

**Connecticut Department of Transportation  
Safety Techniques Enhancement Plan**

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# Standard Conversions

| <b>SI* (MODERN METRIC) CONVERSION FACTORS</b>                      |                             |                             |                             |                     |
|--|-----------------------------|-----------------------------|-----------------------------|---------------------|
| <b>APPROXIMATE CONVERSIONS TO SI UNITS</b>                         |                             |                             |                             |                     |
| <b>Symbol</b>  | <b>When You Know</b>        | <b>Multiply By</b>          | <b>To Find</b>              | <b>Symbol</b>       |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| in   | inches                      | 25.4                        | millimeters                 | mm                  |
| ft   | feet                        | 0.305                       | meters                      | m                   |
| yd   | yards                       | 0.914                       | meters                      | m                   |
| mi   | miles                       | 1.61                        | kilometers                  | km                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| in <sup>2</sup>  | square inches               | 645.2                       | square millimeters          | mm <sup>2</sup>     |
| ft <sup>2</sup>  | square feet                 | 0.093                       | square meters               | m <sup>2</sup>      |
| yd <sup>2</sup>  | square yard                 | 0.836                       | square meters               | m <sup>2</sup>      |
| ac   | acres                       | 0.405                       | hectares                    | ha                  |
| mi <sup>2</sup>  | square miles                | 2.59                        | square kilometers           | km <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| fl oz  | fluid ounces                | 29.57                       | milliliters                 | mL                  |
| gal  | gallons                     | 3.785                       | liters                      | L                   |
| ft <sup>3</sup>  | cubic feet                  | 0.028                       | cubic meters                | m <sup>3</sup>      |
| yd <sup>3</sup>  | cubic yards                 | 0.765                       | cubic meters                | m <sup>3</sup>      |
| NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup> |                             |                             |                             |                     |
| <b>MASS</b>  |                             |                             |                             |                     |
| oz   | ounces                      | 28.35                       | grams                       | g                   |
| lb   | pounds                      | 0.454                       | kilograms                   | kg                  |
| T  | short tons (2000 lb)        | 0.907                       | megagrams (or "metric ton") | Mg (or "t")         |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °F   | Fahrenheit                  | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius                     | °C                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| fc   | foot-candles                | 10.76                       | lux                         | lx                  |
| fl   | foot-Lamberts               | 3.426                       | candela/m <sup>2</sup>      | cd/m <sup>2</sup>   |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| lbf  | poundforce                  | 4.45                        | newtons                     | N                   |
| lbf/in <sup>2</sup>  | poundforce per square inch  | 6.89                        | kilopascals                 | kPa                 |
| <b>APPROXIMATE CONVERSIONS FROM SI UNITS</b>                       |                             |                             |                             |                     |
| <b>Symbol</b>  | <b>When You Know</b>        | <b>Multiply By</b>          | <b>To Find</b>              | <b>Symbol</b>       |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| mm   | millimeters                 | 0.039                       | inches                      | in                  |
| m  | meters                      | 3.28                        | feet                        | ft                  |
| m  | meters                      | 1.09                        | yards                       | yd                  |
| km   | kilometers                  | 0.621                       | miles                       | mi                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| mm <sup>2</sup>  | square millimeters          | 0.0016                      | square inches               | in <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 10.764                      | square feet                 | ft <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 1.195                       | square yards                | yd <sup>2</sup>     |
| ha   | hectares                    | 2.47                        | acres                       | ac                  |
| km <sup>2</sup>  | square kilometers           | 0.386                       | square miles                | mi <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| mL   | milliliters                 | 0.034                       | fluid ounces                | fl oz               |
| L  | liters                      | 0.264                       | gallons                     | gal                 |
| m <sup>3</sup>   | cubic meters                | 35.314                      | cubic feet                  | ft <sup>3</sup>     |
| m <sup>3</sup>   | cubic meters                | 1.307                       | cubic yards                 | yd <sup>3</sup>     |
| <b>MASS</b>  |                             |                             |                             |                     |
| g  | grams                       | 0.035                       | ounces                      | oz                  |
| kg   | kilograms                   | 2.202                       | pounds                      | lb                  |
| Mg (or "t")  | megagrams (or "metric ton") | 1.103                       | short tons (2000 lb)        | T                   |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °C   | Celsius                     | 1.8C+32                     | Fahrenheit                  | °F                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| lx   | lux                         | 0.0929                      | foot-candles                | fc                  |
| cd/m <sup>2</sup>  | candela/m <sup>2</sup>      | 0.2919                      | foot-Lamberts               | fl                  |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| N  | newtons                     | 0.225                       | poundforce                  | lbf                 |
| kPa  | kilopascals                 | 0.145                       | poundforce per square inch  | lbf/in <sup>2</sup> |

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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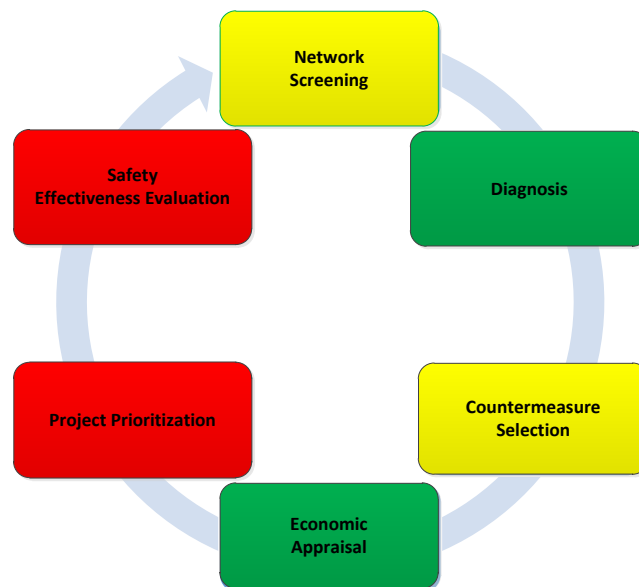
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## Executive Summary

This *Safety Techniques Enhancement Plan* project was developed jointly by the Connecticut Department of Transportation (ConnDOT) and the University of Connecticut: Connecticut Transportation Institute, Transportation Safety Research Center (UCONN). The objectives of the project are to:

- Identify options for addressing current safety analysis problems and limitations.
- Establish a vision of ConnDOT highway safety analysis employing state-of-the-practice methods and meets Highway Safety Improvement Program (HSIP) requirements and Departmental operational needs.
- Describe specific capabilities (e.g., network screening, intervention cost effectiveness) and collaborations among Departmental operations (e.g., planning, programming, scoping, design, operations, and maintenance).
- Identify specific system enhancements and supporting elements needed to implement the vision.
- Serve as an implementation plan for attaining the vision, including cost, schedule, and sequencing of major improvements and supporting elements (e.g., user guides, training).

The *Highway Safety Manual* (HSM) defines a six-step cycle of safety management processes. The figure below shows the six safety management steps color coded to show how the current ConnDOT processes match to the state-of-the-practice suggested in the HSM. Green indicates that the ConnDOT processes closely mirror those in the HSM. Yellow is for processes that are partially in line with HSM guidelines. Red is for those processes in need of major revision.





**Network Screening**

ConnDOT’s Network Screening uses some excellent analytic processes that are close to the HSM’s guidance. We recommend using a single process for all public roads and by implementing Safety Performance Functions to set critical crash rates.

**Diagnosis**

ConnDOT’s Diagnosis process uses crash diagrams and summary statistics as recommended in the HSM.

**Countermeasure Selection**

ConnDOT’s Countermeasure Selection process makes use of resources such as the Crash Modification Factor (CMF) Clearinghouse, but the process could be improved through use of CMF values calibrated to Connecticut’s experience.

**Economic Appraisal**

ConnDOT’s Economic Appraisal process makes use of benefit/cost ratio analyses as recommended in the HSM. Some improvements could be achieved with better financial and project tracking, along with calibrated CMFs.

**Project Prioritization**

ConnDOT’s Project Prioritization process needs review and revision. In particular, the process should more explicitly include the Safety Engineering staff as well as other stakeholders.

**Safety Effectiveness Evaluation**

ConnDOT’s Safety Effectiveness Evaluation process needs review and revision. The methods recommended in the HSM require additional skills and analytic tools that ConnDOT will need to acquire through training or external sources.

In addition, the HSM (Part C) includes a description of Predictive Methods that ConnDOT should consider adopting for use in alternatives analysis and the design exception process of highway design.

This *Safety Techniques Enhancement Plan* provides recommendations for improvement in each step of the safety management process and a strategic plan for achieving the vision established by the stakeholders:

**Connecticut has a rigorous, efficient, and automated safety management process coupled with experienced and expert staff that can use the results to improve decision-making on the entire transportation network.**

The document concludes with an Action Plan (provided in full as an Excel spreadsheet) that shows the Goals, Objectives, Tasks, and steps to improving ConnDOT’s safety analyses and decision-making processes. The Strategic Plan is designed for easy tracking and maintenance by the involved parties within ConnDOT so that a status report on all action items can be available at any time.

# Introduction

This project was developed jointly between the Connecticut Department of Transportation (ConnDOT) and the University of Connecticut: Connecticut Transportation Institute, Transportation Safety Research Center (abbreviated as UCONN hereafter).

## Objectives:

The objectives of this project are to develop a *Safety Techniques Enhancement Plan* that:

- Identifies options for addressing current safety analysis problems and limitations.
- Establishes a vision of ConnDOT highway safety analysis that employs state-of-the-practice methods and meets Highway Safety Improvement Program (HSIP) requirements and Departmental operational needs.
- Describes specific capabilities (e.g., network screening, intervention cost effectiveness) and collaboration among Departmental areas of responsibility (e.g., planning, programming, scoping, design, operations, and maintenance).
- Identifies the specific system enhancements and supporting elements needed to implement the vision.
- Provides an implementation plan for attaining the vision, including cost, schedule, and sequencing of major improvements and supporting elements (e.g., user guides, training).

## Roadmap for this Document:

This *Safety Techniques Enhancement Plan* is in the format of a strategic plan for adopting advanced safety analysis techniques like those described in the *Highway Safety Manual (HSM)* and as supported by various analytic tools and resources, including AASHTOWare Safety Analyst™. The report includes:

- Recommendations on how ConnDOT should develop and structure the necessary software, data systems, network architecture, data collection elements and methods, and reporting features.
- A flow diagram showing which data systems/departments at ConnDOT would feed the safety analysis system as well as what systems/departments would need the resulting output from this system.
- Phasing and implementation schedule of new analysis methods, new data collection efforts, and data storage schemes.
- Recommendations and identification of demands on staffing and training. This would include the identification of seminars, reference materials, and in-house or national training opportunities which are aligned with the desired safety analysis system.
- Estimates of potential costs associated with the development of the systems, infrastructure, training, and resources to incorporate new analysis methods. The research team will work to include an estimated cost broken down by each phase of the implementation as well as a timeline.

The strategic plan includes the following sections:

1. Overview of the Highway Safety Manual: Providing an overview of the HSM with a description of the applicable procedures and methods. The first sub-section is introduction to the HSM, including human factors and fundamentals. The second subsection is the state-of-the-practice six-step safety management process. The third sub-section is the predictive method and the fourth subsection is crash modification factors (CMFs) applicable to design or evaluation processes. The final subsection discusses integrating the HSM into the

project development process.

2. **Current Capabilities:** Providing an overview of ConnDOT's current capabilities for safety analyses. This section follows the same flow as the Overview of the Highway Safety Manual section. ConnDOT's current capabilities are discussed in terms of the HSM.
3. **Planned Capabilities:** Providing an overview of ConnDOT's future desired safety analysis capabilities. This section follows the same flow as the Overview of the Highway Safety Manual section. ConnDOT's planned capabilities are discussed in terms of the HSM.
4. **Achieving the Planned Capabilities:** Providing an overview of the issues ConnDOT faces to achieve the planned capabilities. Data governance issues, platform/functionality, project records/location history, desired output, potential tools and resources, and data requirements are presented.
5. **Plan Goals, Objectives, Tasks:** Provides details describing the goals, objectives, and recommended tasks for achieving the goals and objectives. For each goal, tasks are presented along with the necessary steps to complete those tasks.
6. **Action Plan:** This section is presented as an appendix in this report. The Action Plan is intended for updating throughout the period of the Strategic Plan so that those involved may update the status of tasks; or add, edit, or remove tasks.

# Overview of the Highway Safety Manual

The American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM) (*AASHTO, 2010*)<sup>1</sup> is intended to support data driven decision-making for transportation professionals in planning, highway design, and traffic engineering. Specifically, the HSM provides analytical techniques for quantifying the potential safety effects of decisions made in planning, design, operations, and maintenance. Using the information contained within the HSM, agencies are better prepared to integrate safety in the decision-making process.

The HSM is comprised of four parts:

1. Part A: Introduction, Human Factors, and Fundamentals
2. Part B: Roadway Safety Management Process
3. Part C: Predictive Method
4. Part D: Crash Modification Factors

Part A describes the purpose and scope of the HSM, including the relationship to planning, design, operations, and maintenance activities. Part A also presents an overview of human factors principles for road safety and fundamental information needed to apply the predictive method (Part C) and crash modification factors (CMFs) (Part D).

Part B presents the roadway safety management process, which is used to monitor and reduce crash frequency and severity on the existing roadway network. Part B is most relevant to transportation planning and traffic engineering activities.

Part C presents the predictive method, which is used to estimate the expected average crash frequency of a network, facility, or individual site. Estimates can be made for existing facilities, proposed facilities, or for alternative conditions. Part C is most relevant to highway design activities such as developing and evaluating design alternatives for a specific project.

Part D provides a catalog of CMFs for treatments organized by roadway segments, intersections, interchanges, special facilities, and roadway networks. CMFs quantify the change in expected average crash frequency as a result of geometric or operational modifications to a site that differs from a set of base, or existing, conditions.

## **Part A: Introduction, Human Factors, and Fundamentals**

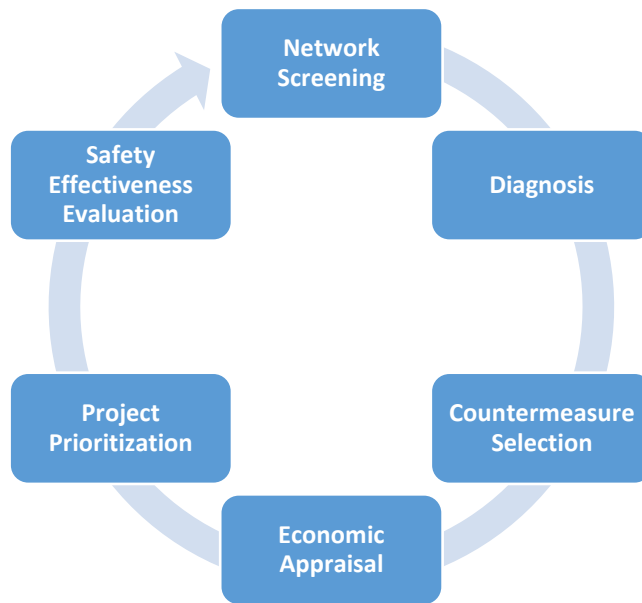
Part A describes the purpose and scope of the HSM and also presents an overview of human factor principles and fundamentals of the processes and tools described in the HSM. The fundamentals chapter provides background information needed to apply the Part B roadway safety management process, Part C predictive method, and Part D crash modification factors.

## **Part B: Roadway Safety Management Process**

Part B of the HSM presents a methodology to monitor and identify sites for safety improvement on an existing roadway network. Figure 1 identifies the chapters in Part B, based on the six-step roadway safety management process. Following Figure 1 is a description of each step.

---

<sup>1</sup> American Association of State Highway and Transportation Officials (AASHTO). Highway Safety Manual, 1st Edition, Washington, DC, 2010.



**Figure 1. Six-Step Safety Management Process.**

### **Step 1: Network Screening**

Network screening is the process of analyzing the entire network to identify potential sites or issues for further investigation based on selected performance measures. It is not possible to conduct a detailed assessment of the entire network, so network screening is used to pare down the network to a manageable list.

There are two types of network screening:

1. Site-specific: The objective is to identify specific sites for further analysis (typically those with high crashes or over-represented crashes).
2. Systemic: The objective is to identify common risk factors of crashes (typically those that are most prevalent across the network).

There are various performance measures that can be used in the network screening analysis and these are provided in Table 1. The performance measures are listed in approximate order of preference where the measures that account for both RTM bias and set a performance threshold are the more rigorous measures. **Error! Reference source not found.** identifies the data requirements for each of the performance measures. Note that the more rigorous methods also require more data and require the use of safety performance functions (SPFs).

**Table 1. Network Screening Performance Measures.**

| <b>Performance Measure</b>   | <b>Accounts for RTM Bias</b> | <b>Method Incorporates Performance Threshold</b> |
|--|------------------------------|--|
| Average Crash Frequency  | No                           | No   |
| Crash Rate   | No                           | No   |
| Equivalent Property Damage Only (EPDO)<br>Average Crash Frequency                    | No                           | No   |
| Relative Severity Index  | No                           | Yes  |
| Critical Rate  | No                           | Yes  |
| Excess Predicted Average Crash Frequency<br>Using Method of Moments                  | No                           | Yes  |
| Level of Service of Safety   | No                           | Yes  |
| Excess Expected Average Crash Frequency<br>Using SPFs                                | No                           | Yes  |
| Probability of Specific Crash Types Exceeding<br>Threshold Proportion                | Not Affected                 | Yes  |
| Excess Proportions of Specific Crash Types   | Not Affected                 | Yes  |
| Expected Average Crash Frequency with EB<br>Adjustments                              | Yes                          | Yes  |
| Equivalent Property Damage Only (EPDO)<br>Average Crash Frequency with EB Adjustment | Yes                          | Yes  |
| Excess Expected Average Crash Frequency<br>with EB Adjustments                       | Yes                          | Yes  |

**Table 2. Data Requirements for Network Screening Performance Measures.**

| Performance Measure  | Crash | Roadway | Traffic | Other               |
|--|-------|---------|---------|---------------------|
| Average Crash Frequency  | X     | X       |         |                     |
| Crash Rate   | X     | X       | X       |                     |
| Equivalent Property Damage Only (EPDO)<br>Average Crash Frequency                    | X     | X       |         | EPDO<br>Factors     |
| Relative Severity Index  | X     | X       |         | Relative<br>Indices |
| Critical Rate  | X     | X       | X       |                     |
| Excess Predicted Average Crash Frequency Using<br>Method of Moments                  | X     | X       | X       |                     |
| Level of Service of Safety   | X     | X       | X       | SPF                 |
| Excess Expected Average Crash Frequency Using<br>SPFs                                | X     | X       | X       | SPF                 |
| Probability of Specific Crash Types Exceeding<br>Threshold Proportion                | X     | X       |         |                     |
| Excess Proportions of Specific Crash Types   | X     | X       |         |                     |
| Expected Average Crash Frequency with EB<br>Adjustments                              | X     | X       | X       | SPF                 |
| Equivalent Property Damage Only (EPDO)<br>Average Crash Frequency with EB Adjustment | X     | X       | X       | SPF                 |
| Excess Expected Average Crash Frequency with<br>EB Adjustments                       | X     | X       | X       | SPF                 |

### Step 2: Diagnosis

Diagnosis is the process of further investigating the sites/issues identified in Step 1 (network screening). The objective of diagnosis is to identify existing and potential safety issues. It is important to diagnose the underlying issues and contributing factors before developing potential countermeasures. Diagnosis often involves a review of the crash history, traffic operations, and general site conditions as well as a field visit to observe road user behaviors. Note that this step can be achieved through a Road Safety Audit (RSA).

