massDOT
Massachusetts Department of Transportation

Final Report

State and Local Government Data Analysis Tools to Support Policy and Decision Making for Roadway Safety – MassDOT IMPACT Safety Analysis Module

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16. Abstract

The Massachusetts Department of Transportation (MassDOT) identified the need to build safety analysis tools into the recently-developed Interactive Mapping Portal for Analysis and Crash Tracking (IMPACT) Crash Data Portal. MassDOT worked with highway safety stakeholders to summarize their needs then developed four tools to be added: Crash-Based Network Screening Maps, Risk-Based Network Screening Maps, a Crash Tree Maker, and a Test of Proportions Tool. MassDOT contracted with VHB to perform the supporting safety analysis and develop the proposed IMPACT tools with funding from the United States Department of Transportation (USDOT) Safety Data Initiative. MassDOT used Empirical Bayes methods to develop crash-based network screening maps and systemic safety analysis techniques to develop risk-based network screening maps. MassDOT developed the tools using an Agile project management approach using the Angular library. MassDOT learned and summarized numerous lessons from this project. Additionally, MassDOT is planning improvements to these tools in a future development phase of IMPACT.

The tools described herein can be accessed at https://apps.impact.dot.state.ma.us/cdp/home.

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INTRODUCTION

This document is the Final Report describing the approach the Massachusetts Department of Transportation (MassDOT) took to develop and implement the IMPACT Safety Analysis Module. This document includes:

- A review of the safety problem statement and research questions.
- A review of the knowledge gaps identified entering this project.
- A description of the end products and how they address the knowledge gaps.
- A brief summary of the data and methodology used for the supporting safety analysis.
- A review of the tools, highlighting insights users can gain and how the tools can be used for project, program, and policy decision making.
- A summary of lessons learned and challenges to the analysis and tool development.
- Links to the tools and the reports summarizing the safety analysis.

MassDOT contracted VHB to assist with the work described in this document.

SAFETY PROBLEM STATEMENT

In 2018, the Commonwealth of Massachusetts updated their Strategic Highway Safety Plan (SHSP) and established 2022 short-term goals of reducing fatalities and serious injuries by 12 percent and 21 percent, respectively, and a long-term goal of achieving zero roadway fatalities. These would be significant reductions, as Massachusetts has failed to achieve such reductions over the past years, as evidenced by the fatality data shown in Figure 1 and the serious injury data shown in Figure 2. Massachusetts has seen some success reducing serious injury rates; however, fatality rates have stayed consistent over previous years (see Figure 3).

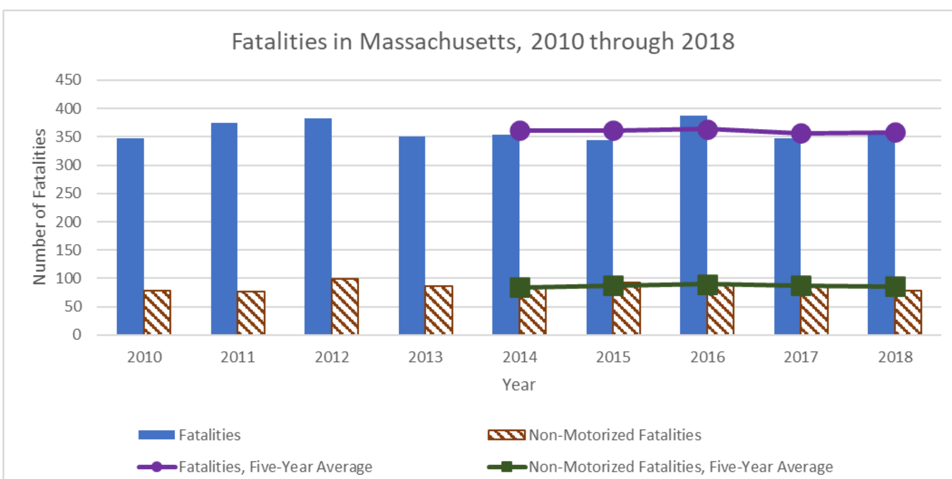

Figure 1. Summary of Massachusetts highway fatalities between 2010 and 2018.

