


Strategic Investment Decisions for Highway Improvement Projects

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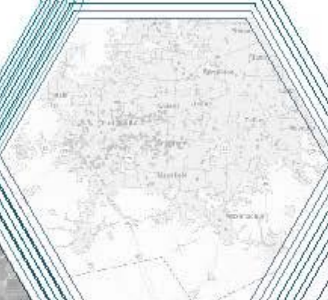

FINAL REPORT

CENTER FOR TRANSPORTATION EQUITY, DECISIONS & DOLLARS

STRATEGIC INVESTMENT DECISIONS FOR HIGHWAY IMPROVEMENT PROJECTS

FINAL PROJECT REPORT

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16. Abstract

Quantitative safety is now being recognized as an essential element in project selection process at the planning phase. Quantitative evaluation of safety performance of particular roadway facilities, for example, segments and intersections, is critical to understand where safety concerns need to be addressed on a priority basis. A process that provides guidance to agencies for implementing appropriate safety improvements to a prioritized set of locations is critical to safety programing based on a systemic approach. This project documents the development of such a process, programmed in an MS Excel spreadsheet, as a tool—Strategic Investment Decisions for Highway Improvement Projects (Hi-ImPct). The key features of this tool include alignment with the agency's strategic highway safety plan, customizability, and incorporation of state-of-the-art safety management research. The tool incorporates historical crash data, roadway inventory data, estimates for unit cost of improvements, and high-quality Crash Modification Factors (from the CMF Clearinghouse). Emphasis Areas identified in the Florida Strategic Highway Safety Plan (SHSP) and roadway functional classification are used to organize the output and support better-informed decision-making. Hi-ImPct is expected to support a more strategic application of limited funding. The tool is customizable to support the decision-making process for state, local, and regional agencies with different safety Emphasis Areas.

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Abstract

Quantitative safety is now being recognized as an essential element in project selection process at the planning phase. Quantitative evaluation of safety performance of particular roadway facilities, for example, segments and intersections, is critical to understand where safety concerns need to be addressed on a priority basis. A process that provides guidance to agencies for implementing appropriate safety improvements to a prioritized set of locations is critical to safety programing based on a systemic approach. This project documents the development of such a process, programmed in an MS Excel spreadsheet, as a tool—Strategic Investment Decisions for Highway Improvement Projects (Hi-ImPct). The key features of this tool include alignment with the agency's strategic highway safety plan, customizability, and incorporation of state-of-the-art safety management research. The tool incorporates historical crash data, roadway inventory data, estimates for unit cost of improvements, and high-quality Crash Modification Factors (from the CMF Clearinghouse). Emphasis Areas identified in the Florida Strategic Highway Safety Plan (SHSP) and roadway functional classification are used to organize the output and support better-informed decision-making. Hi-ImPct is expected to support a more strategic application of limited funding. The tool is customizable to support the decision-making process for state, local, and regional agencies with different safety Emphasis Areas.

Chapter I: Introduction

1.1 Background

Quantitative safety is now being recognized as an essential element in project selection and prioritization at the planning phase. As strategic highway safety plans (SHSP) take shape at the state and local agency levels, there is a need to align the prioritization process with the agency Emphasis Areas identified in these plans. With multiple safety improvements being considered at candidate locations, decision-makers need tools that will support the allocation of funding more strategically along different corridors of roadway facilities. The objective of this report is to document the process of development and application of such a tool.

The tool potentially can support the decision-making process in the planning phase of project selection at the state, local, and regional levels. Based on a detailed literature review, stakeholder discussions, and review of the agency's SHSP, key elements for such a tool are identified herein. These elements include:

- Alignment with Emphasis Areas identified in the SHSP
- Incorporation of state-of-the-art from the latest safety management research (i.e., Crash Modification Factors [CMFs], methods to address the impact of multiple safety improvements among others)
- Customizability for changes in costs and Emphasis Areas

This tool, Strategic Investment Decisions for Highway Improvement Projects (Hi-ImPct), has been developed for any highway agency (for example, the Florida Department of Transportation [FDOT]). It uses historical crash data, roadway inventory data, unit cost of improvements, and CMFs (from the CMF Clearinghouse) organized by Emphasis Areas identified in the Florida SHSP. Hi-ImPct will help planners and decision-makers at departments of transportation allocate limited funding for highway improvements that lead to the most effective safety outcomes. This tool may also be used for proactive decision-making in prioritizing safety improvements in different Emphasis Areas for implementing action targeted at "Vision Zero." Subsequent sections of this report document a literature review, data and methodology, tool development, and application, followed by discussion and conclusions.

1.2 Importance of Project

With a data-driven tool, policy-makers have more choices to impact highway safety at the state or local level. Following a quantitative approach and with objective data, policy-makers can influence reductions in fatalities and serious injuries as follows:

- Provides guidance to address systemwide safety problems in terms of fatalities and serious injuries by Emphasis Area in an SHSP

- Provides a clear assessment of benefits in implementing safety projects on specific roadways to address safety issues by Emphasis Area against the cost of improvements
- Helps to understand what countermeasures are cost-effective to address safety issues of fatalities and serious injuries by roadway class.

From the standpoint of policy implementation on roads and infrastructure, the benefit of an objective tool can address the issues noted above.

1.3 Project Objectives and Benefits

The objective of this project was to develop an investment decision-making tool focusing on roadway improvement. The cost of project improvements under specific strategies was estimated against the benefit of reductions in the severity of crashes by implementing particular strategies on specific Emphasis Areas in the Florida SHSP. The tool enables the flexibility to select necessary strategies in different functional classes of roadway under each Emphasis Area to yield cost effectiveness from the agency standpoint.

Total centerline mileage in Florida under the State system accounts for 10% of statewide mileage and represents 54% of vehicle miles traveled (VMT), resulting in about 60% of total fatalities. It is critical for Florida to determine where the most return of safety benefit can be expected. As such, the Hi-ImPct tool focuses on Florida's State Highway System for relevant Emphasis Areas of the SHSP that will be highly impacted by highway improvement projects, with a target of reducing fatalities and serious injuries.

The benefits of this project are as follows:

- The benefit-cost analysis at the roadway level functional class for Emphasis Areas of the SHSP provides a clear picture of the return of benefits from the invested resources.
- The effect of single or multiple countermeasures and the methodology to incorporate them into the benefit-cost analysis can provide insights to practitioners, safety engineers, and design engineers.
- Flexibility in incorporating new countermeasures and their CMFs can be added to this tool considering future expansion.
- Simple visualization can provide feedback to an informed decision-making process for policy-makers.

This report documents a literature review, data and methodology, tool development, tool application, and interpretations of the results with discussion and conclusions. The appendices (A to E) includes the definitions of emphasis area (A), trends of fatalities and serious injuries over the study year (B), CMF consideration for crash types by emphasis areas (C), user guidance for using the tool (D), and finally some cross-checks of preliminary data used to develop this tool (E).

Chapter II: Literature Review

2.1 Background

Florida shares the national traffic safety vision of "Toward Zero Deaths" and formally adopted its own version, "Driving Down Fatalities," in 2012. The SHSP aims to realize that vision with the latest version of the plan released in 2016 [1]. The data-driven SHSP focuses on 13 Emphasis Areas that reflect ongoing and emerging highway safety issues in Florida. Key strategies related to each Emphasis Area are identified, as are overarching strategies that apply across the Emphasis Areas. These strategies align with the "4 Es"—engineering, education, enforcement, and emergency response [1].

In realizing "Vision Zero" through Emphasis Areas and strategies, a systemic approach to safety is needed. This involves assessment of widely-implemented improvements based on high-risk roadway features correlated with specific severe crash types. According to the Federal Highway Administration (FHWA), a systemic approach to safety [2]:

- Identifies a "problem" based on systemwide data such as rural lane departure crashes, urban pedestrian crashes, etc.
- Examines characteristics (e.g., geometry, volume, location) frequently present in severe crashes
- Focuses on deploying one or more countermeasures to address the underlying circumstances contributing to crashes on a majority of roads

Quantitative safety is a critical component of a project selection process at the planning phase [3]. Quantitative evaluation of safety performance of particular roadway facilities, for example, segments and intersections, is critical to understanding safety concerns that need to be addressed on a priority basis. Moreover, it is also vital to implement appropriate safety improvements to a prioritized set of locations where the promise of safety benefits is the highest. In this regard, this work is a step in the direction of adopting a systemic approach to safety planning.

The *Highway Safety Manual* (HSM) [3] contains a process for estimating the annual average frequency by crash severity through predictive models that use safety performance functions (SPFs), CMFs, and other adjustment factors (e.g., local calibration factor) to predict the number of crashes that a roadway segment will experience based on its specific characteristics. SPFs are regression models that estimate the average crash frequency for a specific roadway type based on Annual Average Daily Traffic (AADT), segment length, and regression constants. A CMF is a ratio between the number of crashes per unit of time expected after a modification or measure is implemented and the number of crashes per unit of time estimated at the same segment/intersection without the said modification [3].

2.2 Safety Performance Measures

Performance indicators and measures are important in assessing a transportation network. Public agencies vary in their expectations for the transportation systems they manage. The objectives of a public agency (e.g., "Toward Zero Death") affect the implementation and management of performance indicators. Also, stakeholder interests or requirements (private users of roads, commercial road users, etc.) affect performance indicators [4]. Performance measurements can assist in justifying program expenditures or requests for funding. Many performance indicators focus on system condition and preservation, safety, accessibility, and mobility. In this project, the focus is on safety-related performance measures that are critical for public agencies such as state DOTs. A Canadian survey for public agencies found that safety performance is being measured through the following criteria [6]:

- Crash rates per million vehicle kilometers (MVK)
- Fatalities per MVK
- Injuries per MVK
- Property-damage-only incidents
- Percent of incidents involving trucks per MVK
- Rail grade crossing incidents

Similarly, FHWA set criteria for national safety performance measures with the following [7]:

- Number of fatalities
- Fatalities per 100 M-VMT
- Number of serious injuries
- Serious injuries per 100 M-VMT
- Fatalities and serious injuries of non-motorized road users

It was noted by the Canadian study that crash rates per million vehicle kilometers were the most common performance indicator. With these safety performance indicators, public agencies can assess the safety of their highways. This aligns with three of the 4 E's in the Florida SHSP. Safety performance indicators allow engineers to evaluate their design effectiveness, and safety performance measures communicate and educate the public on the safety of a current or implemented design. Finally, safety performance indicators can assist emergency response**.**

To conduct a life-cycle benefit-cost analysis (LCBCA), crash counts need to be converted into crash costs using FHWA or state-level data [8]. Another important aspect associated with LCBCA of safety-related improvements is the cost of implementing such improvements. For efficiency purposes, safety-related improvements are often included in larger construction contracts and, as such, the costs can vary significantly. Frustaci et al. [9] recommended that construction costs of safety-related improvements, such as initial cost, periodic rehabilitation cost, and annual maintenance costs, must be prepared outside the benefit-cost analysis tool by an analyst rather than built into a tool such as the one developed through this research. In this research, we employed preliminary cost estimates using Caltrans' online tool to demonstrate the application of the tool.

2.3 Countermeasure Methods

Another complication associated with safety-related improvements is that, often, multiple countermeasures are implemented at the same time and their combination influences safety outcomes. Elvik [10] discussed the following methods to assess combined safety impacts:

- Dominant Effect
- Additive Method
- Multiplicative Method
- Dominant Common Residuals Method

These methods range from providing a conservative estimate of the impact (i.e., Dominant Effect method) to providing a more reasonable estimate through the Dominant Common Residuals Method. The best combination method may vary based on context, and, hence, a tool providing analysts with the option of all these methods may be more appropriate to select which countermeasures are more effective in terms of benefits against cost. Pack [11] discussed the importance of data visualization to provide more compelling evidence to the general public and transportation practitioners. In this regard, a tool that provides some degree of visualization for safety impacts is likely to be more useful.

There is a need for agency-specific tools to help execute an agency's SHSP in light of the Emphasis Areas outlined in the plan. The tool needs to be flexible in allowing for cost-related input, since the safety improvements are delivered through a wide variety of project delivery processes. A tool that allows for multiple safety improvements in candidate locations will help decision-makers allocate funding more strategically along different corridors of roadway facilities considering the safety concerns of different Emphasis Areas outlined in an agency's SHSP. The data required for tool development will include historical crash data, roadway inventory, unit cost of improvements and crashes by severity, and CMFs (from the CMF Clearinghouse). Graphics that support visualization of the most salient results from the tool will also make the tool more compelling. For the tool to be most valuable to an agency, it must categorize the countermeasures based on the Emphasis Areas.

Chapter III: Data and Workflow

3.1 Background

This project was heavily dependent on data including crash databases, roadway inventory, Emphasis Area definition, countermeasures, CMFs, and cost of safety improvement projects.

Figure 3-1 depicts the data sources and their workflow in developing a tool that incorporates lessons from the review documents. The following information and data sources were used:

- *Florida SHSP* – to identify and categorize crash data by Emphasis Area. It is the first step for implementing a systemic approach to safety, as documented in the previous section.
- *Florida crash data* – organized by SHSP Emphasis Areas and functional classification.
- *Crash countermeasures and corresponding CMFs* – organized by injury severity from FHWA's CMF Clearinghouse; only high-quality CMFs (Star Rating >=3) are used.
- *Cost of crashes by injury severity and cost estimates for the countermeasures* – for preliminary exploration with the tool.

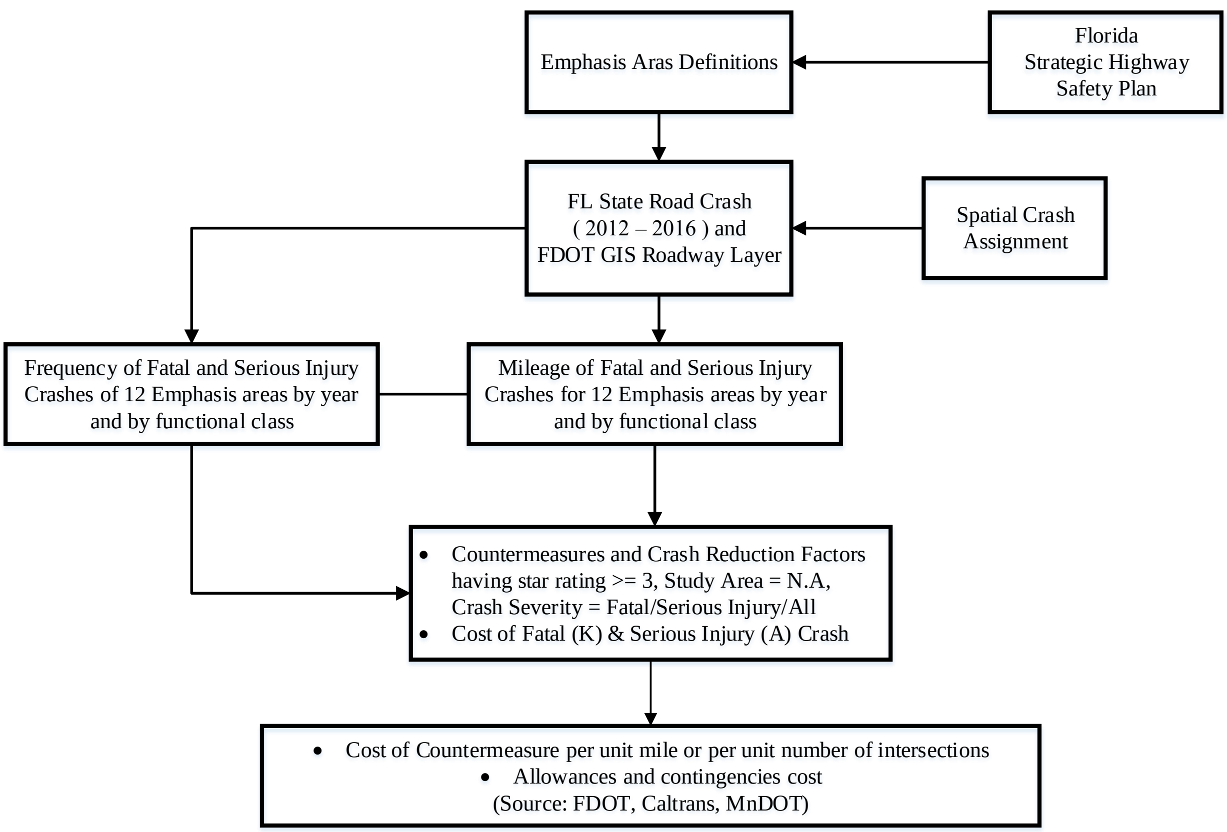


Figure 3.1 Data Processing Work Steps towards Tool Development

3.2 Data and Processing Steps

Data elements from major data sources and processing steps are described below.