### Step 3: Countermeasure Selection

Countermeasure selection is the process of identifying and assessing ways to address or mitigate the underlying safety issues identified in Step 2 (diagnosis). Potential countermeasures should directly target the identified issues, and may include engineering, education, enforcement, and EMS-related measures (i.e., the 4E approach). Note that this step can also be achieved through the RSA process, and there are several guides to help in selecting appropriate countermeasures:

1. Engineering:
  - a. FHWA Proven Countermeasures (<http://safety.fhwa.dot.gov/provencountermeasures/>).

- b. National Cooperative Highway Research Program (NCHRP) Report 500 Series (<http://safety.transportation.org/guides.aspx>).
2. Education/Enforcement:
  - a. NHTSA Countermeasures that Work ([www.nhtsa.gov/staticfiles/nti/pdf/811727.pdf](http://www.nhtsa.gov/staticfiles/nti/pdf/811727.pdf)).

#### **Step 4: Economic Appraisal**

Economic appraisal is the process of comparing the relative costs and benefits of the various alternatives. It is often not feasible or practical to implement all of the identified countermeasures. As such, it is necessary to estimate the cost and expected benefits of each potential countermeasure, and identify a cost-effective strategy or set of strategies for each location. The cost of projects is usually straightforward, but estimating the potential benefits is a relatively new component of the data driven and quantitative safety management process. Crash modification factors (CMFs) are used to estimate the expected change in crashes after the implementation of a given countermeasure. The CMF Clearinghouse is the primary source of CMFs, including those presented in the Highway Safety Manual (<http://www.cmfclearinghouse.org/>).

#### **Step 5: Project Prioritization**

Project prioritization is the process of developing a portfolio of projects for a given fiscal year. The final choice of projects is based on the available budget as well as other factors such as agency goals, political pressure, and public acceptance.

#### **Step 6: Safety Effectiveness Evaluation**

Safety effectiveness evaluation is the process of estimating the safety impacts of implemented projects. This is the final step of the safety management process, but provides a critical feedback link for future planning. Evaluation can and should be conducted at various levels:

1. Program-level: The objective of program evaluation is to determine the effectiveness of the overall safety program. The primary performance measures are the number and rate of crashes, injuries, and fatalities on the network. Program evaluation could also include the assessment of specific programs such as intersection safety, roadway departure, and pedestrian safety. If the agency is targeting roadway departure crashes, then it may be appropriate to compare the number and cost of related safety improvement projects each year to the number and trend in roadway departure crashes, injuries, and fatalities.
2. Project-level: The objective of project evaluation is to determine the effectiveness of individual projects or groups of similar projects. For example, the agency may have installed rumble strips on several sections of two-lane roads. A project-level evaluation could be conducted to determine the safety impacts of each individual rumble strip project. These projects could also be combined to determine the average impact of rumble strips on two-lane roads. This is how CMFs are developed.

This six-step process is a continuous cycle designed to support decision-making and improve the safety of a transportation network. The roadway safety management process provides a systematic and repeatable process for identifying and diagnosing safety issues, selecting and implementing effective countermeasures, and evaluating the impacts of safety-related efforts.

### **Part C: Predictive Method**

Part C provides a predictive methodology for estimating average crash frequency for a network, facility, or individual site. The predictive methodology is applicable for existing conditions, alternative conditions, or proposed new facilities. The predictive method provides a quantitative measure of expected average crash frequency for existing and



proposed conditions, allowing proposed roadway conditions to be assessed with other quantitative performance measures such as capacity, delay, and cost, among others.

The predictive method is applied to a particular time period, average annual daily traffic (AADT) volume, and geometric characteristics of a roadway. The average crash frequency is estimated based on the AADT assuming base geometric conditions. CMFs are applied to account for specific variations from base conditions. The predictive method provides SPFs and CMFs based on previous research for similar roadway types, and a calibration factor is applied to adjust for local conditions. HSM users can develop and implement their own jurisdiction-specific SPFs and CMFs. Including approved chapters for the next edition of the HSM, the predictive method contains information applicable to the following facility types:

- Rural two-lane roadway segments.
- Rural two-lane roadway intersections.
- Rural multilane highway segments.
- Rural multilane highway intersections.
- Urban and suburban arterial segments.
- Urban and suburban arterial intersections.
- Freeway segments.
- Ramp segments and terminals.

The predictive method is most applicable for alternatives analysis when developing and assessing multiple solutions for a specific location.

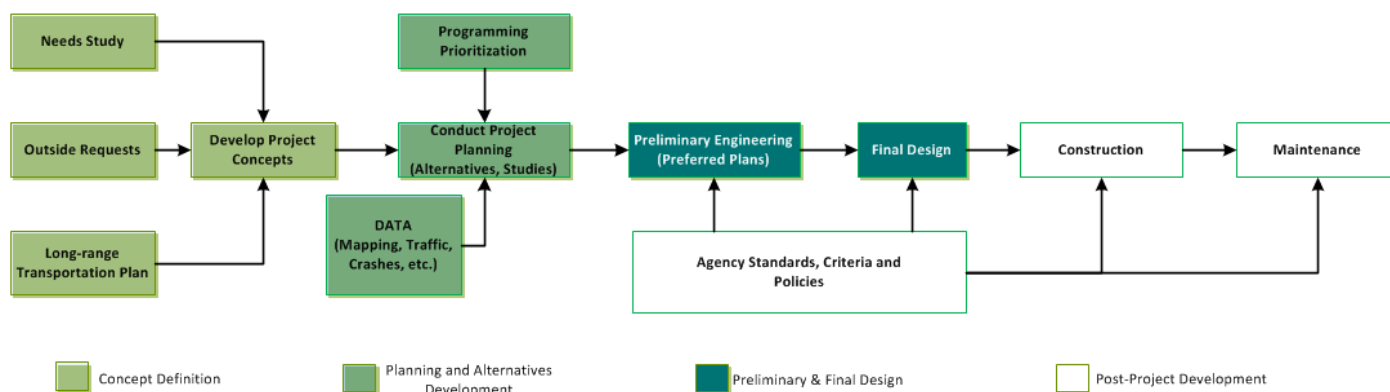
#### **Part D: Crash Modification Factors**

Part D provides information regarding the effects of treatments, or countermeasures, for various facility types. This information is used to estimate the effectiveness of a countermeasure or set of countermeasures in reducing crashes at a specific location. The CMFs presented in Part D are all contained in the CMF clearinghouse ([www.cmfclearinghouse.org](http://www.cmfclearinghouse.org)), but have all passed a screening process of an expert panel and are deemed to be sufficiently reliable. The screening process was based on the quality and quantity of completed research on the particular treatment's effect on crash frequency. Part D CMFs can be used as a resource for selecting countermeasures, conducting economic appraisal, and for the Part C predictive method. The treatments with CMFs are organized by:

- Roadway segments.
- Intersections.
- Interchanges.
- Special facilities and geometric situations.
- Road networks.

## Integrating the HSM in the Project Development Process

Figure 2 presents a typical project development process as outlined by AASHTO's *A Guide for Achieving Flexibility in Highway Design* (2004). According to the guide, the project development process can be characterized as having four distinct stages. The stages are concept definition, planning and alternatives development, preliminary and final design, and post-project development. While this terminology does not cover the wide range of terminology used throughout the U.S., the process shown below is generally accepted.



Adapted from *A Guide to Achieving Flexibility in Design* (AASHTO, 2004)

**Figure 2. Typical Project Development Process.**

The HSM has a wide variety of applications that fit into all stages of the project development process. In the concept definition phase, the purpose and need for a project are determined from several inputs, including long-range systems planning, needs studies, and outside requests. Safety history can be monitored and is incorporated into needs studies. Part B of the HSM is a vital performance monitoring tool for existing roadways with poor safety histories as it is devoted to identifying sites with potential for safety improvement, and diagnostic and countermeasure selection tools. Safety prediction models from Part C of the HSM can be used at a coarse level in the concept definition phase to evaluate high-level alternatives for new roadway alignments. Data such as design traffic volumes and preliminary cross-section configurations may be available during this phase; however, many critical design elements are not yet determined. As such, prediction tools may be used to determine the safety implications of significant alterations to roadway alignments (e.g., two-lane roadway converted to four-lane roadway).

The greatest opportunities and challenges for a flexible transportation solution occur in the planning and alternatives development phase. In this stage, it is important to utilize the flexibility in geometric design criteria to propose, study, and evaluate a full range of alternatives. Predictive methods that utilize SPFs and CMFs can be used to determine the safety effects of various geometric changes for a proposed project. Coarse evaluations that were conducted in the concept definition phase can be refined in this stage as well. Several different design alternatives can be evaluated using HSM methodologies and preliminary crash-based safety estimates can be generated for each alternative. Preliminary safety estimates (e.g., predicted crash frequency and severity by location) can be utilized in this stage for discussion with public agencies and communities to address concerns.

The preliminary design phase follows the selection of an alternative for implementation. This phase begins the transition to lower flexibility in design and a higher mathematical development of the geometric design. This is the stage where applicable criteria are applied to roadway geometric elements and where there is a greater confidence in results that can be obtained through application of the HSM methodologies. At this point, design plans generally evolve based on constructability issues and maintenance of traffic during construction. There is less flexibility for

design changes due to safety issues in this phase; however, there are opportunities to quantify the safety impacts of design exceptions. A design exception (or waiver or variance) may be required if the applicable design criteria of a geometric design element cannot be met for some reason. In these cases, substandard values may be proposed, particularly when the cost of meeting the design standard appear to out-weight the safety, operational, economical, and environmental impacts. The Part C predictive method and Part D CMFs can be used to quantify the safety impacts of a design exception compared to alternatives such as meeting the design standard.

In the final design phase, complete plans, specifications, and contract documents are developed. As in the preliminary design phase, the input data necessary to predict safety on the project alignment are known, but the flexibility to alter geometric elements is limited in this phase.

In the post-project development phase, the roadway safety management process (Part B) is applicable. Safety effectiveness evaluations can be performed to evaluate the change in crashes from implemented safety treatments. The safety evaluation is performed to identify how crash frequency or severity has changed (or remained unchanged) due to a treatment or set of treatments. For treatments that have been applied at multiple similar sites, CMFs can be estimated. Additionally, the effectiveness evaluation methods in Part B can be used to determine how well safety funds have been invested. This will drive future allocations of safety funds and will increase confidence in economic analyses of proposed countermeasures and future projects.

## ConnDOT's Current Capabilities

This section provides an overview of ConnDOT's current capabilities for safety analyses. This section follows the same flow as the Overview of the Highway Safety Manual section. ConnDOT's current capabilities are discussed in terms of the HSM.

### Part A: Introduction, Human Factors, and Fundamentals

ConnDOT utilizes human factors information through the Highway Safety Office, which develops programs based on improving driver and other roadway user behaviors. The HSO makes use of driver behaviors, physical characteristics, and cognitive abilities to develop countermeasures and prevention schemes for problem areas (e.g., impaired driving). Additionally, the Crash Data and Analysis Unit, Traffic Engineering Division, and Safety Engineering Unit make use of fundamentals found in Part A of the HSM (e.g., crash estimation for network screening). However, there is potential to enhance the level of fundamental safety knowledge across the Department and other partner agencies.

### Part B: Safety Management Process

#### Step 1: Network Screening

This section describes what the current capabilities are for network screening in the context of the major responsibility areas, offices, and sections within ConnDOT. This section is necessarily split into data providers and implementation. Data providers are responsible for gathering, updating, and maintaining the data necessary for network screening to occur. Data implementation involves the groups, offices, and units responsible for using the data provided to perform network screening for Suggested List of Surveillance Study Sites (SLOSSS) locations and systemic safety issues.

#### Data Providers

The Roadway Information Systems group is in the middle of a transition from the Roadway Inventory System (RIS) to an Exor based system. When completed, and when the statewide Linear Referencing System (LRS) and roadway inventory data collection are complete, this section will be able to serve as a resource on statewide network screening and they will provide roadway inventory and AADT data as well as perform essential quality control tasks as part of overall data management responsibilities.

ConnDOT is in the process of developing a custom LRS system. Their current referencing system is based on route and milepost, and includes data on all State-owned roadway miles as well as limited information for other public roadways. The system currently operates on the desktop; however, a web-based system is planned for the future. The LRS data table is complete for State roads, but only partially complete for the local roads. Figure 3 shows the status of the creation of the local roads as of October 17, 2014.

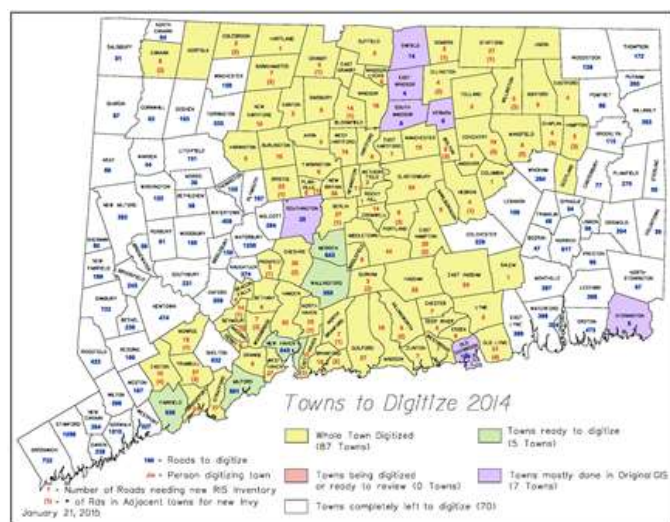


Figure 3. Local road digitization status.

The Roadway Information Systems group manages the RIS, which contains roadway feature data and traffic counts for locations specified in the route-milepost LRS. RIS is slated for replacement by the new Exor system—a data migration project is underway now, and ConnDOT is hiring to fill a position dedicated to integration and development support for this effort. ConnDOT is also increasing the amount and resolution of roadway data; moving to a dual-carriageway representation and going from .01 mile to .001 accuracy. Eventually, ConnDOT will re-inventory all 22,000 miles of roadway (4,000 State-maintained and 18,000 local roadway miles). There is an ongoing data collection project using instrumented van-based technology to collect spatial coordinates, lanes, cross-slope, signs, markings, and pavement condition. All of this data can be exported from RIS into Exor. The Exor system is described as “Model Inventory of Roadway Elements (MIRE)-capable”, but there are multiple data elements and roadways for which the data is incomplete. These improvements are all part of ongoing multi-year efforts that will ultimately result in an enterprise, statewide GIS road network that contains detailed records for all public roads. The local roads are anticipated to be completed over approximately the next year. ConnDOT is considering purchasing a data collection van for use in the longer term.

Traffic volume data are also collected by Roadway Information Systems and is currently stored in the RIS—this data will also migrate to Exor. The traffic volume data are used for program and project development and for input to various Federal, State, municipal, and other public or private sector reports. The system consists of GIS, Photo Log, and Traffic Monitoring, fulfilling All Roads Network of Linear Referenced Data (ARNOLD) requirements. The State maintains 40 permanent count stations, the data from which are used to develop factors (i.e., seasonal) for use in adjusting temporary counts for AADT calculations. AADT is available for all State roads. Other than for HPMS-required reporting, there is no systematic standardized reporting of local road traffic volume counts for inclusion in RIS or Exor.

The Crash Data and Analysis section is the custodian of the statewide crash database—the Accident History File (AHF). Data entry, data management, and reporting of crash data are accomplished using the Collision Analysis System (CAS). CAS1 was implemented in 2003, major updates to the crash data system are underway which required an update to the CAS system. The new CAS system was deployed at the start of 2015 and, for the purposes of this report, will be referred to as CAS2. CAS1 replaced a mainframe system which is still usable for access to records older than 2003. CAS1 was designed to manage ConnDOT’s manual data entry of paper crash reports. Beginning in 2012, ConnDOT began planning for the replacement of CAS1 with a system to meet a variety of new needs identified by the Agency and key stakeholders including metropolitan planning organizations (MPOs), law enforcement agencies, and crash data users. At the same time, the State Traffic Records Coordinating Committee voted to create a new crash report form that is nearly 100 percent compliant with the National Highway Traffic Safety Administration (NHTSA) Model Minimum Uniform Crash Criteria (MMUCC) guideline. While the new form and CAS1 replacement have been in development, ConnDOT also contracted with UCONN to implement a Crash Data Repository. As part of that effort, UCONN assisted ConnDOT in eliminating the backlog of paper crash reports awaiting data entry. During this same timeframe, the Connecticut State Police implemented a field data collection system and have been submitting crash data electronically for over a year—this represents approximately 35 percent of the total of approximately 110,000 reports processed annually by ConnDOT.

CAS2, the replacement for CAS1, was deployed in early 2015. The new MMUCC-compliant crash report form was implemented on January 1, 2015. ConnDOT plans to change its processes to eliminate paper crash report handling with the implementation of the new form by offering law enforcement agencies a number of options for collecting and submitting their data electronically. At the minimum, the new form will be implemented as a fillable-pdf that can be uploaded into CAS2 through a secure data transfer from the ConnDOT E-Crash SFTP site. There are a growing number of law enforcement agencies with field data collection systems, and records management systems will be able to

provide data from those systems directly to ConnDOT for automated import into CAS2. Ultimately, there should be no paper reports submitted to ConnDOT; however, both ConnDOT and the Crash Data Repository will retain the capability to enter crash data manually if needed. The CAS2 database is complete, but the front end for data management is still under development.

The Department of Technology Services in the Office of Management and Technology Services (OMTS) supports all of the internal ConnDOT systems and provides a link between ConnDOT and UCONN. OMTS developed the new CAS2 database and completed the front-end interface for data management before the January 1, 2015 system implementation. OMTS also develops query tools used for ad-hoc reporting of crash experiences.

In addition to the above data descriptions which focus primarily on engineering data sources and application, the HSO makes use of the Fatality Analysis Reporting System (FARS) data and safety relevant data such as census counts, citation/adjudication data, arrest information, and toxicology reports, and is preparing to make use of injury surveillance data. These uses are in support of programs aimed at improving drivers' and other road users' behaviors. The HSO will benefit from many of the data improvements discussed here as they also could make use of more timely crash data for all levels of crash severity and more comprehensive roadway information at the local level. Note also that the data sources most commonly used for behavior-related analyses may also be used in support of engineering decision-making. This is particularly true of the FARS data on fatal crashes.

### ***Implementation***

The Crash Data and Analysis Unit uses OMTS-developed query tools to perform ad-hoc reporting of crash experiences, including the Traffic Accident Surveillance Report (TASR) and SLOSSS. They use crash data, roadway inventory, and traffic volume data in these analyses. This section also provides data extracts and works with local agencies to provide data and analytic support.

TASR analyses are produced by the Crash Data and Analysis Unit for the most recent three-year period, showing crash totals, traffic counts, crash rates, and various roadway features for the entire highway system. For each state road location, TASR displays location characteristics, crash totals, number of vehicles passing through the location, million vehicle miles of travel, average crash rate for that location, critical crash rate for that location, and the ratio of the actual crash rate to the critical crash rate. TASR is sorted by route and cumulative mileage.

SLOSSS reports list locations based on TASR results showing abnormally high crash rates for the corresponding three-year period. Each TASR location with 15 or more crashes and whose observed crash rate is greater than its critical crash rate is included in the SLOSSS. The SLOSSS analysis incorporates roadway, traffic, and crash data and distributes crashes onto the roadway network by location type (e.g., rural vs urban, type of intersection, signal/control type). The rate number quality control method is used to produce a ranked list of sites with safety needs. SLOSSS displays similar information to TASR, with the addition of a sequence number that is used to rank the locations by the ratio of the observed crash rate to the critical crash rate. SLOSSS is used by the Traffic unit as a network screening tool, and by consultants and Regional Planning Organizations (RPOs). The SLOSSS list is based on a critical rate, and thus shares that feature with advanced network screening techniques such as those described in the HSM. The definition of the critical rate, however, is based on traditional practice rather than a statistical analysis of safety data. The tool could be used for statewide safety analysis based on state-of-the-art performance measures if local roadway inventory and traffic volume data are added and a non-linear rate calculation method is incorporated (i.e., a calibrated safety performance function).