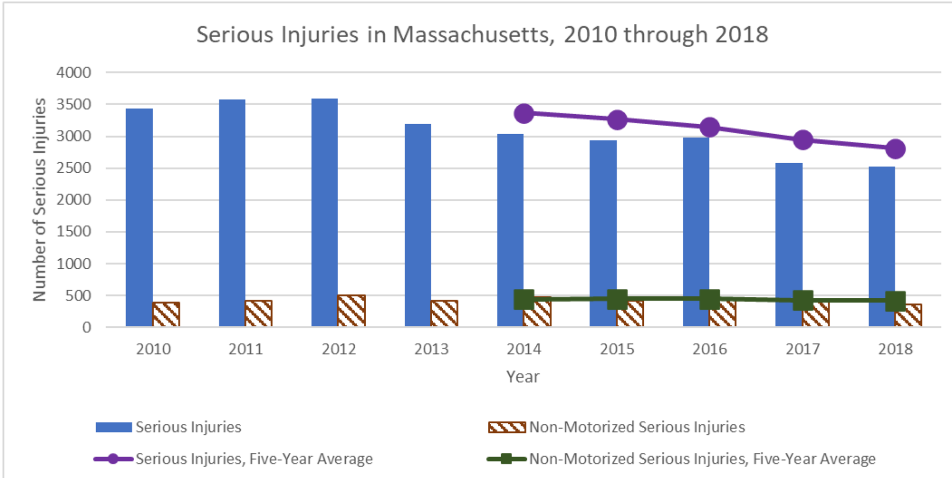

Figure 2. Summary of Massachusetts highway serious injuries between 2010 and 2018.

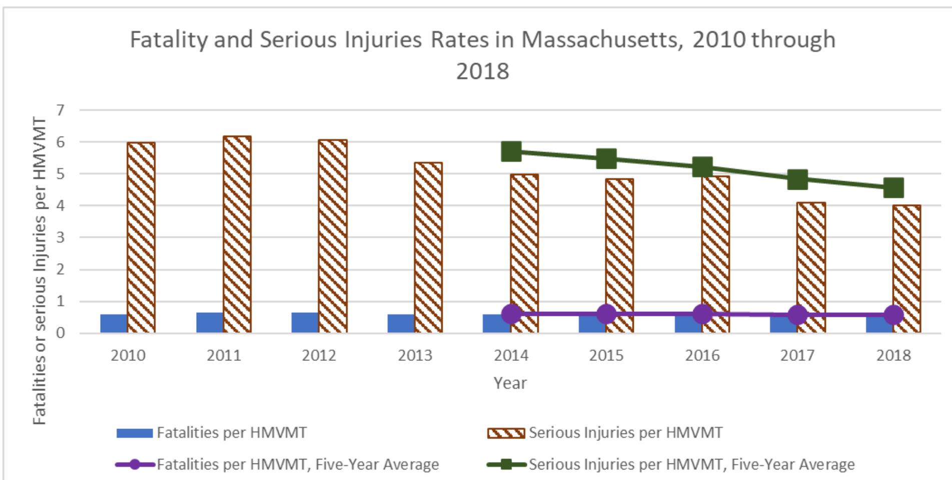

Figure 3. Summary of Massachusetts highway fatality and serious injury rates between 2010 and 2018.

To counteract this stagnation and focus their efforts, Massachusetts identified 14 emphasis areas based on annual fatalities and serious injuries:

- Lane Departure Crashes
- Motorcycle Crashes
- Occupant Protection
- Younger Drivers
- At-Grade Rail Crossings
- Impaired Driving
- Speeding and Aggressive Driving
- Driver Distraction
- Safety of Persons Working on Roadways
- Bicyclists
- Large Truck-Involved Crashes

- Older Drivers
- Intersection Crashes
- Pedestrians

MassDOT aspired to empower their safety partners to use a data-driven approach to the roadway safety management process, specifically to develop strategies and safety improvement projects to address these emphasis areas. The best opportunity to do this is through IMPACT, a crash data portal designed to encourage public safety initiatives and crash information awareness. Users engage with crash-related data through easy-to-understand pre-built dashboards and reports or conduct their own self-driven analysis.

After IMPACT launched in 2019, MassDOT worked with safety partners to identify potential improvements to address their needs. MassDOT identified the needs of three user groups to address through the United States Department of Transportation's (USDOT) "*State and Local Government Data Analysis Tools to Support Policy and Decision Making for Roadway Safety*" funding opportunity:

- Regional Planning Agencies (RPAs), Metropolitan Planning Organizations (MPOs), and other local agencies.
- Law Enforcement Agencies (LEAs).
- Emphasis Area Action Teams (EAATs) of the SHSP.

