to \$1.30 million. These aggregate results are consistent with the site-level SMF and CMF values reported above, all of which were below 1.0. When adjusted SMF and CMF values are reported, they should be interpreted as the site change relative to similar comparison corridors. Values below 1.0 indicate that the treated site improved more than the

corresponding control group, while values above 1.0 indicate that the treated site improved less than the control group or worsened relative to the control trend.

Table 14 Aggregated before-after outcomes from the HSIP pilot evaluation

Measure	Before period	After period	Overall change / interpretation
Total detected risk factors	10,632	5,537	47.9% reduction in aggregated factor count
Expected monthly crash frequency	10.37 crashes	7.58 crashes	Approximately 26.9% reduction
Expected monthly crash cost	\$1.75 million	\$1.30 million	Approximately 25.7% reduction
SMF range across sites	N/A	0.48 to 0.94	All evaluated sites had SMF values below 1.0
CMF range across sites	N/A	0.48 to 0.95	All evaluated sites had CMF values below 1.0

The before-after results also show why multiple indicators are needed. A reduction in total factor count is useful, but it does not fully account for exposure, crash severity, or the different economic consequences of crash types. For this reason, the recommended interpretation is to review factor counts, normalized factor rates, affected-journey shares, expected crash frequency, and expected crash cost together. This integrated interpretation is especially important when factor counts are sparse, when the site boundary includes several roadway elements, or when the before and after datasets come from different telematics vendors.

The Task 6 pilot also showed that the tool can communicate safety change in terms that are meaningful for implementation. The SMF provides a compact measure of expected crash-frequency change, while the CMF translates the same before-after comparison into expected crash-cost change. Together, these outputs allow an analyst to identify whether a project appears to reduce both crash occurrence and crash consequences, and whether the largest estimated benefits are associated with crash-frequency reduction, crash-severity reduction, or both.

3.8 Additional Risk Mitigation Hotspot Tool Result Figures

The summary results in Section 3.2 show the factor counts and dominant factor types for the six Risk Mitigation Hotspot Tool pilot sites. To provide more direct evidence of the tool outputs, this subsection adds representative interface and site-level result figures from the Task 3 and Task 5 reports. These figures show how analysts select factor layers and thresholds, review mapped factor records, and interpret site-specific spatial concentrations of risk factors.

 Map Layers & Options

Crash

Recorded crash reports within the selected time range.

☐ Show


Rapid Acceleration

Triggered when longitudinal acceleration exceeds the threshold, representing aggressive speeding behavior.

☐ Low


ft/s²

☐ Medium


ft/s²

☐ High


ft/s²

Hard Braking

Triggered when longitudinal deceleration magnitude exceeds the threshold, representing abrupt braking behavior.

☐ Low


ft/s²

☐ Medium


ft/s²

☐ High


ft/s²

High Jerk

Triggered when longitudinal jerk exceeds the threshold, representing unstable acceleration or deceleration behavior.

☐ Low


ft/s³

☐ Medium


ft/s³

☐ High


ft/s³

Sharp Turning / Lane Change

Triggered when lateral acceleration exceeds the threshold, representing sharp turning or rapid lane-changing behavior.

☐ Low


ft/s²

☐ Medium


ft/s²

☐ High


ft/s²

Speed Above Limit

Triggered when the vehicle's speed exceeds the posted speed limit, representing speeding severity.

☐ Low


mph

☐ Medium


mph

☐ High


mph

Figure 11 Risk Mitigation Hotspot Tool factor-layer and severity-threshold controls.

The factor-layer panel allows users to display or hide each risk factor, including Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit. The same panel also allows users to review or adjust severity thresholds. This function is important because it makes the tool useful for both default screening and sensitivity testing.

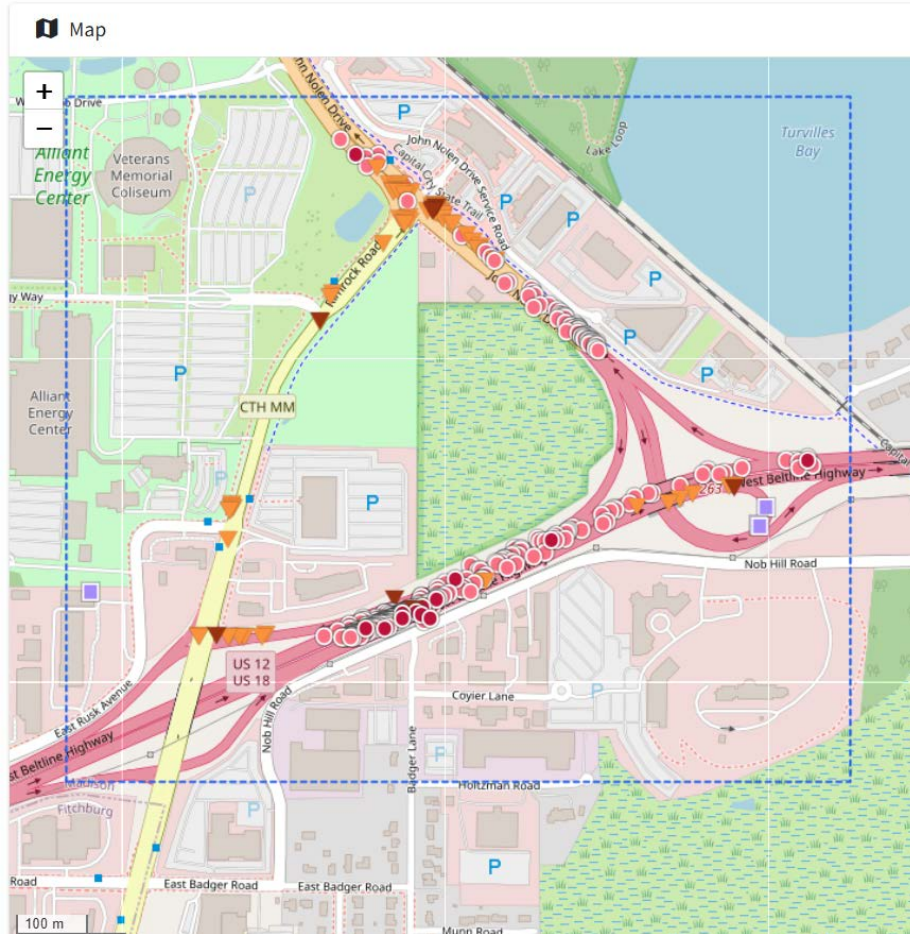


Figure 12 Example mapped risk-factor output from the Risk Mitigation Hotspot Tool.

The mapped output demonstrates how event-level factors are displayed after spatial, temporal, and factor-type filters are applied. Each point represents a sustained risk-factor event rather than a raw telematics point, which helps users focus on interpretable driving-behavior patterns.

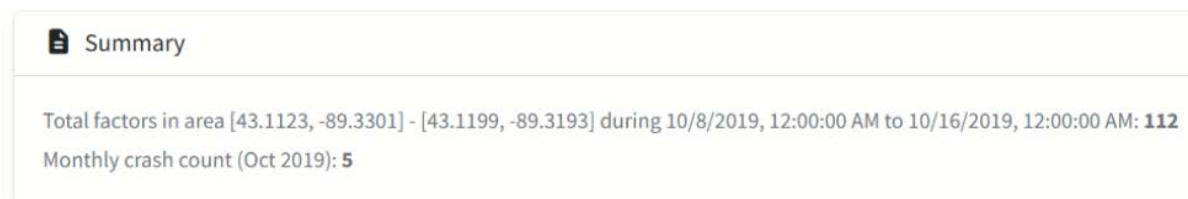
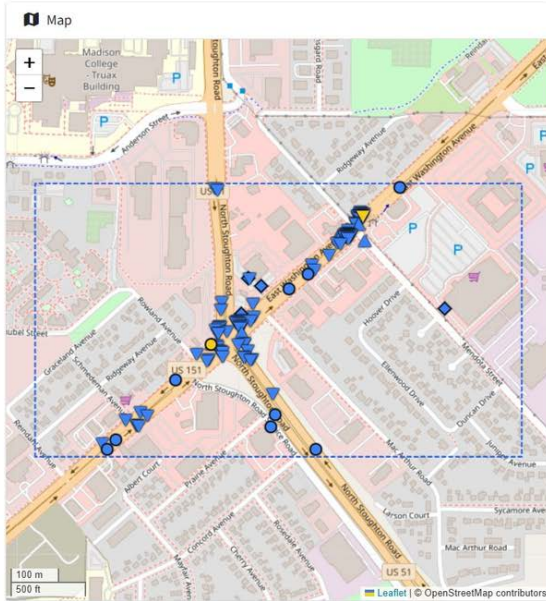


Figure 13 Example summary output from the Risk Mitigation Hotspot Tool.