3.2.1 Organizing Crash Data by Emphasis Area

Crash data from January 1, 2012, to December 31, 2016, were extracted from Florida's Crash Analysis Reporting (CAR) system and filtered for the State Highway System only. The total centerline mileage in the State system accounts for 10% of statewide mileage but represents 54% of vehicle miles traveled (VMT) and about 60% of total fatalities. As such, the State system is critical in terms of potential safety benefits—hence, the focus of the tool. The 12 Emphasis Areas in the SHSP are Lane Departure, Impaired Driving, Pedestrians, Bicyclists, Intersections, Motorcyclists, Older Drivers, Speeding and Aggressive Driving, Commercial Vehicles (Trucks), Younger Drivers, Distracted Driving, and Work Zones.

3.2.2 Geocoding Crashes and Organizing by Roadway Functional Class

GIS roadway layers were spatially linked with crash data using a spatial join method and a 100-ft buffer. Based on this spatial crash assignment, mileage and crashes associated with each Emphasis Area were summarized by the functional classification of the roadway for fatalities and serious injuries separately.

3.2.3 Summarizing Crashes by Injury severity

The numbers of fatal and serious injury crashes based on the KABCO Injury Severity Scale were summarized for each Emphasis Area. Based on the first three steps, for example, fatal and serious injury crashes under the Lane Departure Emphasis Area may be estimated for Principal Arterial—Interstate, Principal Arterial—Expressway, Principal Arterial—Other, Minor Arterial, Major Collector, and Minor Collector. Also, mileage for fatal and serious injury crashes was summarized for all Emphasis Areas, as were intersection crashes by 3-legged and 4-legged signalized intersections and stop-and yield intersections in Florida. FDOT intersection layers were processed and verified with Google Earth imagery.

3.2.4 Crash Countermeasures and CMFs

The CMF Clearinghouse repository includes all the latest CMFs from safety performance research, which are stored in a publicly-accessible database. The data were filtered for high-quality CMFs (Star Rating 3 and above). Also, particular attention on selecting CMFs was related to any student conducted in North America (N.A.).

3.2.5 Incorporating the Cost of Crashes and Improvement Projects

The cost of fatal and serious injury crashes for Florida was extracted from FDOT documents. The cost of highway improvement projects by linear mileage was estimated based on FDOT, Caltrans, and Minnesota DOT project cost documents, which are publicly available through their websites. Depending on how the improvement projects were conceived and delivered in the local jurisdiction, this cost estimate may vary. Hence, the tool gives analysts the choice of altering the improvement cost estimates.

Finally, the 12 Emphasis Areas were arranged by functional class of roadway or intersection type that experienced fatalities and serious injuries over a five-year period. Density of fatalities and serious injuries were considered over their corresponding length of mileage in the State Highway System or by number of intersections. Cost of the improvement projects was considered per linear mileage, and the benefit of reducing fatalities and serious injuries was also scaled to linear mileage so the benefit-cost ratio can be estimated on the same normalized scale.

Chapter IV: Tool Development and Analysis

4.1 Background

The summarized data were programmed into an MS Excel spreadsheet for a simple, user-friendly application. Figure 4-1shows the interface of the Hi-ImPct tool and details the information under each tab for use by the analyst to compute the benefit-cost ratio for highway improvement projects under different Emphasis Areas.

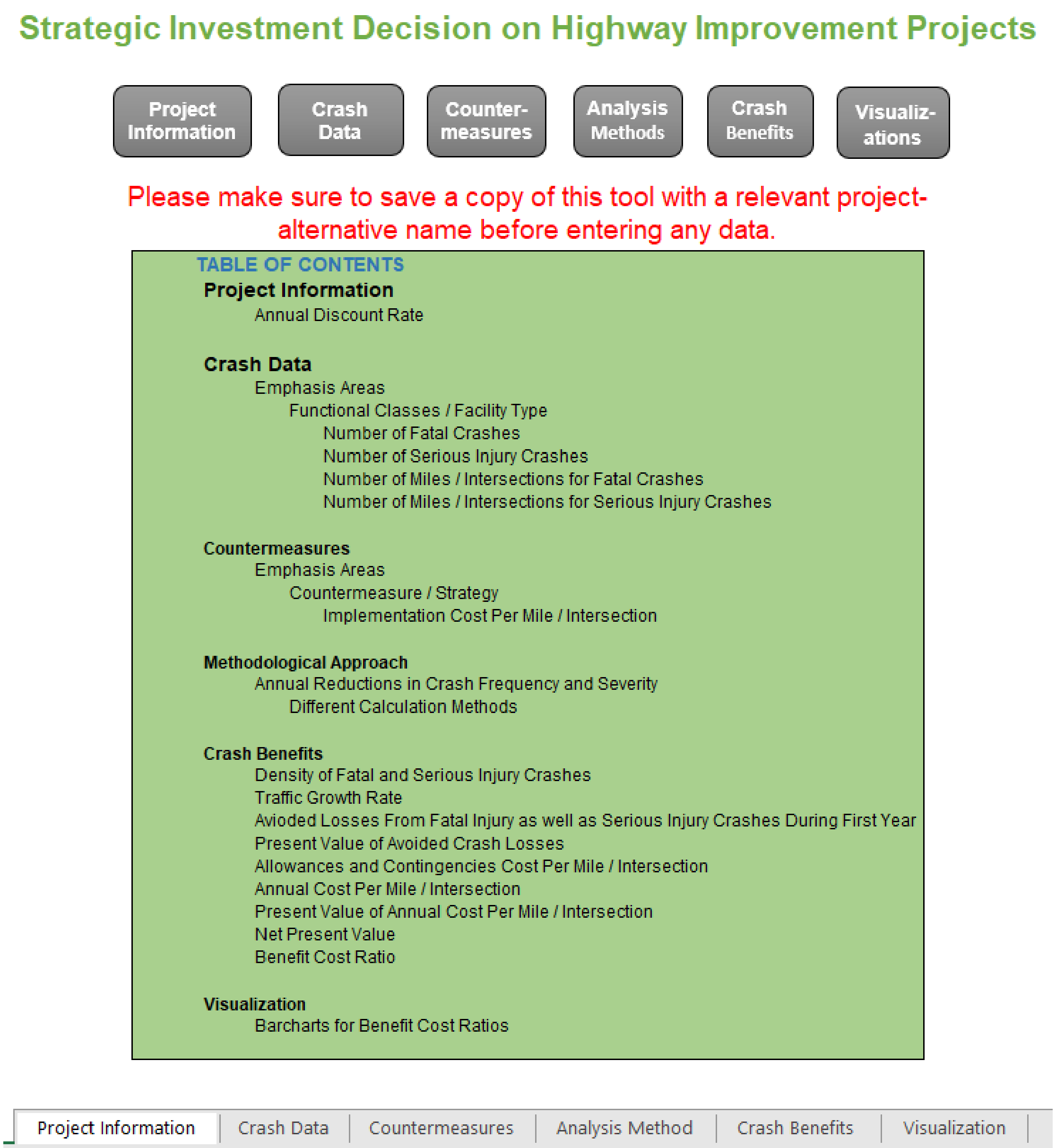


Figure 4.1 Interface for Hi-ImPct tool

As an example, Figure 4-2 shows summaries of fatal and serious injury crashes for Lane Departure crashes by functional class of roadways to understand what functional class of roadways need immediate improvements.

	Injury Data		Roadway System Data		
	Number of Fatal Crashes	Number of Serious Injury Crashes	Number of Miles for Fatal Crashes	Number of Miles for Serious Injury Crashes	Total Number of Miles/ Intersections
1. Lane Departure					
Principal Arterial - Interstate (Rural and Urban)	381	2011	2402	10770	13172
Principal Arterial - Expressway (Rural and Urban)	90	565	605	5136	5741
Principal Arterial - Other (Rural and Urban)	554	2557	699	2856	3555
Minor Arterial (Rural and Urban)	233	1003	401	1459	1860
Major Collector (Rural and Urban)	48	245	81	289	370
Minor Collector (Rural and Urban)	6	36	7	28	35

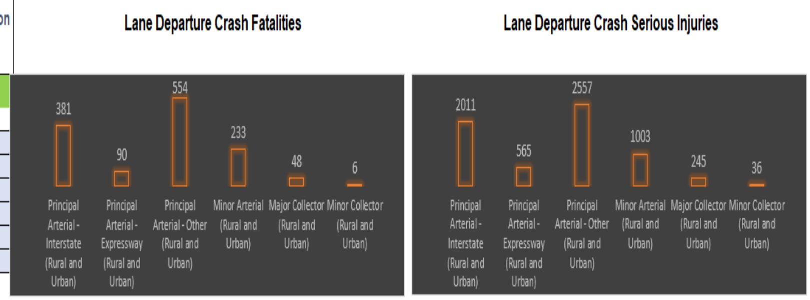


Figure 4.2 Crash summary for Lane Departure Emphasis Area

For each Emphasis Area, countermeasures are documented and extracted from the CMF Clearinghouse with CMF ID, CMF value, target crash types, and their corresponding Star rating. Project improvement cost per mile for each countermeasure was derived from the FDOT website. In this case, FDOT data were available; the tool also used California and Minnesota data for some countermeasures. It is important to note that due to discount rates and other contingencies, an equal present value of cost is added for maintenance, rehabilitation, labor, and other uncertain aspects of projects. The analyst has the flexibility to enter more accurate measures of costs as available. Also, in the countermeasures list, some countermeasures are listed; additional countermeasures are highlighted in the green cell at the bottom so the analyst may input additional CMFs and their details, if desired.

Figure 4.3 shows the methods for application of different countermeasures with single or multiple application, showing benefits in terms of annual reduction (as shown on the bar chart on the right for fatal and serious injury crashes).

Figures 4.4 and 4.5 show the detailed output steps of Lane Departure crashes for different functional classes (in rows) and their summarized fatal and serious injury crashes (in columns), density, CMFs, unit cost of improvement projects, present value of cost and benefit, and a benefit-cost ratio for each. It is important to note that the analyst needs to input the deployment length of the functional class of the highway that needs the improvement and the service life of the improvement projects; green cells represent analyst input. Finally, based on the benefit-cost ratio, six ranges of are color-coded—0–5, 6–10, 11–15, 16–20, 21–25, and >25.

Project Crash Data

This sheet calculates annual reductions in crash frequency and severity for single or multiple countermeasures.

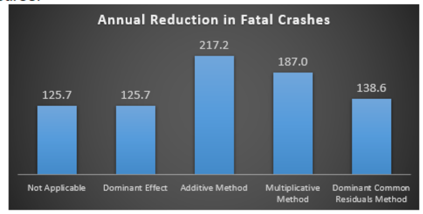
I) Emphasis Area	Lane Departure
II) Functional Class / Facility Type	Principal Arterial - Interstate (Rural and Urban)
III) Single or Multiple Countermeasure	Multiple Countermeasures
IV) Calculation Method	Multiplicative Method
V) Countermeasure 1	Install Edge Line Rumble Strips
VI) Countermeasure 2	Install High Tension Cable Median Barrier

Baseline Crash Data and Crash Modification Factors

Enter estimated annual crashes without treatment and Crash Modification Factors (CMF).

Injury Severity Scale	Estimated Annual Crashes without Treatment	CMF1	CMF2
K	381	0.67	0.76
A	2011	0.67	0.76
CMF Clearinghouse ID		3394	8215

CMF Lists



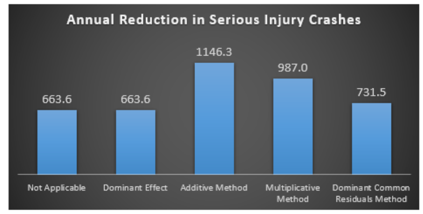


Figure 4.3 Comparative Analysis for Countermeasures for Lane Departure Emphasis Area

Emphasis Area	Functional Class/ Facility Type	Fatal Crash K (No)	Serious Injury Crash A (No)	Mileage / No of Intersections for Fatal Crashes	Mileage / No of Intersections for Serious Crashes	Years of Crash Data	Total Mileage	Deployment Mileage for Improvement	Crash Density (KA)
Lane Departure									
Install Edge Line Rumble Strips	Principal Arterial - Interstate (Rural and Urban)	381	2011	2402	10770	5	13172	50	0.04
	Principal Arterial - Expressway (Rural and Urban)	90	565	605	5136	5	5741	50	0.02
	Principal Arterial - Other (Rural and Urban)	554	2557	699	2856	5	3555	50	0.18
	Minor Arterial (Rural and Urban)	233	1003	401	1459	5	1860	50	0.13
	Major Collector (Rural and Urban)	48	245	81	289	5	370	50	0.16
	Minor Collector (Rural and Urban)	6	36	7	28	5	35	50	0.24
	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Not Found
Install High Tension Cable Median Barrier	Principal Arterial - Interstate (Rural and Urban)	381	2011	2402	10770	5	13172	50	0.04
	Principal Arterial - Expressway (Rural and Urban)	90	565	605	5136	5	5741	50	0.02
	Principal Arterial - Other (Rural and Urban)	554	2557	699	2856	5	3555	50	0.18
	Minor Arterial (Rural and Urban)	233	1003	401	1459	5	1860	50	0.13
	Major Collector (Rural and Urban)	48	245	81	289	5	370	50	0.16
	Minor Collector (Rural and Urban)	6	36	7	28	5	35	50	0.24
	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Not Found
Install Central Line Rumble Strips	Principal Arterial - Interstate (Rural and Urban)	381	2011	2402	10770	5	13172	50	0.04
	Principal Arterial - Expressway (Rural and Urban)	90	565	605	5136	5	5741	50	0.02
	Principal Arterial - Other (Rural and Urban)	554	2557	699	2856	5	3555	50	0.18
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	Major Collector (Rural and Urban)	48	Plot Area	81	289	5	370	50	0.16
	Minor Collector (Rural and Urban)	6	36	7	28	5	35	100	0.24
	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Not Found