MassDOT used this funding to expand IMPACT with a Safety Analysis Module. MassDOT used systemic safety analysis to identify risk factors for most SHSP emphasis areas and developed maps which identified priority sites based on risk. MassDOT also provided planning and diagnostic tools for users to identify potential sites for safety improvement projects, common contributing factors, and common times and locations. Agencies and teams using this Safety Analysis Module can gain detailed insight about safety problems in their emphasis area or jurisdiction, empowering them to develop engineering, education, and enforcement solutions to reduce fatalities and serious injuries.

EXISTING APPROACH AND KNOWLEDGE GAPS

The new Safety Analysis Module of IMPACT supports three types of partners: MPOs/RPAs, LEAs, and EAATs.

RPAs and MPOs

MassDOT identifies locations for needed safety improvements and MPOs/RPAs ideate safety improvement projects for those locations, commonly done through network screening. Previously, MassDOT used separate network screening approaches for intersections and roadway segments. For segments, the approach was naïve and labor intensive. MassDOT would publish roadway segment crash rates by facility type and analysts would then compare these statewide/districtwide baseline rates to calculated rates for individual segments. Roadway segments exceeding the baseline average were eligible for the Highway Safety Improvement Program (HSIP). This screening method was sensitive to regression-to-the-mean (RTM) bias as it was based only on observed crashes. Further, the calculation only featured total crashes and did not reflect Massachusetts's priorities as defined by the SHSP emphasis areas. As a result, the RPAs, MPOs, and MassDOT identified the following needed capabilities for IMPACT:

1. A public-facing automated network screening approach which measures excess expected total and injury crashes and addresses RTM bias. Automatic identification of HSIP-eligible road segments to reduce the workload of local agencies.
2. A method to identify potential sites for improvement based on the risk of emphasis area crashes. Without emphasis area-specific maps, the agencies struggle to identify potential project locations for emphasis area safety improvements.
3. Automated diagnostic tools to review crash data in the agency's footprint as well as at specific sites. RPAs, MPOs, and other local agencies have limited resources to perform diagnostics of potential improvement sites and often lack the capabilities that diagnostic tools such as crash trees can provide.

LEAs

Law enforcement involvement is important in all emphasis areas with a particular focus on impaired driving, speeding and aggressive driving, occupant protection, and distracted driving.

LEAs lack a sufficient method to use crash data to monitor trends and locations for these critical emphasis areas. LEAs need the ability to gain this insight and assist MassDOT in reducing fatalities and serious injuries. Based on this feedback, MassDOT identified the need for LEAs to be able to review behavioral emphasis area crashes.

EAATs

Massachusetts created EAATs for each SHSP emphasis area to support the implementation of the SHSP. The teams develop emphasis area action plans and monitor the SHSP implementation progress. IMPACT provides EAAT members with high-level statistics for each emphasis area. Although useful for overall progress, these dashboards lack detailed insight. EAAT members require detailed crash information for their emphasis area. Based on feedback from EAAT members, MassDOT identified the need for automated review of emphasis area crashes.

END PRODUCTS

Based on the user needs described in the previous section, MassDOT developed four tools to add to IMPACT within a newly formed Safety Analysis Module. All tools were built using Angular[1] libraries. All tables within the tool were built using AG GRID[2].

Network Screening Maps

The new visualization tool includes two forms of network screening maps – crash-based and risk-based.

Crash-Based Network Screening

The crash-based visualization tool displays the Top 5 percent and Next 10 percent of sites ranked based on excess expected crash frequency, which is calculated using the Empirical Bayes

[1] https://angular.io/
[2] https://www.ag-grid.com/

method. Users can view rankings by either all-severity crashes or just fatal and injury crashes. Users can rank sites statewide or by RPA and can use a Filter/Find tool to focus in on corridors of interest. The tool also includes a statistics tab which can be used to summarize the queried segments by traffic volume, facility type, functional class, and RPA. Finally, users can export the visual and tabular data, as well as access the supporting GIS data. Figure 4 is a screenshot of the tool. The tool is available at https://apps.impact.dot.state.ma.us/sat/HotSpotNetworkScreening and the documentation supporting the analysis is available at https://www.mass.gov/lists/network-screening-methodology-reports#development-of-safety-performance-functions-. Charts used in tool were built using Chart.js[3] and the maps are visualized using ArcGIS Online[4].