The summary output provides a concise count of the factor records returned for the selected spatial and temporal query. Together with the map display, this output supports quick review of the number and type of risk factors detected within the user-defined area.

Urban Site 1: E. Washington & Mendota



Urban Site 2: Rimrock Road / US-18

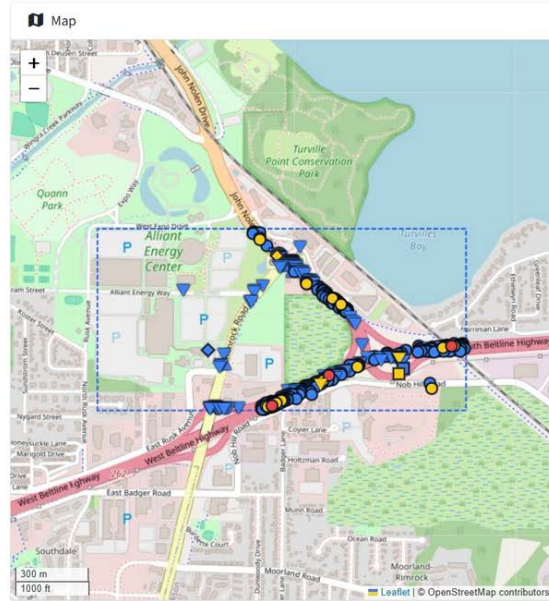
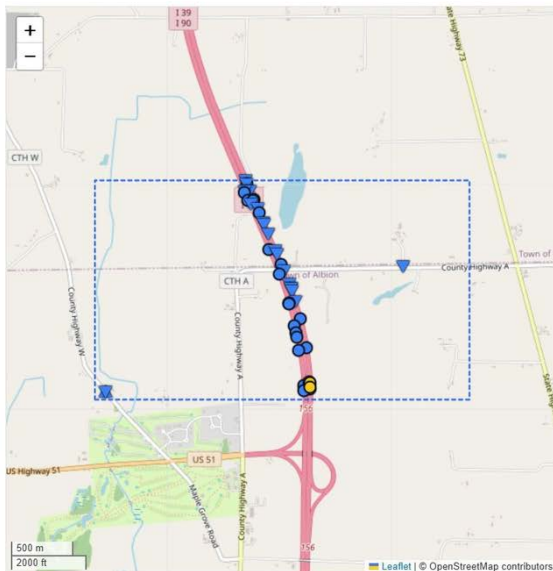


Figure 14 Detailed Tool 1 map outputs for two urban pilot sites.

The two urban examples show different spatial patterns. The E. Washington and Mendota site shows a concentrated pattern around the arterial intersection area, while the Rimrock Road / US-18 site shows factor records distributed along a corridor and interchange context. These differences illustrate why site-level map review is necessary in addition to aggregate factor-count summaries.

Rural Site 2: CTH PB & Red Stone Lane



Rural Site 3: WI-19 & WI-78

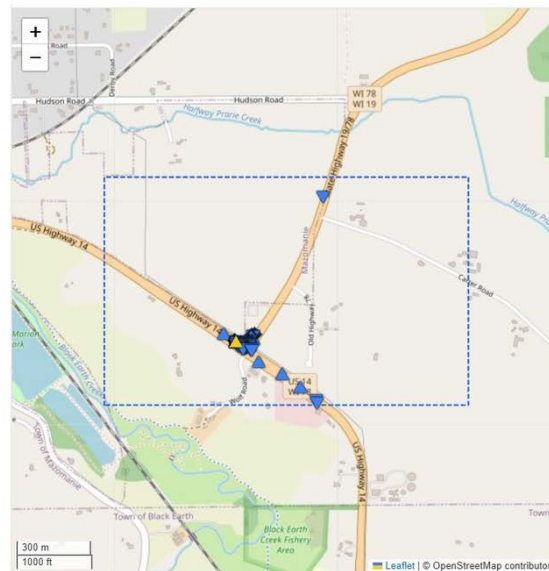


Figure 15 Detailed Tool 1 map outputs for two rural pilot sites.

The rural examples show that the tool can also identify risk-factor patterns outside dense urban networks. The CTH PB and Red Stone Lane site shows a strong vertical corridor pattern, while the WI-19 and WI-78 site shows a more localized intersection-related pattern. These outputs support the use of the hotspot tool across both rural and urban contexts.

3.9 Additional Safety and Cost Mitigation Assessment Tool Result Figures

The Safety and Cost Mitigation Assessment Tool was evaluated at 10 selected HSIP sites. Section 3.3 summarized the numerical before-after results. The following figures add the site-level map and tool-output panels from the Task 6 pilot evaluation. These panels show the before-period and after-period factor maps together with the corresponding SMF, CMF, expected crash, and expected cost outputs generated by the tool.



Figure 16 Risk-factor marker legend used in the Safety and Cost Mitigation Assessment Tool pilot maps.

The marker legend uses shape to distinguish factor type and color to distinguish severity. This visual encoding allows users to interpret factor composition and severity directly from the map outputs before reviewing the quantitative SMF and CMF results.