The Division of Traffic Engineering is responsible for the Strategic Highway Safety Plan (SHSP); they develop, implement, and evaluate the SHSP under the HSIP. They manage the spot safety improvement program using the SLOSSS list and they identify systemic safety issues by identifying crash types or severities that are symptomatic of problem characteristics for candidate locations that do not necessarily have abnormally high crash rates. The Division of Traffic Engineering solicits improvements from MPOs and RPOs, on behalf of their member towns, to address identified hazardous elements.

RPOs may recommend low-cost improvements that can be expected to eliminate or reduce the severity of a hazardous location or will address lane departure crashes on a systematic basis. RPOs are responsible for identifying these locations and ConnDOT is responsible for implementing the projects and administering the program. For safety analyses, MPOs and RPOs typically use local police data because it is more complete than the State's database with respect to crashes on local roads. They use the SLOSSS list to identify candidate locations for safety projects, with crash characteristic data made available by ConnDOT, where available. Since data required to develop the SLOSSS are not typically available for local roadways, different measures—including number of crashes and crash severity—are used to identify promising candidate sites.

Taken as a unified pair, TASR and SLOSSS analyses represent a comprehensive network screening process with critical rate setting specific thresholds for selected roadway types. The limitations of the current network screening method include:

- The entire public roadway network is not included (as yet).
- The critical rate considers the average crash rate for a reference group, which does not consider the potential non-linear relationship between AADT and crash frequency.
- Does not account for regression to the mean bias.
- The minimum threshold value of 15 crashes in three years is somewhat of a “convenience” – the threshold was established over 25 years ago to arrive at a manageable number of locations on the SLOSSS list.

## **Step 2: Diagnosis**

The Division of Traffic Engineering is responsible for identifying safety needs. Traffic engineers are assigned to SLOSSS investigations. There are approximately 30 engineers in the Traffic Engineering Division that work on or supervise SLOSSS investigations. Traffic Engineering is tasked with reviewing the top 100 SLOSSS locations in each district and all locations on the fatality and severe injury (K & A) SLOSSS. However, the Division of Traffic Engineering has difficulty completing this task due to other responsibilities and priorities. The engineers prepare crash diagrams for every SLOSSS investigation to graphically represent crashes and help identify potential problems through reoccurring patterns. At one time, ConnDOT purchased an off the shelf program to automate the process of creating collision diagrams from crash data; however, the program is no longer supported. Engineers also use the crash summaries produced by CAS1 to help identify potential problems, patterns, and trends. Sites are screened for abnormal crash patterns that appear susceptible to reduction in frequency and/or severity. Many locations studied have random and/or normal patterns of crashes, none of which are susceptible to reduction through ordinary countermeasures.

The Safety Engineering Unit within the Division of Traffic Engineering works with RPOs when they submit applications for further study, which include information on the type of safety issue and crash history. Additionally, the five engineers in the Safety Engineering Unit focus on systematic safety improvements and developing a new SHSP, leaving the spot improvement projects to others in the Division of Traffic Engineering.

Highway Design performs a safety assessment for the majority of all projects, and develops collision diagrams by hand, even for projects that are not safety-related. They consider the crash history and identify what can be done in the

future to improve safety. They record the data in the preliminary design statement, even on pavement preservation projects. The typical sequence is as follows:

- 1) Record the data in the preliminary design statement.
- 2) Perform a safety assessment and note if there has been a crash problem.
- 3) Drive the roadway and look for safety issues.
- 4) Record the safety issues for others to consider as part of a future scope.
- 5) Note if a project is a SLOSS location.

### **Step 3: Countermeasure Selection**

Currently, the Safety Engineering Unit within Traffic Engineering initiates a project (identifying the problem and providing a concept design) and this is handed off to the design group. Traffic Engineering is involved in developing the mitigation measures. Traffic Engineering encourages use of the CMF Clearinghouse, but recognizes that there are no specific CMFs developed for Connecticut to date. In most instances, a countermeasure is selected based on the traffic engineer's experience, training, and judgment. On some occasions, traffic engineers refer to the NCHRP 500 series reports or FHWA's proven safety countermeasures. The Safety Section is often used as a resource in the countermeasure selection process. At this point, there is no formal list of countermeasures that has been distributed.

Traffic engineers consult with district offices requesting that low-cost, near-term countermeasures (e.g., signing, striping, signal timing changes, tree trimming) be implemented prior to a larger capital investment. The Safety Engineering Unit also helps RPOs with developing potential mitigation measures.

The Office of Construction primarily deals with work zone safety. They perform quality assurance (QA) work zone safety reviews throughout the year in conjunction with the Traffic unit and FHWA. The office typically tries to look at real-time crash data within work zones or from similar work zone types to identify and support the use of applicable countermeasures.

Connecticut Accident Summary Tables (CAST) reports are produced by the Crash Data and Analysis Unit. CAST tables report total crashes, vehicles, and persons for selected fields contained in the Accident History File database. They can be produced by type of crash as well as for total crashes. These reports are used for diagnosis and countermeasure selection.

In addition to the above analytic tools, which focus primarily on engineering decision-making using location-based analyses, the HSO focuses on drivers' and other road users' behavior. The HSO makes use of various tools, including the FARS data analysis system, standard reports from NHTSA such as *Countermeasures that Work*, and various guidelines for each of the behavioral program areas. These analyses are readily available for others to use, including the engineering-focused areas within ConnDOT.

### **Step 4: Economic Appraisal**

Through 2008, the Crash Data and Analysis Unit produced Q-Factors reports, which displayed injury and fatal crash cost factors sorted by roadway group and intersection types for State roadways. These were produced for a three-year period, displaying fatal crashes, injury accidents, PDO crashes, fatalities, injuries, crash totals, and cost estimates based on the National Safety Council's annual average costs of crash-related property damage, injuries, and fatalities. ConnDOT continues to produce benefit/cost (B/C) ratios to determine if projects are economically justified. Anticipated project benefits are quantified and the anticipated benefits are compared to the project costs. Project costs consider but are not limited to preliminary engineering, right-of-way, utilities, construction costs, annual maintenance costs, and operations costs.



Projects paid for with safety money are tracked in the ConnDOT financial systems, and this information is readily available to the engineers performing economic appraisal. There are gaps, however, in financial reporting if a safety-related project is paid for with funds other than those designated as “safety dollars”. This creates difficulties for assessing the effectiveness of safety projects because, for some safety-related activities, the spending is hard to identify. This is especially true when safety-related aspects are only a portion of a much larger project – it is difficult to define how much of the spending was for safety purposes. While not necessarily a barrier to calculating realistic B/C ratios as part of a safety project’s economic appraisal, additional details on safety-related portions of larger projects (including a cost-breakdown attributable to the safety activities) would help ConnDOT refine its B/C calculations as well as bring this type of appraisal into broader application throughout the Department’s design processes.

The Safety Engineering Unit identifies potential cost for local agencies for proposed mitigation measures. A B/C ratio is developed for each proposed local project. Historically, each RPO could submit four candidates and an unaffiliated town could submit one candidate, for projects with an estimated cost under a soft cap of \$500,000. However, the Department now considers any local safety project that is economically justified.

### **Step 5: Project Prioritization**

Currently, the HSIP program is managed by the Division Chief of Traffic Engineering. The Safety Engineering Unit is responsible for identifying systemic improvements on the ConnDOT system; currently, all projects are funded, provided the activity is in the Strategic Highway Safety Plan (SHSP), or the B/C ratio is greater than one. Other sections within the Traffic Engineering Division are responsible for identifying projects for spot improvements. For spot improvements, the location needs to be on the SLOSS list and the B/C ratio must be greater than one. Due to the amount of projects being moved through, there is typically no need for prioritization; all projects meeting the necessary criteria are funded.

For local roadways, the Safety Engineering Unit looks at the balance of HSIP funds along with B/C ratios to determine how many projects can be funded. There used to be an artificial cap on the amount of safety dollars that could be applied to one project, but now there is not a cap if the project is worthy of funding. In the last few years, there has been little competition, possibly because the funding process is too cumbersome and restrictive.

The Highway Safety Office uses pre-programmed reports, FARS analyses, and contractor support to produce analyses for the annual Highway Safety Plan, and to make program-level project prioritization and selection decisions. Most of the decisions are based on fatal crashes alone as the annual crash data close out comes too late in the planning cycle to be of use. As CAS2, the new report form, and electronic data submission have their effect on the timeliness of crash data, it is likely that the HSO will see greater utility in the full crash database. The HSO will greatly benefit from more timely annual crash data as well as a more complete set of crash data elements.

### **Step 6: Safety Effectiveness Evaluation**

Using the language of the HSM, ConnDOT sometimes uses naïve before and after (B/A) studies completed by the Crash Data and Analysis Unit in conjunction with the Annual Safety Report by the Division of Traffic Engineering. For example, B/A studies are periodically done for safety improvement projects to evaluate cost-effectiveness. The effectiveness evaluations to date have all been at the project level rather than evaluating an entire program or developing an average crash modification factor for a group of similar projects. The analysis requires a consistent roadway network across time. Since the roadway network changes each year, based on miles added or removed from construction projects, it is currently difficult to conduct effectiveness evaluations.

The Safety Group reports safety related projects annually through the HSIP annual report. They report basic statistics on safety-related projects regardless of funding sources. Currently, they sift through the Office of Construction stand-

alone spreadsheet of projects to identify project types related to safety. A separate database is used for financials, and it is therefore difficult to identify safety projects with their funding sources. Other departments tap into safety funds without reporting to safety group that these funds are being used. This makes the reporting task very difficult.

### **Part C: Predictive Method**

Highway Design does not perform “hard scientific analyses.” In general, they focus on preventing injury crashes. They conduct only limited quantitative analyses for design exceptions and alternatives analysis. Highway Design will typically ask Traffic Engineering for B/C analyses, rather than conduct the analyses themselves.

Design produces hand-drawn collision diagrams for the majority of projects, to identify future work that can improve safety. However, these analyses are not used to evaluate alternatives for the current design project. Safety effects of alternatives are considered, but B/Cs are typically completed in another unit (Traffic Engineering). Benefit-cost analyses are sent to the Safety group to look for a B/C ratio of one or more.

Effectiveness is sometimes assessed for personal interest, or they may contact the police department to ask about crashes since construction. These findings are considered anecdotally and are not used quantitatively to assess trade-offs or safety effectiveness of alternatives in future work.

### **Part D: Crash Modification Factors**

CMFs are infrequently used by the Traffic Engineering Division for analyses; however, it was noted that some engineers are using resources that are more than a decade old for determining countermeasure effectiveness. Highway Design is not currently using CMFs. Designers can see the benefit to using CMFs but currently prefer to perform qualitative analyses.

## ConnDOT's Planned Capabilities

This section provides an overview of ConnDOT's future desired safety analysis capabilities. This section follows the same flow as the Overview of the Highway Safety Manual section. ConnDOT's planned capabilities are discussed in terms of the HSM.

### Vision

In the planning session held at the beginning of this project, the stakeholders were asked to develop a statement that articulates the desired end-state – where the group wishes to go in the future. A vision statement is forward-looking and, in this case, describes the way that ConnDOT conducts safety analysis. The planning session participants jointly developed the following high-level vision:

Connecticut has a rigorous, efficient, and automated safety management process coupled with experienced and expert staff that can use the results to improve decision-making on the entire transportation network.

This high-level vision statement is clearly stated and points the way forward: ConnDOT will develop both its processes and its staff, it will seek to improve safety-related decision-making for all public roads, and it will seek out efficiency and analytic rigor. This statement is sufficient to serve as a guide for identifying needs in research, tool selection, and staff capabilities. In the strategic planning process, the statement can also help to keep project participants focused on selecting those actions which bring the State closer to the vision and rejecting or de-emphasizing those that do not. With this focus in mind, the remainder of this chapter presents the participants' discussion of needs and hoped-for solutions arising from the planning session. The discussion follows the four parts of the HSM.

### Part A: Introduction, Human Factors, and Fundamentals

When applying the advanced analytic methods in the Highway Safety Manual, engineers and analysts will be required to understand the foundations to the analytical procedures. Part A will be used as a supplement and guide for employing the advanced analytics discussed in the next three sections. Human factors and fundamentals will also be important for further understanding of crash patterns and diagnoses.

### Part B: Safety Management Process

In order to maximize efficiency, the safety tools used by ConnDOT and its safety partners should be automated as much as possible. Additionally, tools should also represent valid, reliable, and scientifically rigorous methods. Commercially available or freely available tools will allow ConnDOT to automate the roadway safety management process, incorporating functionality not currently considered in ConnDOT's process. HSM-based tools provide a defensible and repeatable methodology for the six steps of the roadway safety management process.

### Network Screening

One possibility to achieve this would be to upgrade the current SLOSSS methodology so that the critical rate method is calculated using SPFs, or a more advanced network screening performance measure is utilized. SLOSSS would also have to be expanded to apply to all roadway types (incorporating local roadways) so that candidate locations for safety treatment could be identified through a modern network screening process that compares individual segments or intersections to all segments or intersections of a similar type. Alternatively, ConnDOT may choose to adopt and adapt network screening tools available through FHWA, AASHTO, and others. Custom tools developed by ConnDOT may be difficult to implement in a timely manner, but this presents a third option to explore – the creation of new tools

specifically designed to meet the needs of ConnDOT and its partner agencies. ConnDOT recognizes that existing off-the-shelf tools may be easier to implement; however, any such tools will need to be customizable to meet ConnDOT's needs and data systems. There are no solutions that can be implemented without some effort spent in customization as well as training.

The most comprehensive resource available for identifying valid, reliable, and rigorous safety analysis methods is the HSM. The HSM presents several methods for network screening. As noted earlier, the current SLOSS reports are based on a sophisticated analysis supporting network screening. The main shortcomings of the SLOSS method are that the critical rate method—used to identify locations of interest for follow-up safety review—is based on a linear relationship between crashes and traffic volume, does not correct for regression to the mean (RTM) bias, and the threshold three year crash total is set arbitrarily. The HSM describes methods that could be adopted into an upgraded SLOSS methodology that would address the RTM bias and the non-linear relationship between crash frequency and traffic volume. Whatever methods are selected, they will have to apply to all public roads. The group's discussion centered on the need for basic roadway inventory and traffic data on local roads—the data structure is in place for capturing this information into a shared, centralized resource, but the data itself is missing. The group also discussed a gradual approach to meeting the needs for local roadway integration into network screening by starting with the HPMS segments. A survey conducted among local agencies (including the MPOs) gained support among the participants as a way to find out what capabilities and data sources already exist and to describe the local agencies' needs. The TRCC can also help identify what data should be available to whom.

Incorporating the HSM-based network screening procedure requires agency personnel to have the skills and manpower necessary to:

- Establish focus.
- Identify networks based on facility type.
- Understand and select appropriate performance measures.
- Select a valid screening method.
- Evaluate the results.

The HSM method allows the agency to not only identify and rank sites where improvements have the potential to reduce the number of crashes, but it also provides a method to evaluate a network to identify sites with a particular crash type or severity in order to formulate and implement a policy (e.g., rumble-strip implementation program). Secondly, the HSM provides the necessary background to appropriately identify specific facility types within the entire network; similar groupings can be used for more refined screening.

Most importantly, ConnDOT analysts will understand the different performance measures that are used for network screening, and will understand the advantages (e.g., accounts for RTM bias) and disadvantages (e.g., requires more data) to each. Refer to Tables 1 and 2 for network screening performance measures, their data requirements, and whether the measures account for RTM bias and incorporate a performance threshold.

The HSM methodology allows the analyst to select between different screening methods: simple ranking, sliding window, and peak searching. The simple ranking method lists sites from high to low based on the selected performance measure. The sliding window method breaks the segment into smaller windows, selected by the user, to identify the windows with the greatest potential for reduction. The peak searching method is similar to the sliding window method, where the segment is subdivided into smaller parts, but now the individual windows are analyzed based on statistical significance. If significance is not achieved, then windows are aggregated until they span the length

of the entire segment, if necessary. It is likely that the Crash Data and Analysis Unit and the Safety Engineering Unit will be tasked with implementing and using these methods. AASHTOWare Safety Analyst™, among other tools, will help to automate the process.

### **Diagnosis**

HSM-based tools will provide ConnDOT a systematic process to perform safety data reviews, assess supporting documentation, and assess field conditions. Application of these tools will serve to formalize the processes already in place at ConnDOT. The Traffic Engineering Division and Highway Design will benefit from using these tools. Traffic Engineering will maintain responsibility for diagnosis using similar methods to those already in place. AASHTOWare Safety Analyst™, among other tools, will help to automate the process.

### **Countermeasure Selection**

ConnDOT, specifically the Traffic Engineering Division, the Safety Engineering Unit, and Highway Design, will benefit from using tools such as application guides, informational guides, and information sources to select appropriate countermeasures based on information from national and local resources. The HSM provides a three-step methodology to identifying and selecting countermeasures for a site:

1. Identify contributing factors for crashes at the site (the previous step; Diagnosis).
2. Identify countermeasures which may address the contributing factors (the current step; Countermeasure Selection).
3. Conduct B/C analysis to select preferred treatments (the next step; Economic Appraisal).

Publicly available tools use site-specific data to identify contributing factors and potential countermeasures to address the contributing factors. Potential resources for identifying contributing factors and selecting countermeasures include the FHWA's Proven Safety Countermeasures, the NCHRP Report 500 series, and NHTSA's Countermeasures that Work. Once potential countermeasures are selected, calculating the expected benefit can be data intensive. Desired data are presented below (NCHRP Report 500 Series (<http://www.trb.org/Main/Blurbs/152868.aspx>).

Data Requirements), for which countermeasures exist in AASHTOWare Safety Analyst™, Interactive Highway Safety Design Model (IHSDM), and Parts C and D of the HSM.

### **Economic Appraisal**

Economic Appraisal considers both benefits and costs associated with countermeasure implementation. HSM-based tools allow for monetary benefits to be calculated, using advanced methodologies to estimate the effectiveness of countermeasures which are then converted to a dollar value using average crash costs. These methodologies include the use of CMFs, SPFs, or if necessary, sensitivity analyses using engineering judgment. The CMF Clearinghouse, HSM Part D, AASHTOWare Safety Analyst™, and IHSDM provide estimates of the effectiveness of various countermeasures. HSM-based tools also provide a more complete picture of project costs, considering design, construction, and maintenance costs. Non-monetary considerations are also provided. HSM-based tools, such as AASHTOWare Safety Analyst™ have the built-in functionality to perform these calculations, with base values for costs. These costs can be updated to reflect those for Connecticut.

### **Project Prioritization**

ConnDOT will benefit from using HSM-based tools, application guides, and informational guides for prioritizing economically justified projects by economic effectiveness measures, incremental B/C analysis rankings, or optimization methods. This list would be methodical and defensible. Three HSM-based prioritization methods include:

- Ranking by economic effectiveness measures.
- Incremental B/C ranking.
- Optimization methods.

The simplest methodology is to rank sites by economic effectiveness measures (e.g., monetary value of project benefits). If few sites are being compared, projects can be compared across multiple criteria. The incremental B/C ratio is the next simplest methodology, comparing the ratio in differences in benefits and costs for selected projects. Finally, the most complex methodology is to use optimization methods. Optimization methods identify a project set that will maximize benefits within a fixed budget and other constraints. In the case of incremental B/C ranking and optimization, only projects that are found to be economically justified are included. HSM-based tools, such as AASHTOWare Safety Analyst™, are capable of automating the process of project prioritization.

### **Safety Effectiveness Evaluation**

HSM-based tools will help ConnDOT to evaluate the effectiveness of safety-related construction projects. Safety effectiveness evaluation is important for both program and project level evaluations. Evaluating the effectiveness of countermeasures would allow ConnDOT to determine what countermeasures are economically justified, and would provide State-specific CMFs for use in future economic appraisal and project prioritization. Additionally, safety effectiveness evaluation is used to evaluate a program, considering the overall safety effectiveness of countermeasures in comparison to their costs. There are two basic study designs generally used for safety effectiveness evaluations:

- Observational B/A studies.
- Observational cross-sectional studies.

ConnDOT will benefit from using both types of study designs. Safety effectiveness evaluation can be implemented by DOT staff, or may be completed through contract research. HSM-based tools, such as AASHTOWare Safety Analyst™, can help ConnDOT to implement a safety effectiveness evaluation program in-house.

