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Final Report

GIS-based Instructional Tool for Crash-Prediction Methods

(Project # 2013-030)

Authors: Ilir Bejleri, Ph.D., Sivaramakrishnan Srinivasan, Ph.D., Nahal Hakim, Phillip Haas and Dan Brown
(University of Florida)

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AUTHORS

Ilir Bejleri

Sivaramakrishnan Srinivasan

Nahal Hakim

Phillip Haas

Dan Brown

ABSTRACT

Problem: The first version of the Highway Safety Manual (HSM) was released in 2010 and is currently being deployed by several states as the primary methodology for performing predictive analysis to identify critical segments of the network and to evaluate the benefits of countermeasures. In this context, it is critical to train the current and future professionals on the underlying theory behind these methods and the effective application of the same. Although the HSM methods rely on vast amounts of spatial data (roadway network and geometry, geo-coded crashes etc.) the training materials rely mostly on spreadsheet-based tools for application of the methods and the HSM software are also non-spatial and do not directly integrate with Geographic Information Systems (GIS).

Objective: The intent of this study was to develop a GIS-based instructional tool which can be used by both graduate students and current professionals to learn about the HSM-based predictive methods. The GIS platform of the tool is immensely beneficial so that the students can appreciate (visually) the context in which these methods are being applied. As such, this study contributes to both the educational and technology transfer goals of STRIDE.

Methodology: The overall project methodology comprises two steps. First, the HSM crash-prediction methods are coded into the Signal Four Software for selected facility types. This involved coding in the appropriate Safety Performance Functions and Crash Modification Factors. Next, an Instructional Module provides overviews of both the software and the analytical methods in addition to providing step-by-step guidance for segment- and intersection-level analyses.

Results: This project developed an interactive GIS web-based instructional tool for Crash Prediction Models. Included is a self-instructing tutorial which can be used by students either independently or in the context of a course. These tutorials use data from Florida however since the software is web-based, the tool can be accessed and used easily by anyone within the region. The GIS-environment facilitates the students appreciating the context in which the data are obtained and methods applied and thereby leading to improved understanding of the methods.

Contribution: The project directly contributes to enhancing the goals of transportation safety within the region. The instructional module will facilitate improved understanding of the HSM-based predictive methods and the appropriate application of the same. In the longer term, we envision that the consistency checks and comparative analysis capabilities supported by the software will also lead to improvements in data and methods, which in turn, would translate into better predictive capabilities. The instructional module is designed to allow future scalability into a full crash prediction feature of the Signal Four Analytical system in order to support the needs of researchers and practitioners in the traffic safety improvements efforts.

EXECUTIVE SUMMARY

Problem: The first version of the Highway Safety Manual (HSM) was released in 2010 and is currently being deployed by several states as the primary methodology for performing predictive analysis to identify critical segments of the network and to evaluate the benefits of countermeasures. In this context, it is critical to train the current and future professionals on the underlying theory behind these methods and the effective application of the same. Although the HSM methods rely on vast amounts of spatial data (roadway network and geometry, geo-coded crashes etc.) the training materials rely mostly on spreadsheet-based tools for application of the methods and the HSM software are also non-spatial and do not directly integrate with Geographic Information Systems (GIS).

Objective: The intent of this study was to develop a GIS-based instructional tool which can be used by both graduate students and current professionals to learn about the HSM-based predictive methods. The GIS platform of the tool is immensely beneficial so that the students can appreciate (visually) the context in which these methods are being applied. As such, this study contributes to both the educational and technology transfer goals of STRIDE.

Methodology: The HSM crash-prediction methods are coded into the S4 Analytics for selected facility types. This involved coding the appropriate Safety Performance Functions and Crash Modification Factors for intersections and segments. Safety Performance Functions are estimated using the exposure measures. For segments, the applied exposure measures are Annual Average Daily Traffic (AADT) and segment length derived from the Florida Roadway Characteristics Inventory (RCI). For intersections, exposure measure is the AADTs along the minor and major intersecting facilities according to RCI. In addition, the SPF calculation for signalized intersections includes vehicle-pedestrian and vehicle-bicycle crashes as well. Pedestrian crossing volume and a maximum number of lanes crossed by a pedestrian are two variables required for estimating vehicle-pedestrian crashes. Pedestrian crossing volume was estimated by visually inspecting Google satellite images considering the presence of bus stops, schools etc., and the maximum number of lanes was derived from Google satellite images as well. The tool allows users to examine the changes of Safety Performance Functions under different AADT by changing the AADT manually in the table.

Crash Modification factors are coded based on the HSM formulas and take into account the range of characteristics which include lane width, shoulder width and shoulder type, horizontal curves, super elevation variance, grade, driveway density, centerline rumble strips, passing lanes, left-turn lanes, hazard rating, lighting, and speed enforcement (for segments) and left turn lanes, type of left-turn signal phasing, right-turn lanes, prohibited right-turn on red, lighting, red light cameras (for intersections)

All roadway characteristics of the selected facilities are obtained from the RCI. The RCI values were attached to the S4 Analytics GIS streets which uses the Florida GIS streets unified basemap. In addition, for intersections, the vehicle-pedestrian CMF is estimated by applying the data about bus stops, schools, and alcohol establishments within a 300-meter distance from the intersection.