3.9.1 Site 1 Evaluation Output

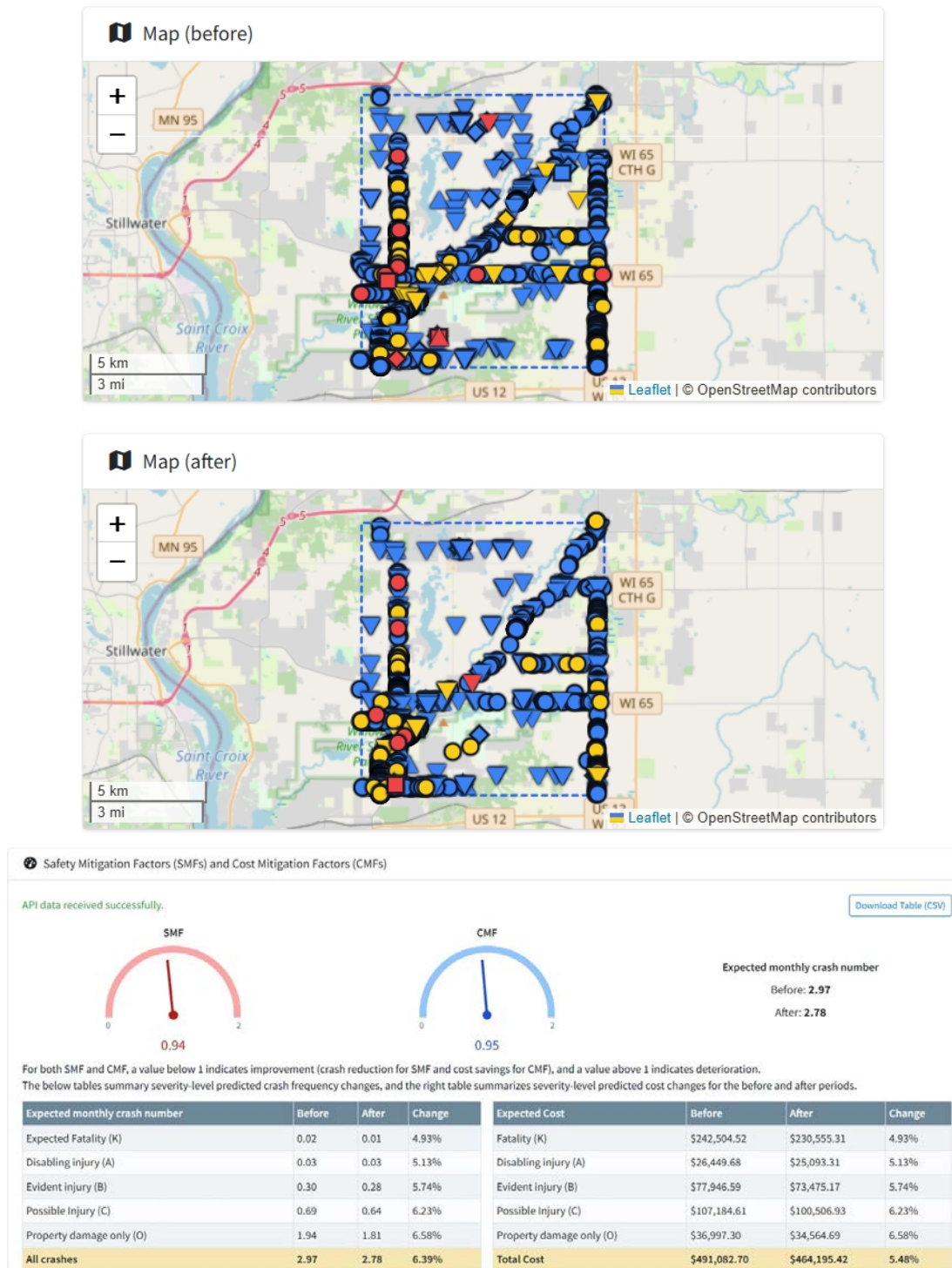


Figure 17 Safety and Cost Mitigation Assessment Tool output for Site 1: St. Croix: CTH U to Mackin Rd.

3.9.2 Site 2 Evaluation Output

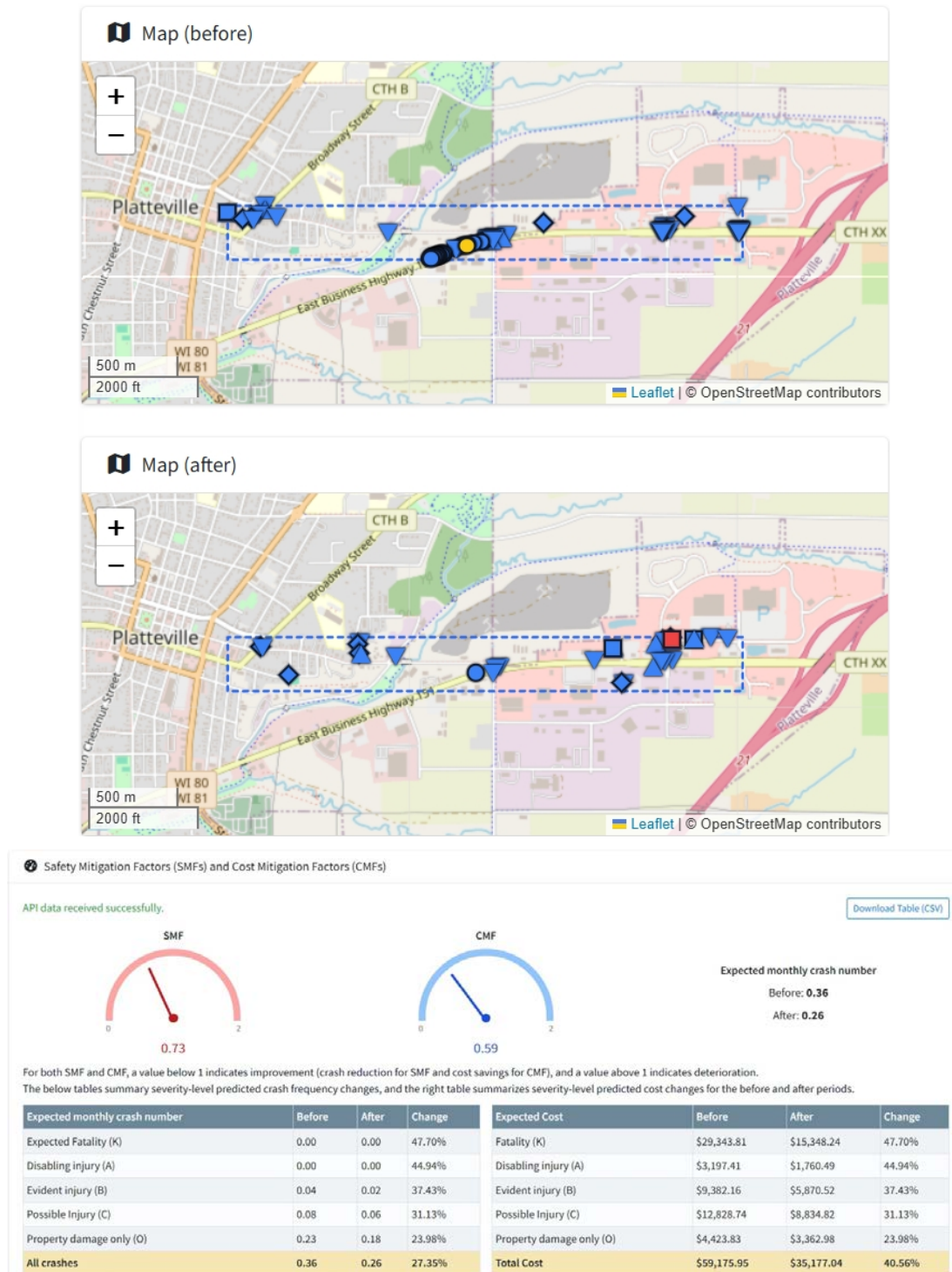


Figure 18 Safety and Cost Mitigation Assessment Tool output for Site 2: Grant: Platteville Business 151 corridor.