### **Part C: Predictive Methods**

ConnDOT will benefit from incorporating the HSM Part C predictive method in the alternatives analysis phase and design exception process of highway design. The predictive method can be used to evaluate tradeoffs in design decisions or to identify what combinations of features would result in the lowest predicted crash frequency for a project. Several tools have been developed to help agencies use the predictive method for predicting the average crash frequency for existing roadways, proposed alternatives, or for proposed roadways. These include:

- HSM Part C Spreadsheets: ConnDOT can use this tool to implement the Part C predictive method of the HSM. This tool can be used to estimate the expected number of crashes for segments and intersections for the applicable roadway types from Part C of the HSM. This tool will allow ConnDOT to consider multiple segments within a safety project, reporting predicted average crash frequency, expected average crash frequency, and potential for safety improvement for existing conditions. The advantage of this spreadsheet tool is that it is customizable, which is what some other States are doing, allowing for additional CMFs applicable to ConnDOT to be included. It can also be customized to include B/C tools.
- Interactive Highway Safety Design Model: This tool has several evaluation modules that can be used by ConnDOT, including the crash prediction module, design consistency module, intersection review module, policy review module, traffic analysis module, and driver/vehicle module. While all modules can be applied to

two-lane rural highways, the crash prediction module can also be applied to rural four-lane highways, urban and suburban arterials, and freeways. The tool will help ConnDOT evaluate tradeoffs of design decisions on roadway projects.

- Interchange Safety Analysis Tool Enhanced (ISATe): ConnDOT can use this tool to estimate the safety performance of an existing interchange, predict the safety performance of design alternatives for an existing interchange, or predict the safety performance of design alternatives for a new interchange. The tool can be used to evaluate freeway sections, ramps or collector-distributor roads, and crossroad ramp terminals. As with IHSDM, ISATe can evaluate combinations of multiple components.

In general, these tools will most effectively be used by Highway Design for consideration of alternatives or for quantifying safety for design exceptions. Additionally, these tools are applicable for the Safety Engineering Unit and the Traffic Engineering Division for quantifying the crash benefits of geometric design decisions for economic analysis in the roadway safety management process.

#### **Part D: Crash Modification Factors**

ConnDOT will also benefit from incorporating the HSM Part D CMFs in the alternatives analysis phase and design exception process of highway design. CMFs will help the Traffic Engineering Division to quantify the safety effectiveness of proposed alternatives or countermeasures, and to conduct B/C analyses. Additionally, CMFs can be used to quantify the impacts of not meeting specific design criteria when considering design exceptions. Note that CMFs can also be found in the CMF Clearinghouse. In the future, ConnDOT will develop Connecticut-specific CMFs, which will provide a higher level of confidence for alternatives analysis and for design exceptions. Additionally, ineffective alternatives or countermeasures can be excluded from the process if no safety benefit is found.

## Achieving the Planned Capabilities

This section provides an overview of the issues ConnDOT faces to achieve the planned capabilities. Data governance issues, platform/functionality, project records/location history, desired output, potential tools and resources, and data requirements are presented.

### Data Governance

All ConnDOT divisions and offices represented at the group planning session will have a stake in the functionality and use of safety systems supporting data driven decision-making. Some offices, such as the Office of Construction or the Office of Maintenance will more likely be contributors to the system rather than users of the system. However, several offices, such as the Traffic Engineering Division, the Highway Safety Office, and Highway Design will need to understand and use the analytic functions of the system as well as data integrated from several sources. An open source would allow for regions, municipalities, MPOs and RPOs, and other stakeholders to contribute data (such as local road geometry and volumes), but may require the use of a gate-keeper to protect the flow of information (e.g., multiple users may try to provide different updates for the same data). Additionally, ConnDOT will need to identify who is responsible for the data (potentially the owner) and who is responsible for maintaining the data. ConnDOT will ultimately be responsible for setting data standards, both in accordance with FHWA guidelines and based on its own requirements. The local agencies who supply data will need to understand and implement ConnDOT guidance in collecting and reporting data. ConnDOT OMTS will need to know the requirements for initial development as well as for ongoing maintenance. The maintenance processes, to the extent that they rely on local data sources, will require careful specification of roles and responsibilities, and multiple interagency agreements.

### Training

Training will need to be provided in a timely manner and should be coordinated with the roll-out of the new system—rather than having the training too far in advance—or after roll-out. It is likely that more than one training course will be needed—each one tailored to the needs and implementation schedule of a specific set of data analysts and system users. Training should be coordinated between State and local agencies so that everyone who uses the system can understand the outputs of the tools and speak a common language.

### Platform/Functionality

ConnDOT should have analytical tools that are as automated as possible. Staff availability to work through computations is limited; therefore, it is ConnDOT's vision to adopt national tools where possible. These tools should be off-the-shelf, but should be customizable if necessary. For example, ConnDOT would benefit from jurisdiction-specific SPFs and the use of Connecticut-specific CMFs. Additionally, the software should be able to incorporate updated crash, roadway, and traffic data to update SPFs and CMFs as well as calculate CMFs for new treatments. The tool should be able to accommodate data from both a linear referencing system and geographic information systems in order to fully leverage the databases currently developed and maintained by ConnDOT.

OMTS will need to specifically know what hardware, software, and security needs exist for the potential new tools before they can be installed on the network. Alternatively, ConnDOT may choose to continue using existing systems (with upgraded capabilities) to house data and perform analyses. For example, the SLOSS system can be updated with more rigorous methods from the HSM (e.g., Empirical Bayes procedures) by introducing SPFs rather than utilizing a crash rate. This system would additionally need to be enhanced to include local roadways (in terms of both crash data and roadway inventory data). In such cases, OMTS would still need to understand specifications for the upgraded systems and be ready to manage any hardware and security changes implemented.



The Roadway Information Systems group is interested in developing a web-based tool to share roadway data through a GIS platform. It should be capable of overlaying volumes, signal locations, and roadside elements. The number of fields should be expanded to incorporate MIRE data. Additionally, the Roadway Information Systems group may be responsible for collecting additional data used for SPF and CMF development and use. The Roadway Information Systems group will need to know what data to collect, the required format of the data, and where the data should be housed.

### **Project Records/Location History**

ConnDOT needs to be able to incorporate continuous records of changes to the system in an integrated environment. Changes to the roadway environment are constantly occurring, and ConnDOT needs a tool that can track these changes. This is important for B/A safety effectiveness analysis. Additionally, the Construction and Maintenance offices need to be able to update their activities in a manner that is recorded within the database such that the Traffic Engineering Division and the Highway Safety Office can summarize and report the data. ConnDOT needs this information to be accessible for each location based on the route and milepost LRS.

### **Desired Output**

ConnDOT desires a system that supports all business practices. Specifically, the output from analytic tools should be easily incorporated into performance measures for the HSIP and SHSP. Additionally, it must provide a network screening list of sites of interest, provide crash data for development of collision diagrams, and support alternatives analysis and design exceptions.

### **Potential Tools and Resources**

Several of the off-the-shelf tools and custom tools, as well as associated guidebooks, fit ConnDOT's desired safety analysis system, products, and desired capabilities. The tools presented in this Chapter should be considered as alternatives or supplementary to the existing tools and their potential upgrades that are currently used by ConnDOT. Note that there are additional tools that could be considered for performing subsets of the Part B roadway safety management process if a single tool such as AASHTOWare Safety Analyst™ becomes undesirable or infeasible, or there is a need to provide standalone tools to local partners.

Potential tools applicable for the roadway safety management process include:

- AASHTOWare Safety Analyst™: This tool was developed to implement the Part B roadway safety management process from network screening to safety effectiveness evaluation. ConnDOT, with some planning, can import the complete roadway network, including all data required for network screening. This tool includes the Empirical Bayes method to account for RTM bias, and uses SPFs to account for the non-linear relationship between crashes and traffic volume. This tool would provide ConnDOT with the ability to diagnose sites with site-specific or system-wide safety issues. Additionally, AASHTOWare Safety Analyst™ would allow ConnDOT to estimate the expected effectiveness of infrastructure countermeasures using CMFs and estimate the cost-effectiveness of potential countermeasures, and perform project prioritization. The software requires a license and is available for an annual fee. Additional information is available at: <http://www.safetyanalyst.org/index.htm>.
- AgileAssets SafetyAnalyst: This tool has similar capabilities to AASHTOWare SafetyAnalyst in applying the HSM Part B roadway safety management process; however, it does not allow for Safety Effectiveness Evaluation of previous projects completed. The software is available for a fee. Additional information is available at: <http://www.agileassets.com/products/safety-analyst/>.

- Pedestrian and Bicycle Crash Analysis Tool (PBCAT): This tool supports Part B Diagnosis and Countermeasure Selection. It can provide CTDOT and local partners with the ability to analyze crashes between motor vehicles and pedestrians or bicyclists. The software conducts a crash typing analysis of imported crashes, and helps users to identify appropriate countermeasures to address pedestrian and bicycle safety issues. The tool is available free of charge at the following link: [http://www.pedbikeinfo.org/pbcat\\_us/](http://www.pedbikeinfo.org/pbcat_us/).
- Pedestrian and Bicycle GIS Safety Tools: This tool supports Part B network screening, diagnosis, and countermeasure selection and can provide ConnDOT with the ability to use GIS software to link crash data with geographical data for spatial analysis and mapping for pedestrian and bicycle crashes. The tool can aid ConnDOT with generating walking and bicycle routes to schools based on the shortest or safest routes. The Highway Safety Office would also benefit from this GIS tool for use in funding distribution. The tool is available free of charge at: <http://www.hsisinfo.org/ped-bike-gis.cfm>. More information can be found in the FHWA tech brief at: <http://safety.fhwa.dot.gov/tools/docs/gis.pdf>.
- UPLAN: This online tool could be a useful resource for ConnDOT to share data among work units in a GIS environment, as well as share select data with the public. It can allow for better planning through collaborative information. Currently, Utah presents maps for the safety index (similar to SLOSS score), crash rate score, crashes per mile score, severe crash rate score, severe crashes per mile score, and safety STIP projects. This tool can be used to support Part B network screening and for HSIP and SHSP reporting. Additional information can be found at: <http://tig.transportation.org/Pages/UPlan.aspx>.
- Vision Zero Suite (VZS): This tool is designed to implement an analytical procedure similar to Part B of the HSM. VZS provides decision support analysis for network screening, diagnosis, countermeasure selection, economic analysis, and treatment prioritization. The tool is customized to meet agency needs and has-off system road capabilities for use by cities and counties. An additional capability of this tool is pattern recognition analysis used in diagnosis. Approximately two days of training are required to become a “Master Analyst.” The tool is available for a fee and further information can be found at: <http://diexsys.com/>.

Applicable resources supporting the safety management process and/or application of the above tools include:

- A Guide to Developing Quality Crash Modification Factors ([http://www.cmfclearinghouse.org/collateral/CMF\\_Guide.pdf](http://www.cmfclearinghouse.org/collateral/CMF_Guide.pdf)).
- CMF Clearinghouse (<http://www.cmfclearinghouse.org/>).
- CMFs in Practice (<http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/>).
- Development of Guidance for States Transitioning to New Safety Analysis Tools (<http://search.proquest.com/docview/850523231>).
- FHWA Proven Safety Countermeasures (<http://safety.fhwa.dot.gov/provencountermeasures/>).
- FHWA Systemic Project Selection Tool (<http://safety.fhwa.dot.gov/systemic/index.htm>).
- Highway Safety Improvement Program (HSIP) Manual (<http://safety.fhwa.dot.gov/hsip/resources/fhwasa09029/>).
- Highway Safety Manual (<http://www.highwaysafetymanual.org>).

- Highway Safety Training Synthesis/Roadmap (*not yet available*).
- NCHRP Report 500 Series (<http://www.trb.org/Main/Blurbs/152868.aspx>).
- NCHRP Report 600: Human Factors Guidelines for Road Systems ([http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_600Second.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf)).
- NHTSA Countermeasures that Work (<http://www.ghsa.org/html/publications/countermeasures.html>).
- Recommended Protocols for Developing Crash Modification Factors ([http://www.cmfclearinghouse.org/collateral/CMF\\_Protocols.pdf](http://www.cmfclearinghouse.org/collateral/CMF_Protocols.pdf)).
- Safety Performance Function Decision Guide: SPF Calibration vs SPF Development ([http://safety.fhwa.dot.gov/rsdp/downloads/spf\\_decision\\_guide\\_final.pdf](http://safety.fhwa.dot.gov/rsdp/downloads/spf_decision_guide_final.pdf)).
- Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs ([http://safety.fhwa.dot.gov/rsdp/downloads/spf\\_development\\_guide\\_final.pdf](http://safety.fhwa.dot.gov/rsdp/downloads/spf_development_guide_final.pdf)).
- The Art of Appropriate Evaluation: A Guide for Highway Safety Program Managers (<http://www.nhtsa.gov/people/injury/research/ArtofAppEvWeb/>).
- User's Guide to Develop Highway Safety Manual (HSM) Safety Performance Function (SPF) Calibration Factors ([http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07\(332\)\\_FinalGuide.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07(332)_FinalGuide.pdf)).

Potential tools applicable for design and construction include:

- HSM Part C Spreadsheets: ConnDOT can use this tool to implement the Part C predictive method of the HSM. This tool can be used to estimate the expected number of crashes for segments and intersections for the applicable roadway types from Part C of the HSM. This tool will allow ConnDOT to consider multiple segments within a safety project, reporting predicted average crash frequency, expected average crash frequency, and potential for safety improvement for existing conditions. The advantage of this spreadsheet tool is that it is customizable, which is what some other States are doing, allowing for additional CMFs applicable to ConnDOT to be included. It can also be customized to include B/C tools. The tool is available free of charge at: <http://www.highwaysafetymanual.org/Pages/default.aspx>.
- Interactive Highway Safety Design Model (IHSDM): The IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on highways. It is a decision-support tool for individual locations, and is not intended to be used as a safety management tool for an entire network. Intended users include highway project managers, designers, and traffic and safety reviewers in State and local highway agencies and engineering consulting firms. IHSDM currently includes six evaluation modules:
  - Crash prediction module: Estimates the expected frequency of crashes on a highway using geometric design and traffic characteristics. IHSDM is a faithful implementation of the predictive methods in the HSM.
  - Design consistency module: Estimates the magnitude of potential speed inconsistencies to help identify and diagnose safety issues at horizontal curves of existing highways or proposed designs.
  - Intersection review module: Performs a diagnostic review to systematically evaluate an intersection design for typical safety concerns.

- Policy review module: Checks highway segment design elements for compliance with relevant highway geometric design policy at several stages during the highway design process.
- Traffic analysis module: Estimates operational quality-of-service measures for an existing or proposed design under current or projected future traffic flows.
- Driver/Vehicle module: Estimates a driver's speed and path along a highway and corresponding measures of vehicle dynamics.

All modules can be applied on two-lane rural highways. Only the crash prediction module is applicable to other facility types, such as four-lane rural highways, urban and suburban arterials, and freeways. The crash prediction module is a faithful implementation of Part C of the HSM and has the same data requirements as the HSM predictive methodology. Its advantage over the Part C spreadsheets is that the CAD drawings of the alignment can be directly imported into the IHSDM instead of having to be manually entered into a spreadsheet. The tool will help ConnDOT evaluate tradeoffs of design decisions on roadway projects. The tool is available free of charge at: <http://www.ihsdm.org/wiki/Welcome>.

- Interchange Safety Analysis Tool Enhanced (ISATe): ConnDOT can use this tool to estimate the safety performance of an existing interchange, predict the safety performance of design alternatives for an existing interchange, or predict the safety performance of design alternatives for a new interchange. The tool can be used to evaluate freeway sections, ramps or collector-distributor roads, and crossroad ramp terminals. As with IHSDM, ISATe can evaluate combinations of multiple components. The tool is available free of charge at: <http://www.highwaysafetymanual.org/Pages/default.aspx>.
- Roadside Safety Analysis Program (RSAP): This tool supports Part B Countermeasure Selection, Economic Appraisal, and Project Prioritization. RSAP is used to evaluate alternatives of roadside safety-related projects. Specifically, this tool can help users to evaluate the benefits and costs of roadside improvements, and compute the incremental B/C ratio for roadside improvement alternatives. The software is available free of charge at: <http://rsap.roadsafellc.com/>.

Applicable resources supporting the project development process and/or application of these tools include:

- CMF Clearinghouse (<http://www.cmfclearinghouse.org/>).
- CMFs in Practice (<http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/>).
- Integrating the Highway Safety Manual into the Highway Project Development Process ([http://safety.fhwa.dot.gov/hsm/hsm\\_integration/hsm\\_integration.pdf](http://safety.fhwa.dot.gov/hsm/hsm_integration/hsm_integration.pdf)).
- NCHRP Report 500 Series (<http://www.trb.org/Main/Blurbs/152868.aspx>).

## Data Requirements

### MIRE FDE Minimum Dataset and ARNOLD

As a result of Moving Ahead for Progress in the 21<sup>st</sup> Century (MAP-21) legislation, the Model Inventory of Roadway Elements (MIRE) Fundamental Data Elements (FDE) were identified as the elements needed to support the HSM roadway safety management process and related analytical tools. The MIRE FDE are a subset of MIRE elements and are equivalent to some Highway Performance Monitoring System (HPMS) elements that States submit for Federal-Aid

Highways. MIRE FDE are divided into a full set of MIRE FDEs and a reduced set for road with an annual average daily traffic (AADT) less than 400 vehicles per day. Table 3 and

Table 4 summarize the MIRE FDE.

**Table 3. MIRE FDE for All Public Roads with AADT ≥ 400 Vehicles per Day.**

| <b>Roadway</b>                 |   |  |
|--------------------------------|---|--|
| Segment Identifier             | Route Number  | Route/Street Name  |
| Federal-aid/Route Type         | Rural/Urban Designation                                       | Surface Type   |
| Begin Point Segment Descriptor | End Point Segment Descriptor                                  | Segment Length   |
| Direction of Inventory         | Functional Classification                                     | Median Type  |
| Access Control                 | Median Type   | One/Two-Way Operations                                     |
| Number of Through Lanes        | AADT  | AADT Year  |
| Type of Government Ownership   |   |  |
| <b>Intersection</b>            |   |  |
| Unique Intersection Identifier | Location Identifier for Road 1<br>Crossing Point              | Location Identifier for Road 2<br>Crossing Point           |
| Intersection Geometry          | Intersection Traffic Control                                  | Intersection Road AADT                                     |
| Intersection Road AADT Year    | Unique Approach Identifier                                    |  |
| <b>Interchange/Ramp</b>        |   |  |
| Unique Interchange Identifier  | Location Identifier for Roadway at<br>Beginning Ramp Terminal | Location Identifier for Roadway at<br>Ending Ramp Terminal |
| Ramp Length                    | Roadway Type at Beginning Ramp<br>Terminal                    | Roadway Type at Ending Ramp<br>Terminal                    |
| Interchange Type               | Ramp AADT   | Ramp AADT Year   |
| Functional Classification      | Type of Government Ownership                                  |  |

**Table 4. MIRE FDE for All Public Roads with AADT < 400 Vehicles per Day.**

| Roadway                        |  |  |
|--------------------------------|--|--|
| Segment Identifier             | Functional Classification                        | Surface Type                                     |
| Type of Government Ownership   | Number of Through Lanes                          | AADT   |
| Begin Point Descriptor         | End Point Descriptor                             | Rural/Urban Designation                          |
| Intersection                   |  |  |
| Unique Intersection Identifier | Location Identifier for Road 1<br>Crossing Point | Location Identifier for Road 2<br>Crossing Point |
| Intersection Geometry          | Intersection Traffic Control                     |  |

The two tables show that all public roadways will need to be identified and characterized in terms of location, number of lanes, functional classification, area type, and AADT. This requirement will be consistent with the ARNOLD, which requires ConnDOT to develop a basemap inclusive of all public roads within Connecticut. Additionally, ConnDOT is required to geolocate all crashes on the basemap, giving priority to fatal and serious injury crashes. Combining this data with the MIRE FDE data will provide ConnDOT with an integrated database that can provide easy access to data for analysis and evaluation. The Exor platform is an ideal tool to integrate this data, which can then be exported for network screening, exported to other programs listed above, and exported for use in HSIP reporting. A feedback system should be in place for construction reporting and Roadway Information Systems data collection to update any data (i.e., baseline segments, AADT, number of lanes) that is then exported for further use.