The HSM Part C Instructional Module is built as a web-based tool using the same technology platform as S4 Analytics. As it is a web-based solution, nothing needs to be installed in user's computer.

The computation engine of the tool is driven by the crash prediction engine built based on the HSM prediction methods. The calculation logic for SPFs, CMFs and Predicted Crashes is encapsulated in a class library that is designed to maximize re-use while easily supporting the expected expansion to additional facility types. Another important feature of the class library is the ability to plug in newer versions of the Highway Safety Manual and its myriad lookup tables as they become available. Using the object-oriented principle of inheritance, only those HSM tables that are changed would need to be overridden in the newer version, all others are simply inherited from the older version.

The visible user front-end of the tool is map centric. The available facility types are shown on the map or on the aerial photography in their geographic context. The facility database includes a set of roadway segments and intersections. The users can select to apply the prediction tool on any of the available segments or intersections and create 'what if' prediction scenarios.

Results: This project developed an interactive GIS web-based instructional tool for Crash Prediction Methods. The tool can be accessed at https://s4.geoplan.ufl.edu/analytics-stride

The crash prediction methodology is based on the part C of the HSM and the ultimate output is the expected crash frequency for selected facilities which, at this time, include Rural 2-lane Undivided Segments and Urban 4-leg Signalized Intersections. The tool provides users a tabular interface to interact with SPF parameters, CMFs, and the predicted crashes for any of the selected facilities. The SPF section presents a list of exposure measure values for that specific facility as well as the estimated SPF based on the exposure measures. In the CMFs section, the base and site conditions are listed for each characteristic and the resulting CMFs are presented based on the difference between the base and site conditions. The last section of the table presents the predicted crashes adjusted for CMFs and Calibration factor (C). In all sections, the tool allows user to change the characteristics and the exposure measures in order to develop different scenarios and export the results of each scenario in CSV or Excel XML formats. This allows users to evaluate the impact of each CMFs on crash reductions and conduct various what-if analysis for each facility. Moreover, by comparing the predicted crashes with the historical crashes gives users a better picture of the safety problem of the selected segments or intersections. At the same time, to help the understanding of the calculations and the results, the tool also allows the user to quickly look up the formulas and methods applied to each step of the calculation.

Included is a self-instructing tutorial providing step-by-step guidance for segment- and intersection- level analyses. This tutorial can be used by students either independently or in the context of a course. This tutorial uses data from Florida, however, since the software is web-based, the tool can be accessed and used easily by anyone within the region. The GIS-environment facilitates the students' appreciation of the context in which the data are obtained and how the methods are applied and thereby leading to improved understanding of the methods.

Discussion: The tool developed as a results of this effort is fully operational and it can be used by students and professionals for the purpose of assisting the understanding of the HSM-based predictive methods via a visual GIS platform and an interactive integration of the inputs and the results with the formulas used for the calculations.

It should be noted that at this time the tool is limited to two facility types: Rural 2-lane Undivided Segments and Urban 4-leg Signalized Intersections. This was by design because the primary goal of this project was to figure out the method and the software architecture to construct an operational tool while allowing further expansion with the rests of the facility types, as well as support newer versions of HSM and its lookup tables in the future. The project has successfully achieved this goal by structuring the computation engine in an encapsulated software class library designed to maximize re-use while easily supporting the expected expansion with additional facility types, as well as using the object-oriented principle of inheritance to simply inherit unchanged tables from the older version while overriding only HSM tables changed in the newer versions.

Limitations: The main challenge of the project was the availability and integration of the necessary data. RCI facility attributes had to be attached to the unified GIS streets map used by S4 Analytics. While this data processing step successfully prepared the data for the intended instructional purposes, the complete availability of the roadway characteristics as part of the GIS streets map will be needed for the expansion of the tool into a fully functional GIS-based safety planning tool. Additionally, to take advantage of the GIS abilities in the S4 Analytics, the required attributes for the vehicle-pedestrian CMFs (location of bus stops, schools, and alcohol establishments) can be extracted directly from the S4 GIS layers instead of manually assembling this information from Google maps or other sources. Last, historical crash frequency data were based on the Florida's Crash Analysis Reporting System (CARS), which doesn't include all the observed crashes such as the short-form crash reports. While the use of these crash frequencies is acceptable for instructional purposes, the intention of this project is to implement the available complete crash database from the S4 Analytics in future.

The tool can accept a calibration factor if one is available and use it in the calculation for crash frequency prediction. The software cannot be used to calibrate the model.