Figure 4.4 Crash Benefits for Lane Departure Emphasis Area

					Treatment Cost					Input		Costs			Cost Effectiveness			
CMF	Service Life in years (Treatment Cost)	Traffic Growth Rate (Road System Data)	Avoided Crash Losses in First Year (KA)	Present Value of Avoided Crash Losses for Service Life	Unit Cost	Unit	Allowances & Contingencies per Unit	Total Initial Cost per Unit	Annual Cost per unit	Amount Deployed	Unit	Initial Cost	Present Value of Annual Costs	Present Value of All Costs	Net Present Value	Benefit Cost Ratio	Range of Benefit Cost Ratio	
0.67	10	0	$ 7,149,957.42	$ 1,787,489.17	$ 6,000.00	Miles	$ 600.00	$ 6,600.00	$ 6,000.00	50	Miles	$ 330,000.00	$ 74,999.99	$ 404,999.99	$ 1,382,489.18	4.4	B/C = 1 ~ 5	
0.67	10	0	$ 4,492,082.82	$ 1,123,020.59	$ 6,000.00	Miles	$ 600.00	$ 6,600.00	$ 6,000.00	50	Miles	$ 330,000.00	$ 74,999.99	$ 404,999.99	$ 718,020.60	2.8	B/C = 1 ~ 5	
0.67	10	0	$ 34,455,170.87	$ 8,613,791.83	$ 6,000.00	Miles	$ 6,000.00	$ 12,000.00	$ 6,000.00	50	Miles	$ 600,000.00	$ 74,999.99	$ 674,999.99	$ 7,938,791.84	12.8	B/C = 11 ~ 15	Click Here for Visualization
0.67	10	0	$ 26,163,722.15	$ 6,540,929.87	$ 6,000.00	Miles	$ 6,000.00	$ 12,000.00	$ 6,000.00	50	Miles	$ 600,000.00	$ 74,999.99	$ 674,999.99	$ 5,865,929.88	9.7	B/C = 6 ~ 10	
0.67	10	0	$ 31,178,836.04	$ 7,794,708.21	$ 6,000.00	Miles	$ 6,000.00	$ 12,000.00	$ 6,000.00	50	Miles	$ 600,000.00	$ 74,999.99	$ 674,999.99	$ 7,119,708.22	11.5	B/C = 11 ~ 15	
0.67	10	0	$ 47,247,109.91	$ 11,811,776.27	$ 6,000.00	Miles	$ 6,000.00	$ 12,000.00	$ 6,000.00	50	Miles	$ 600,000.00	$ 74,999.99	$ 674,999.99	$ 11,136,776.27	17.5	B/C = 16 ~ 20	
Not Found	10	0	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Not Found	Not Found	Not Found	Not Found	Not Found	Not Valid	-	
0.76	10	0	$ 5,199,969.03	$ 1,299,992.12	$ 8,000.00	Miles	$ 800.00	$ 8,800.00	$ 8,000.00	50	Miles	$ 440,000.00	$ 99,999.99	$ 539,999.99	$ 759,992.13	2.4	B/C = 1 ~ 5	
0.76	10	0	$ 3,266,969.33	$ 816,742.25	$ 8,000.00	Miles	$ 800.00	$ 8,800.00	$ 8,000.00	50	Miles	$ 440,000.00	$ 99,999.99	$ 539,999.99	$ 276,742.26	1.5	B/C = 1 ~ 5	
0.76	10	0	$ 25,058,306.09	$ 6,264,575.88	$ 8,000.00	Miles	$ 8,000.00	$ 16,000.00	$ 8,000.00	50	Miles	$ 800,000.00	$ 99,999.99	$ 899,999.99	$ 5,364,575.89	7.0	B/C = 6 ~ 10	Click Here for Visualization
0.76	10	0	$ 19,028,161.57	$ 4,757,039.90	$ 8,000.00	Miles	$ 8,000.00	$ 16,000.00	$ 8,000.00	50	Miles	$ 800,000.00	$ 99,999.99	$ 899,999.99	$ 3,857,039.91	5.3	B/C = 6 ~ 10	
0.76	10	0	$ 22,675,517.12	$ 5,668,878.70	$ 8,000.00	Miles	$ 8,000.00	$ 16,000.00	$ 8,000.00	50	Miles	$ 800,000.00	$ 99,999.99	$ 899,999.99	$ 4,768,878.71	6.3	B/C = 6 ~ 10	
0.76	10	0	$ 34,361,534.48	$ 8,590,382.74	$ 8,000.00	Miles	$ 8,000.00	$ 16,000.00	$ 8,000.00	50	Miles	$ 800,000.00	$ 99,999.99	$ 899,999.99	$ 7,690,382.75	9.5	B/C = 6 ~ 10	
Not Found	10	0	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Not Found	Not Found	Not Found	Not Found	Not Found	Not Valid	-	
0.55	10	0	$ 9,749,941.93	$ 2,437,485.23	$ 10,800.00	Miles	$ 1,080.00	$ 11,880.00	$ 10,800.00	50	Miles	$ 594,000.00	$ 134,999.99	$ 728,999.99	$ 1,708,485.25	3.3	B/C = 1 ~ 5	
0.55	10	0	$ 6,125,567.49	$ 1,531,391.71	$ 10,800.00	Miles	$ 1,080.00	$ 11,880.00	$ 10,800.00	50	Miles	$ 594,000.00	$ 134,999.99	$ 728,999.99	$ 802,391.73	2.1	B/C = 1 ~ 5	
0.55	10	0	$ 46,984,323.91	$ 11,746,079.77	$ 10,800.00	Miles	$ 10,800.00	$ 21,600.00	$ 10,800.00	50	Miles	$ 1,080,000.00	$ 134,999.99	$ 1,214,999.99	$ 10,531,079.79	9.7	B/C = 6 ~ 10	Click Here for Visualization
0.55	10	0	$ 35,677,802.94	$ 8,919,449.82	$ 10,800.00	Miles	$ 10,800.00	$ 21,600.00	$ 10,800.00	50	Miles	$ 1,080,000.00	$ 134,999.99	$ 1,214,999.99	$ 7,704,449.83	7.3	B/C = 6 ~ 10	
0.55	10	0	$ 42,516,594.60	$ 10,629,147.56	$ 10,800.00	Miles	$ 10,800.00	$ 21,600.00	$ 10,800.00	50	Miles	$ 1,080,000.00	$ 134,999.99	$ 1,214,999.99	$ 9,414,147.58	8.7	B/C = 6 ~ 10	
0.55	10	0	$ 128,855,754.29	$ 32,213,935.27	$ 10,800.00	Miles	$ 10,800.00	$ 21,600.00	$ 10,800.00	100	Miles	$ 2,160,000.00	$ 269,999.97	$ 2,429,999.97	$ 29,783,935.30	13.3	B/C = 11 ~ 15	
Not Found	10	0	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	50	Miles	Not Found	Not Found	Not Found	Not Found	Not Valid	-	

Figure 4.5 Crash Benefits for Lane Departure Emphasis Area

4.2 Calculations Used in Hi-ImPct Tool

Formulas and details are provided in the following subsections on how the data are summarized, and parameters are set to compute the benefit-cost ratio with input from the analyst.

4.2.1 Deployment Mileage for Improvement

Analysts may input any number of miles for the deployment of selected countermeasure based on the agency's available resources. Deployment mileage is used to calculate avoided crash losses in the first year with fatal and serious injury (KA) combined. Figure 4-6 shows where the analyst may input for deployment mileage.

Deployment Mileage for Improvement	Crash Density (KA)	CMF	Service Life in years (Treatment Cost)	Traffic Growth Rate (Road System Data)
50	0.04	0.67	10	0.0
50	0.02	0.67	10	0.0
50	0.18	0.67	10	0.0
50	0.13	0.67	10	0.0
50	0.16	0.67	10	0.0
50	0.24	0.67	10	0.0
50	Not Found	Not Found	10	0.0

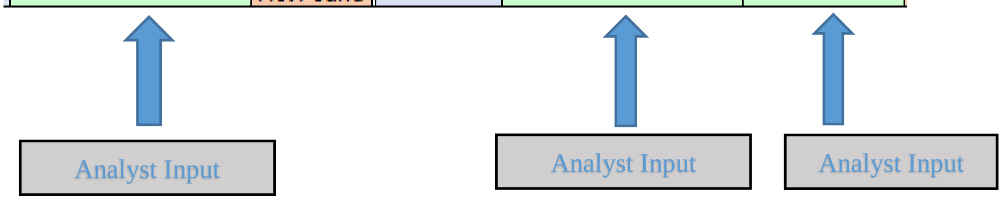

Figure 4-6 Analyst input for Benefit-Cost Analysis

4.2.2 Crash Density

Crash density is a model output calculated using Eq. (1):

$$\mathit{Crash\ Density\ KA} = \frac{\mathit{Fatal\ Crashes} + \mathit{Serious\ Injury\ Crashes}}{\mathit{Total\ Miles\ or\ Number\ of\ Intersections\ for\ Fatal\ and\ Serious\ Injury\ Crashes} \times \mathit{Number\ of\ Years\ of\ Crash\ Data}} \quad (1)$$

4.2.3 Service Life

This field is provided to control a period of use in service for the selected countermeasure. Typically, these are values or range of values indicated by the agency. This model assumes 10 years as the default value for calculation of crash benefit parameters, but the analyst may input different values as appropriate. Figure 4-6 shows where the analyst cab input service life.

4.2.4 Traffic Growth Rate

This field is provided to input traffic growth rate in the future; the analysts can input rate and review crash benefits. This model assumes a default value of traffic growth rate as 0. Although the model has assumed specific default values for the fields highlighted in green, the analyst can input estimates for these cells.

4.2.5 Avoided Crash Losses in First Year with Fatal and Serious Injury (KA) Combined

This is a model output parameter, calculated using Eq. (2):

$$Avoided\ Crash\ losses\ in\ First\ Year\ KA = \frac{Fatal\ Crashes + Serious\ Injury\ Crashes}{Total\ Miles\ or\ Intersections\ for\ Fatal\ and\ Serious\ Injury\ Crashes} \times \frac{(Deployment\ Mileage\ for\ Improvement)}{Number\ of\ Years\ of\ Crash\ Data} \times (1 - CMF) \times (Comprehensive\ Crash\ Unit\ Cost\ for\ Combined\ KA\ Crashes) \quad (2)$$

Table 4-1 presents FDOT adopted unit crash cost for predictive benefit-cost analysis.

Table 4-1 Unit Crash Cost for Predictive Benefit-Cost Analysis in Florida (8)

Severity of Crash	Comprehensive Crash Unit Cost (2013)	Comprehensive Crash Unit Cost (2016)
Fatal Crash	$10,100,000	$11,361,126
Serious Injury Crash	$818,636	$920,854

Note: 2016 value calculated from 2013 value with assumed discount rate of 4%.

4.2.6 Present Value of Avoided Crash Losses for Service Life

This is a model output parameter, calculated using Eq. (3):

$$\begin{aligned} Present\ Value\ of\ Avoided\ Crash\ Losses\ for\ Service\ Life &= (Avoided\ Crash\ Losses\ in\ First\ year \\ &\times ((Annual\ Discount\ Rate - Traffic\ Growth\ Rate)^{-1}) \\ &\times (1 - \left(\frac{1 + Traffic\ Growth\ Rate}{1 + Annual\ Discount\ Rate}\right)^{Service\ Life\ in\ Years}) \end{aligned} \quad (3)$$

4.2.7 Total Initial Cost per Mile or Intersection

This parameter is calculated using Eq. (4). It may change based on the unit cost value supplied by the analyst.

$$\begin{aligned} &Total\ Initial\ Cost\ per\ Mile\ or\ per\ Intersection = \\ &Cost\ of\ Implementation\ per\ Mile\ or\ per\ Intersection \\ &+ Allowances\ and\ Contingencies\ Cost\ per\ Mile\ or\ per\ Intersection \end{aligned} \quad (4)$$

4.2.8 Initial Cost

This is an output parameter, calculated using Eq. (5). It will change according to the value supplied by the analyst in the field titled "Amount Deployed."

$$Initial\ Cost = Total\ Initial\ Cost\ Per\ Unit \times Number\ of\ Miles\ or\ Intersections\ considered\ for\ Deployment \quad (5)$$

4.2.9 Present Value of Annual Costs

This is an output parameter, calculated using Eq. (6). It will change according to the value supplied by the analyst in the field titled "Amount Deployed."

$$Present\ Value\ of\ Annual\ Costs = \frac{Number\ of\ Miles\ or\ Intersections\ Considered\ for\ Deployment \times Annual\ Cost\ per\ Unit \times \left(1 - ((1 + Annual\ Discount\ Rate)^{-Service\ Life\ in\ Years}\right)}{Annual\ Discount\ Rate} \quad (6)$$

4.2.10 Present Value of All Costs

This is a model-calculated parameter; it will change with changes in the input parameters such as amount deployed and annual discount rate. It is calculated using Eq. (7):

$$Present\ Value\ of\ all\ Costs = Initial\ Cost + Present\ Value\ of\ Annual\ Costs \quad (7)$$

4.2.11 Net Present Value

This is an output parameter calculated using Eq. (8). It will change with changes in the annual discount rate, traffic growth rate, and amount deployed for treatment or implementation of countermeasures.

$$Net\ Present\ Value = Present\ Value\ of\ Avoided\ Crash\ Losses\ for\ Service\ Life - Present\ Value\ of\ all\ (\quad (8)$$

4.2.12 Benefit-Cost Ratio

This is a final output parameter, calculated using Eq. (9); it also will change with changes in the annual discount rate, traffic growth rate, and amount deployed for treatment or implementation of countermeasures.

$$Benefit\ Cost\ Ratio = \frac{Present\ Value\ of\ Avoided\ Crash\ Losses\ for\ Service\ Life}{Present\ Value\ of\ All\ Costs} \quad (9)$$

Finally, the benefit-cost ratio is further sub-divided into six ranges with color-coding, as discussed above.

Chapter V: Conclusions and Recommendations

The intent of this research was to incorporate the systemic evaluation of countermeasure(s) to support decision-making at the agency level. The Hi-ImPct tool evaluates different countermeasures by Emphasis Area and highway functional class and can quantitatively estimate the benefits of highway improvement projects in reducing fatalities and serious injuries. To make progress on “Vision Zero” milestones, in light of limited resources, agencies need to make well-informed decisions to achieve a significant reduction in fatalities and serious injuries. The Hi-ImPct tool can add value to the current literature by distinguishing itself from other available tools (for example, FHWA benefit-cost tool [7]) for estimating benefit-cost ratio:

- Benefit-cost ratios are estimated for each functional class (some functional classes might bring more benefits relative to others).
- The effect of multiple countermeasures and the different methodologies to incorporate their effects in the benefit-cost analysis can provide insights to traffic safety practitioners, safety engineers, and design engineers.
- The tool has flexibility to incorporate new countermeasures and their CMFs.
- Simple visualization provides feedback on the relative priority setting for different functional classes of the roadway for more informed decision-making.

The benefit-cost visualization for certain countermeasures provides insight on how the benefit-cost ratios for the same countermeasures may vary by functional class of roadway. For example, some higher functional class might experience more fatalities and serious injuries, and the computed benefit-cost ratio might be lower relative to a lower functional class.

The Hi-ImPct tool covers only State highways, as VMT, fatalities, and serious injuries are disproportionately higher on Florida’s State Highway System relative to local highway systems. The tool allows highway safety professionals to make informed decisions about the potential return on investment with minimal input. Analysts are advised to estimate well-researched values for parameters such as traffic growth, discount rates, and service life of treatment to get a more accurate estimate of the benefit. The tool also provides flexibility to add more information as available, for example, future countermeasures that might be of interest to an agency.

The five most recent available years of the crash data were used in this study, but the Hi-ImPct tool has the flexibility to link it with more recent crash data. Moreover, the Emphasis Areas considered by this tool are related to highway improvements projects. Some Emphasis Areas (for example, Occupant Protection) might be more related to other Es (Enforcement and Education).

The Hi-ImPct is expected to support informed-decision in the light of strategic application of limited funding from the agency perspective. More importantly, this tool intends to provide an objective guidance for the agency to select a project or a set of projects to improve safety by addressing the challenges of ‘Vision Zero.’ With that commitment, this tool provides a data-driven process to curb the fatalities and serious injuries on public roads targeting the prioritized safety performance measures mandated by the federal government.

In future, more innovative countermeasures and more recent years of crash data covering State and local roadways can be incorporated into this tool as part of its extension. In addition, micro-level analysis can also be conducted.