### Highway Safety Manual

The Highway Safety Manual has minimum data requirements for analysis. Data requirements vary depending on the application that users select. Requirements for the roadway safety management process include:

- Network screening:
  - Historical crash data by severity and location.
  - Traffic volume.
  - Basic site characteristics.
  - Calibrated safety performance functions and over-dispersion parameters.
- Diagnosis:
  - Crash and roadway data for site condition assessment.
- Economic appraisal:
  - Crash history by severity.
  - Current and future average annual daily traffic volumes.
  - Implementation year for expected countermeasure.
  - Safety performance function (SPF) for current and future site conditions.
  - CMFs for all countermeasures under consideration.
  - Monetary value of crashes by severity.
  - Service life of the countermeasure.
  - Discount rate.
  - Project phasing schedule.
- Safety effectiveness evaluation [Note that there are three basic study designs for safety effectiveness evaluations and the data requirements will vary based on the selected study design]:
  - 10 to 20 treatment sites.

- 10 to 20 comparable non-treatment sites.
- 3 to 5 years of crash and volume “before” data.
- 3 to 5 years of crash and volume “after” data.
- SPF for treatment site types.
- SPF for non-treatment site types.
- Target crash type.

There are also four basic facility types with predictive methods for segments and intersections/Interchanges. The data requirements for the SPFs and CMFs vary by facility type. Not all data are required for using the predictive methodology. Segment length and AADT data are typically required for SPF development, and base values are used for other data elements. However, the more data ConnDOT can provide, the more accurately the predictive methodology can be used to assess safety effectiveness. SPFs and CMFs in the HSM utilize the following data.

- Predictive method for rural two-lane two-way roadway segments:
  - Length of segment.
  - Average annual daily traffic (AADT).
  - Lane width.
  - Shoulder width.
  - Shoulder type.
  - Horizontal Curves.
    - Length.
    - Radius.
    - Superelevation.
    - Presence or Absence of Spiral Transitions.
  - Vertical Grade.
  - Driveway density.
  - Presence or absence of centerline rumble strips.
  - Presence or absence of a passing lane.
  - Presence or absence of a short four-lane section.
  - Presence or absence of a two-way left-turn lane.
  - Roadside hazard rating.
  - Presence or absence of roadway segment lighting.
  - Presence or absence of automated speed enforcement.
- Predictive method for rural two-lane two-way roadway intersections:
  - Major and minor road traffic volume.
  - Number of intersection legs.
  - Type of traffic control.
  - Intersection skew angle.
  - Number of approaches with intersection left-turn lanes.
  - Number of approaches with intersection right-turn lanes.
  - Presence or absence of intersection lighting.
- Predictive method for rural multilane highway segments:
  - Length of segment.
  - AADT.
  - Lane width.
  - Shoulder width.
  - Shoulder type.
  - Side slope.
  - Presence of lighting.
  - Presence of median and median width.
  - Presence of automated speed enforcement.

- Predictive method for rural multilane highway intersections:
  - Major and minor road traffic volume.
  - Number of intersection legs.
  - Type of traffic control.
  - Intersection skew angle.
  - Presence of left-turn and right-turn lanes.
  - Presence or absence of lighting.
- Predictive method for urban and suburban arterial segments:
  - Length of segment.
  - AADT.
  - Number of through lanes.
  - Presence of two-way left-turn lane.
  - Presence/type of median.
  - Presence/type of on-street parking.
  - Number of driveways for each driveway type.
  - Roadside fixed object density.
  - Average offset to roadside fixed objects from edge of traveled way.
  - Presence or absence of roadway lighting.
  - Posted speed limit or actual traffic speed.
  - Presence of automated speed enforcement.
- Predictive method for urban and suburban arterial intersections:
  - Major and minor road traffic volume.
  - Number of intersection legs.
  - Type of traffic control.
  - Number of approaches with intersection left-turn lane.
  - Number of major-road approaches with intersection signal phasing.
  - Number of approaches with intersection right-turn lane.
  - Number of approaches with intersection right-turn-on-red operation prohibited.
  - Presence or absence of intersection lighting.
  - Maximum number of traffic lanes to be crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands.
  - Proportions of nighttime crashes for unlighted intersections.
  - For signalized intersections, land use and demographic data needed include:
    - Number of bus stops within 1,000 feet of the intersection.
    - Presence of schools within 1,000 feet of the intersection.
    - Number of alcohol sales establishments within 1,000 feet of the intersection.
    - Presence of red light camera.
    - Number of approaches on which right-turn-on-red is allowed.
- Predictive method for freeway segments:
  - Area type.
  - Number of lanes.
  - Median type.
  - Freeway speed-change lane presence.
  - Freeway speed-change lane type.
  - AADT.
  - Peak hour factor.
  - Segment length.
  - Entrance ramp AADT.
  - Exit ramp AADT.
  - Horizontal curve length.
  - Horizontal curve radius.



- Length of horizontal curve in segment.
- Number of roadbed curves.
- Lane width.
- Inside shoulder width.
- Outside shoulder width.
- Shoulder rumble strip presence.
- Median width.
- Median barrier presence.
- Proportion of segment with roadside barrier.
- Distance from edge of inside shoulder to barrier face.
- Hours where volume exceeds 1000 vehicles per hour per lane.
- Upstream ramp entrances and downstream ramp exit locations.
- Length of ramp entrance.
- Length of ramp exit.
- Length of ramp in segment.
- Ramp side indicator.
- Type B weaving section presence.
- Type B weaving section length.
- Type B weaving section in segment.
- Proportion of segment with a barrier on the roadside.
- Clear zone width.
- Distance from edge of outside shoulder to barrier face.
- Outside barrier presence.
- Predictive method for ramp segments and terminals:
  - Number of lanes.
  - Ramp type (entrance or exit).
  - Collector-distributor road presence.
  - Area type.
  - Ramp segment length.
  - Ramp AADT.
  - Length of collector-distributor segment.
  - Collector-distributor segment AADT.
  - Number of curves in ramp segment.
  - Radius of horizontal curve.
  - Length of horizontal curve.
  - Length of horizontal curve in segment.
  - Lane width.
  - Right shoulder width.
  - Left shoulder width.
  - Distance from edge of right shoulder to barrier face.
  - Proportion of segment length with a barrier present on the right side.
  - Distance from edge of left shoulder to barrier face.
  - Proportion of segment length with a barrier present on the left side.
  - Proportion of segment length adjacent to taper associated with lane add or drop.
  - Lane add or drop presence.
  - Ramp speed-change lane presence.
  - Proportion of segment length adjacent to speed-change lane for a connecting ramp.
  - Weaving section presence.
  - Weaving section length.
  - Proportion of segment length within a weaving section.
  - Number of ramp terminal legs.

- Ramp terminal control type.
- Crossroad number of lanes.
- Ramp terminal configuration.
- Proportion of total leg AADT on exit ramp leg.
- AADT volume for entrance ramp.
- AADT volume for exit ramp.
- AADT volume for crossroad leg between ramps.
- AADT volume for crossroad leg outside of interchange.
- Effective number of lanes serving exit ramp traffic.
- Number of lanes serving exit ramp traffic.
- Presence of non-ramp public street leg at terminal.
- Exit ramp skew angle.
- Distance to the next public street intersection on the outside crossroad leg.
- Distance to adjacent ramp terminal.
- Presence of protected left-turn operation.
- Exit ramp right-turn control type.
- Crossroad median width.
- Number of through lanes on the inside crossroad approach.
- Number of through lanes on the outside crossroad approach.
- Number of lanes on the exit ramp leg at the terminal.
- Presence of right-turn channelization on the inside crossroad approach.
- Presence of right-turn channelization on the outside crossroad approach.
- Presence of right-turn channelization on the exit ramp approach.
- Presence of a left-turn lane on the inside crossroad approach.
- Presence of a left-turn lane on the outside crossroad approach.
- Width of left-turn lane on the inside crossroad approach.
- Width of left-turn lane on the outside crossroad approach.
- Presence of a right-turn lane on the inside crossroad approach.
- Presence of a right-turn lane on the outside crossroad approach.
- Number of driveways on the outside crossroad leg.
- Number of public street approaches on the outside crossroad leg.
- AADT volume for the inside crossroad leg.

### **AASHTOWare Safety Analyst™**

AASHTOWare Safety Analyst™ is a suite of tools to be used by State and local highway agencies for the implementation of the Highway Safety Manual safety management process. It requires upfront work to structure and import safety data, but can then be used as a management tool for housing data, prioritizing project work, maintaining records of updated conditions, and evaluating countermeasure safety effectiveness. Ultimately, AASHTOWare Safety Analyst™ supports the decision-making process through state-of-the-art safety management approaches.

Data requirements include roadway characteristics, traffic volume, and crash data for the roadway network of interest. Most roadway required elements are readily available from ConnDOT; however, initial effort is required to import and manage these data. Safety Analyst is capable of working with a vast array of desirable data, but the minimum set of data to use the software includes the following:

- Roadway Segment Characteristics:
  - Segment number.
  - Segment location.
  - Segment length.

- Area type.
- Number of directional through lanes.
- Median type.
- Access control.
- Two-way vs. one-way operation.
- Traffic volume (AADT).
- Intersection Characteristics:
  - Intersection number.
  - Intersection location.
  - Area type.
  - Number of intersection legs.
  - Type of intersection traffic control.
  - Major-road traffic volume (AADT).
  - Minor-road traffic volume (AADT).
- Ramp Characteristics:
  - Ramp number.
  - Ramp location.
  - Area type.
  - Ramp length.
  - Ramp type.
  - Ramp configuration.
  - Ramp traffic volume (AADT).
- Crash Data:
  - Crash location.
  - Date.
  - Collision type.
  - Severity.
  - Relationship to junction.
  - Maneuvers by involved vehicles.

These data are required to:

- Assign crashes to sites and to locate them within the site.
- Determine the site subtype for each site.
- Compute the expected crash frequency for each site using the appropriate site subtype SPF.
- Characterize the crash experience of each site by type, manner of collision, severity, and location.

Administrators can additionally manage global defaults that include:

- SPF coefficients.
- Crash cost estimates.
- Types of countermeasures.
- Countermeasure implementation costs and services lives.
- CMFs of countermeasures.

### **Highway Safety Manual Part C Spreadsheets and ISATe**

The Highway Safety Manual Part C Spreadsheets and ISATe spreadsheet tools were created to assist in application of the predictive methods contained in the HSM. These tools have the same data requirements as the HSM predictive methods for appropriate facility types. The worksheets include three specific color codes to help users identify

locations where input data is required, restricted, or optional. Default data are provided by the program (i.e., SPFs, calibration coefficients, and crash distributions). The spreadsheets can be customized to fit the needs of individual agencies as has been completed in Alabama, Illinois, Ohio, and Washington. To customize the tool, users may develop local SPFs, calibration coefficients, and crash distributions to modify the default values.

### **Interactive Highway Safety Design Model (IHSDM)**

The Interactive Highway Safety Design Model (IHSDM) data requirements depend on the module(s) selected for analysis. In general, data requirements may include highway segment geometry (horizontal alignment, vertical alignment, and cross section), roadside geometry, intersection geometry, traffic volume data, and crash data. All modules require horizontal and vertical alignment data and highway segment data. In addition, the crash prediction module requires intersection data and crash data. Specifically, the crash prediction model uses the data required for the predictive method of the HSM. The intersection review module requires intersection data. Much of the highway segment geometry data required by IHSDM is available in civil design software packages used in highway geometric design.

# Plan Goals, Objectives, Tasks, and Activities

This section provides details describing the goals, objectives, and recommended tasks for achieving the goals and objectives. The discussion revolves around the existing process and data flow (Figure 4) and proposed process and data flow (Figure 5).

## Existing and Proposed Process Flows

Connecticut DOT Safety Analysis Process  
2014

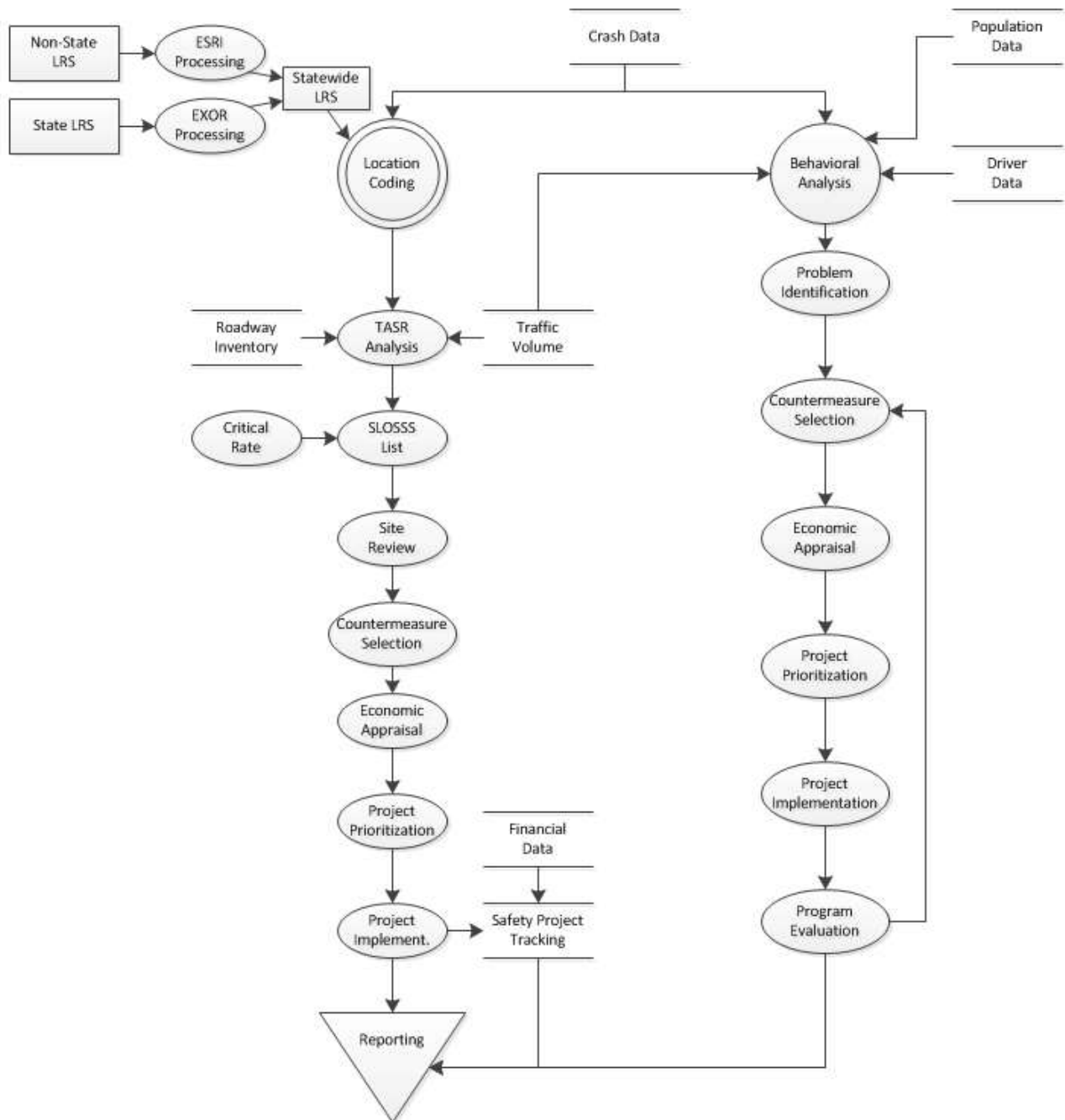
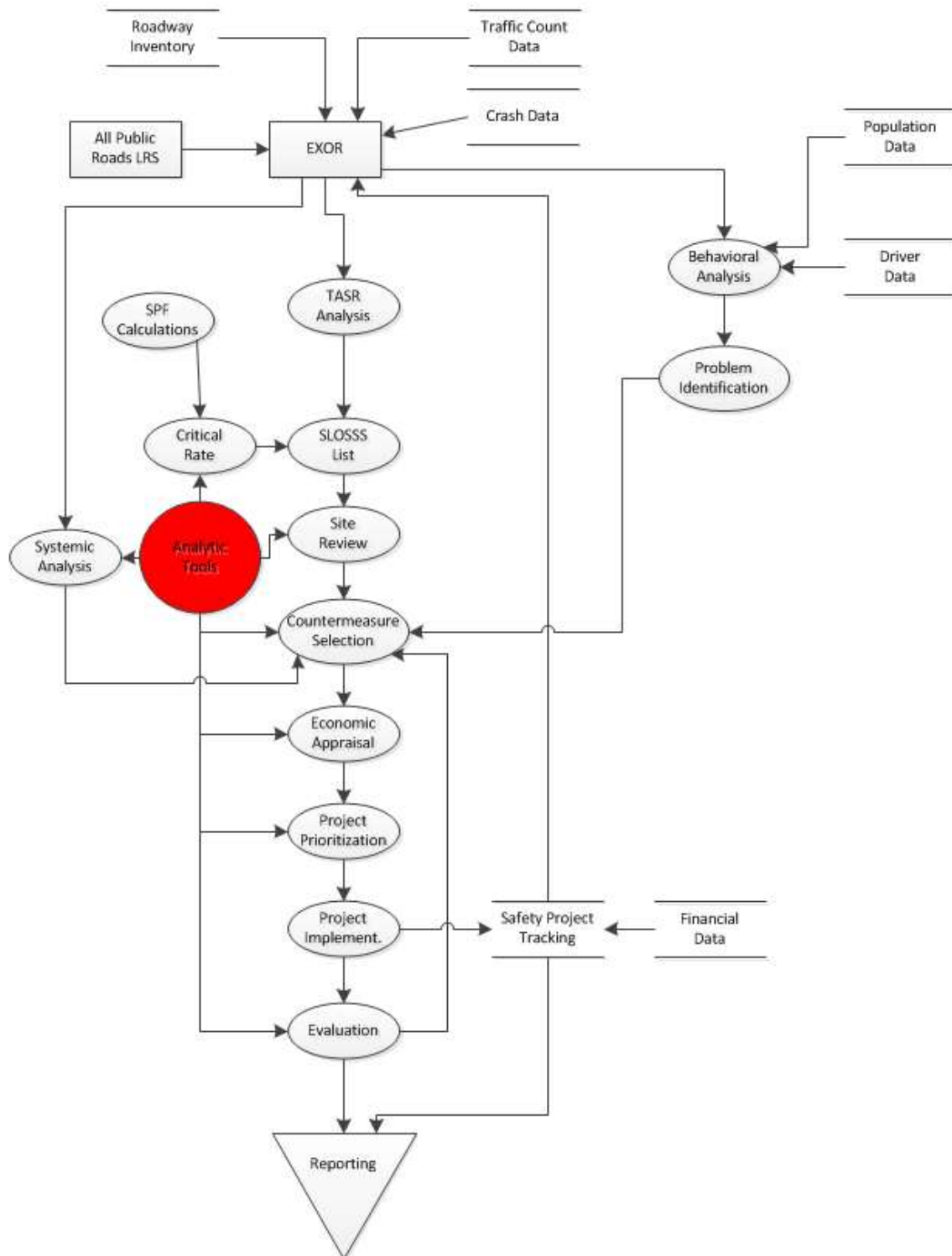


Figure 4. Current Safety Analysis Process Flow.