Example use cases and insights for this tool include:

- A district engineer receives a public complaint about crash history on a corridor. The engineer can provide feedback whether the corridor is or is not experiencing excess crash frequency.
- A planner for an RPA can review their region to identify and prioritize corridors for further review and potential safety improvements.
- LEAs can review maps in their area to identify high-crash locations which they may consider addressing with enforcement strategies.
- MassDOT HSIP managers can identify districts and regions with a high number of sites with excess crashes and adjust safety funding and project distribution to assist those areas.

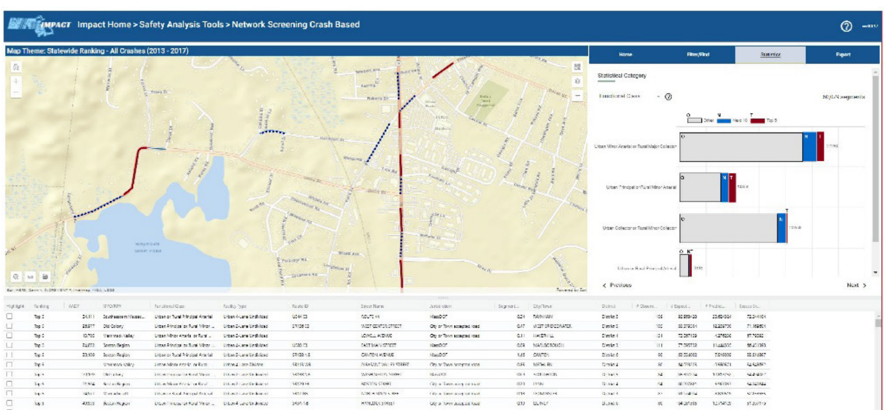

Figure 4. Screenshot of the IMPACT Network Screening Crash-Based tool.

Risk-Based Network Screening

The risk-based visualization tool displays primary and secondary risk sites ranked using a normalized risk score – essentially the percentage of the total potential risk score for a site. Primary risk sites include all sites ranked (including ties) in the 95th percentile or above for normalized risk score. Secondary risk sites include all sites ranked (including ties) in the 85th to

[3] https://www.chartjs.org/

[4] https://www.arcgis.com/index.html

95th percentile for normalized risk score. The tool includes maps for all emphasis areas except safety of persons working in roadways and at-grade rail crossings.

As with the crash-based tool, users can select statewide or RPA-level rankings, and view the data summarized by traffic volume, RPA, functional class, and jurisdiction using the Statistics tab. Users can also print their visualizations and download the supporting GIS data. The tool is available at https://apps.impact.dot.state.ma.us/sat/NetworkEmphasisArea and the supporting documentation can be found at https://www.mass.gov/lists/network-screening-methodology-reports#reports-. Charts used in this tool were built using Chart.js[5] and the maps are visualized using ArcGIS Online[6].

Example use cases and insights for this tool include:

- A planner for an RPA can identify severe crash types which are at the highest risk of occurring in their region and develop safety plans to address those crashes and their potential causes.
- LEAs can identify the towns and corridors in their jurisdiction which are at highest risk for severe impaired driving or speeding crashes and develop strategies to address them.
- EAATs can identify the areas in Massachusetts most at risk for their respective emphasis area crashes and develop and promote strategies to address those issues.
- MassDOT HSIP managers can program systemic safety projects to implement low-cost safety countermeasures at sites with the highest risk for fatalities and serious injuries.

The resulting risk-based network screening maps look similar to the crash-based results in Figure 4.

Crash Tree Builder

To increase diagnostic capabilities, MassDOT developed a Crash Tree Builder which agencies can use to review crash data and contributing factors. The Crash Tree Builder provides an automated analysis and visualization of crash data. The user can select key data elements, gradually building a tree which shows common characteristics of crashes in their jurisdiction. The crash tree builder can also be used to evaluate crashes at a pre-selected site. IMPACT users can export results from the Data Query and Visualization Tool to the crash tree builder for additional investigation.

The Crash Tree Builder provides functionality at the crash-level, vehicle-level, and person-level for all crashes in the MassDOT IMPACT database. Users can combine attributes as they see fit, move nodes to develop their own structure, and print their crash tree. The team used the Cytoscape.js[7] library to facilitate the layout of the nodes. The crash tree builder is available at https://apps.impact.dot.state.ma.us/sat/CrashTree.