3.9.3 Site 3 Evaluation Output

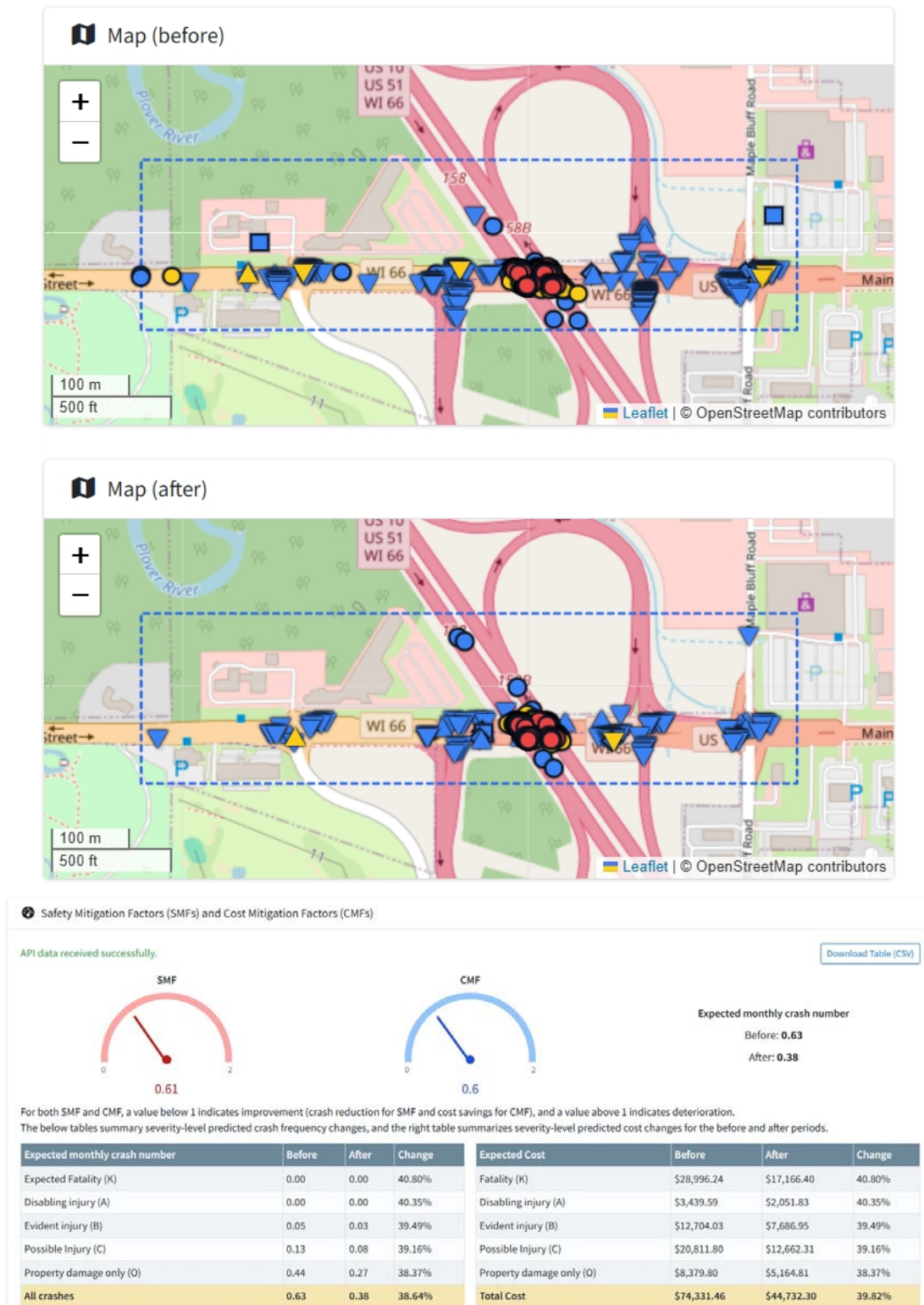


Figure 19 Safety and Cost Mitigation Assessment Tool output for Site 3: Portage: US 51 / WI 66 interchange area.

3.9.4 Site 4 Evaluation Output

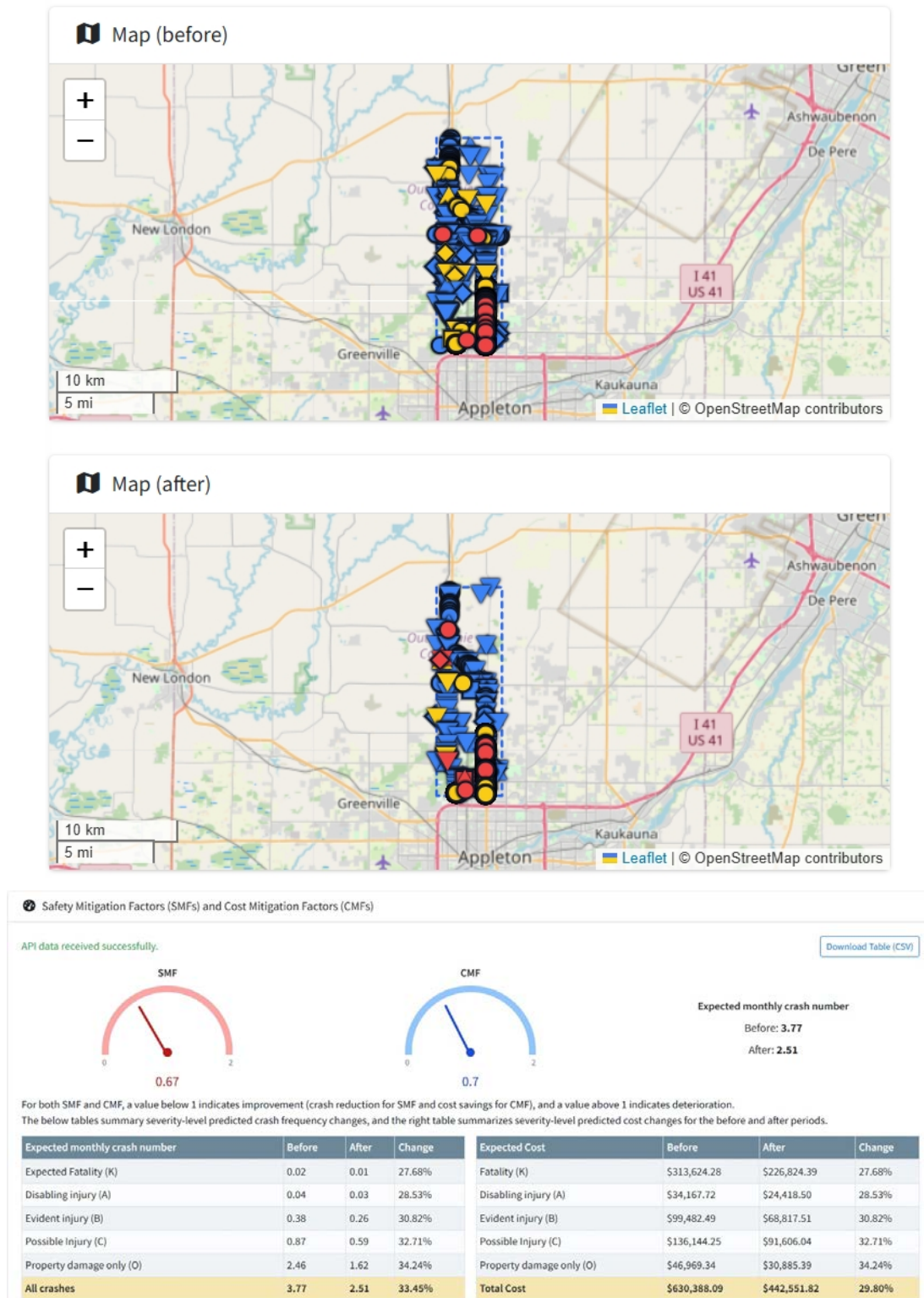


Figure 20 Safety and Cost Mitigation Assessment Tool output for Site 4: Outagamie: STH 47 corridor.

3.9.5 Site 5 Evaluation Output

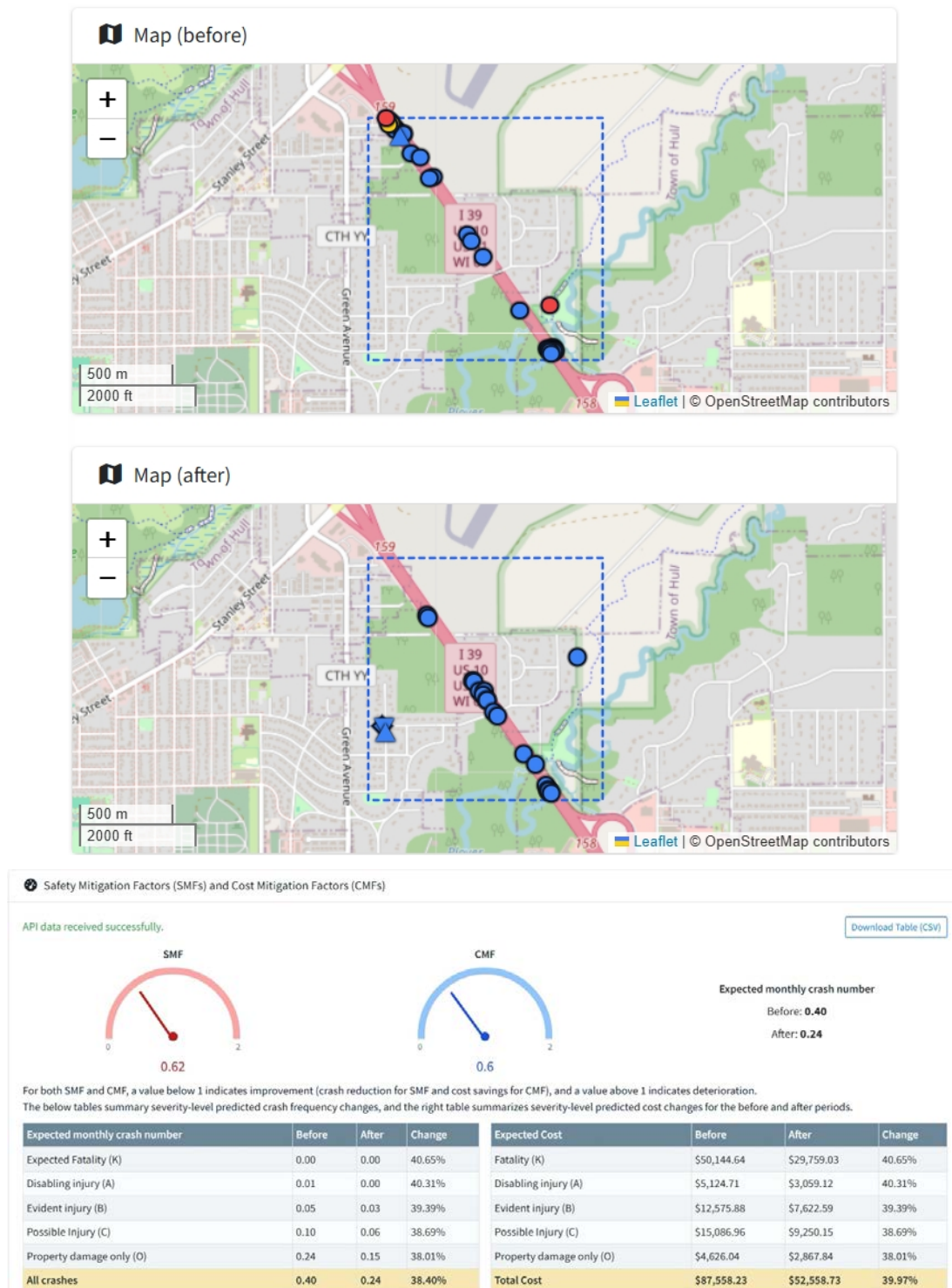


Figure 21 Safety and Cost Mitigation Assessment Tool output for Site 5: Portage: Elk Road to Division Street.