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Appendix A: Emphasis Area Definitions

1. **Young Driver (15–19)**
   Definition: At least one drivers was age 15–19.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
   - Person Extract: Person Type = Dr (Driver)
     - Where Driver Age = 15–19

2. **Older Driver (65+)**
   Definition: At least one driver over age 65. Excludes age "99" (unknown).
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
   - Person Extract: Person Type = Dr (Driver)
     - Where Driver Age = 65 or greater [excluding 99]

3. **Speeding/Aggressive Driving**
   Definition: Crash where first cause was Exceeding Authorized Speed Limit, Exceeding Safe Speed for Conditions, Failing to Reduce Speed to Avoid Crash, or Operating Vehicle in an Erratic, Reckless, Careless, Negligent, or Aggressive Manner.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
     - Drivers First Action at time of the crash Code = 12, 17, 31

   Speeding = 12 (Drove Too Fast for Conditions) or 17 (Exceeded Posted Speed) or 31 (Operated MV in an Erratic, Reckless or Aggressive Manner)

4. **Impaired Driving**
   Definition: At least one driver impaired by alcohol or drugs, medicated, or had been drinking.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
   - Person Extract: Person Type = Dr (Driver)
     - Where Driver Condition = 9 (Under influence of Medication/Drugs/Alcohol) or 7 (Physically Impaired)

5. **Pedestrian**
   Definition: A fatality or A-Type injury where person injured was a pedestrian.
   - Person Extract : Person Type = Dr (Driver)
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injury)
     - Total of Pedestrian Number > 0

6. **Bicyclist**
   Definition: A fatality or A-Type injury where person injured was a pedestrian.
   - Person Extract : Person Type = Dr (Driver)
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injury)
     - Total of Pedal cycle Number > 0

7. **Motorcycle**
   Definition: Crash that involved at least one motorcycle.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
   - Vehicle Extract
     - Vehicle body type = 11 (Motorcycle)

8. **Heavy Vehicle (Commercial Motor Vehicle Configuration)**
   Definition: At least one vehicles was a bus or a truck.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
   - Vehicle Extract
     - Where Commercial Motor Vehicle Configuration = 1–9 (Truck)

9. **Lane Departure**
   Definition: Crash where collision type was Overturned, Hit Fixed Object, Sideswipe-Opposite –Direction, or Head-On.
   - Crash Extract
     - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
     - Where first harmful event = 1, 19–39 and 42–46

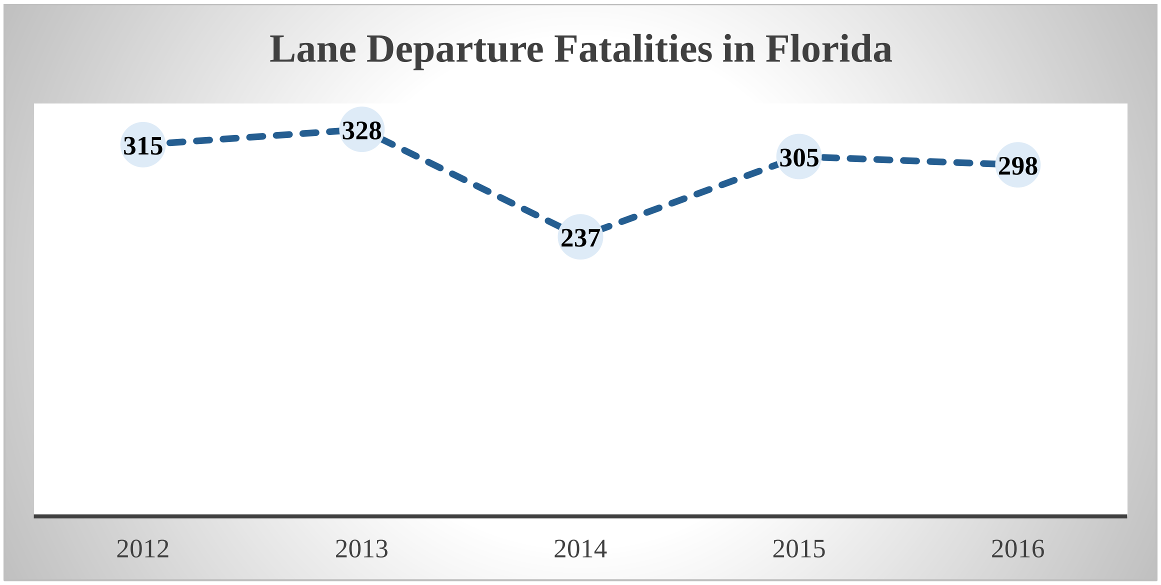
10. **Intersection-Related**
    Definition: Crash that was intersection related.
    - Crash Extract
      - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
      - Intersection related = 2 or 3

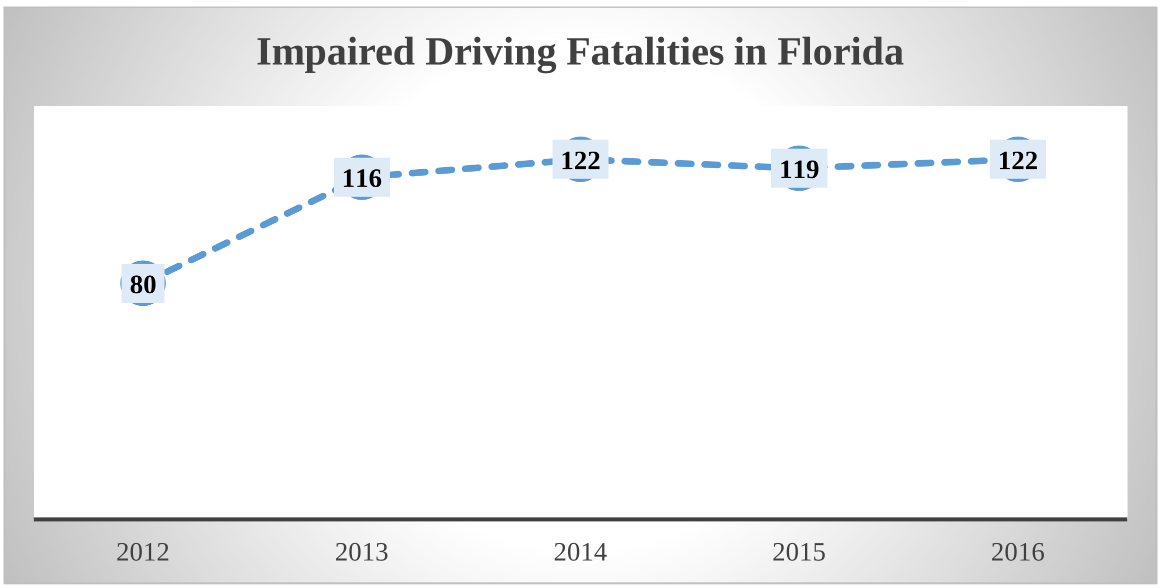
11. **Work Zone Crash**
    Definition: Crash in construction zone, maintenance zone, utility work zone, or work zone–unknown.
    - Crash Extract
      - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)
      - Where Work Zone Related – 2 (yes)

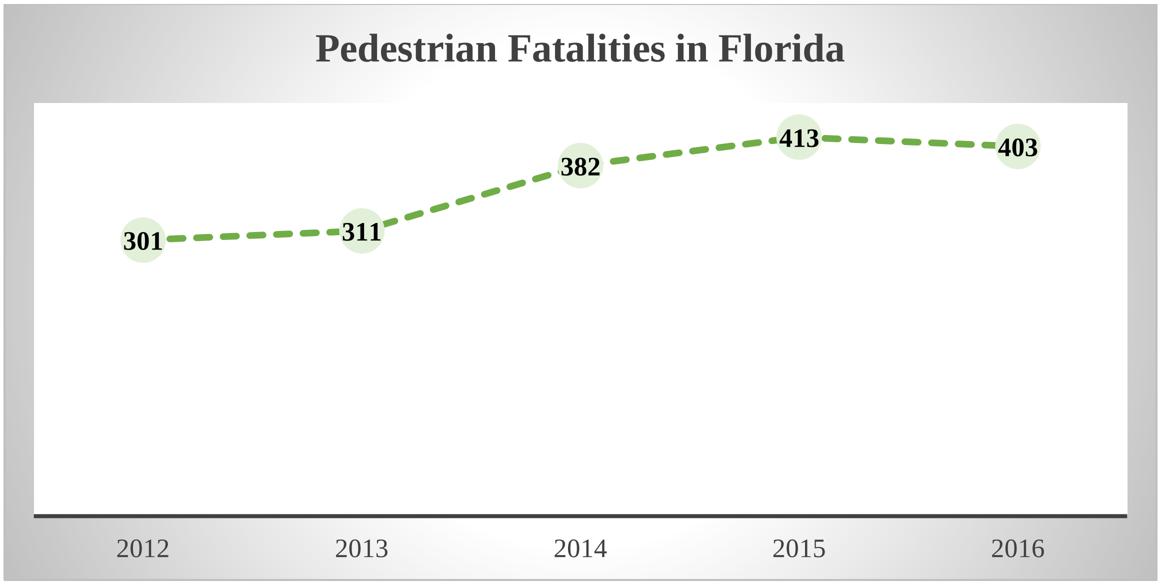
12. **Distracted Driving**

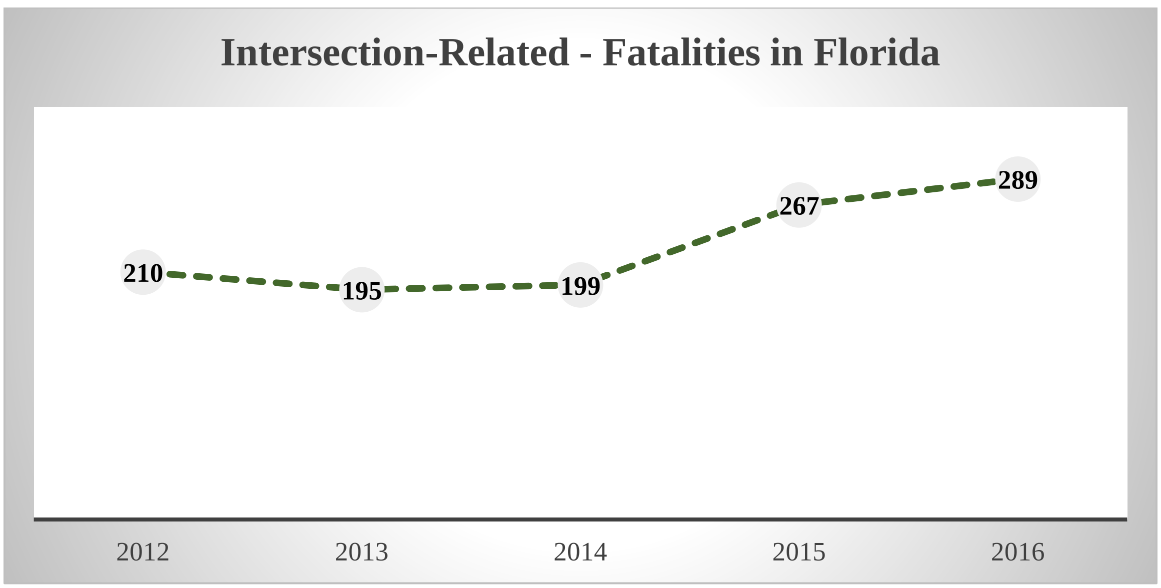
    Definition: Driver distracted by 2 (Electronic Communication Devices), 3 (Other Electronic Devices), 4 (Other Inside Vehicle), 5 (External Distraction), 6 (Texting) or 7 (Inattentive)
    - Crash Extract
      - Injury Severity = 5 (Fatality) or 4 (A-Type Injuries)

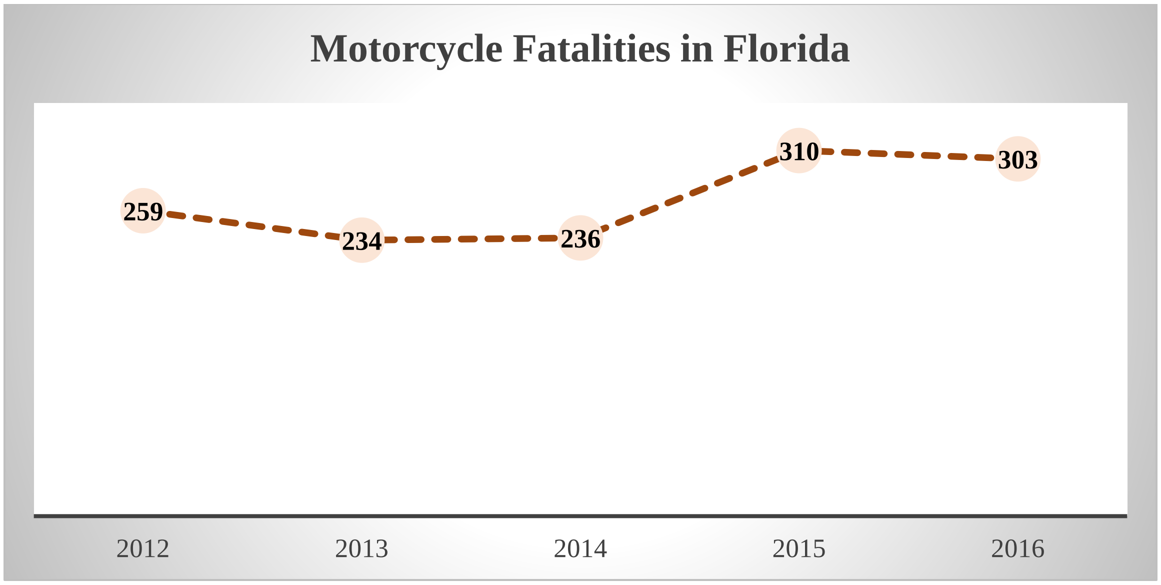
Appendix B: Fatalities and Serious Injuries by Emphasis Area