## Connecticut DOT Safety Analysis Process Future



**Figure 5. Proposed Future Process Flow.**

Figure 4 presents the existing process and data flows for ConnDOT Safety Management. Figure 5 displays the proposed new process and data flows based on the recommended actions in this Strategic Plan. The key differences between the

two diagrams is captured in the Strategic Plan's Goals, Objectives, and Tasks as described in the next section of this document. In brief, however, the following are important features of the current and proposed flows:

- Spatial data will all reside in a GIS. This need will be met by the Exor system for the most part, although there is at least the possibility that some spatial data may be manipulated or managed in other systems or with non-Exor tools. In the current flow diagram, there are some spatial data that reside outside the GIS and are integrated with other spatial data only as the need arises for analytic purposes.
- Location coding for crash report data is currently a process that takes place as a separate process from those for managing spatial data resources – it is a function of crash data management. Eventually this will change in that crash data are expected to arrive at ConnDOT with spatial coordinates already in the record upon submission from the law enforcement agencies. This will be accomplished through an incident locator tool being developed. At that point, the crash data can be treated like any other spatial data resource and, it is hoped, location coding will switch to a quality control/validation role from within the GIS.
- Currently, Engineering and Behavioral Safety management are, for the most part, separate processes using different methodologies, tracking, and reporting systems. In the future flow diagram, the common steps among the two safety management processes offer opportunities to develop support systems and functions to serve all safety management needs. This is a longer-term prospect, but eventually it should be possible to use the same *management* tools, tracking systems, and financial reporting functions for all safety-related spending whether it is aimed at engineering solutions, behavioral programs, and whether or not it is grant funded or funded with Departmental funds. This will set up ConnDOT to take advantage of new analytic techniques in the behavioral safety program areas, just as it is doing now with the HSM techniques for engineering.
- There are portions of the six-step Safety Management Process that are missing from the current process and data flows. Most notably, effectiveness evaluation is not a formal, required part of the process, and predictive analysis is present, but not a core aspect of the engineering analyses supporting safety decision-making. In the future process and data flow, the effectiveness evaluation step has been formalized, and analytic tools (including predictive analytics) are a central part of the process. On the surface, it appears as though more work will be required in the roadway safety management process; however, with automation and reduced overlap in analyses, the process will require fewer analysts and less time to complete.
- Feedback from later steps in the safety management process is only partially in place. In the future, results of effectiveness evaluation, project tracking, and financial reporting data will be routinely used (and feed back into) the safety analysis process.
- In the future, systemic analysis will become a formal part of the ConnDOT safety management process and the Department will examine both site-specific and systemic safety countermeasures when deciding how best to allocate safety resources. This effort will also benefit from improved tracking systems aimed at identifying all safety-related activities regardless of funding source or primary purpose for the project, and collecting relevant information about the affected sites, techniques employed, costs of safety-related actions, and effects.

## Goals, Objectives, and Tasks (Summary)

The following lists the goals, objectives and recommended tasks for achieving the goals and objectives. Subsequent sections describe the rationale and recommended methods for addressing each of the items listed here.

### Goal 1: Formalize Safety Analysis Processes

#### ***Objective 1.1: Define Roles and Responsibilities***

Task 1.1.1: Identify most efficient roles for offices and units involved with roadway safety management and project development.

Task 1.1.2: Document potential working relationships between offices and units to improve efficiency.

#### ***Objective 1.2: Add Missing Components***

Task 1.2.1: Add a formal Safety Effectiveness Evaluation component to the safety management process.

Task 1.2.2: Add a Predictive Analysis component to the project development process.

#### ***Objective 1.3: Define Processes and Procedures***

Task 1.3.1: Document the procedures for each step in the engineering-related safety management process.

Task 1.3.2: Document the procedures for each step in the behavior-related safety management process.

Task 1.3.3: Document the procedures for each step in the project development process.

#### ***Objective 1.4: Develop/Refine Performance Measures***

Task 1.4.1: Document data and operational definitions for existing engineering safety performance measures.

Task 1.4.2: Identify, test, and implement additional engineering safety performance measures.

Task 1.4.3: Document data and operational definitions for existing behavioral safety performance measures.

Task 1.4.4: Identify, test, and implement additional behavioral safety performance measures.

Task 1.4.5: Establish a “dashboard” for reporting safety performance measures.



***Objective 1.5: Adopt Department-wide Process Flows (Engineering and Behavioral Safety)***

Task 1.5.1: Identify common process flow steps in safety management.

Task 1.5.2: Incorporate all safety management activities in the formal safety management process descriptions.

## **Goal 2: Adopt Advanced Analytic Methods**

### ***Objective 2.1: Implement Analytic Techniques and Tools***

Task 2.1.1: Update/Implement Network Screening methods and tools

Task 2.1.2: Update/Implement Diagnostics methods and tools

Task 2.1.3: Update/Implement Countermeasure Selection methods and tools

Task 2.1.4: Update/Implement Economic Appraisal methods and tools

Task 2.1.5: Update/Implement Prioritization methods and tools

Task 2.1.6: Update/Implement Safety Effectiveness Evaluation methods and tools

Task 2.1.7: Update/Implement Predictive Analysis methods and tools

Task 2.1.8: Update and integrate financial and project tracking

### ***Objective 2.2: Collect Necessary Data to Conduct Selected Analyses***

Task 2.2.1: Identify data gaps comparing requirements of selected methods and tools to current data resources.

Task 2.2.2: Identify sources of required missing data.

### ***Objective 2.3: Attain Proficiency in Selected Analytic Techniques and Tools***

Task 2.3.1: Deliver training to key employees.

Task 2.3.2: Identify training needs of external safety partners.

## **Goals, Objectives, and Tasks (Detail)**

The following provides details describing the goals, objectives and recommended tasks for achieving the goals and objectives. For each goal in the plan, a justification is provided describing the current status and the desired end state. Objectives are the key projects that are needed to accomplish each goal. Tasks are the main milestones in each of the projects defined by the objectives. Under each task, a number of activities (or steps under that task) are listed describing how the task can best be completed.

### **Goal 1: Formalize Safety Analysis Processes**

The ConnDOT safety management process is well-established and has been maintained for years. However, not all of the recommended steps in the safety management process are well defined, state-of-the-practice, or routinely part of all safety projects/programs managed by ConnDOT. The most important gaps in the present processes are safety effectiveness evaluation and predictive analysis; however, all of the safety management processes need to be formalized with documented procedures, specific steps, and performance measures. In addition, there is a clear dividing line between roadway engineering-related safety management and behavior-related safety management processes. While these processes are different in their contents and analytic techniques, the commonalities among them can be emphasized for the purposes of documenting a department-wide safety management program. One benefit of doing so would be that ConnDOT would be in a position to readily adopt future advances in behavioral safety analysis as may eventually be part of future editions of the HSM.

#### ***Objective 1.1: Define Roles and Responsibilities***

The roadway safety management process and project development process require inputs and analyses from multiple offices and units within ConnDOT. It is not always clear what office or unit should lead each process, or with whom they should be coordinating. ConnDOT will benefit from understanding and defining the roles and responsibilities of all who are involved in roadway safety management and project development, which will increase efficiency and improve working relationships.

Task 1.1.1: Identify most efficient roles for offices and units involved with roadway safety management and project development.

Crash Data and Analysis, the Highway Safety Office, Highway Design, and the Safety Engineering Unit and Traffic Engineering Units within the Division of Traffic Engineering all contribute to highway safety. Each group has a stake and are responsible for certain tasks within the roadway safety management and project development processes. These efforts are not always coordinated and lead to potential inefficiencies in execution. By taking an objective approach at defining the role of each group, increased efficiency and improved working relationships will result.

Step 1.1.1.1: Identify each office's and unit's responsibility and reporting requirements in the roadway safety management and project development process.

Step 1.1.1.2: Identify the expertise and skillset that each group brings into their respective process.

Step 1.1.1.3: Document the role of each office and unit in the roadway safety management process and project development process.

Task 1.1.2: Document potential working relationships between offices and units to improve efficiency.

Once the role and responsibility of each individual office and unit has been defined, and documented, consideration should be given to the benefit of interoffice collaboration and communication. For example, the Safety Engineering Unit brings a skillset to the table that can be utilized by Traffic Engineering Unit's responsible for implementing the roadway safety management process for spot-safety improvements. Additionally, the Safety Engineering Unit is responsible for HSIP and SHSP documentation and reporting, and will benefit from collaboration with all other offices and units, including construction and financial offices.

Step 1.1.2.1: Describe external data needs or expertise for each office's and unit's responsibility in the roadway safety management process and project development process.

Step 1.1.2.2: Identify offices and units responsible for required data or expertise.

Step 1.1.2.3: Formalize a process to share required data or expertise between offices and units.

### ***Objective 1.2: Add Missing Components***

The roadway safety management process being used by ConnDOT effectively mirrors the process outlined in Part B of the Highway Safety Manual; however, it is missing key steps for a comprehensive analytical process. There is currently no formal Safety Effectiveness Evaluation component to assess the safety effectiveness of projects or programs being implemented. ConnDOT will benefit by understanding the safety effectiveness for countermeasure selection and economic evaluation of future projects and programs. Additionally, ConnDOT will benefit from incorporating predictive analyses into the project development process. Including these two components will align ConnDOT's process with that of the Highway Safety Manual.

Task 1.2.1: Add a formal Safety Effectiveness Evaluation component to the safety management process. Safety Effectiveness Evaluation quantifies the impact of countermeasures for individual projects, as an average for all similar projects, or for Connecticut-wide programs. This task can be completed by developing a standard design for evaluating projects and programs, and developing CMFs. Additionally, analysts will need to be trained on implementing the process and executing the various study designs and statistical procedures. A process for developing study designs based on available information should be developed and should be consistent with the HSM and A Guide to Developing Quality CMFs. The study design will determine:

- An appropriate study methodology.
- Desired level of significance and/or quality of the CMF (if applicable).
- Required sample size (number of treatment and comparison sites).
- Years of B/A or cross-sectional data.
- Whether or not SPFs will be required for the analysis.

This task will require timely crash data, knowledge of treatment installation dates and locations, knowledge of additional safety related countermeasures applied at treatment sites within the study period, roadway and traffic data used to perform disaggregate analyses, and a repository for information developed from the safety effectiveness evaluation (i.e., warehouse for CMFs).

Step 1.2.1.1: Identify an appropriate tool or method for performing safety effectiveness evaluations.

Step 1.2.1.2: Train analysts on statistical procedures and study designs.

Step 1.2.1.3: Train analysts on applying appropriate study designs for treatments being implemented.

Step 1.2.1.4: Identify required data and analytical tools/techniques to execute study designs.

Step 1.2.1.5: Provide appropriate analytical tools (e.g., statistical software packages) for analysts to conduct analyses.

Step 1.2.1.6: Provide access to requisite data to implement study designs.

Step 1.2.1.7: Execute analyses and store results in a repository available to others to use for CMFs and cost-effectiveness studies.

Task 1.2.2: Add a Predictive Analysis component to the project development process.

Part C of the HSM provides a predictive method for estimating the expected average crash frequency of a network, facility, or individual site. The predictive method provides a quantitative measure of expected average crash frequency for existing conditions and for proposed conditions which are not necessarily in place. This task can be completed by integrating predictive analyses into processes used by Highway Designers (i.e., the project development process). Highway designers must not see this as an additional task, but rather as a tool to help them complete their work more effectively. Currently, designers are completing crash diagrams and performing site visits, the results of which are for documentation, not necessarily to improve designs. If these results are provided to designers by traffic engineers who are also completing these steps, then designers will have more availability to incorporate predictive analyses in the project development process.

Predictive analyses are data intensive, and designers should have access to necessary data to complete analyses with the highest level of accuracy. Safety performance functions, developed for network screening, will serve as calibrated models for base safety prediction. Site-specific data are then used to account for conditions which vary from the baseline and for alternatives analyses. Designers should have access to SPFs, CMFs, site-specific geometry, and historic crash data to most effectively use this component. This process can similarly be utilized by Traffic Engineers developing countermeasures in the roadway safety management process.

Step 1.2.2.1: Identify appropriate existing processes in which to incorporate the predictive methods for highway designers.

Step 1.2.2.2: Train designers and traffic engineers on Parts C and D of the HSM.

Step 1.2.2.3: Identify path to access of pertinent data for designers and traffic engineers.

Step 1.2.2.4: Identify appropriate tools for implementation of the HSM Part C predictive method and CMFs. Additionally, identify the best methods to import data into tools. For example, in the IHSDM, data can be imported in tabular form by the analyst, or data can be imported directly from CAD or Microstation files.

Step 1.2.2.5: Train designers and traffic engineers on using appropriate implementation tools.

Step 1.2.2.6: Identify appropriate storage for results of analyses and justifications for design decisions being-made based on predictive analyses. Spreadsheets or IHSDM files should be saved for future use.



### ***Objective 1.3: Define Processes and Procedures***

Procedural documentation serves as an aid to training and makes it possible for staff who are new to a process to understand and reproduce the methods. Documentation also helps an agency maintain continuity and standards in the face of staffing changes. Having a clearly defined roadway safety management process will help analysts better understand their role in the process and enable them to make more informed decisions. Additionally, a documented process will allow different offices to share results, avoid duplication of effort, and standardize on a department-wide basis.

Task 1.3.1: Document the procedures for each step in the engineering-related safety management process. With a few exceptions, ConnDOT currently has a roadway safety management process that is consistent with the HSM Part B six-step roadway safety management process. While the current ConnDOT process mirrors the HSM process, it is not formalized and can be executed with a higher degree of sophistication and efficiency. With documented procedures, each office will have an understanding of its role and responsibility in the process.

Step 1.3.1.1: Define the roles and responsibilities of each office in the roadway safety management process.

Step 1.3.1.2: Formalize the analyses being performed by each office.

Step 1.3.1.3: Create a document that integrates the responsibilities of each office, what outputs should be developed as part their responsibilities, and what inputs are required for each office to execute their responsibilities.

Task 1.3.2: Document the procedures for each step in the behavior-related safety management process.

The Highway Safety Office manages an effective behavior-related safety program including steps mirroring those in the engineering safety management process. The HSM does not deal directly with behavior-related safety programs, however, there are some obvious tie-ins between the two types of process, including the fact that the base data (crashes) apply to both types of safety analysis and that cost-effective approaches to safety management will include consideration of both engineering and behavioral solutions.

Step 1.3.2.1: Document behavioral program-related problem identification processes.

Step 1.3.2.2: Document behavior program-related countermeasure selection processes.

Step 1.3.2.3: Document behavior program-related economic appraisal processes.

Step 1.3.2.4: Document behavior program-related project selection and prioritization processes.

Step 1.3.2.5: Document behavior program-related project and program effectiveness evaluation.

Step 1.3.2.6: Identify commonalities among the engineering and behavioral program-related safety management processes.

Task 1.3.3: Document the procedures for each step in the project development process.

Highway designers are performing analyses consistent with those already performed by traffic engineering in the diagnosis phase. A documented process for using the predictive method will allow designers to utilize more advanced analytical techniques and will help to avoid reproduction of similar analyses.

Step 1: Define the roles and responsibilities of each office in the project development process (Objective 1.1).

Step 2: Formalize the predictive analyses being used.

Step 3: Create a document that integrates the responsibilities of each office, what outputs should be developed as part their responsibilities, and what inputs are required for each office to execute their responsibilities.



#### ***Objective 1.4: Develop/Refine Performance Measures***

The Moving Ahead for Progress in the 21<sup>st</sup> Century (MAP-21) legislation, along with implementation guidance from USDOT administrations (FHWA, NHTSA, and FMCSA in particular) place strong emphasis on performance measurement. The goal of these efforts at the National level is to foster data driven decision-making by States and local agencies covering all aspects of safety. Up to the present, most State DOTs have used a small number of common indicators of safety performance (total fatalities and the fatality rate are most common). Moving forward, it is clear that the list of safety performance measures will grow to include both a greater emphasis on non-fatal crash experience (e.g., serious injury crash frequency and rate) as well as measures focused on road users' expected risk (e.g., using population-based exposure measures, linking data from citations, adjudications, and injury surveillance datasets with the information describing crashes and roadways). While ConnDOT is adjusting its analytic approaches, adopting more advanced methods, it is a perfect time to consider new safety performance measures. As analyses are automated, so too can ConnDOT automate reporting of a broader range of safety performance measures. This objective describes a series of tasks that approaches this expansion methodically and with appropriate controls over the development and use of new performance measures.

Task 1.4.1: Document data and operational definitions for existing engineering safety performance measures. This task is designed to standardize calculation and reporting of current safety performance measures to serve as examples for the development and documentation of new performance measures.

Step 1.4.1.1: Identify (with precision) the data sources for fatality counts, traffic volume data, and the resulting fatality rate calculations.

Step 1.4.1.2: Produce the baseline data for these existing performance measures from history files.

Step 1.4.1.3: Produce formal operational definitions detailing the steps used to calculate these performance measures.

Task 1.4.2: Identify, test, and implement additional engineering safety performance measures.

Based on decision-makers' needs and the new analyses adopted for engineering-related safety management, ConnDOT will be in a position to develop a new set of safety performance measures. These should be tested carefully to ensure that they are valid, accurate, and useful for safety decision-making.

Step 1.4.2.1: Identify potential new performance measures – potentially using an expert panel approach involving analysts and decision makers. This group should suggest new measures and commit to reviewing the utility of each measure as it is developed.

Step 1.4.2.2: Develop evaluation versions of selected new performance measures (e.g., serious injury rate) to include a baseline value and calculated values for reporting monthly, quarterly, and annual trends as well as comparisons among geographic subdivisions of the State.

Step 1.4.2.3: Select those measures meeting the expert panel's approval for formal development and use in reporting.

Task 1.4.3: Document data and operational definitions for existing behavioral safety performance measures.

The behavioral safety programs managed by ConnDOT already have multiple safety performance measures. They may differ from those used for engineering, but it is likely that at least some of the performance measures are important as indicators of specific safety problems (some of which may impact or interact with engineering safety programs). For example, helmet use, occupant restraint use, and driving under the influence of alcohol or drugs all have an impact on the fatality and serious injury experience in the State. ConnDOT can benefit from a broadened awareness of all the safety-related performance measures to determine the most effective ways to spend safety dollars as a Department. Note that this task is similar to Task 1.4.1—the two tasks could be combined.

Step 1.4.3.1: Identify (with precision) the data sources for existing behavior-related safety performance measures.

Step 1.4.3.2: Produce the baseline data for these existing performance measures from history files.

Step 1.4.3.3: Produce formal operational definitions detailing the steps used to calculate these performance measures are created.

Task 1.4.4: Identify, test, and implement additional behavioral safety performance measures.

As with engineering-related safety performance measures, the list of behavior-related measures could be expanded. The same expert panel that is recommended in Task 1.4.2 could be used to help identify a desired set of new behavior-related safety performance measures. The list of Steps is the same.

Step 1.4.4.1: Identify potential new performance measures – potentially using an expert panel approach involving analysts and decision makers. This group should suggest new measures and commit to reviewing the utility of each measure as it is developed.

Step 1.4.4.2: Develop evaluation versions of selected new performance measures (e.g., serious injury rate) to include a baseline value and calculated values for reporting monthly, quarterly, and annual trends as well as comparisons among geographic subdivisions of the State.

Step 1.4.4.3: Select those measures meeting the expert panel's approval for formal development and use in reporting.

Task 1.4.5: Establish a “dashboard” for reporting safety performance measures.

Easy, shared access to safety performance measures is one way to promote the inclusion of “safety” across multiple parts and functional areas of the Department. From a management information perspective, a simple, at-a-glance display of the major safety performance indicators is useful because it can quickly convey the status of the Department's efforts and point to any areas of concern. This type of “dashboard” display has been implemented in several states. It has the advantages of being easy to update, easy to provide and control access, and easy for most users to understand.

Step 1.4.5.1: Select a desired dashboard design.

Step 1.4.5.2: Select safety performance measures to include on the dashboard.

Step 1.4.5.3: Determine levels of access (open/public, local safety partners, internal ConnDOT, etc.) for each indicator and access to underlying detail records.