[5] https://www.chartjs.org/

[6] https://www.arcgis.com/index.html

[7] https://js.cytoscape.org/

Figure 5 is a screenshot of the IMPACT Crash Tree Builder. Example use cases and insights for this tool include:

- A planner for an RPA determines that fixed object lane departure crashes account for the highest proportion of severe injury crashes on local roads in their region.
- The pedestrian EAATs determines that severe pedestrian crashes are just as likely to occur at mid-block crossings as they are at intersections and are more likely to occur in the evening than during the day.
- A district engineer planning a Road Safety Audit (RSA) uses the Crash Tree Builder to summarize the crashes that have occurred at the study site in the previous five-years. Through this crash tree, they identify that half of the crashes at the site are angle crashes at night, the reason for which can be investigated during the RSA.

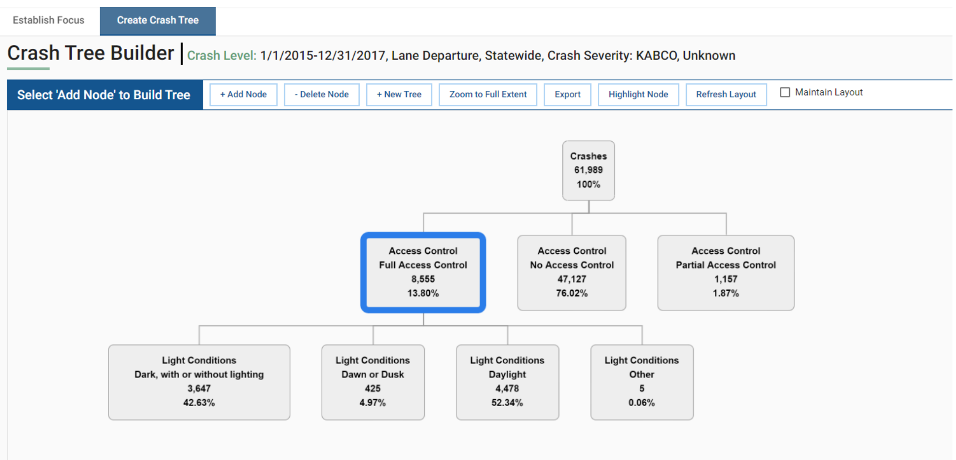

Figure 5. Screenshot of the IMPACT Crash Tree Builder.

Test of Proportions Tool

Another tool MassDOT developed to increase diagnostic capabilities is the Test of Proportions tool, which automatically identifies crash attributes which are overrepresented within a sample compared to up to 3 comparison groups. Users can employ the Data Query and Visualization Tool or otherwise filter the data through the configure window to define the subject and comparison group(s). Users can select crash-level, vehicle-level, and person-level fields. The tool flags and highlights a crash attribute if it is determined to be overrepresented. The table in the tool was built using AG GRID.

The methodology used to define "overrepresentation" is based on a confidence interval built around the subject proportion and comparison proportion using the sampling error. A attribute is identified as overrepresented if the lower bound of the subject proportion's confidence interval (calculated in Figure 6) is larger than the upper bound of the comparison proportion's confidence interval (calculated in Figure 7). The calculations use the proportion of subject crashes (p_s), the number of subject crashes (N_s), the proportion of comparison crashes (p_s), the number of comparison crashes (N_s), and the Z-statistic (Z) selected by MassDOT (the default value is 1.96, but MassDOT can change this).

$$Subject\ Proportion\ Confidence\ Interval, Lower\ Bound\ = p_s - Z * \sqrt{\frac{p_s(1-p_s)}{N_s}}$$

Figure 6. The lower bound of the confidence interval for the subject data proportion.

$$Comparison\ Proportion\ Confidence\ Interval, Upper\ Bound\ = p_c + Z * \sqrt{\frac{p_c(1-p_c)}{N_c}}$$

Figure 7. The upper bound of the confidence interval for the comparison data proportion.