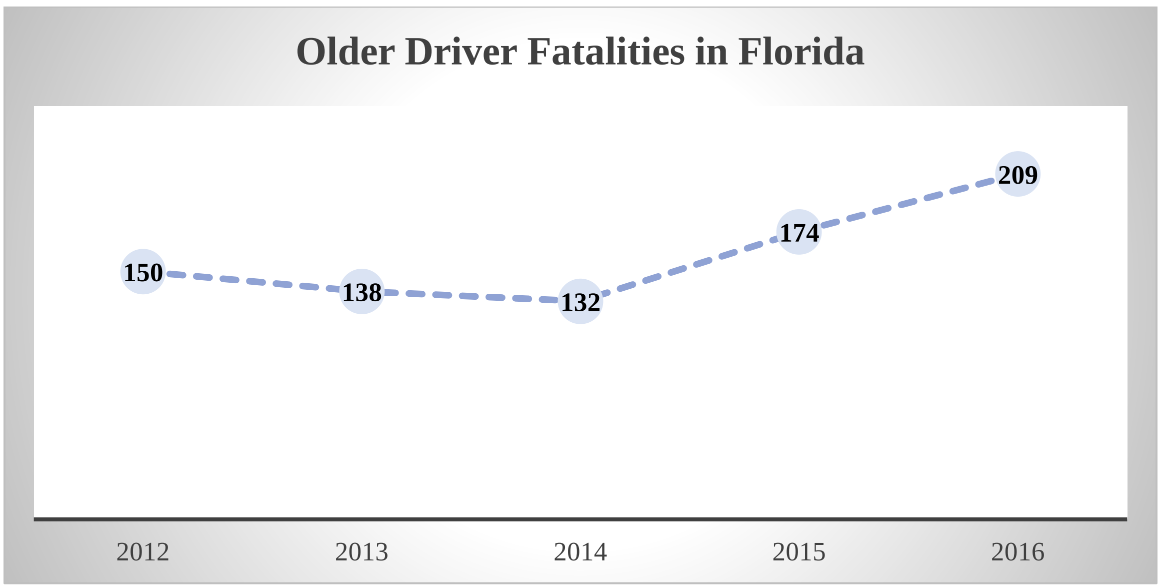


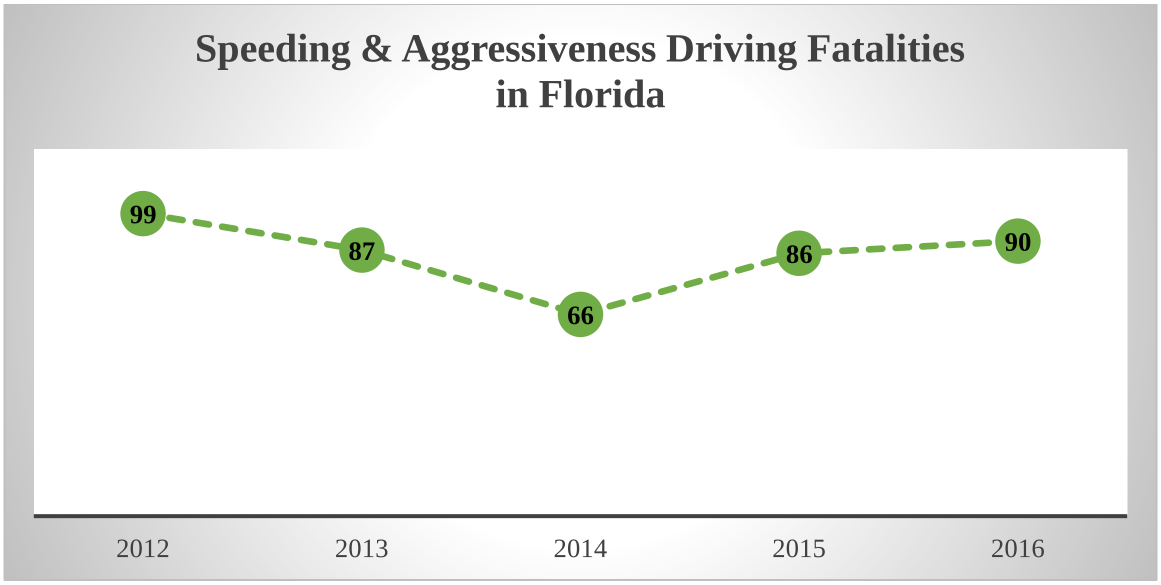


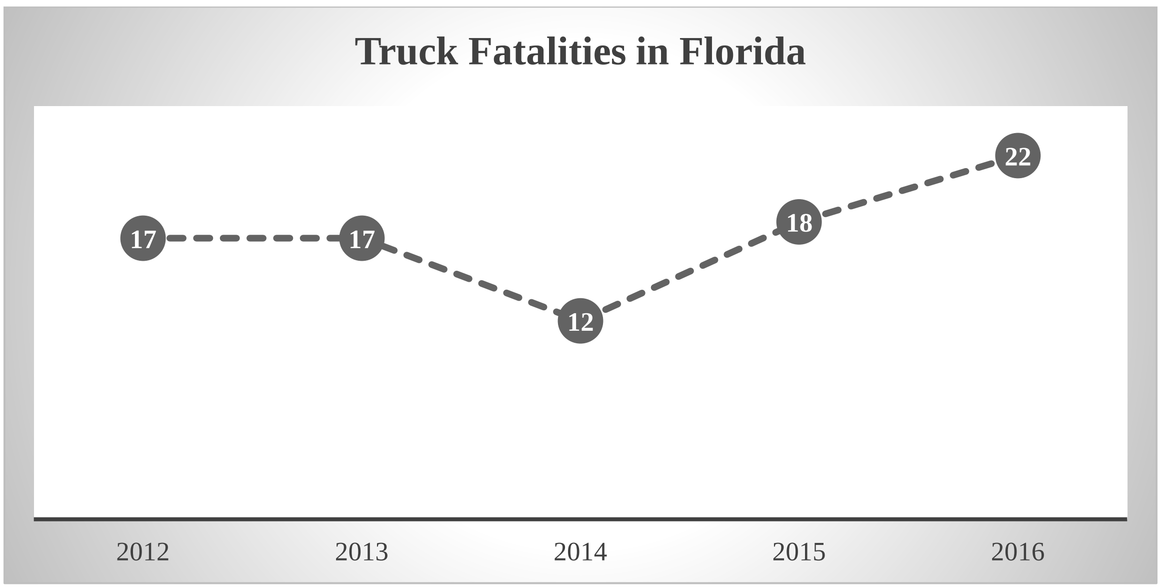

Pedestrian Fatalities in Florida
301
311
382
413
403
2012
2013
2014
2015
2016

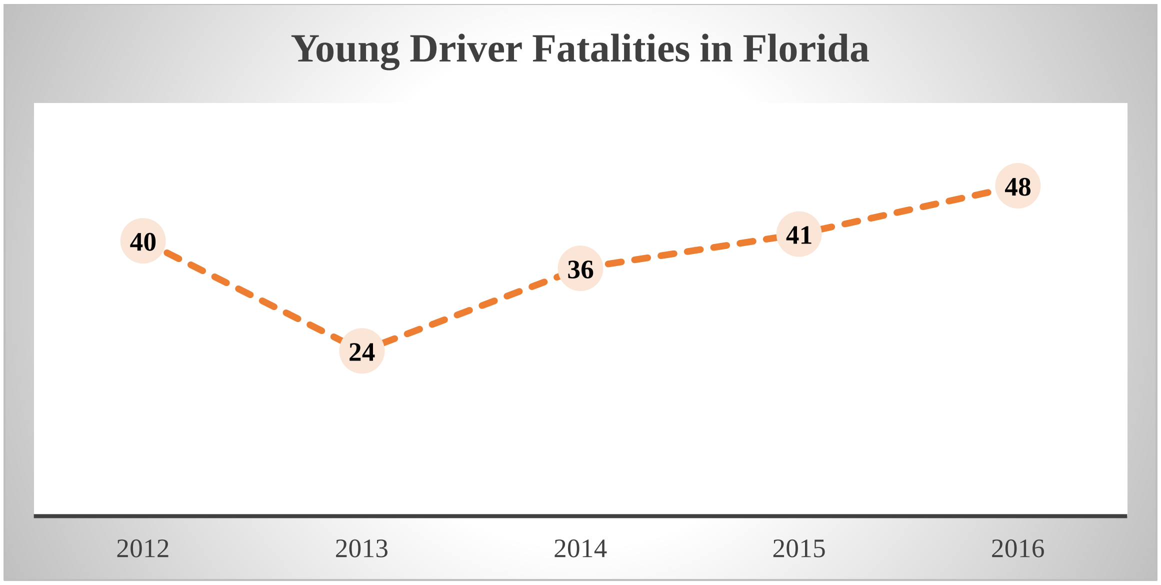

Intersection-Related - Fatalities in Florida
210
195
199
267
289
2012
2013
2014
2015
2016

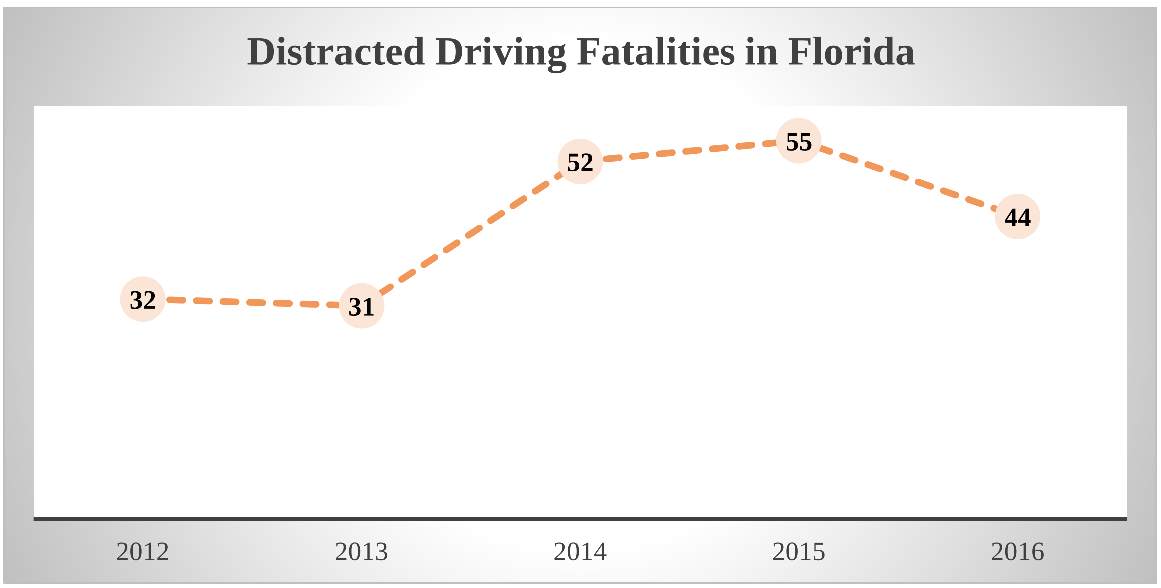

Motorcycle Fatalities in Florida
259
234
236
310
303
2012
2013
2014
2015
2016

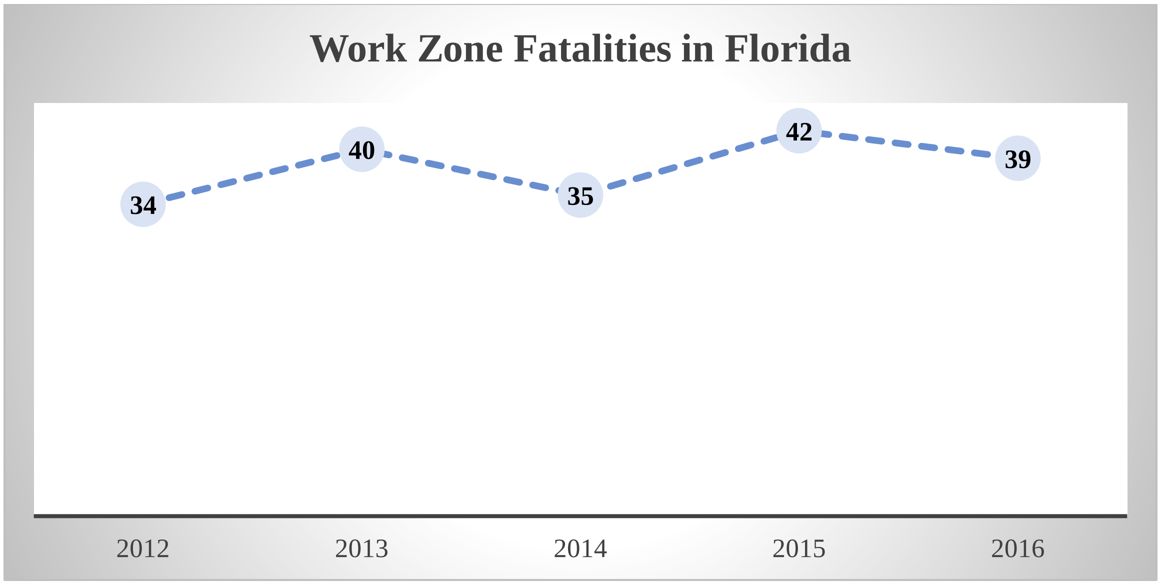

Older Driver Fatalities in Florida
150
138
132
174
209
2012
2013
2014
2015
2016

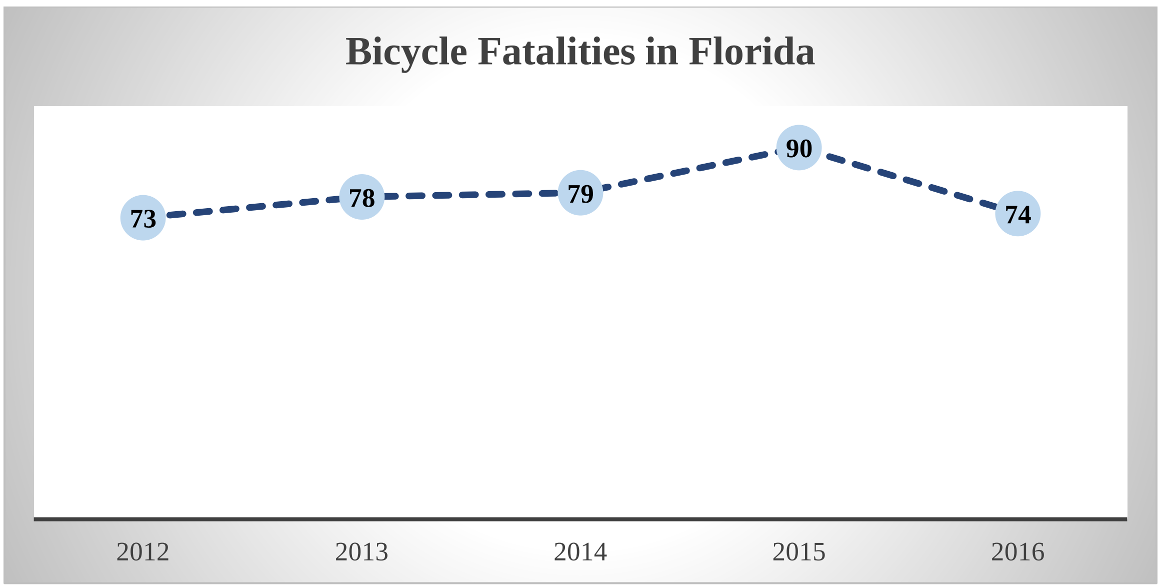

Speeding & Aggressiveness Driving Fatalities in Florida
99
87
66
86
90
2012
2013
2014
2015
2016