Step 1.4.5.4: Implement the dashboard and refine based on user feedback.

***Objective 1.5: Adopt Department-wide Process Flows (Engineering and Behavioral Safety)***

ConnDOT has a small number of offices that have primary responsibility over the safety management processes. Traffic Engineering and highway design areas both focus on engineering treatments and will share a set of methods and tools for safety analysis. The Highway Safety Office is responsible for managing NHTSA grant funding, and behavioral safety programs that generally align with the NHTSA grants program as outlined in MAP-21 (e.g., occupant protection; driving under the influence; younger/older/at risk drivers; motorcycles; pedestrians, etc.). The two types of safety decision-making processes have very similar process flows, even though the analytic techniques differ substantially: the HSM applies to engineering programs almost exclusively and does not include advanced analytic methods for behavior-related safety). Building on the common aspects of safety management, ConnDOT has the opportunity to define a global process flow for safety management which can apply in each of the relevant areas.

Task 1.5.1: Identify common process flow steps in safety management.

In order to develop a unified process flow, as depicted in Figure 5, ConnDOT could make use of existing staff in the traffic, design, and highway safety office sections of the Department to identify the common features of the safety management processes used by each.

Step 1.5.1.1: Identify a panel of safety management staff knowledgeable in the practices of their specific areas.

Step 1.5.1.2: Identify the common process flow steps.

Step 1.5.1.3: Develop step-by-step descriptions of the safety management process steps for each area.

Task 1.5.2: Incorporate all safety management activities in the formal safety management process descriptions.

Using the formal process flow descriptions in Objective 1.3, the panel established in Task 1.5.1.1 can develop a unified process covering safety management for the entire Department.

Step 1.5.2.1: Review process flow descriptions from Objective 1.3.

Step 1.5.2.2: Develop unified descriptions of each step in the safety management process.

## **Goal 2: Adopt Advanced Analytic Methods**

Advanced analytics will help ConnDOT to more effectively identify sites with the most potential for reductions in crash frequency or severity, identify factors contributing to crashes, identify potential countermeasures to address contributing factors, conduct economic appraisals and prioritize projects, evaluate the crash reduction benefits of implemented treatments, and estimate the potential effects on crash frequency or severity of planning, design, operations, or policy decisions. Additionally, advanced analytics provide a method for identifying safety-related issues that most efficiently utilize safety funds and they provide a quantifiable estimate of safety that can be compared in conjunction with operational benefits and environmental benefits on transportation projects.

### ***Objective 2.1: Implement Analytic Techniques and Tools***

Analytical tools and techniques help to automate advanced analytical procedures that can be difficult for engineers to implement. By having an understanding of the general analytical processes, inputs, and outputs, engineers can effectively make use of difficult processes and advanced statistical methodologies without having to spend more time or hire additional analysts. This is especially important since analytical tools will allow for more spot improvement sites, and systemic improvements, to be considered simultaneously. Several different tools are available that can implement the six-step roadway safety management process, but each will be most effective if implemented for the entire process. Additionally, freely-available tools are available for using the HSM predictive method and these can be implemented with existing staff.

#### **Task 2.1.1: Update/Implement Network Screening methods and tools**

ConnDOT has a sophisticated method for identifying sites with abnormally high three-year crash rates. However, the HSM provides several performance measures that can be used for network screening that will help to reduce biases in site selection. The HSM methodology will help to reduce potential biases, such as RTM, which are currently not considered. Additionally, performance measures that use safety performance functions based on appropriate reference groups, with Empirical-Bayes adjustments, will provide the most reliable and accurate performance thresholds.

Step 2.1.1.1: Determine an automated process for estimating performance measures. This includes selecting between off-the-shelf tools, such as AASHTOWare Safety Analyst™, or upgrading the in-house SLOSSS procedure. Consideration must be given to ConnDOT's interest in automation. While upgrading the SLOSSS procedure may be the most cost-efficient answer, off-the-shelf tools will help with implementing the other five steps of the roadway safety management process. ConnDOT may benefit from automating all steps, not just network screening. OMTS will need to determine the functional requirements for any software being considered, and should work with Roadway Information Systems and Crash Data and Analysis to determine if required data elements are compatible with current data collection procedures. If data are incompatible, a process to generate compatible data elements should be developed.

Step 2.1.1.2: Identify the procedures to either A) implement a new automated screening tool or B) update the SLOSSS. Implementation of AASHTOWare Safety Analyst™ will require up-front work to convert segments and intersections into a useable format for the software and into a format that can be updated annually as changes are made to the network. Train the Crash Data and Analysis Unit on updated network screening methods or tools.

Step 2.1.1.3: Identify the appropriate performance measure(s) and data requirements for network screening, including the selection of appropriate reference populations.

Step 2.1.1.4: Identify an appropriate methodology for screening sites based on the performance measure(s).

Task 2.1.2: Update/Implement Diagnostics methods and tools

ConnDOT already utilizes an HSM-based methodology for diagnosis. The typical diagnosis procedure includes performing a safety data review, assessing supporting documentation, and assessing field conditions.

ConnDOT will benefit from automating this process using an automated tool selected for network screening. These tools will help identify underlying patterns through graphical summaries, automating the process for intersection collision diagrams, and conducting statistical tests on crash frequencies and/or proportions.

Step 2.1.2.1: Identify an appropriate tool or method for performing diagnosis.

Step 2.1.2.2: Train traffic engineers and Safety Engineering personnel on new tools and procedures.

Step 2.1.2.3: Identify a documentation process for the results of diagnosis to be used for countermeasure selection and for highway designers.

Task 2.1.3: Update/Implement Countermeasure Selection methods and tools

ConnDOT sometimes utilizes tools such as the CMF Clearinghouse, the NCHRP 500 series reports, or FHWA's proven safety countermeasures to select countermeasures for implementation. ConnDOT will benefit from utilizing these tools and others that focus on contributing factors identified during diagnosis to develop specific countermeasures that target those contributing factors. However, none of these documents provide ConnDOT with Connecticut-specific CMFs for potential countermeasures. CMFs, particularly Connecticut-specific CMFs, will help to increase confidence, and to conduct B/C analyses to select preferred treatments. Some software packages aid the engineer with selecting countermeasures that may address contributing factors and identify a potential crash reduction.

Step 2.1.3.1: Identify an appropriate tool or method for performing countermeasure selection.

Step 2.1.3.2: Train traffic engineers and Safety Engineering personnel on new tools and procedures.

Step 2.1.3.3: Utilize CMFs from the CMF Clearinghouse or from other resources to quantify potential benefit.

Step 2.1.3.4: As countermeasures are being used, perform safety effectiveness evaluations to develop Connecticut-specific CMFs.

Step 2.1.3.5: Develop repository for Connecticut-specific countermeasures and related CMFs for traffic engineers and highway designers to utilize.

Step 2.1.3.6: Utilize Connecticut-specific CMFs to refine future analyses.

Task 2.1.4: Update/Implement Economic Appraisal methods and tools

The Safety Engineering Unit performs basic economic appraisal for mitigation measures proposed by local agencies. They also perform economic analyses to determine if projects are economically justified. Advanced analytical tools provide these analyses, making use of pertinent data to report cost-effectiveness, cost-effectiveness weighted by severity, B/C ratio, and net benefit. Inputs used for the analyses are generally customizable to Connecticut's data.

Step 2.1.4.1: Identify an appropriate tool or method for performing economic appraisal.

Step 2.1.4.2: Train traffic engineers on new tools and procedures.

Step 2.1.4.3: Use advanced techniques to calculate benefits and costs.

Task 2.1.5: Update/Implement Prioritization methods and tools

Project prioritization includes ranking countermeasures at a specific location or ranking sites that have had an economic appraisal based on specified countermeasures. Projects may be ranked by economic effectiveness measures, incremental B/C analysis, or by optimization. Simple ranking measures include ranking projects by cost, monetary value of benefit, number of crashes (or specific crash type) reduced, cost-effectiveness index, or by net present value. On the other extreme, candidate projects may be ranked using advanced analytical methods, such as basic optimization. Analytical tools can perform basic optimization, identifying the set of proposed countermeasures that maximizes the overall safety benefit of any expenditure, considering budgetary constraints.

Step 2.1.5.1: Identify appropriate ranking method and appropriate economic effectiveness measures.

Step 2.1.5.2: Identify an appropriate tool or method for performing project prioritization.

Step 2.1.5.3: Train traffic engineers on new tools and procedures.

Step 2.1.5.4: Use advanced techniques to prioritize projects for implementation.

Task 2.1.6: Update/Implement Safety Effectiveness Evaluation methods and tools

Task 2.1.6 is consistent with Task 1.1.1. ConnDOT will benefit from incorporating safety effectiveness evaluation methods into their current process and will further benefit from using advanced methods and tools. Advanced tools, such as AASHTOWare Safety Analyst™ can calculate the safety effectiveness of single projects, groups of similar projects, and B/C of countermeasures for HSIP reporting. Additionally, these tools can perform statistical tests to identify shifts in the proportion of specific collision types.

Step 2.1.6.1: Identify an appropriate tool or method for performing safety effectiveness evaluation.

Step 2.1.6.2: Train traffic engineers on new tools and procedures.

Step 2.1.6.3: Identify appropriate safety effectiveness evaluation type for outcome.

Step 2.1.6.4: Identify appropriate study design.

Step 2.1.6.5: Identify required data and analytical tools/techniques to execute study designs.

Step 2.1.6.6: Provide appropriate analytical tools (e.g., statistical software packages) for analysts to conduct analyses.

Step 2.1.6.7: Provide access to requisite data to implement study designs.

Step 2.1.6.8: Execute analyses and store results in a repository available to others to use for CMFs and cost-effectiveness studies.

Task 2.1.7: Update/Implement Predictive Analysis methods and tools

Task 2.1.7 is consistent with Task 1.1.2. ConnDOT will benefit from incorporating predictive analysis methods and tools into the current roadway safety management process and project development process. Tools that are available for the predictive method are generally available for free, and can be customized to fit Connecticut's needs. However, the level of sophistication in tools varies from simple spreadsheets to sophisticated software programs. ConnDOT will need to weigh the amount of up-front development time with long-term benefits of using more sophisticated programs. For example, the IHSDM has a learning curve, but once learned, it can be quicker to import CAD-based highway alignments than manually entering elements into spreadsheets. The more information that is entered into spreadsheets or software programs, the more confident the designer or analyst can be in the results. For use of CMFs, much data will be required; however, base values can be utilized, especially if refined geometric elements are not yet known for initial analyses.

Step 2.1.7.1: Identify potential tools to implement predictive methodologies.

Step 2.1.7.2: Consider the strengths and weaknesses of each tool to select appropriate tools for ConnDOT's needs and capabilities.

Step 2.1.7.3: Train designers and traffic engineers on Parts C and D of the HSM.

Step 2.1.7.4: Identify path to access of pertinent data for designers and traffic engineers.

Step 2.1.7.5: Identify appropriate tools for implementation of the HSM procedure and CMFs. Additionally, identify the best methods to import data into tools. For example, in the IHSDM, data can be imported in tabular form by the analyst, or data can be entered through CAD drawings.

Step 2.1.7.6: Train designers and traffic engineers on using appropriate implementation tools.

Step 2.1.7.7: Identify appropriate storage for results of analyses and justifications for design decisions based on predictive analyses. Spreadsheets or IHSDM files should be saved for future use.

Task 2.1.8: Update and integrate financial and project tracking

Task 2.1.8 is designed to address current gaps in project tracking, especially with respect to financial data and the ability to link *all* safety-related spending and activities to projects that are not using safety funds. This is likely to be a larger issue than just safety as it may require changes to the Department's core business systems (finance, project monitoring/reporting, etc.). As such, the steps here are to be considered recommendations for consideration by upper level management, rather than pointing to the need for safety-specific tracking systems only.

Step 2.1.8.1: Engage in a data gaps analysis aimed at identifying needs for additional data and linkage capabilities between the existing financial and project tracking systems at ConnDOT. Safety should be one focus of this analysis.

Step 2.1.8.2: Design the necessary data collection/reporting, storage, and governance for the missing data elements and system capabilities. Project manager reporting features should be included in this design step.

Step 2.1.8.3: Develop or procure the required tracking systems.

Step 2.1.8.4: Implement upgraded financial and project tracking systems.





## ***Objective 2.2: Collect Necessary Data to Conduct Selected Analyses***

Advanced safety analyses vary in the amount of requisite data. Analyses can often be conducted with a minimum amount of site-specific data; however, this can impact the level of confidence in the results. The predictive methodology requires only traffic volume, segment length (or number of intersection legs and control) and data on any specific alternatives that are being considered. Base values can be considered if the data are unknown. With more complete data, fewer base values are needed, providing a more realistic prediction of expected average crash frequency.

Task 2.2.1: Identify data gaps comparing requirements of selected methods and tools to current data resources.

ConnDOT currently collects several data elements required to perform selected analyses. However, not all data elements used in safety analyses are collected. Currently, MIRE FDE data are required to be collected and stored, which serve to provide definitions of reference groups for network screening. Many data elements that can be used in the predictive method are not currently collected and can be used to refine processes in both the predictive method and roadway safety management process. ConnDOT would benefit from identifying data elements of interest for advanced safety analyses and comparing this list to data elements that are currently collected. Through this method, gaps in data can be identified.

Step 2.2.1.1: Identify required and desired data elements based on analytical techniques from the roadway safety management process and predictive method.

Step 2.2.1.2: Compare required and desired elements to data elements currently collected by Roadway Information Systems and Crash Data and Analysis Unit.

Task 2.2.2: Identify sources of required missing data.

Field data collection procedures may not be required to collect all missing data elements. Some data may come from alternative sources, such as existing as-built roadway drawings or desktop data collection. It will be worthwhile for ConnDOT to identify the most cost-effective sources of missing data before embarking on any data collection. Some data elements may be interconnected, or it may be more cost-effective to add data collection of elements to an instrumented van.

Step 2.2.2.1: Identify if missing data exist in any form in other databases.

Step 2.2.2.2: Identify the appropriate format and units for data to be collected.

Step 2.2.2.3: Identify the most efficient method to collect each missing data element.

Step 2.2.2.4: Modify existing databases as needed to accept required data.

Step 2.2.2.5: Collect required data from identified sources.

**Objective 2.3: Attain Proficiency in Selected Analytic Techniques and Tools**

Advanced analytic methods in highway safety analysis are complex, and require more statistical background and knowledge than has generally been required for traffic engineers and highway designers. Before implementing any new procedures, it is imperative that requisite personnel receive training on analytical techniques related to their area of expertise. Additionally, training should be considered outside of traditional areas of expertise so that engineers and designers are fluent in the results of analyses and can understand from where they come.

Task 2.3.1: Deliver training to key employees.

Key employees will not only need to be fluent in safety analyses for which they are directly responsible, but they should also understand how other safety data processes are conducted, and how outputs are obtained. For example, Crash Data and Analysis (or some other entity) will be responsible for network screening, but it is important for traffic engineers to understand what performance measures are used for network screening, what they represent (e.g., crash frequency versus excess crash frequency), and how that information can be used to support their analyses. ConnDOT will benefit from providing directly relevant and indirectly relevant training to key employees to create a safety conscious environment.

Step 2.3.1: Identify key employees from each office/group.

Step 2.3.2: Identify relevant expertise for each office/group.

Step 2.3.3: Identify relevant training for each area of expertise.

Step 2.3.4: Procure and deliver training.

Task 2.3.2: Identify training needs of external safety partners.

ConnDOT works with external safety partners in the towns, MPOs, and RPOs. External safety partners help to contribute crash data, local roadway data, and potential safety projects. For all contributors, training will be required in one form or another, particularly to help them understand how the data that they collect will ultimately be used in the decision-making process. Police officers provide crash data and will require training for new data collection forms and for the incident locator tool. Local agencies have the potential to provide roadway characteristic and AADT data. It will be helpful for them to know what formats are required for the data they will contribute. MPOs and RPOs contribute to the development of safety related projects for their roadway networks. It will be helpful for them to have access to data and to understand and contribute to roadway safety analyses.

Step 2.3.2.1: Identify external safety partners.

Step 2.3.2.2: Identify external safety partner contributions.

Step 2.3.2.3: Identify key personnel to receive training.

Step 2.3.2.4: Procure and deliver training to external safety partners.

## APPENDIX A: ACTION PLAN SUMMARY

The following is a static display of the Action Plan's top-level tracking information. The full Action Plan is provided to ConnDOT in spreadsheet form for use in project tracking. It contains all of the Goals, Objectives, Tasks, and Steps to achieve each goal.

| Number  | Name  | Start     | End        | Precursors          | Dependents                        | Who Leads?         | Current Status | Notes  |
|---|---|-----------|------------|---------------------|-----------------------------------|--------------------|----------------|--|
| <b>Goal 1: Formalize Safety Analysis Processes</b>      |   |           |            |                     |                                   |                    |                |  |
| <b>Objective 1.1: Define Roles and Responsibilities</b> |   |           |            |                     |                                   |                    |                |  |
| 1.1.1   | Identify most efficient roles for offices and units involved with roadway safety management and project development | 6/1/2015  | 11/30/2015 | none                | 1.1.2; 2.3.1; 2.1.6; 2.1.7; 2.3.2 | Safety Engineering |                | Combine with 1.3.3.1. This should be coordinated across ConnDOT offices and local agencies             |
| 1.1.2   | Document potential working relationships between offices and units to improve efficiency                            | 10/1/2015 | 12/31/2015 | 1.1.1               | 2.1.6; 2.1.7; 2.3.1; 2.3.2        | Safety Engineering |                | Combine with 1.3.3.1. This should be coordinated across ConnDOT offices and local agencies             |
| <b>Objective 1.2: Add Missing Components</b>            |   |           |            |                     |                                   |                    |                |  |
| 1.2.1   | Add a formal Safety Effectiveness Evaluation component to the safety management process                             | 6/1/2015  | ongoing    | 2.3.1; 2.3.2; 2.2.1 | 1.3.1                             | Safety Engineering |                | Combine with 2.1.6. 2.3.1; 2.3.2; and 2.2.1 are partial precursors for completing the steps identified |
| 1.2.2   | Add a Predictive Analysis component to the project  | 6/1/2015  | ongoing    | 2.3.1; 2.3.2        | 1.3.3                             | Safety Engineering |                | Combine with 2.1.7. 2.3.1; 2.3.2; and 2.2.1 are partial precursors for completing the steps            |

| Number | Name                | Start | End | Precursors | Dependents | Who Leads? | Current Status | Notes      |
|--------|---------------------|-------|-----|------------|------------|------------|----------------|------------|
|        | development process |       |     |            |            |            |                | identified |

### Objective 1.3: Define Processes and Procedures

|       |  |          |           |       |       |                        |  |   |
|-------|--|----------|-----------|-------|-------|------------------------|--|---|
| 1.3.1 | Document the procedures for each step in the engineering-related safety management process | 6/1/2015 | 2/28/2016 | 1.2.1 | 1.5.1 | Safety Engineering     |  | 1.2.1 and 1.2.2 are partial precursors for completing 1.3.1 because the two new processes cannot be documented until they are created |
| 1.3.2 | Document the procedures for each step in the behavior-related safety management process    | 6/1/2015 | 2/28/2016 | none  | 1.5.1 | Highway Safety Program |  | Refer to Tasks 2.1.1 to 2.6.1 for implementation for Engineering-related roadway safety management process                            |
| 1.3.3 | Document the procedures for each step in the project development process                   | 6/1/2015 | 2/28/2016 | 1.2.2 | none  | Safety Engineering     |  | Once the existing processes are defined in 1.2.2.1, documentation may begin   |