The Test of Proportions tool is available at https://apps.impact.dot.state.ma.us/sat/TestofProportions. Figure 8 is a screenshot of the tool from IMPACT, which highlights and flags overrepresented attributes. Example use cases for this tool include:

- The large vehicle EAAT identifies severe crashes involving tractor trailers are overrepresented for District 5, suggesting the need for targeted countermeasures in that area.
- An RPA planner finds that severe bicycle crashes are overrepresented in their region compared to the statewide average, suggesting the need for bicycle safety improvements in that region.
- An LEA finds that distracted driving crashes are overrepresented in their jurisdiction compared to neighboring areas, suggesting the need for targeted enforcement strategies.

Test Of Proportions: Crash Level, Crash Year 2015-2017 Export

K: Fatal Injury | A: Serious Injury | B: Minor Injury | C: Possible Injury | O: No Apparent Injury | U: Unknown | OVR: Subject group is Over-represented

Y= Subject data is over-represented against the comparison group ; N= Subject data is NOT over-represented against the comparison group ; Z Value= 1.96 was used for calculating over-representation

	Subject						Comparison Group					
	Crash Severity: K,A Emphasis Area: All Data Evaluate: All Crashes Location: BRPC (Berkshire)						Crash Severity: K,A Emphasis Area: All Data Evaluate: All Crashes Location: Statewide					
ATTRIBUTES	2015-2017	%	OVR	2017	2016	2015	2015-2017	%	OVR	2017	2016	2015
Overall Numbers (crash-level data)												
Blank	0	0%	N	0	0	0	0	0%	N	0	0	0
Fatal injury	33	19.64%	Y	10	12	11	1021	12.33%	Y	334	361	326
Non-fatal injury	135	80.36%	N	35	44	56	7258	87.66%	N	2221	2544	2493
Not Reported	0	0%	N	0	0	0	0	0%	N	0	0	0
Property damage only (none injured)	0	0%	N	0	0	0	1	0.01%	N	0	0	1
Reported but invalid	0	0%	N	0	0	0	0	0%	N	0	0	0
Unknown	0	0%	N	0	0	0	0	0%	N	0	0	0
Access Control (crash-level data)												
Blank	20	11.90%	Y	5	7	8	484	5.85%	Y	148	157	179
Full Access Control	13	7.74%	N	5	4	4	1176	14.20%	N	392	422	362
No Access Control	132	78.57%	N	34	45	53	6387	77.14%	N	1945	2248	2194
Partial Access Control	3	1.79%	N	1	0	2	233	2.81%	N	70	78	85
First Harmful Event (crash-level data)												
Blank	0	0%	N	0	0	0	0	0%	N	0	0	0
Cable Barrier	0	0%	N	0	0	0	0	0%	N	0	0	0
Cargo Equipment loss or shift	0	0%	N	0	0	0	0	0%	N	0	0	0
Collision with animal - deer	3	1.79%	N	1	0	2	10	0.12%	N	4	3	3

Figure 8. Screenshot of the IMPACT Test of Proportions tool.

DATA

All data used in this analysis and tool are publicly available. The current version of IMPACT uses two forms of data: crash and roadway data, which form a linked dataset via a geocoding process from the MassDOT Highway Division. This linked dataset was used for the systemic safety analysis and in the IMPACT tool itself. The MassDOT Planning Division owns and maintains the roadway data for all roads (not just MassDOT-owned roadways) via ESRI's Roads and Highways platform, which is extracted quarterly and used in IMPACT. Further, the Registry of Motor Vehicles (RMV) Division of MassDOT supplies the crash data to IMPACT via an automated and regular syncing process. The existing IMPACT system pulls crashes over from the RMV nightly and geocodes them using the quarterly extract of the roadway file provided by Planning. The crash data are then returned, nightly, to the RMV along with the accompanying crash coordinates. A copy of the crash data and linked roadway data is then maintained in the IMPACT system. Therefore, all data for this project are readily available and in sync with data at the RMV.

Additional datasets used for systemic safety analysis are also publicly available through MassDOT's Open Data Portal, an extensive library of geospatial data available for use by the public. Potential additional data include United State Census Data, liquor license data, and public health data. MassDOT documented additional data sources in the respective systemic analysis reports.

DATA ANALYSIS METHODOLOGY AND APPROACH

The only data analysis performed as part of this project was the systemic safety analysis. FHWA's approach to systemic safety includes planning, implementation, and evaluation. The data analysis in this project falls under the *planning* step. Within the planning step, the first two actions are to 1) identify focus crash types, facility types, and risk factors and 2) screen and prioritize candidate locations.