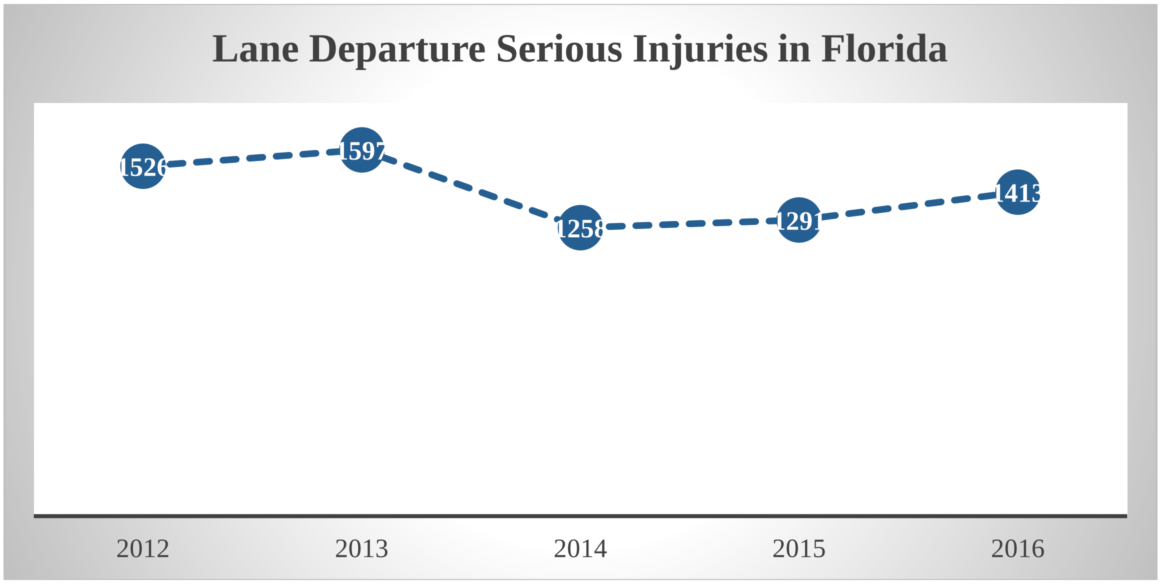

Truck Fatalities in Florida
17
17
12
18
22
2012
2013
2014
2015
2016

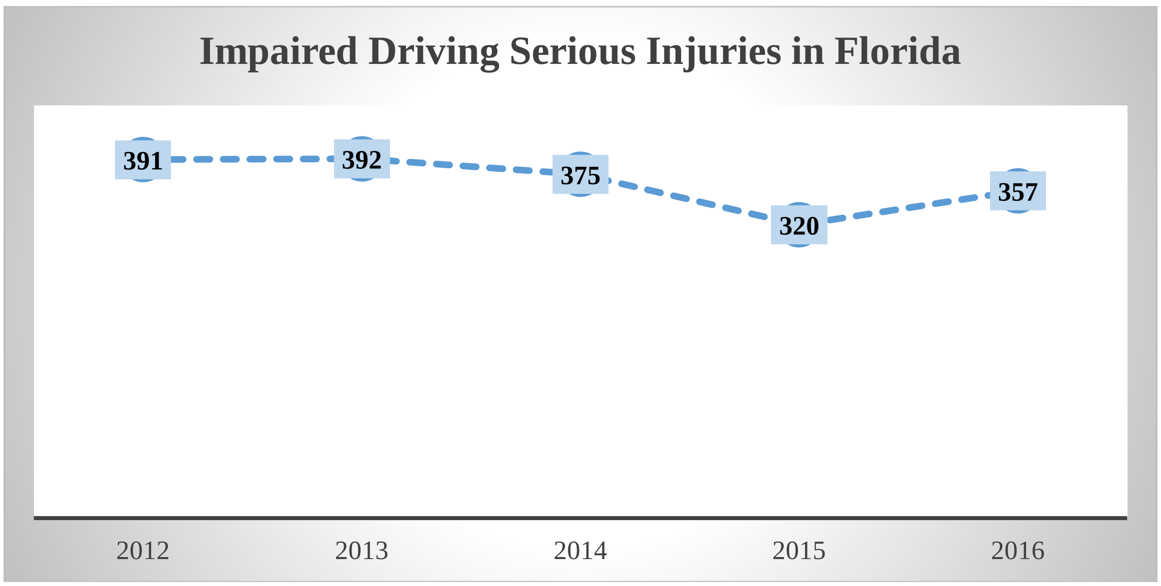

Young Driver Fatalities in Florida
40
24
36
41
48
2012
2013
2014
2015
2016

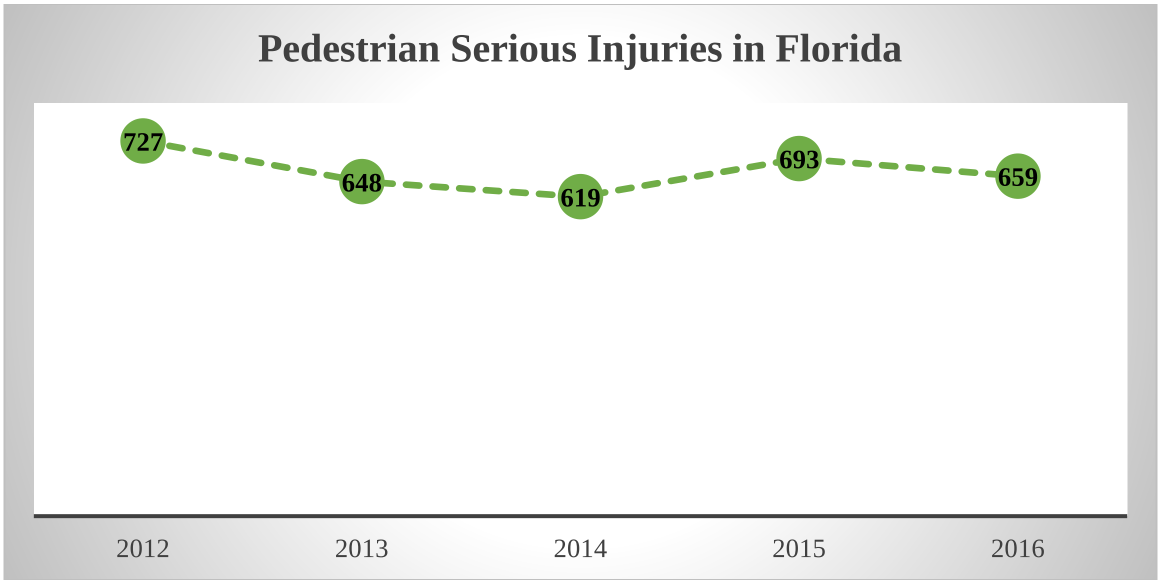

Distracted Driving Fatalities in Florida
32
31
52
55
44
2012
2013
2014
2015
2016

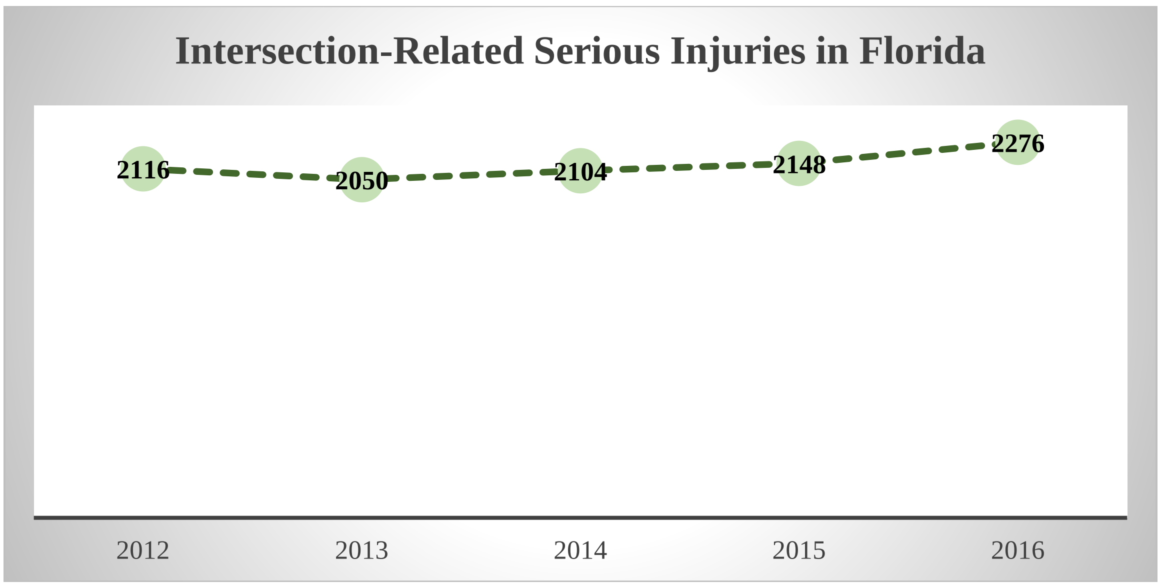

Work Zone Fatalities in Florida
34
40
35
42
39
2012
2013
2014
2015
2016

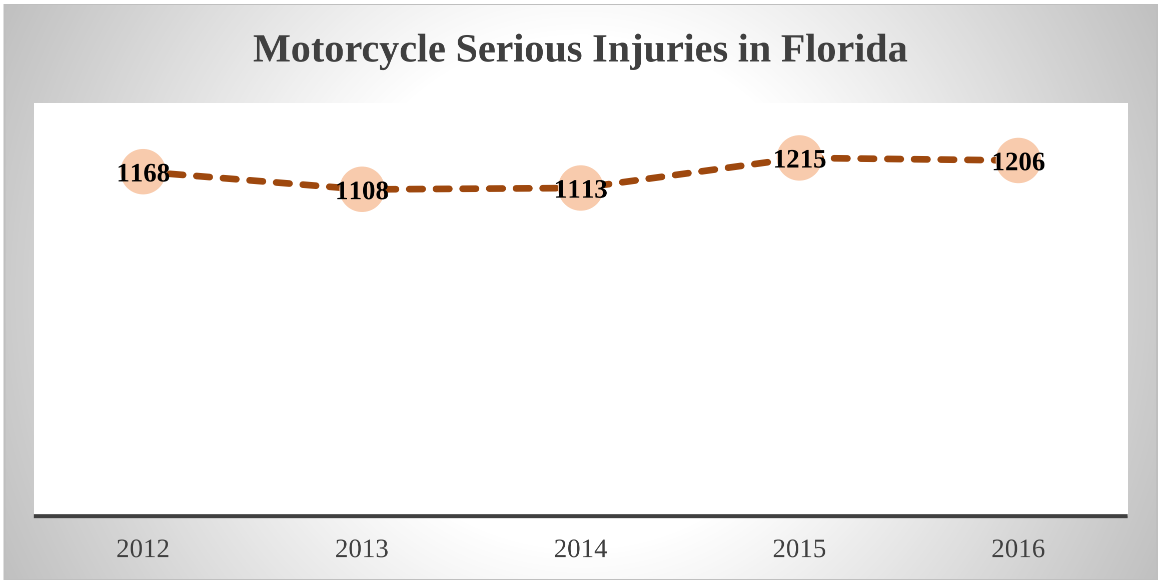

Bicycle Fatalities in Florida
73
78
79
90
74
2012
2013
2014
2015
2016

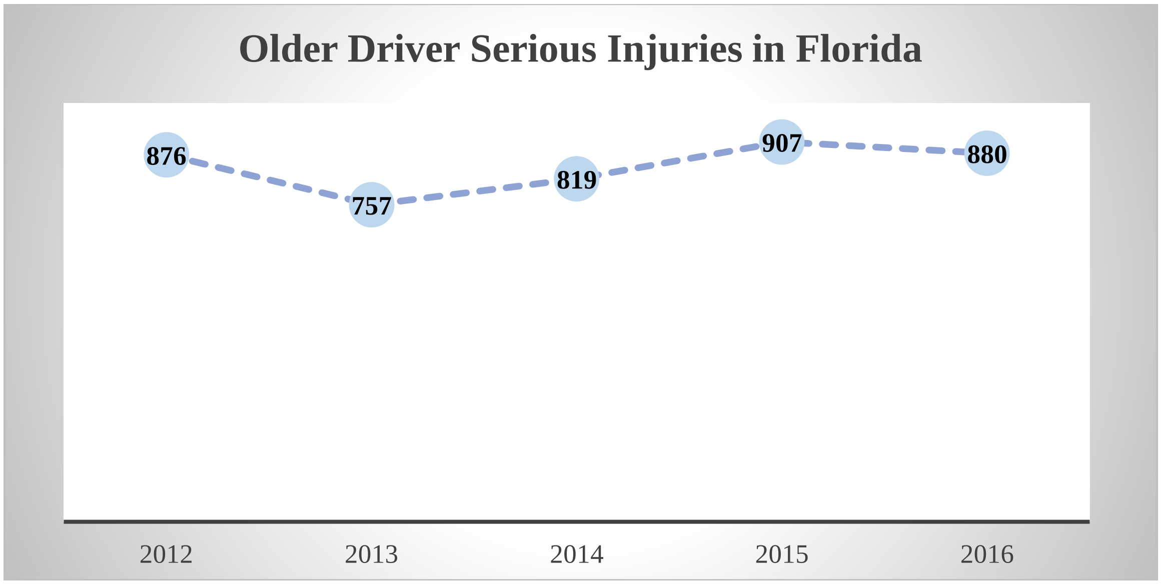

Lane Departure Serious Injuries in Florida
1526
1597
1258
1291
1413
2012
2013
2014
2015
2016

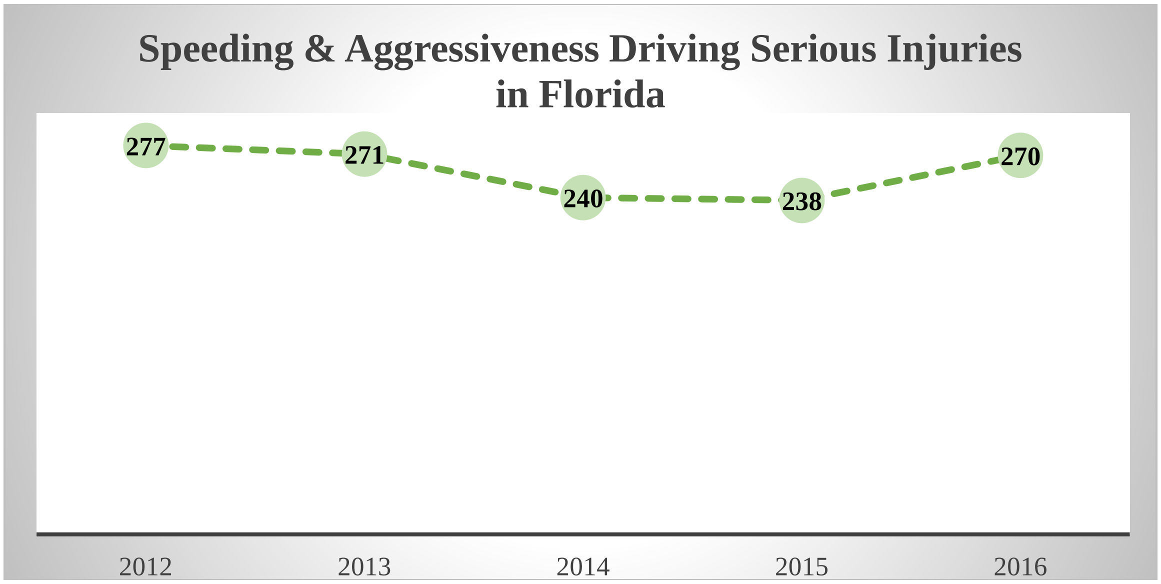

Impaired Driving Serious Injuries in Florida
391
392
375
320
357
2012
2013
2014
2015
2016

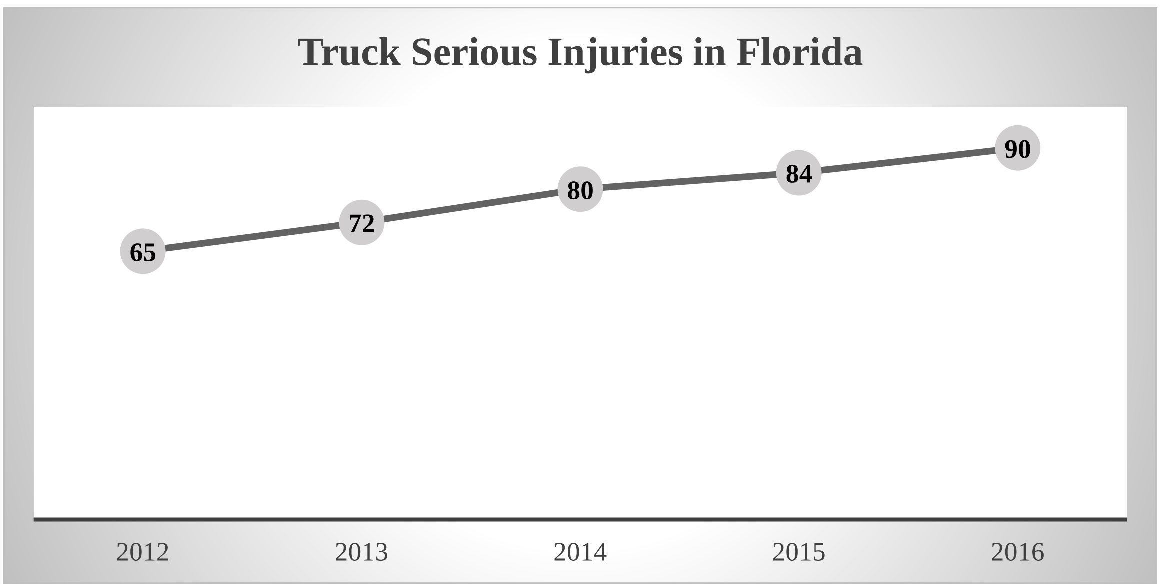

Pedestrian Serious Injuries in Florida
727
648
619
693
659
2012
2013
2014
2015
2016

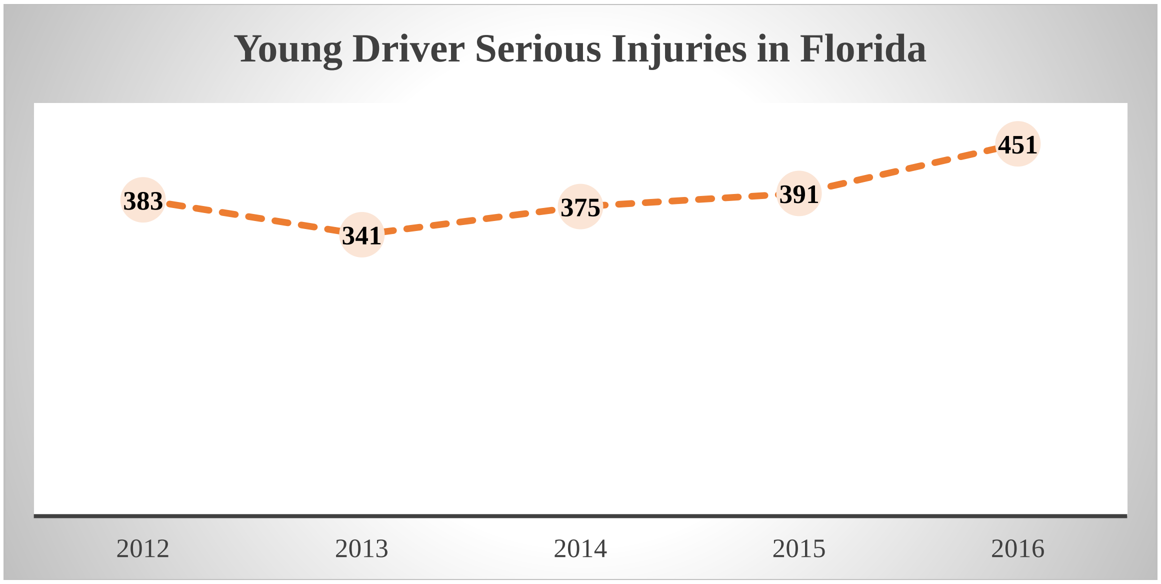

Intersection-Related Serious Injuries in Florida
2116
2050
2104
2148
2276
2012
2013
2014
2015
2016