3.9.6 Site 6 Evaluation Output

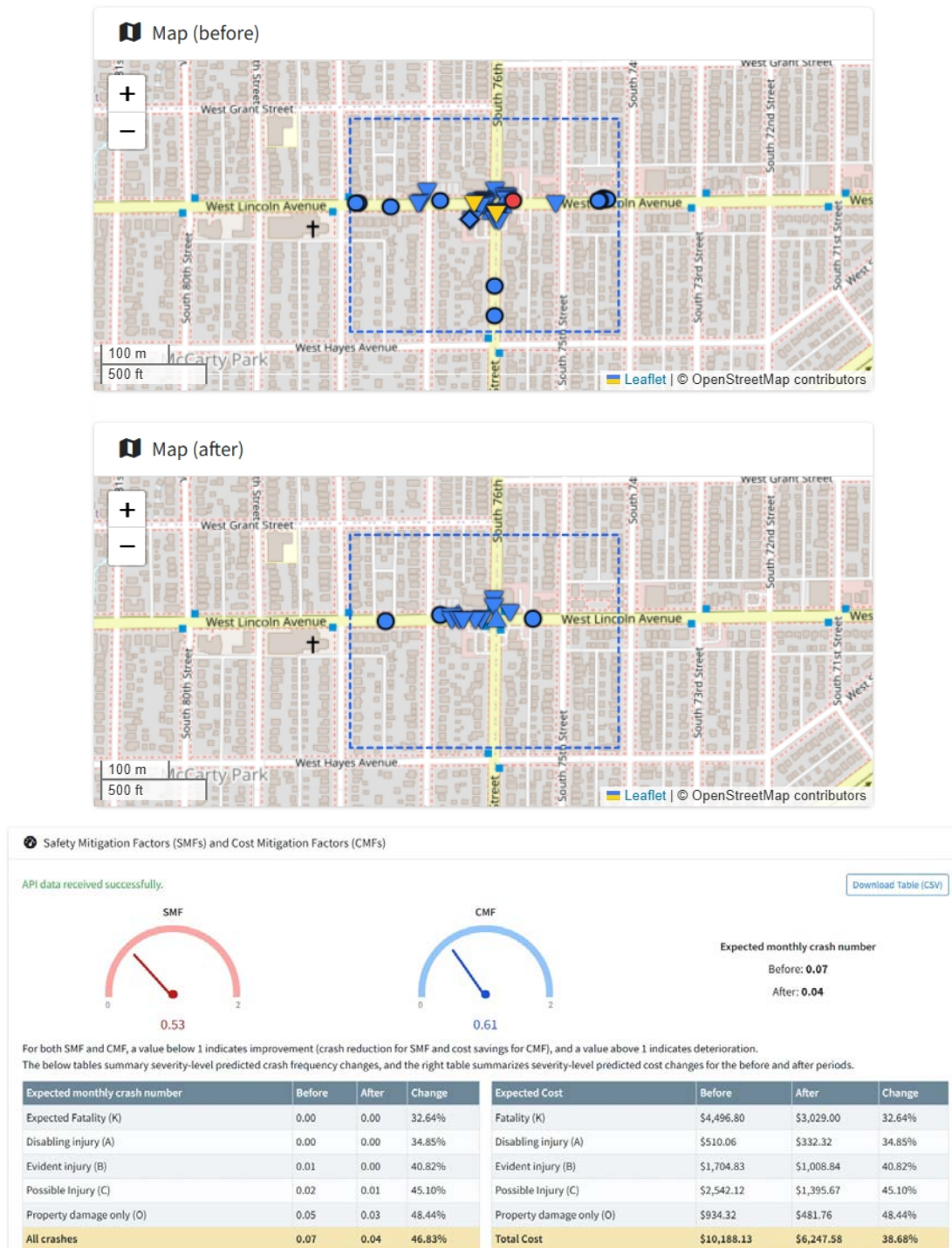


Figure 22 Safety and Cost Mitigation Assessment Tool output for Site 6: Milwaukee: W. Lincoln Avenue intersections.

3.9.7 Site 7 Evaluation Output

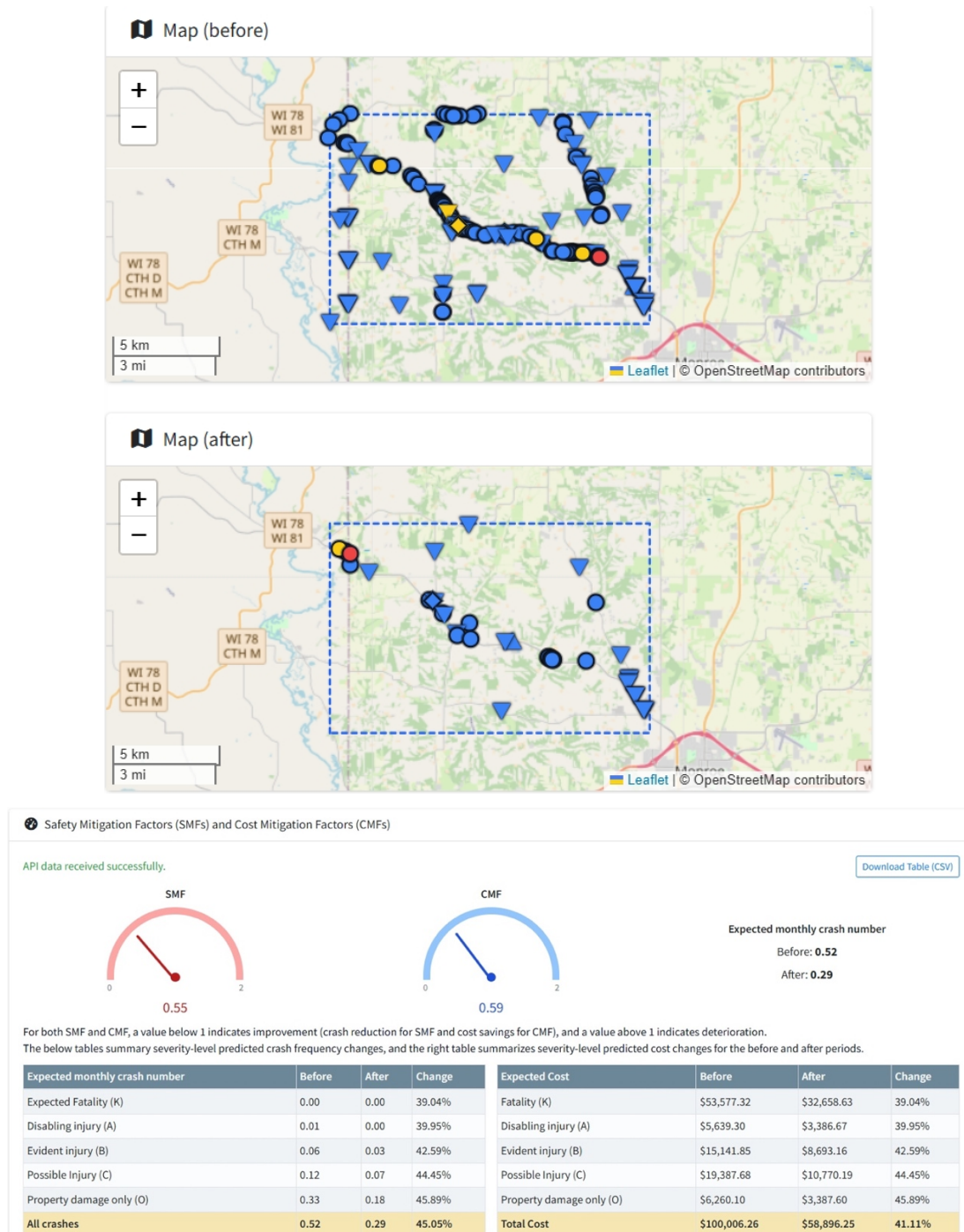


Figure 23 Safety and Cost Mitigation Assessment Tool output for Site 7: Green: STH 81 corridor.