MassDOT performed a systemic safety analysis for most emphasis areas following the procedures laid out in the FHWA Systemic Safety Project Selection Tool (Preston et al., 2013)[8]. MassDOT used crash data from 2013 to 2017 to identify the focus crash type for each emphasis area.

Once focus crash types were identified, MassDOT identified focus facility types. This was done using both crash trees and overrepresentation. Crash trees showed the facility types on which the focus crashes occurred most frequently, while overrepresentation showed at which facility types these crashes occurred more frequently than expected.

Finally, MassDOT identified risk factors which are common for fatal and serious injury focus crashes at focus facility types. To identify risk factors, MassDOT used crash trees, overrepresentation, and additional data evaluation techniques, such as trend analysis, histograms, and binary logistic regression to identify relationships between crash frequency and site characteristics. These risk factors include crash, roadway, traffic, equity, and other environmental-related attributes. Risk factors were identified at the road segment, block group, and town level. MassDOT then assigned scoring schemes to the risk factors and calculated a normalized risk score, which is the risk score for the segment divided by the total potential risk score. Supporting documentation summarizing the approach to risk factor identification for each emphasis area is available at https://www.mass.gov/lists/network-screening-methodology-reports#reports-.

[8] https://safety.fhwa.dot.gov/systemic/fhwasa13019/sspst.pdf

LESSONS LEARNED

MassDOT and its partner VHB identified the following lessons learned from this project. Agencies taking on similar efforts should consider the following:

- **Be aware of data quality issues**. MassDOT encountered data quality issues with their road inventory data, specifically exceptionally small segments that were called "shrapnel". Initial attempts to identify risk sites were made difficult because a significant proportion of primary and secondary risk sites were less than 50 feet long. To address this issue, MassDOT dissolved the road inventory segments using the risk factor fields to develop risk sites and corridors with realistic lengths for safety improvement projects.
- **Regular, structured communication was necessary for success**. VHB and MassDOT held weekly design meetings, bi-weekly check-in meetings, and sprint recap meetings every three weeks, as well as many ad-hoc meetings. These meetings allowed for regular updates between the MassDOT and VHB teams, provided consistent opportunities for feedback, and encouraged accountability for the team to meet the deadline established by USDOT.
- **Strong project management**. Both MassDOT and VHB project managers actively tracked the development of the tools. This tracking included active management and grooming of the backlog, ensuring stories that were targeted for sprints were completed, and regular demonstration of completed stories to end users.
- **Solicitation of feedback from users**. This idea for these improvements came about through discussions with existing users of IMPACT. As such, MassDOT wanted to tailor the improvements to those users. MassDOT maintained active communication with potential users about the tools so their needs could be incorporated into the design. This feedback was done through formal web meetings as well as informal discussions.
- **Realistic understanding of scope, schedule, and budget.** MassDOT and VHB realized that only specific work could be accomplished within the timeline and budget laid out by USDOT. As such, the team maintained a "wish list" of items that are not critical for functionality but would be nice to have and will improve the tool. MassDOT would like to incorporate these features in the future, having sacrificed these improvements to make sure the project remained on schedule. Some potential improvements include a combined map viewer where users can see if a site is at risk for multiple focus crash types, improved user experience for the crash tree builder, and the incorporation of soon-to-be-completed intersection data for filter and find functionality.
- **Include thorough help documentation**. Some of the tools, particularly the Crash Tree Builder, can produce some results that may seem counterintuitive. For instance, a user can generate a crash tree where the sub-nodes sum to more than 100 percent of the crashes of the parent node. The team developed clear, concise messaging to explain why these results occur. These are included in the tools themselves as well as in the help documentation.
- **Allow for flexibility in the delivery strategy.** This tool was built using an "Agile" approach. It is critical that all parties, especially stakeholders are aligned on the functionality that must be included and what can be adjusted. Though the whole idea of

Agile is to be flexible there can be times where all parties must effectively compromise to avoid the risk of significant scope creep.

- **Advancements to the systemic knowledge base.** The analysis supporting this tool highlighted methods for identifying risk factors for both infrastructure-based and behavioral-based focus crash types. Additionally, the analysis showed how an agency can consider road-level features as well as higher-level features, such as town-based or block group-based risk factors for systemic analysis. Other agencies attempting similar projects should be open to alternative and innovative forms of data to improve the analysis.