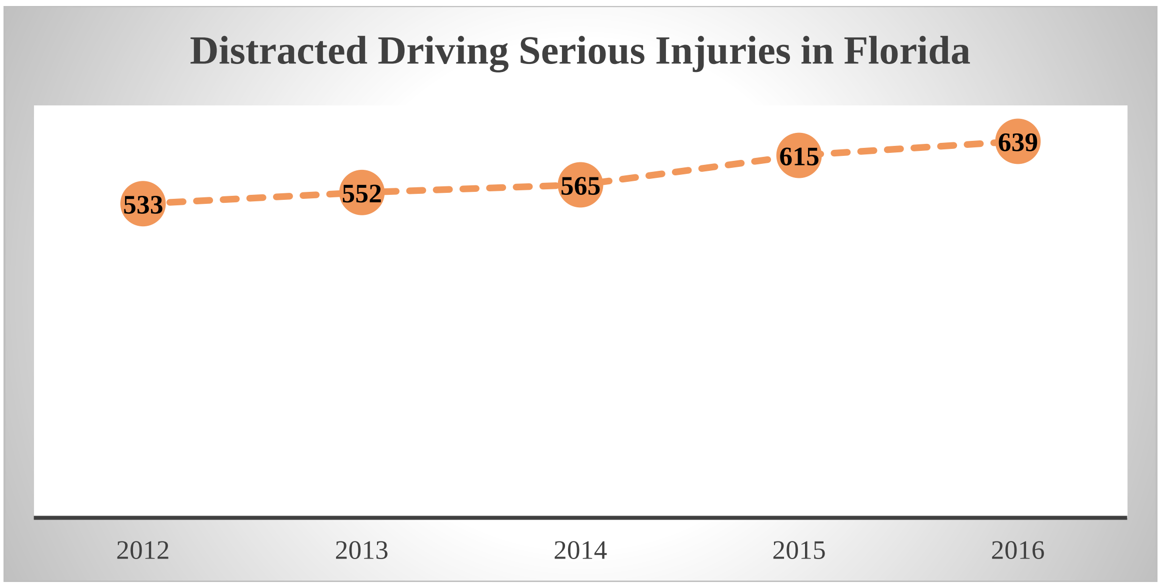

Motorcycle Serious Injuries in Florida
1168
1108
1113
1215
1206
2012
2013
2014
2015
2016

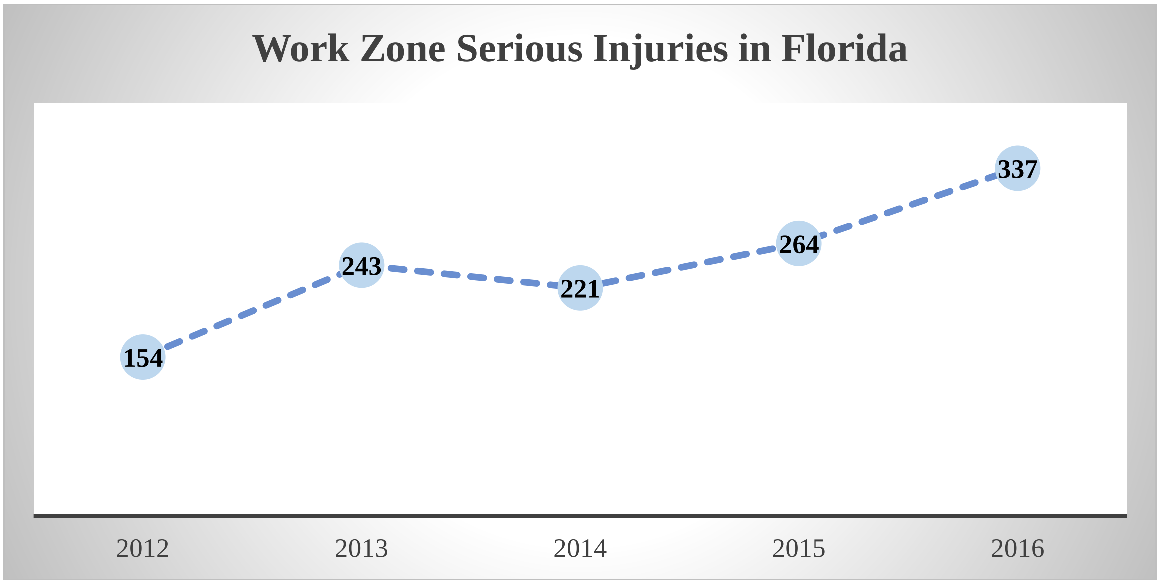

Older Driver Serious Injuries in Florida
876
757
819
907
880
2012
2013
2014
2015
2016

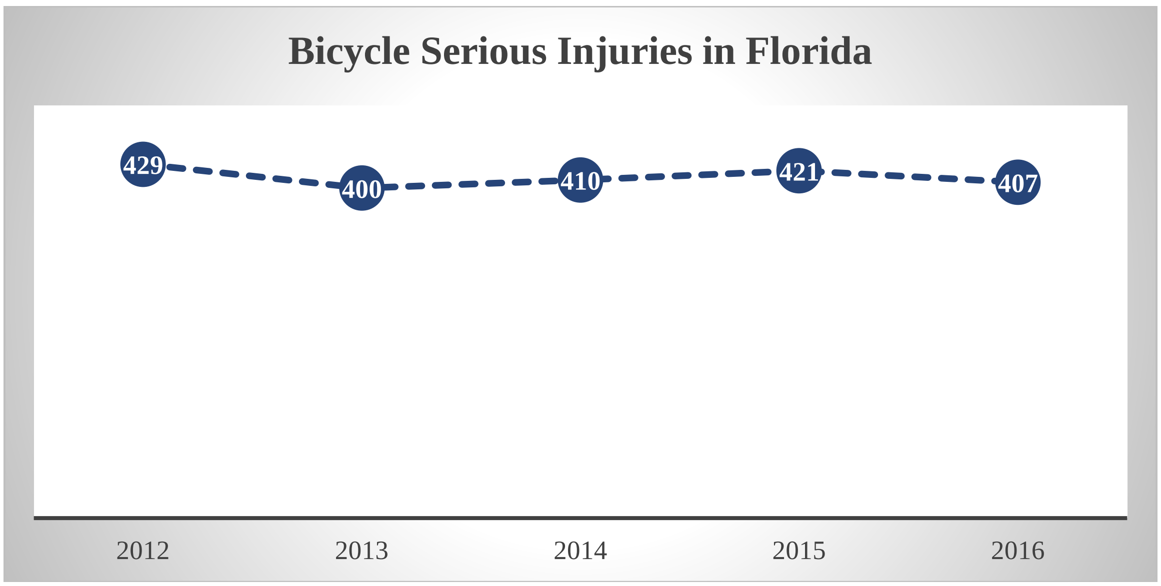

Speeding & Aggressiveness Driving Serious Injuries in Florida
277
271
240
238
270
2012
2013
2014
2015
2016


Truck Serious Injuries in Florida
65
72
80
84
90
2012
2013
2014
2015
2016


Young Driver Serious Injuries in Florida
383
341
375
391
451
2012
2013
2014
2015
2016


Distracted Driving Serious Injuries in Florida
533
552
565
615
639
2012
2013
2014
2015
2016


Work Zone Serious Injuries in Florida
154
243
221
264
337
2012
2013
2014
2015
2016


Bicycle Serious Injuries in Florida
429
400
410
421
407
2012
2013
2014
2015
2016

Appendix C: Crash Types by Emphasis Area

Emphasis Area – Lane Departure

Countermeasure	Crash Type
Install central line rumble strips	Head On, Sideswipe
Install edge line rumble strips	Run-Off-Road
Install cable median barrier	Other
Install high tension cable median barrier	Other
Install W-beam guardrail	Run off Road, Other

Emphasis Area – Speeding & Aggressiveness

Countermeasure	Crash Type
Install fixed-speed cameras	All
Implement automated speed enforcement cameras	All
Install chevron signs on horizontal curves	Non-Intersection
Install combination of chevron signs, curve warning signs, and/or sequential flashing beacons	All
Install variable speed limit signs	All
Install transverse rumble strips as traffic calming device	All

Emphasis Area – Impaired Driving

Countermeasure	Crash Type
Install chevron on horizontal curves	Non-Intersection
Install central line rumble strips	Head On, Sideswipe
Install edge line rumble strips	Run Off Road
Install transverse rumble strips as traffic calming device	All
Implement automated speed enforcement cameras	All
Install combination of chevron signs, curve warning signs, and/or sequential flashing beacons	All

Emphasis Area – Distracted Driving

Countermeasure	Crash Type
Install Central Line Rumble Strips	Head On, Sideswipe
Install Edge Line Rumble Strips	Run Off Road
Install Transverse Rumble Strips as Traffic calming Device	All

Emphasis Area – Work Zone-Related Crashes

Countermeasure	Crash Type
Increase outside shoulder width inside work zone by 1 ft	All
Increase inside shoulder width inside work zone by 1 ft	All
Implement mobile automated speed enforcement system	All
No active with no lane closure	All

Emphasis Area – Signalized Intersection-Related Crashes

Countermeasure	Crash Type
Dynamic signal warning flasher	Angle
Change from permissive-only to flashing yellow arrow protected/permissive left turn	All
Improve signal-control visibility	All
Left-turn phase improvement	All

Emphasis Area – Unsignalized Intersection-Related Crashes

Countermeasure	Crash Type
Install traffic control	All
Install intersection conflict warning system	All
Increase retro reflectivity of stop signing	All
Improve signal-control visibility	All

Emphasis Area – Young Driver

Countermeasure	Crash Type
Install central line rumble strips	Head On, Sideswipe
Install edge line rumble strips	Run-Off-Road
Install cable median barrier	Other
Install cable median barrier–high tensile	Other
Implement automated speed enforcement cameras	All
Implement mobile automated speed enforcement system	All
Install profile thermoplastic pavement markings	All
Upgrade existing marking to wet-reflecting pavement marking	All
Install W beam guardrail	Run Off Road, Other

Emphasis Area – Older Driver

Countermeasure	Crash Type
Implement mobile automated speed enforcement system	All
Install lighting	All
Install profile thermoplastic pavement markings	All
Upgrade existing marking to wet-reflecting pavement marking	All
Install wider marking with resurfacing	All

Emphasis Area – Signalized Pedestrians

Countermeasure	Crash Type
Install pedestrian signals	All
Convert pelican crossing to puffin crossing	All
Install pedestrian hybrid beacon	All

Emphasis Area – Unsignalized Pedestrians

Countermeasure	Crash Type
Install lighting	All
Install raised median with or without marked crosswalk (uncontrolled)	All

Emphasis Area – Motorcycle

Countermeasure	Crash Type
Install lighting	All
Improve pavement friction	All
Install chevron signs on horizontal curves	Non-Intersection
Install new fluorescent curve signs or upgrade existing signs to fluorescent	Non-Intersection
Widen shoulder width	All
Install safety edge treatment	All

Emphasis Area – Truck

Countermeasure	Crash Type
Install central line rumble strip	Head On, Sideswipe
Install edge line rumble strip	Run-Off-Road
Install wider edge line, 4–6 in.	Nighttime, Single Vehicle
Install wider marking, both edge line and center line rumble strips with resurfacing	All
Install in-lane curve warning, pavement markings	All

Emphasis Area – Bicycle

Countermeasure	Crash Type
Increase bike lane width	Multi vehicle
Increase median width	Vehicle/Bicycle
Widen shoulder width	All
Median treatment for pedestrian/bicycle safety	All
Install bicycle boulevard	Vehicle/Bicycle

Appendix D: User Guidance

Introduction

The Hi-ImPct Strategic Investment Decision Making on Highway Improvement project tool is designed to provide methods for preparing a simple economic analysis of infrastructure projects. This tool helps users quantify projects costs and direct safety-related benefits of project alternatives such as avoided crash losses in the first year, present value of avoided crash losses for chosen service life, etc.

Overview of Hi-ImPct Tool

Table D-1 Tool Worksheet Summary

Worksheet	Description
Home Page	Provides navigation menu and contact information.
Project Information	Provides space to enter project-related data and support documentation of contracts.
Crash Data	Summarizes number of fatal and serious injury crashes and mileage or number of intersections after crash assignments.
Countermeasures	Provides wide list of countermeasures and their cost and crash types.
Methodological Approach	Provides calculation methods to calculate and visualize annual reduction in fatal and serious injury crashes.
Crash Benefits	Provides benefit-cost ratios for wide range of countermeasures for each Emphasis Area and facility type or functional class.
Output Visualizations	Provides visual representation of benefit-cost ratios in form of bar charts.

Instructions

Cell Color Codes 1

Cells are color-coded to assist analysts in the data entry and calculation processes. Table D-2 summarizes the color codes.

Table D-2 Cell Color Codes 1

Cell Type	Color Coding	Description
Analyst-supplied Data		Allows data input from analyst.
Model Default		Contains values assumed by model. No input required.
Model Calculation		Contains model-calculated parameters. No user input required.

Cell Color Codes 2

Table D-3 shows the "Crash Benefit" tab color coding for the last column, "Range of Benefit-Cost Ratio."

Table D-3 Cell Color Codes 2

Color Coding	Description
	Benefit-Cost Ratio – 1 ~ 5
	Benefit-Cost Ratio – 6 ~ 10
	Benefit-Cost Ratio – 11 ~ 15
	Benefit-Cost Ratio – 16 ~ 20
	Benefit-Cost Ratio – 21 ~ 25
	Benefit-Cost Ratio – 26 ~ 30

Project Information

Users begin the data entry process by entering the following basic project information, which is used to identify the analysis presented on the Results worksheet:

- **Agency** – name of transportation agency conducting benefit-cost analysis
- **Project Title** – title of project
- **Date** – date of analysis
- **Analyst –** name of analyst conducting benefit-cost analysis.
- **Build Alternative Name –** name of build alternative analyzed in benefit-cost analysis
- **Analysis Period (years) –** length of analysis period in years.
- **Length of Construction Period (years)** – expected duration of construction in years.
- **Total Period** – calculated total of analysis period + construction period
- **Annual Discount Rate (Percent) –** discount rate used to calculate benefits and costs over analysis period; default is 4%

Crash Data

The Strategic Highway Safety Benefit Cost Analysis Tool contains information about important Emphasis Areas studied during development of the tool. Each Emphasis Area contains information about functional classes or facility types and number of fatal and serious injury crashes observed under that functional class or facility type. As shown in Table D-4, all the Emphasis Areas are divided into two categories—those related to intersections and those related to roadways. All functional classes or facility types are combined to get the total count of crashes from rural and urban areas. Figure D-2 shows an example of an Emphasis Area containing information about crashes and number of miles for both fatal and serious injury crashes. The information has been summarized from crash data 2012–2016. The last column shows the total number of miles for fatal and serious injury crashes combined and can be found under the sheet "Project Crash Data." Values highlighted in blue are treated as model default values when calculating model parameters such as crash density, avoided crash losses, net present value, benefit-cost ratio, etc.

PROJECT INFORMATION

Agency:		
Project Title:		
Date:		
Analyst:		
Build Alternative Name		
Analysis Period (Years)		
Length of Construction Period (Years)		
Total Period		(Analysis Period Years Plus Construction Period Years)
Annual Discount Rate (Percent)	4	

Figure D-1 Project Information Input

1. Lane Departure

Principal Arterial - Interstate (Rural and Urban)	381	2011	2402	10770	13172
Principal Arterial - Expressway (Rural and Urban)	90	565	605	5136	5741
Principal Arterial - Other (Rural and Urban)	554	2557	699	2856	3555
Minor Arterial (Rural and Urban)	233	1003	401	1459	1860
Major Collector (Rural and Urban)	48	245	81	289	370
Minor Collector (Rural and Urban)	6	36	7	28	35

Figure D-2 Crash Data – Model Defaults

Table D-4 Functional Classes for Each Emphasis Area

No.	Type of Emphasis Area	Name of Emphasis Area	Functional Class/Facility Type (Rural and Urban)
1	Roadway-related	Lane Departure	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector VI. Minor Collector
2	Intersection-related	Intersection-related – Signalized	I. 4-Leg Signalized Intersection II. 3-Leg Signalized Intersection
		Intersection-related – Unsignalized	I. 4-Leg Stop/Yield/warning/flashing II. 3-Leg Stop/Yield/warning/flashing
3	Roadway-related	Speed & Aggressiveness	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector VI. Local

No.	Type of Emphasis Area	Name of Emphasis Area	Functional Class/Facility Type (Rural and Urban)
4	Roadway-related	Impaired Driving	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector
5	Roadway-related	Distracted Driving	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector
6	Roadway-related	Work Zone-related Crashes	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector
7	Roadway related	Young Driver	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector
8	Roadway-related	Older Driver	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector VI. Minor Collector VII. Local
9	Intersection-related	Pedestrian – Signalized	I. 4-leg Signalized Intersection II. 3-leg Signalized Intersection
		Pedestrian – Unsignalized	I. 4-Leg Stop/Yield/warning/flashing II. 3-Leg Stop/Yield/warning/flashing
10	Roadway-related	Bicycle	I. Principal Arterial – Other II. Minor Arterial III. Major Collector IV. Minor Collector V. Local
11	Roadway-related	Motorcycle	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial V. Major Collector VI. Minor Collector VII. Local
12	Roadway-related	Truck	I. Principal Arterial – Interstate II. Principal Arterial – Expressway III. Principal Arterial – Other IV. Minor Arterial

Countermeasures

Each Emphasis Area studied during the development of this tool has associated countermeasures that will help design engineers choose an appropriate strategy. Figure D-3 shows information about the five countermeasures (displayed in light blue) that are treated as model defaults for the Emphasis Area Lane Departure.