3.9.8 Site 8 Evaluation Output

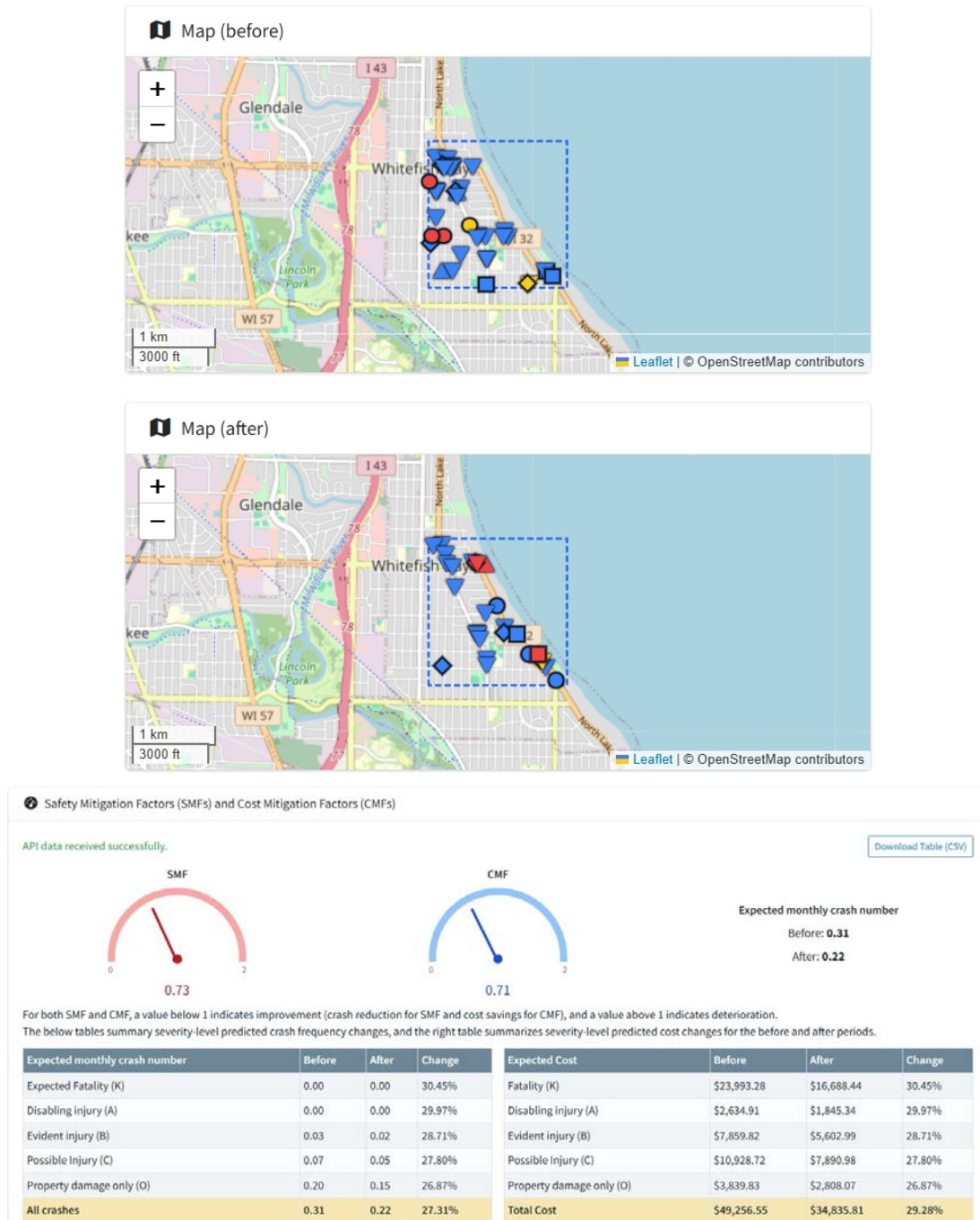


Figure 24 Safety and Cost Mitigation Assessment Tool output for Site 8: Milwaukee: Lake Drive corridor.

3.9.9 Site 9 Evaluation Output

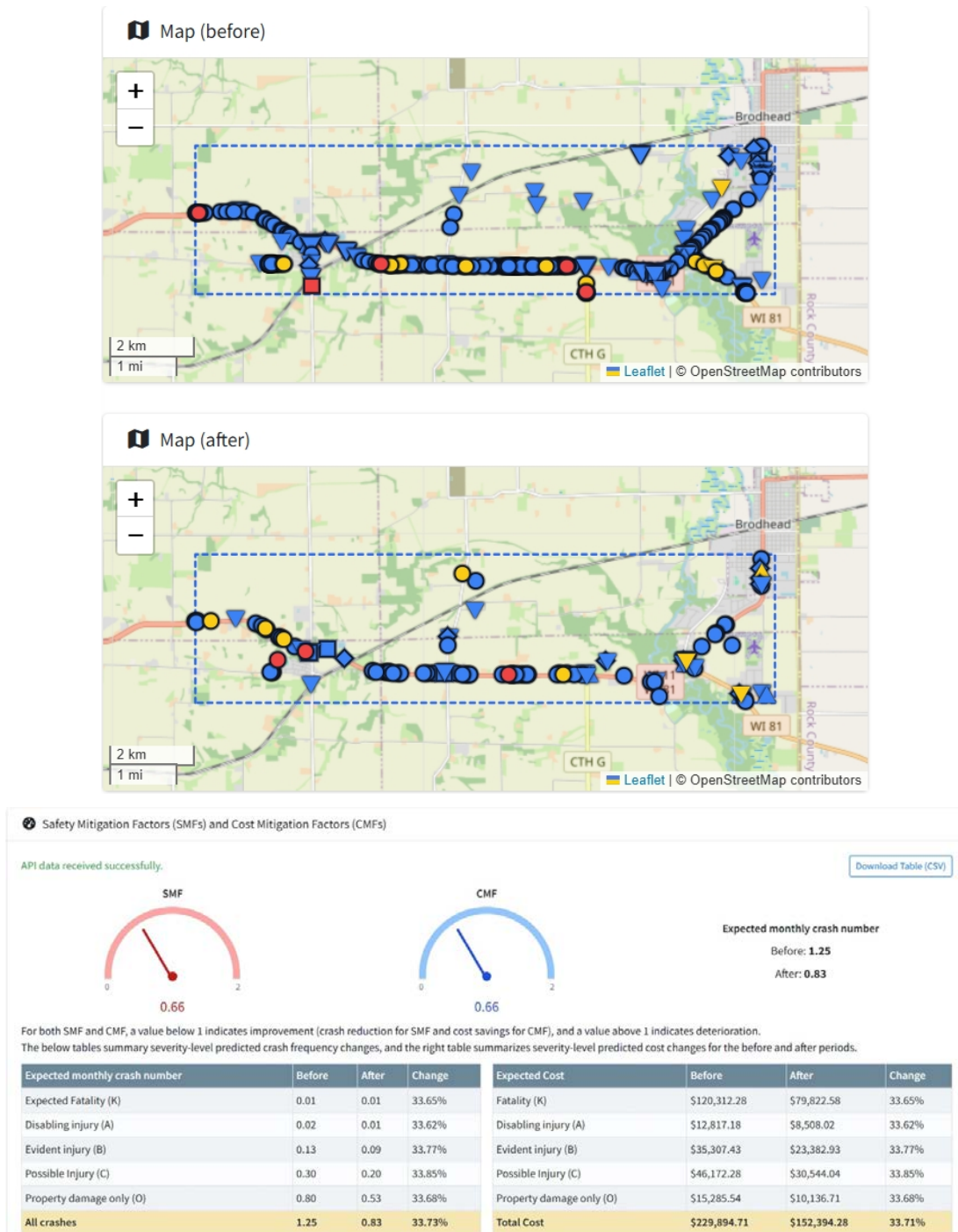


Figure 25 . Safety and Cost Mitigation Assessment Tool output for Site 9: Green: STH 11 Monroe-Brodhead corridor.