### Objective 1.4: Develop/Refine Performance Measures

| Number | Name   | Start     | End       | Precursors | Dependents | Who Leads?             | Current Status     | Notes  |
|--------|--|-----------|-----------|------------|------------|------------------------|--------------------|--|
| 1.4.1  | Document data and operational definitions for existing engineering safety performance measures | 6/1/2015  | 9/30/2015 | none       | 1.4.5      | Safety Engineering     | Partially complete | Some measures are already reported publicly in the ConnDOT Quarterly Performance Measures Summary reports; Annual Highway Safety Reports, and the Annual Highway Safety Plan reports |
| 1.4.2  | Identify, test, and implement additional engineering safety performance measures               | 10/1/2015 | ongoing   | 1.4.1      | 1.4.5      | Safety Engineering     |                    |  |
| 1.4.3  | Document data and operational definitions for existing behavioral safety performance measures  | 6/1/2015  | 9/30/2015 | none       | 1.4.5      | Highway Safety Program | Partially complete | Some measures are already reported publicly in the ConnDOT Quarterly Performance Measures Summary reports; Annual Highway Safety Reports, and the Annual Highway Safety Plan reports |
| 1.4.4  | Identify, test, and implement additional behavioral safety performance measures                | 9/1/2015  | ongoing   | 1.4.3      | 1.4.5      | Highway Safety Program |                    |  |

| Number | Name  | Start    | End       | Precursors                          | Dependents | Who Leads?   | Current Status | Notes  |
|--------|---|----------|-----------|-------------------------------------|------------|--|----------------|--|
| 1.4.5  | Establish a "dashboard" for reporting safety performance measures | 6/1/2015 | 4/30/2016 | 1.4.1;<br>1.4.2;<br>1.4.3;<br>1.4.4 | none       | OMTS; TRCC;<br>Safety Engineering;<br>Highway Safety Program |                | As documentation and testing is complete for each performance measure it can be added to the dashboard. The dashboard can begin with existing information as shown in ConnDOT Quarterly Performance Measures Summary reports |

### Objective 1.5: Adopt Department-wide Process Flows (Engineering and Behavioral Safety)

|       |   |           |            |                 |      |   |  |  |
|-------|---|-----------|------------|-----------------|------|---|--|--|
| 1.5.1 | Identify common process flow steps in safety management   | 9/1/2016  | 12/30/2016 | 1.3.1;<br>1.3.2 | none | Safety Engineering;<br>Highway Safety Program |  | This could potentially involve the TRCC          |
| 1.5.2 | Incorporate all safety management activities in the formal safety management process descriptions | 12/1/2016 | 5/31/2017  | 1.5.1           | none | Safety Engineering;<br>Highway Safety Program |  | IT and Data Governance groups should be involved |

## Goal 2: Adopt Advanced Analytic Methods

### Objective 2.1: Implement Analytic Techniques and Tools

| Number | Name   | Start    | End       | Precursors   | Dependents          | Who Leads?         | Current Status | Notes  |
|--------|--|----------|-----------|--------------|---------------------|--------------------|----------------|--|
| 2.1.1  | Update/implement Network Screening methods and tools               | 6/1/2015 | 5/31/2016 | none         | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support  |
| 2.1.2  | Update/implement Diagnostics methods and tools                     | 6/1/2015 | 5/31/2016 | none         | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support  |
| 2.1.3  | Update/implement Counter Measure Selection methods and tools       | 6/1/2015 | ongoing   | none         | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support. This is an ongoing process once implemented |
| 2.1.4  | Update/implement Economic Appraisal methods and tools              | 6/1/2015 | ongoing   | none         | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support  |
| 2.1.5  | Update/implement Prioritization methods and tools                  | 6/1/2015 | ongoing   | none         | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support. This is an ongoing process once implemented |
| 2.1.6  | Update/implement Safety Effectiveness Evaluation methods and tools | 6/1/2015 | ongoing   | 1.1.1; 1.1.2 | 2.2.1; 2.3.1; 2.3.2 | Safety Engineering |                | Combine with 1.2.1. This one year timeline assumes a mix of training, software procurement, and  |



| Number | Name   | Start    | End       | Precursors      | Dependents             | Who Leads?         | Current Status | Notes  |
|--------|--|----------|-----------|-----------------|------------------------|--------------------|----------------|--|
|        |  |          |           |                 |                        |                    |                | external analytic support. This is an ongoing process once implemented   |
| 2.1.7  | Update/implement Predictive Analysis methods and tools | 6/1/2015 | ongoing   | 1.1.1;<br>1.1.2 | 2.2.1; 2.3.1;<br>2.3.2 | Safety Engineering |                | This one year timeline assumes a mix of training, software procurement, and external analytic support. This is an ongoing process once implemented |
| 2.1.8  | Update and integrate financial and project tracking    | 6/1/2015 | 5/31/2017 | none            | none                   | OMTS               |                | This two year timeline assumes that this project will involve systems that are used throughout the Department, not just for safety projects        |

## Objective 2.2: Collect Necessary Data to Conduct Selected Analyses

|       |   |          |            |                  |              |                    |  |   |
|-------|---|----------|------------|------------------|--------------|--------------------|--|---|
| 2.2.1 | Identify data gaps comparing requirements of selected methods and tools to current data resources | 6/1/2015 | 12/31/2015 | 2.1.1 -<br>2.1.7 | 1.2.1; 2.2.2 | Safety Engineering |  | This task can start immediately after analysis tools / methods are selected and should then run in parallel with acquisition and implementation of the selected tools / methods |
|-------|---|----------|------------|------------------|--------------|--------------------|--|---|

| Number   | Name  | Start    | End     | Precursors                           | Dependents   | Who Leads?  | Current Status | Notes  |
|--|---|----------|---------|--------------------------------------|--------------|---|----------------|--|
| 2.2.2  | Identify sources of required missing data           | 1/1/2016 | ongoing | 2.2.1                                | none         | Safety Engineering  |                | As each tool or method is selected and data gaps are identified, the sources of data can be queried and an acquisition plan put into place.  |
| <b>Objective 2.3: Attain Proficiency in Selected analytic Techniques and Tools</b> |   |          |         |                                      |              |   |                |  |
| 2.3.1  | Deliver training to key employees                   | 6/1/2015 | ongoing | 1.1.1;<br>1.1.2;<br>2.1.1 -<br>2.1.7 | 1.2.1; 1.2.2 | Safety Engineering<br>ConnDOT GIS<br>Crash Data &<br>Analysis |                | Training needs are identified in the listed sections of the Department.  |
| 2.3.2  | Identify training needs of external safety partners | 6/1/2015 | ongoing | 1.1.1;<br>1.1.2;<br>2.1.1 -<br>2.1.7 | 1.2.1; 1.2.2 | Local Agencies<br>ConnDOT RPO<br>Coordination<br>ConnDOT GIS  |                | Local agencies, working through the RPOs and the ConnDOT RPO Coordination can determine who needs what training among the local agencies. At least some of that training will be GIS-related |

## **APPENDIX B: STAFFING, SOFTWARE, AND TRAINING RECOMMENDATIONS**

## **OVERVIEW**

This section provides specific recommendations for ConnDOT detailing the staffing, software implementations, and training required to implement the steps in the Action Plan. There are two basic options for how to obtain the necessary resources to implement the plan:

1. Internal ConnDOT hiring/purchases/training.
2. External consulting services.

### **Recommendations**

Based on the current staffing levels and economic situation within ConnDOT, we recommend a mixed approach where the labor and software are funded by ConnDOT using existing safety dollars, with the labor and purchases (e.g., software procurement, development, and/or deployment) through an external consultant. We recommend using a university-based research center for tasks that have a long-term, ongoing nature, supplemented by on-demand consulting staff as needed for tasks that either need to be accomplished quickly or which have a definite end point in the near future. Training is required for ConnDOT staff and for some members of the recommended university-based support contractor.

### **Alternatives**

Other options include: 1) using a non-university-based consulting team, and 2) staffing the effort entirely within ConnDOT. These alternatives were presented to the DOT committee considered but not pursued based on the following feedback. The external contracting process would likely be more time-consuming and more expensive than working through a University. ConnDOT is also under a continuing hiring freeze, the result of which is that the new work described in the Action Plan would have to be absorbed by existing staff or special hiring approval would need to be sought—neither seems likely to succeed. In particular, the ConnDOT Safety Engineering Unit within the Division of Traffic Engineering and the Office of Information Services are not staffed adequately to take on the jobs listed for them in the Action Plan. In addition, there is one statistician in the Accident Records and Statistics section. This individual is already fully dedicated to required analysis and reporting duties and cannot take on the additional analyses described in this report. In short, ConnDOT is not in a position to take on the tasks required to enhance their safety management processes and analyses as described in this plan. The agency cannot hire the necessary staff and the Agency's IT support is insufficient to take on the new software design and implementation tasks in a reasonable time frame. For these reasons, we strongly recommend that ConnDOT continue to build relationships with a university-based transportation research center to serve as a safety management and analysis resource to the Department.

### **Needs Assessment**

The remainder of this Appendix lists the immediate and long terms needs for staffing, software development/procurement/implementation, training, and consulting services to implement the Action Plan. Each need is described and a cost estimate is provided. The cost estimates are based on VHB's experience in other states plus our own estimates for the level of effort. Final costs will ultimately depend on a multitude of factors such as the manner of implementation, how aggressive the DOT implements this change, timelines, and the degree to which ConnDOT chooses to use in-house, consultant, or university-based resources.

## **IMMEDIATE NEEDS**

The needs described in this section are those needed to implement the Action Plan in the near term—roughly comprising the next 1-3 years of effort aimed at improving the ConnDOT Safety Management Process. With the exception of consulting services (which are viewed as one-time needs ending with a specific product), the needs described here should be viewed as on-going. The actual task assignments for the staff identified in this section may change over time; however, the need for the permanent staff is definitely ongoing. The costs are presented as “first year” and “ongoing” costs, where first year means the first year that the person is hired. We recommend implementation of the full hiring plan described here should take place over the next one to three years as steps in the Action Plan are implemented.

### **Enhanced Analytics Team Leader and Staff Support**

There is a defined role for an implementation team to manage the overall analytics enhancement project. We recommend a team approach where the lead person—a senior engineer—has responsibility for day-to-day management, staffing, and liaison with ConnDOT. The team will include staff support—a single person at a junior engineering level to track progress, maintain the Action Plan status, and aid with implementation, reporting, and overall project management. Other members of this team are listed separately.

#### Costs<sup>2</sup>

Senior Program Manager: \$298,987 annually

Junior Engineer Staff: \$147,278 annually

### ***Statistician***

A statistician with competencies in spatial analysis and HSM-recommended methodologies (including Bayesian analysis) is required. The need is for a single individual to work as part of the recommended enhanced analysis implementation team. This person will be responsible for spatial sampling, quality control analyses, developing Connecticut-specific Safety Performance Functions and Crash Modification Factors, and conducting advanced statistical data analysis as described in the HSM. In addition, this person will supply data to the Accident Records and Statistics statistician for use in the revised SLOSS analysis using Empirical Bayes adjusted SPFs, and assist in developing the revised SLOSS analysis process. We assume that the university-based research center will have available licenses for statistical software packages required for SPF and CMF development and no additional funding will be required to purchase or license statistical software.

#### Costs

Statistician: \$202,997 annually

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<sup>2</sup> Staff costs are shown as “fully loaded” inclusive of overhead plus F&A based on standard rates for professional services through the University of Connecticut.

### ***IT Support for Safety Analysis***

The enhanced analysis implementation team will require skilled IT support in database administration, software design, and programming. The level of need will depend, in part, on the selection of software tools to be implemented which of those will be developed as custom solutions for Connecticut as opposed to using off-the-shelf options. The estimate provided here is based on the assumption that ConnDOT will implement a mix of off-the-shelf and custom applications. The recommendation is that design efforts (which are short term and have a definite end date) may be contracted out, whereas permanent staff would be preferred for database administration, user support, and software maintenance.

The efforts described under this item (IT Support for Safety Analysis) include implementing AASHTOWare Safety Analyst™ or similar (including possible custom software development), data management to provide data as needed for the analytic tools that are implemented, front-end interfaces to the analytic tools, and development of performance measurement dashboard functions as described in the Action Plan.

#### Costs

##### Permanent Staff:

Database Administrator:           \$212,258 annually

User Support:                         \$106,463 annually

Programming:                         \$129,339 annually

##### Consulting Services (plan for one year only):

System Design:                       \$200,000

Programming:                         \$160,000

### ***Consulting Services in Support of Process Improvement and Safety Data Analysis***

#### ***Performance Measurement***

These are short-term needs that are best filled by external consultants who will work on the project to completion and not become part of the permanent resources supporting ConnDOT. We recommend a near-term project to fulfill all of the Action Plan items related to formalizing the safety management process, coupled with a project to develop and enhance the performance measures used by ConnDOT to assess safety performance. The consultant team will facilitate meetings with ConnDOT and their supporting resource staff (i.e., the recommended university-based team) and other stakeholders. The first set of tasks will be to document and formalize the safety management processes; a set of tasks which includes process flows, data definitions, and detailed descriptions of each step in the safety management process. This will involve traffic engineering, safety engineering, design, and behavioral safety program

staff from ConnDOT working with the consulting team for approximately six months. On roughly the same timeframe, the same group will also work to examine existing performance measures and develop new measures as needed. The performance measurement effort will also need to be coordinated with the IT support efforts described earlier in this section, specifically in the development of the performance measurement dashboard.

### Costs

Consulting Services:                   \$200,000

### ***Software Purchases and Maintenance Fees***

ConnDOT is interested in implementing AASHTOWare Safety Analyst™ or a similar suite of programs that are designed to assist in data analyses to support network screening, countermeasure selection, economic appraisal, and outcome evaluations. We recommend a trial period for implementation of AASHTOWare Safety Analyst™ as there are alternatives that ConnDOT may prefer after evaluating the level of effort required and utility of the analytic output from AASHTOWare Safety Analyst™. We further recommend that the staff explore the costs and desirability of developing custom solutions of the type that have been implemented in New Jersey, Kentucky, Virginia, and Florida (as examples). The main advantage of this custom software alternative is that the final system can be tailored to the needs of ConnDOT staff and achieve the level of automated analysis they desire.

AASHTOWare Safety Analyst™ is a sufficient product for the near term, and we recommend at least a trial implementation (in part because the trial costs are low); however, we believe that ConnDOT will be best served by a custom solution. If ConnDOT does decide to implement a custom solution, there will be additional IT costs, most of which would be of a short-term nature and could best be accomplished through consulting services for design and programming, with permanent staffing devoted to system maintenance and user support. This is reflected in the IT support cost estimates provided earlier in this section.

### **AASHTOWare Safety Analyst™ Site License and Training/Support Costs:**

Annual maintenance:                   \$ 25,000  
Estimated training costs:           \$ 45,000 (five service units per year)  
Total:                                       \$ 70,000 per year

NOTE: Alternatives considered include:

**Vision Zero Suite** (initial cost = \$300,000 for customizing to CT data). Annual fee of \$50,000. Training costs are \$10,000 per class, plus expenses.

**Custom Software.** We estimate the cost for developing custom software to support the six-stage safety management process will be in a range from \$500,000 to \$1,000,000 in development costs (over several years) and approximately \$100,000 in annual support.

**IHSDM Software and Training Costs:**

ConnDOT will also benefit from implementing the Interactive Highway Safety Design Model (IHSDM) decision support tool. The tool will be utilized directly by ConnDOT, specifically Highway Design. This advantage of this tool over the HSM Part C spreadsheets is that a CAD-based alignment can be directly imported, rather than done manually. The IHSDM is available free of charge from the FHWA and the IHSDM technical support staff provide technical support free-of-charge to users. The software is updated periodically, and updates are provided free-of-charge.

FHWA's National Highway Institute offers a two-day, onsite IHSDM Training Course (Course Number FHWA-NHI-380071), which includes training for recognizing when and how IHSDM can be used during the project development process. The onsite training is available for \$400 per person. Additionally, a Web-based, instructor-led version of the IHSDM Training Course (Course Number FHWA-NHI-380100) is available for \$200 per participant.

**The IHSDM Site License and Training/Support Costs:**

|                           |                     |
|---------------------------|---------------------|
| Annual maintenance:       | Free-of-Charge      |
| Estimated training costs: | \$ 4,000 (annually) |
| Total:                    | \$ 4,000 per year   |



## LONG-TERM NEEDS

The portions of this staffing and purchase plan that address longer-term needs identified in the Action Plan are shown here as “long-term” needs. What this means for implementation is that ConnDOT should consider these needs beginning three or more years from the start of the project to implement the Action Plan. The estimated costs for these activities are shown as “new” costs; however, it should be recognized that the duties to be performed by the recommended staff could potentially be assigned to existing staff identified under the section on “immediate needs”. At the point where these needs will be addressed under the proposed Action Plan, ConnDOT will have a better sense of the ongoing needs and staff assignments arising from all the preceding portions of the Action Plan. At that point, ConnDOT will be able to assess whether the needs described here would need additional funding or merely a change in priorities and assignments for staff already working on the project.

### *Data Collection, Integration and Quality Control*

ConnDOT is committed to creating a statewide basemap and linear reference system, with associated roadway attribute (inventory) and traffic volume data. This effort is complete for state-maintained roadways and for about 1/3 of the local roads. Under the current plan, it will take several years to complete the first pass of data collection and geolocation work for the local roadway system. Once that is complete, there are needs for maintenance and updates to the data. From a safety analysis perspective, the sooner the first pass data collection and geocoding is done, the better. That will provide a backbone for all the spatial data within the ConnDOT GIS. Ultimately, these data will need to be updated and verified on a reasonable maintenance cycle. ConnDOT has both contract and in-house resources dedicated to the completion of the first pass of data collection and integration. To speed the process up, the in-house staff would need to be supplemented by additional external resources. Further, to establish a continuous maintenance cycle will require additional resources including data collection systems (Instrumented vans) as well as consultants or in-house staff. This is listed as a long term need because we do not see a realistic option for ConnDOT to complete the all-public-roads network sooner than within the next two-to-three years. An effort to contract out for that service did not deliver the data quality that ConnDOT was expecting. Moving forward, ConnDOT may identify a different contractor or, more likely, it will use in-house resources to accomplish the first pass through the local roadway network. This cost item, then does not address that first-pass data collection, but rather deals with the need for Quality Control of the spatial data. The recommendation is to develop a simple user interface for users of the ConnDOT spatial data to report discrepancies and for authorized data managers to implement corrections in the spatial data.

#### Costs<sup>3</sup>

Permanent Staff (annual costs):

User Support: \$106,463 annually

Quality Control: \$219,912 annually

Consulting Staff for interface design and programming (one-time costs):

Web system designer: \$160,000

Programming: \$160,000

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<sup>3</sup> These costs may already be covered under ConnDOT’s Bentley/EXOR project plans

***IT Support for Project and Financial Tracking:***

The enhanced analysis implementation team will require skilled IT support in database administration, software design, and programming to improve existing project tracking and financial systems used throughout the Department.

Costs

Permanent Staff:

Database Administrator:       \$212,258 annually

User Support:                    \$106,463 annually

Programming:                    \$155,207 annually

Consulting Services (one time services):

System Design:                 \$200,000

Programming:                    \$160,000

## COST SUMMARY

### Immediate Needs:

|                                   |                           |                                    |
|-----------------------------------|---------------------------|------------------------------------|
| Permanent Staff:                  | \$ 1,097,322 (first year) | \$1,097,322 (ongoing) <sup>4</sup> |
| Software licenses<br>and training | \$ 74,000 (first year)    | \$ 74,000 (ongoing)                |
| Consulting Services:              | \$ 560,000 (first year)   | \$ 0 (tbd)                         |
| TOTALS                            | \$1,731,322 (first year)  | \$1,171,322 (ongoing)              |

### Long-term Needs:

|             |                         |
|-------------|-------------------------|
| Staffing:   | \$ 800,303 <sup>5</sup> |
| Consulting: | \$ 680,000              |

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<sup>4</sup> The ongoing staff costs have not been adjusted for inflation. They are expressed as 2014 costs and will need to be adjusted to account for cost of living adjustments. An increase of 5% per year should be expected.

<sup>5</sup> The work assignments identified here may be partially addressed with existing staff described under "Immediate Needs". They are not intended to be incurred in year 1.