CMF ID	Countermeasures	CMF Value	Crash Type	Crash Severity	Star Rating	Cost per mile/intersection	Cost of Allowances and Contingencies
							(Project Support + Right-of-way + Construction + Maintenance / Operation + Rehabilitation + Mitigation)
Lane Departure							
3360	Install Central Line Rumble Strips	0.55	Head On, Sideswipe	K (Fatal), A(Serious Injury), B(Minor Injury), C(Possible Injury)	5	$ 10,800.00	$ 10,800.00
3394	Install Edge Line Rumble Strips	0.67	Run Off Road	K (Fatal), A(Serious Injury), B(Minor Injury), C(Possible Injury)	4	$ 6,000.00	$ 6,000.00
6127	Install Cable Median Barrier	0.59	Other	K (Fatal), A(Serious Injury)	3	$ 8,000.00	$ 8,000.00
8215	Install High Tension Cable Median Barrier	0.76	Other	K (Fatal), A(Serious Injury)	3	$ 8,000.00	$ 8,000.00
8402	Install W-Beam Guardrail	0.65	Run Off Road, Other	K (Fatal), A(Serious Injury)	3	$ 6,700.00	$ 6,700.00
							$ -
							$ -
							$ -
							$ -
							$ -

Figure D-3 Countermeasures – Model Defaults and User Inputs

These countermeasures are derived from the CMF Clearinghouse website, and all have been closely studied and observed in the U.S. and Canada. These countermeasures have been used widely and possess a Star rating of 3 and above out of 5.

This tool has made provisions for design or transport engineers to add countermeasures under each Emphasis Area. These new countermeasures can be added in the space provided (in green) below the model default countermeasures. The added new countermeasures can be selected while observing the crash benefits under the sheet "Crash Benefit."

All countermeasures mentioned in Figure D-3 come with a CMF used to calculate reduction in crashes and other important model parameters such as avoided crash losses in the first year of the combined crash (KA).

Every countermeasure described in the Strategic Highway Safety Benefit Cost Analysis tool has an implementation cost associated with it, which can be found under "Cost per Mile/Intersection." These countermeasures also have an associated contingencies and allowances cost, which includes all costs such as project support, right-of-way, construction, maintenance or operation, rehabilitation, and mitigation. The costs have been derived mainly from the California Department of Transportation, Minnesota Department of Transportation, Illinois Department of Transportation, and Florida Department of Transportation.

Methodological Approach

The "Methodological Approach" sheet calculates annual reductions in crash frequency and severity for single and multiple countermeasures. Figure D-4 shows drop downs for every cell in green; users are encouraged to select the appropriate Emphasis Area and functional class from the available choices. The tool provides choices for single and multiple countermeasure strategies. If multiple countermeasure strategies are selected, the user selects an appropriate method for calculation from all available methods in the drop-down menu.

I) Emphasis Area	Motorcycle
II) Functional Class / Facility Type	Principal Arterial - Interstate (Rural and Urban)
III) Single or Multiple Countermeasure	Multiple Countermeasures
IV) Calculation Method	Dominant Effect
V) Countermeasure 1	Install Lightings
VI) Countermeasure 2	Improve Pavement Friction

All Drop Down

Figure D-4 Annual Reduction in Crashes – User Inputs

Users are also encouraged to add countermeasures under any Emphasis Area in the sheet "Countermeasures" and to observe annual reductions in crash severity and frequency either in tabular format or using the bar charts displayed in "Project Crash Data." Calculation methods are available only for multiple countermeasures. Users can also visualize annual reduction in crashes when using different available calculation methods.

Crash Benefits

This sheet calculates model output parameters such as crash density, avoided crash losses, benefit-cost ratio, etc. The sheet allows analysts to review the default model parameters such as number of fatal crashes, number of serious injury crashes, and total number of miles or intersections for fatal and serious injury crashes. It also encourages users to adjust the parameters used to calculate crash benefits such as traffic growth rate, number of miles or intersections selected to deploy the treatment or strategy, service life of countermeasures, etc. Figure D-5 shows information from the "Crash Benefits" sheet with information about selecting an Emphasis Area from the given list in the drop down menu.

Drop Down Here

Drop Down Here

Emphasis Area	Functional Class/ Facility Type
Young Driver	
Install Central Line Rumble Strips	Principal Arterial - Interstate (Rural and Urban)
	Principal Arterial - Expressway (Rural and Urban)
	Principal Arterial - Other (Rural and Urban)
	Minor Arterial (Rural and Urban)
	Major Collector (Rural and Urban)
	Not Found
	Not Found

Figure D-5 Choice of Emphasis Area and Functional Class/Facility Type

When the user selects an appropriate Emphasis Area (in this case, Young Driver), all functional classes or facility types associated with that Emphasis Area are displayed in the next column.

Emphasis Area	Functional Class/ Facility Type	Fatal Crash K (No)	Serious Injury Crash A (No)	Mileage / No of Intersections for Fatal Crashes	Mileage / No of Intersections for Serious Crashes	Years of Crash Data	Total Mileage
Distracted Driving							
Install Edge Line Rumble Strips	rincipal Arterial - Interstate (Rural and Urban)	51	488	312	2563	5	2875
	Principal Arterial - Expressway (Rural and Urban)	17	167	128	1885	5	2013
	Principal Arterial - Other (Rural and Urban)	94	1402	107	1127	5	1234
	Minor Arterial (Rural and Urban)	29	525	33	486	5	519
	Major Collector (Rural and Urban)	10	171	9	113	5	122
	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found

Figure D-6 Crash Data for Every Emphasis Area and Functional Class

After selection of an Emphasis Area, all model default values such as number of fatal and serious injury crashes, mileage or number of intersections for fatal and serious injury crashes, number of years of crash data, and total mileage for fatal and serious injury crashes combined are updated in the displayed cells. These numbers are further used to calculate the model parameters.

The second drop down described is provided to select a countermeasure associated with an already-selected Emphasis Area. Note that crash benefits will not be updated as long as selection of an appropriate countermeasure is not done.

Deployment Mileage for Improvement

Analysts can input any number of miles for deployment of a selected countermeasure. Deployment mileage is used to calculate avoided crash losses in first year (KA) combined.

Crash Density

Crash density is a model output parameter, calculated using Eq. (1):

$$\mathit{Crash\ Density\ KA} = \frac{\mathit{Fatal\ Crash\ No} + \mathit{Serious\ Injury\ Crash\ No}}{\mathit{Total\ Miles\ or\ No\ of\ Intersections\ for\ Fatal\ and\ Serious\ Injury\ Crashes} \times \mathit{No\ of\ years\ of\ Crash\ Data}} \quad (1)$$

Service Life in Years

This field is provided to control a period of use in service for the selected countermeasure. Typically, these are values or range of values indicated by a state source. This model assumes 10 years as the default value for calculation of crash benefit parameters, but analysts may input different values to identify changes in crash benefits.

Traffic Growth Rate

This field is provided to input traffic growth rate in future. Users may input rates and review crash benefits. This model assumes a default value of traffic growth rate as 0; although the model assumes specific default values for the fields described in green, they require user inputs to calculate crash benefits.

Total Mileage	Deployment Mileage for Improvement	Crash Density (KA)	CMF	Service Life in years (Treatment Cost)	Traffic Growth Rate (Road System Data)
2875	50	0.04	0.67	10	0
2013	50	0.02	0.67	10	0
1234	50	0.24	0.67	10	0
519	50	0.21	0.67	10	0
122	50	0.30	0.67	10	0
Not Found	50	Not Found	Not Found	10	0
Not Found	50	Not Found	Not Found	10	0

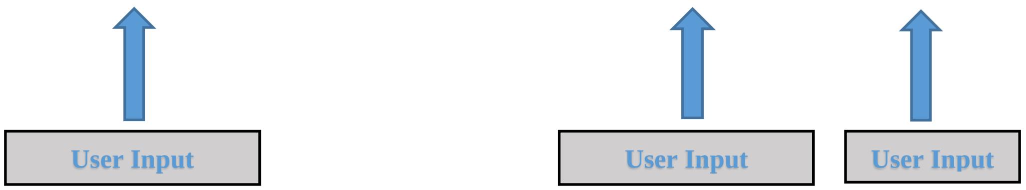


Figure D-7 User inputs for Benefit-Cost Analysis

Avoided Crash Losses in First Year (KA) Combined

This is a model output parameter, calculated using Eq. (2):

$$\text{Avoided Crash losses in First Year KA} = \frac{\text{Fatal Crash No} + \text{Serious Injury Crash No}}{\text{Total Miles or Intersections for Fatal and Serious Injury Crashes}} \times \frac{(\text{Deployment Mileage for Improvement})}{\text{No of Years of Crash Data}} \times (1 - CMF) \times (\text{Comprehensive Crash Unit Cost for Combined K \& A Crashes}) \tag{2}$$

Present Value of Avoided Crash Losses for Service Life

$$\text{Present Value of Avoided Crash Losses for Service Life} = (\text{Avoided Crash Losses in First year} \times ((\text{Annual Discount Rate} - \text{Traffic Growth Rate})^{-1}) \times (1 - \left(\frac{1 + \text{Traffic Growth Rate}}{1 + \text{Annual Discount Rate}}\right)^{\text{Service Life in Years}} \tag{3}$$

This is also a model output parameter, calculated using Eq. (4).

Total Initial Cost per Mile or Intersection

This parameter is calculated using Eq. (4). It may change based on the unit cost value supplied by the user.

$$\begin{gathered}Total\ Initial\ Cost\ per\ Mile\ or\ per\ Intersection = \\ Cost\ of\ Implementation\ per\ Mile\ or\ per\ Intersection \\ +\ Allowances\ and\ Contingencies\ Cost\ per\ Mile\ or\ per\ Intersection\end{gathered} \tag{4}$$

Annual Cost per Mile or Intersection

This parameter is calculated using Eq. (5). It may also change based on the unit cost value supplied by the user.

$$\begin{aligned}&Annual\ Cost\ per\ Mile\ or\ per\ Intersection \\ &\quad = Cost\ of\ Implementation\ per\ Mile\ or\ per\ Intersection\end{aligned} \tag{5}$$

Initial Cost

This is model output parameter and it is calculated using following formula. It will change according to the value supplied by the user in field – Amount Deployed.

$$\begin{aligned}&Initial\ Cost = Total\ Initial\ Cost\ Per\ Unit \\ &\quad \times Number\ of\ Miles\ or\ Intersections\ considered\ for\ Deployment\end{aligned} \tag{6}$$

Present Value of Annual Costs

This is also a model output parameter, calculated using following formula. It will change according to the value supplied by the user in field “Amount Deployed.”

$$\begin{aligned}&Present\ Value\ of\ Annual\ Costs \\ &= \frac{\begin{gathered}Number\ of\ Miles\ or\ Intersections\ Considered\ for\ Deployment \times Annual\ Cost\ per\ Unit\ \times \\ (1 - ((1 + Annual\ Discount\ Rate)^{-Service\ Life\ in\ Years})\end{gathered}}{Annual\ Discount\ Rate}\end{aligned} \tag{7}$$

Present Value of All Costs

This is also a model calculated parameter and will change with changes in the input parameters such as amount deployed and annual discount rate. It is calculated using Eq. (8).

$$\begin{aligned}&Present\ Value\ of\ all\ Costs \\ &\quad = Initial\ Cost + Present\ Value\ of\ Annual\ Costs\end{aligned} \tag{8}$$

Net Present Value

This is also a model output parameter, calculated using Eq. (9). It will change with changes in annual discount rate, traffic growth rate, and amount deployed for treatment or implementation of countermeasures.

$$Net\ Present\ Value = Present\ Value\ of\ Avoided\ Crash\ Losses\ for\ Service\ Life - Present\ Value\ of\ all\ Costs \quad (9)$$

Benefit-Cost Ratio

This is model output parameter and it is calculated using following formula. It will also change with changes in annual discount rate, traffic growth rate and amount deployed for treatment or implementation of countermeasures.

$$Benefit\ Cost\ Ratio = \frac{Present\ Value\ of\ Avoided\ Crash\ Losses\ for\ Service\ Life}{Present\ Value\ of\ All\ Costs} \quad (10)$$

Output Visualizations

Users can see visual representation of benefit-cost analysis in the form of bar charts.

Future Flexibility

The Strategic Investment Decision Making on Highway Improvement project tool allows users to add countermeasures of their choice in the tab "Countermeasure." Blue cells of the tab "Countermeasure" are locked; users are allowed to put values only in green cells (unlocked). As soon as users insert a new countermeasure under any Emphasis Area, provisions are made such that the added new countermeasure can be observed under the drop-down list of that Emphasis Area.

The tab "Crash Benefit" provides 12 blocks for different choices of countermeasures and, hence, the benefit-cost ratio. The Emphasis Areas "Young Driver" has 9 countermeasures, and users can add more countermeasures.

Appendix E: Quality Control Plan

1. QC on Frequency of Fatal and Serious Injury Crashes for each Emphasis Area.

$$\sum_{Year\ (i)}^{EA\ (j)} Fatal\ Crashes\ (K) = \sum_{Year\ (i)\ FC\ (K)}^{EA\ (j)} Fatal\ Crashes\ (K) \qquad \text{Eq 1}$$

$$\sum_{Year\ (i)}^{EA\ (j)} Serious\ Injury\ Crashes\ (A) = \sum_{Year\ (i)\ FC\ (K)}^{EA\ (j)} Serious\ Injury\ Crashes\ (A) \qquad \text{Eq 2}$$

where,
Year (i) = 2012, 2013, 2014, 2015, 2016

EA (j) = List of all the Emphasis Areas: Lane Departure, Young Driver, Old Driver, Intersection Related (Signalized and Un-signalized), Pedestrians (Signalized and Un-signalized), Bike, Motorcycle, Speed and Aggressiveness, Distracted Driving, Work Zone Related, Impaired Driving, Heavy Vehicle (Truck)

FC (k) = List of all the Functional Classes/Facility type (All Rural & Urban) = Principal Arterial – Interstate, Principal Arterial (Expressway), Principal Arterial (Other), Minor Arterial, Major Collector, Minor Collector, Local

2. QC on Mileage of Fatal and Serious Injury Crashes for each Emphasis Area.

$$\sum_{Year\ (i)}^{EA\ (j)} Fatal\ Crashes\ Mileage\ (K) = \sum_{Year\ (i)\ FC\ (K)}^{EA\ (j)} Fatal\ Crashes\ Mileage\ (K) \qquad \text{Eq 3}$$

$$\sum_{Year\ (i)}^{EA\ (j)} Serious\ Injury\ Crashes\ Mileage\ (A) = \sum_{Year\ (i)\ FC\ (K)}^{EA\ (j)} Serious\ Injury\ Crashes\ Mileage(A) \qquad \text{Eq 4}$$

Where,
Year (i) = 2012, 2013, 2014, 2015, 2016

EA (j) = List of all the Emphasis Areas: Lane Departure, Young Driver, Old Driver, Intersection Related (Signalized and Un-signalized), Pedestrians (Signalized and Un-signalized), Bike, Motorcycle, Speed and Aggressiveness, Distracted Driving, Work Zone Related, Impaired Driving, Heavy Vehicle (Truck)

FC (k) = List of all the Functional Classes/Facility type (All Rural & Urban) = Principal Arterial – Interstate, Principal Arterial (Expressway), Principal Arterial (Other), Minor Arterial, Major Collector, Minor Collector, Local

3. Intersection Related and Pedestrian Crashes (Signalized and Un-signalized)

Quality checks were performed on the total number of intersections in Florida State through careful evaluation of each intersection with the help of Google Earth.

For the analysis of intersection points, we had total of 12455 place marks, out of which 5696 place marks were 4 leg and 6759 were 3 leg as stated by FDOT. Based on the analysis of 1003 place marks of district 7 we concluded that 99% of the intersections are signalized.

Therefore, out of 12455 place marks, our predicted distribution is:
12330 – True Signalized
125 – Un-signalized

The further distribution of 12330 signalized intersections looks like this
4 leg – 81% = 9987
3 leg – 19% = 2343

The further distribution of 125 non signalized intersections looks like this
4 leg – 22% = 28
3 leg – 78% = 97

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