3.9.10 Site 10 Evaluation Output

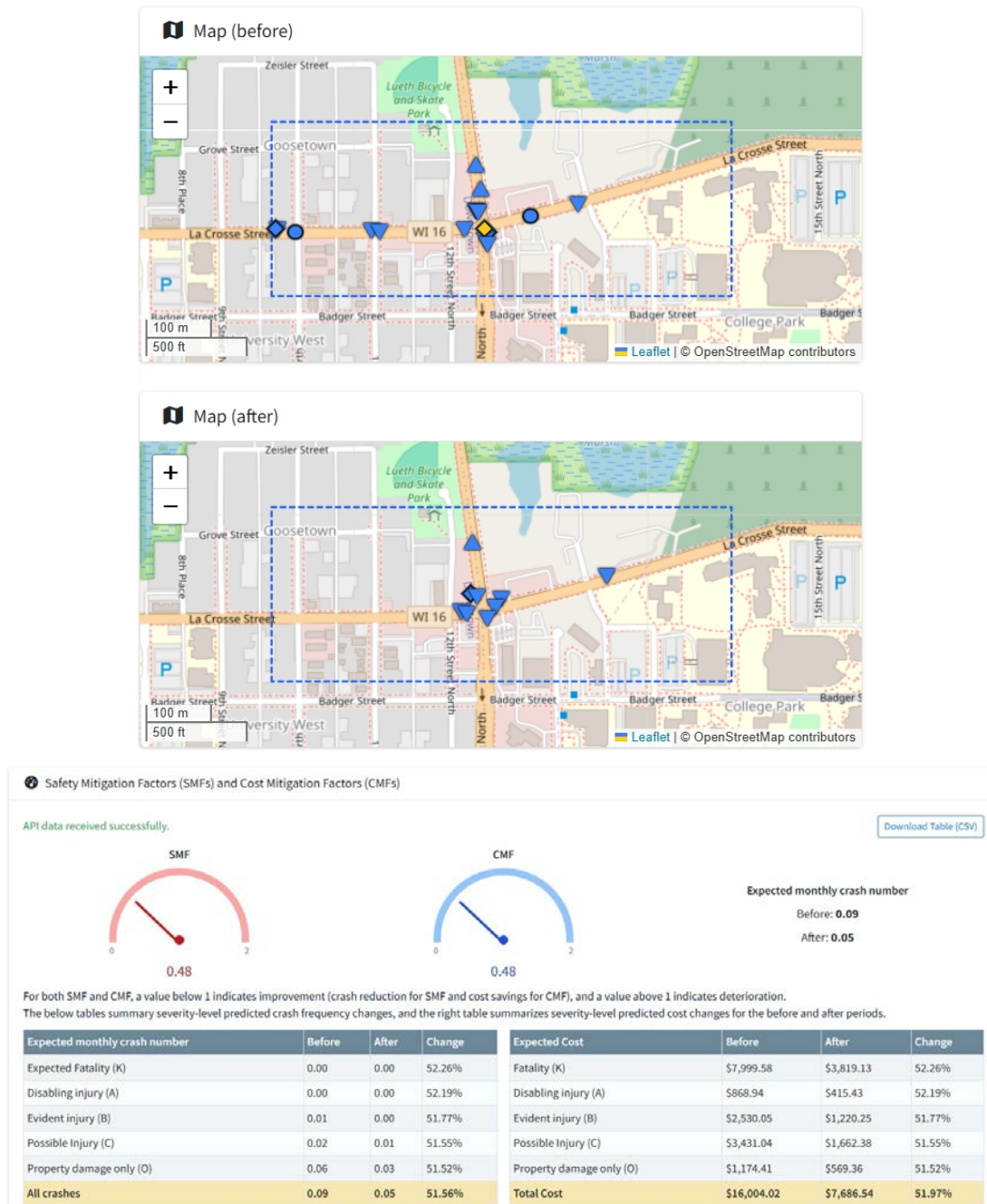


Figure 26 Safety and Cost Mitigation Assessment Tool output for Site 10: La Crosse: STH 16 intersection.

3.10 Interpretation of the Additional Result Figures

The additional figures reinforce the main findings from the numerical analysis. For Tool 1, the map outputs show that risk factors are not uniformly distributed across the roadway network. Instead, events cluster around intersections, ramps, corridors, and other operationally meaningful locations. For Tool 2, the site-level outputs show that the before-after workflow can present maps, predicted crash changes,

predicted cost changes, and mitigation factors in a single reviewable format. This combined presentation is important for implementation because it allows analysts to verify whether model outputs are supported by observable factor patterns at the site level.

The expanded visual results also highlight the importance of using telematics-derived indicators as supplemental evidence. A site may show a large reduction in raw factor counts, a smaller reduction after exposure normalization, or a favorable SMF/CMF result driven by the crash-frequency model. Reviewing the maps, tables, and mitigation factors together gives a more reliable interpretation than relying on any single output alone.

4. Conclusions and Implementable Recommendations

This project developed and piloted a telematics-based safety analysis framework for WisDOT. The framework was designed to supplement traditional crash-based safety analysis by adding a behavioral layer derived from large-scale vehicle trajectory data. The project included literature review, local risk-factor definition, data processing, web-tool development, hotspot pilot testing, and before-after safety and cost evaluation at selected HSIP sites.

4.1 Conclusions

The project supports the following conclusions.

- Telematics data can provide useful supplemental safety information. The project demonstrated that vehicle movement data can be converted into interpretable safety indicators such as Rapid Acceleration, Hard Braking, High Jerk, Sharp Turning / Lane Change, and Speed Above Limit. These indicators are not a replacement for crash records, but they can help identify behavioral patterns that are not visible from crash data alone.
- Local calibration is important. The Task 2 analysis showed that acceleration and braking thresholds should not be copied directly from prior studies or vendor defaults. Using Wisconsin telematics data and Wisconsin crash records, the project identified locally calibrated thresholds of 0.22 g for rapid acceleration and 0.24 g for hard braking. These values provide a stronger basis for Wisconsin implementation than thresholds selected only from the literature.
- Event-level processing makes telematics data more usable for safety analysis. Raw trajectory data are too large and too noisy for direct interpretation by most safety practitioners. The project converted point-level observations into grouped event-level factor records, which made it possible to summarize risk patterns by site, factor type, severity, time period, roadway context, exposure, and journey count.
- The Risk Mitigation Hotspot Tool can identify site-specific driving-risk patterns. The six-site pilot showed that different roadway contexts produced different dominant factors. Urban intersections and

corridors often showed substantial Hard Braking activity, while rural or higher-speed sites often showed higher Speed Above Limit activity. These differences indicate that the tool can support exploratory screening rather than simply counting the same type of event at every location.

- Exposure normalization is necessary for interpretation. Total factor counts alone can be misleading because high-volume locations naturally generate more observations and more factor events. Measures such as factors per 1,000 VMT, factors per 100 journeys, and affected-journey share help compare sites with different traffic volumes and observed telematics sample sizes.
- The Safety and Cost Mitigation Assessment Tool can support before-after project review. The 10-site HSIP pilot showed that the tool can combine telematics-derived factor summaries with predicted crash frequency and crash cost. In the pilot, all evaluated sites had SMF and CMF values below 1.0, indicating estimated reductions in both expected crash frequency and expected crash cost after treatment.
- The Task 6 before-after results were directionally consistent with the intended use of HSIP treatments. Across the 10 pilot sites, expected monthly crash frequency decreased from approximately 10.37 to 7.58 crashes, and expected monthly crash cost decreased from approximately \$1.75 million to \$1.30 million. The analysis also showed reductions across crash severity categories, including property-damage-only, possible-injury, evident-injury, disabling-injury, and fatal crashes.
- Telematics-based results require careful interpretation. Differences in vendor coverage, sampling frequency, vehicle population, spatial accuracy, observation period, and site boundary definition can affect the results. The before-after pilot used Wejo data for 2019 and StreetLight data for 2024; therefore, vendor differences should be considered when interpreting changes over time.

4.2 Implementable Recommendations

The following recommendations are intended to support practical implementation by WisDOT and local partners.

- Use telematics-derived factors as a supplemental screening layer. WisDOT should use the Risk Mitigation Hotspot Tool to support early identification of locations with concentrated risky driving behaviors. The tool should be used alongside crash history, roadway characteristics, field review, and engineering judgment rather than as a stand-alone ranking method.
- Adopt a standard reporting package for hotspot review. Each hotspot review should include a map of factor locations, total factor counts, factor counts by type and severity, factors per 1,000 VMT, factors per 100 journeys, affected-journey share, and a brief interpretation of the dominant factor pattern.
- Apply the before-after workflow to selected safety projects. The Safety and Cost Mitigation Assessment Tool should be used as a supplemental evaluation method for selected HSIP or safety

improvement projects, particularly when agencies want earlier behavioral evidence before multiple years of post-construction crash data are available.

- Use consistent before and after periods where feasible. When possible, the same vendor, comparable months, similar day-of-week coverage, and comparable spatial boundaries should be used for before-after analysis. If different vendors or observation windows are required, the report should explicitly document those differences.
- Maintain the locally calibrated risk-factor definitions as the initial default settings. The 0.22 g rapid-acceleration threshold and 0.24 g hard-braking threshold should be retained as Wisconsin default values until a larger validation dataset supports refinement. The tool should continue to allow threshold adjustment for sensitivity testing and context-specific review.
- Report both raw and exposure-normalized metrics. Total factor counts are useful for understanding event volume, but exposure-normalized measures are necessary for comparing different locations. WisDOT should require both types of outputs in standard tool reports.
- Continue model validation as more sites become available. The crash-frequency and crash-cost models should be updated as additional HSIP sites, treatment types, road classes, and telematics observation periods are added. Validation should examine whether model performance differs by urban/rural context, roadway type, traffic control, and treatment category.
- Protect privacy through aggregation and restricted use. Telematics outputs should be reported at aggregate site, segment, corridor, or project levels. The framework should not be used to identify individual drivers, vehicles, or trips. Privacy-preserving aggregation should remain a core requirement for any future deployment.
- Provide staff training and user documentation. Implementation will be more effective if WisDOT analysts and local agency users receive concise guidance on how to select a study area, interpret factor maps, read normalized metrics, understand SMF and CMF values, and document limitations.
- Integrate the tools with existing WisDOT safety workflows. The greatest practical value will come from using telematics outputs together with WisTransPortal crash data, roadway inventory data, traffic volume data, Community Maps, HSIP project records, and field review notes.

4.3 Suggested Implementation Pathway

A phased implementation pathway is recommended so that WisDOT can use the project outputs while continuing to improve data quality, model validation, and user guidance.

Table 15 Suggested implementation pathway for telematics-based safety analysis

Implementation phase	Main actions	Expected outcome
Short term	Maintain the two web tools; preserve the current database structure; prepare user guidance; apply the tools to selected pilot screening and HSIP review cases.	Operational use of the tools for targeted, analyst-led safety review.
Medium term	Expand the number of evaluated sites; standardize before-after reporting; compare results across roadway types and treatment categories; validate model outputs against additional crash data.	Improved confidence in thresholds, factor interpretation, and SMF/CMF outputs.
Long term	Develop recurring data refresh procedures; integrate tool outputs into WisDOT safety dashboards or GIS workflows; support broader statewide screening where data coverage is sufficient.	A scalable telematics-based safety monitoring layer that complements existing safety management systems.

4.4 Limitations and Future Improvements

The project findings should be interpreted in light of several limitations. First, telematics data coverage is not uniform across vendors, years, locations, vehicle types, or trip purposes. Differences between the 2019 Wejo data and the 2024 StreetLight data may affect before-after comparisons. Second, sampling frequency and spatial accuracy can influence acceleration, jerk, turning, and speed-related measures. Third, the pilot before-after analysis included 10 HSIP sites, which is sufficient to demonstrate the workflow but not sufficient to support final statewide calibration by treatment type.

Fourth, the available telematics data did not consistently include several potentially useful safety-related indicators, such as driver distraction, lane keeping, ABS activation, ESC activation, or direct near-crash warnings. Fifth, severe crashes are rare, so severity-specific estimates for fatal and suspected serious injury crashes should be interpreted cautiously, especially when expected values are small. Finally, the SMF and CMF outputs are model-based estimates and should not be interpreted as definitive causal effects without additional validation.

Future work should expand the number of pilot sites, use longer and more consistent observation periods, evaluate sensitivity to vendor and sampling differences, refine risk-factor thresholds by roadway context, and improve crash-frequency and crash-cost model validation. Future deployments could also add automated quality-control checks, standardized exportable reports, and direct links to WisDOT crash and roadway data platforms.

4.5 Closing Statement

Overall, this project demonstrates that telematics data can be transformed into practical, interpretable, and implementation-oriented safety information for Wisconsin. The two tools developed in the project provide a starting point for incorporating large-scale driving behavior data into hotspot screening and before-after safety evaluation. Used appropriately, the framework can help WisDOT identify behavioral risk patterns earlier, evaluate safety projects with additional evidence, and communicate expected safety and cost impacts in a consistent and data-driven manner.

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Appendix A. Supplementary Materials

In addition to this final report, the project deliverables include a supplementary digital package that supports implementation, review, and future maintenance of the telematics-based safety analysis tools. The supplementary materials are provided as separate files and are not reproduced in full in this appendix.

The supplementary package includes the backend/database code package, frontend website code package, two README files, and two demonstration videos for the web-based tools. The README files serve different purposes. **README.md** is intended as the quick-start entry point for WisDOT users. It provides the most essential steps for starting the system, including how to run the Tool 1 backend, run the Tool 2 backend, run the frontend website, check the main ports, and verify basic health-check endpoints.

DOT_DELIVERY_README.md is the full delivery and operation manual. It provides more detailed documentation on the frontend and backend architecture, proxy routes, environment variables, included and excluded data directories, demo mode, troubleshooting, deployment notes, and pipeline reference information.

Table 16 Supplementary materials provided with the final report

File name	Description
Backend Database.zip	Contains backend and database-related files used to support data processing, database connection, risk-factor querying, backend APIs, and tool outputs.
Frontend Website.zip	Contains frontend website files used to operate the browser-based user interface for the Risk Mitigation Hotspot Tool and the Safety and Cost Mitigation Assessment Tool.
README.md	Provides the quick-start entry point for WisDOT users. It includes the most important startup steps, including running the Tool 1 backend, running the Tool 2 backend, running the frontend website, checking ports, and confirming health-check endpoints.
DOT_DELIVERY_README.md	Provides the full delivery and operation manual. It includes detailed information on frontend/backend architecture, proxy routes, environment variables, included data directories, excluded data, demo mode, troubleshooting, deployment notes, and pipeline reference information.
Demo Video - Tool 1.mp4	Demonstrates the Risk Mitigation Hotspot Tool, including study-area selection, time-window selection, factor-layer display, severity-threshold review, map interpretation, and summary-output review.
Demo Video - Tool 2.mp4	Demonstrates the Safety and Cost Mitigation Assessment Tool, including before-after input selection, risk-factor map review, Safety Mitigation Factor output, Cost Mitigation Factor output, expected crash-frequency results, and expected crash-cost results.

The code packages are provided separately from the report to avoid including lengthy implementation files in the appendix. Users should begin with **README.md** for quick startup and basic navigation. If more detailed information is needed for deployment, troubleshooting, data organization, or long-term maintenance, users should refer to **DOT_DELIVERY_README.md**.

Together, the supplementary code packages, README documentation, and video demonstrations provide the materials needed to review, reproduce, operate, and maintain the web-based tools developed in this project.