<u>Future research:</u> Future research will be concentrated in adding the rest of the HSM facility types, better integration of the roadway characteristics with the GIS streets map, use of all observed crashes from the S4 Analytics database and the expansion of the tool into a full GIS-based safety analytical system that uses HSM predictive methods.

<u>Contribution:</u> The project directly contributes to enhancing the goals of transportation safety within the region. The instructional tool will facilitate improved understanding of the HSM-based predictive methods and their applications. As such this study contributes to both the educational and technology transfer goals of STRIDE. In the longer term, we envision that the consistency checks and comparative analysis capabilities supported by the software will also lead to improvements in data and methods, which in turn, would translate into better predictive capabilities. The instructional module is designed to allow future scalability into a full crash prediction feature integrated into the Signal Four Analytical system in order to support traffic safety improvements efforts of the researchers and practitioners.

Chapter 1. INTRODUCTION

This document is intended as a self-instructing tutorial on the use of the Instructional Module (Version 1.0) for Highway Safety Manual (HSM) Part C powered by Signal Four Analytics. This web-based module is designed to provide a flexible environment to help users learn about the application of the HSM Part C methods using real-world data and a GIS-based environment.

The Highway Safety Manual

The Highway Safety Manual "provides tools to conduct quantitative safety analysis". Part C of this manual titled "Predictive Method" provides methods for "estimating the expected average crash frequency" for both roadway segments and intersections. These methods broadly comprise a Safety Performance Function (SPF), several Crash Modification Factors (CMFs), and possibly, a Calibration Factor (C).

The SPF is a mathematical equation (a negative-binomial regression model) that relates the crash frequency to crash-exposure variables assuming a standard set of conditions for the various roadway geometry and operational characteristics. In the case of roadway segments, the exposure variables included in the model are the length of the segment and the Annual Average Daily Traffic (AADT). Further separate equations are provided stratified by the location (urban versus rural), facility type (arterials, highways), and number of lanes. In the case of the intersections, the exposure variables are the AADTs along the two (major and minor) intersecting facilities. Further separate equations are provided stratified by the location (urban versus rural), number of approach lanes, and the control type (signal versus stop sign).

As already described, SPFs assume a set of standard or "base" conditions while determine the crashes. The CMFs (one for each of several geometry and operational characteristics) are then applied to adjust the predictions from the SPFs for true local conditions that are different from the assumed base conditions. A CMF value greater than 1 for an attribute indicates that the local conditions on that attribute are more detrimental to safety than the assumed base conditions (for example, narrower lanes than assumed in base condition) requiring the predictions from the SPF to be scaled up. In contrast, a CMF value less than 1 for an attribute indicates that the local conditions on that attribute are less detrimental to safety than the assumed base conditions (for example wider lanes than assumed in the base condition) requiring the predictions from the SPF to be scaled down.

Finally, certain regions may have calibrated the equations from the HSM using local data to reflect systematic differences between the location(s) in which the models were estimated and those in which these models are being applied. The calibration factor is applied to the crash rate predicted by the SPF and adjusted by the CMF.

The Federal Highway Administration has developed training material (NCHRP Report 715[1], National Highway Institute Course NHI-380106[2], and the Webinar Series[3]) on the Highway Safety Manual. The "Highway Safety Fundamentals"[4] course is also of interest here. These material predominantly come in one of two flavors. Some focus on theory and analytic procedures (these are often power point presentations) while others provide spreadsheet-based tools for application of the methods.

Signal Four Analytics

Florida *Signal Four Analytics* (S4 Analytics) is an interactive, web-based system designed to support the crash mapping and analysis needs of law enforcement, traffic engineering, and transportation planning agencies, and research institutions in the state of Florida. This system is developed and hosted at the GeoPlan Center at the University of Florida, and funded by the state of Florida. It contains the complete statewide crash database of the last 10 years. The database is current and it is updated daily. The system is available to all Florida public agencies that are involved in traffic safety improvement. Currently the system is used by over 2000 users in more than 300 state, regional and local agencies.

Capabilities of S4 Analytics include ability to query the cash database based on spatial and non-spatial crash attributes, ability to show the results on the map by dynamically clustering the crash points based on the map scale, ability to examine crashes by intersections and street segments. S4 Analytics include charting of results using bar charts and two-dimensional bubble chart that associates various variables e.g. crash severity and crash type. Other functions include collision diagrams, data export, access to individual crash information and individual crash reports, and network ranking based on crash frequency and crash severity.

The Instructional Module

The HSM Part C Instructional Module is the newest addition to the Signal Four Analytics system. The intent of this effort is to develop a prototype tool that allows users to perform several "what-if" analyses as a means to learning the HSM procedures. At the same time the tool also allows the user to quickly look up the formulas and methods corresponding to each step of the calculation thereby increasing the transparency of the methods to the user.

A web-based interactive system is developed so that these may be widely delivered to be used by both graduate students and current professionals to learn about the HSM-based predictive methods. As a prototype the current version of the tool includes these procedures for two facility types (one segment and one intersection) covered by the HSM. It is envisioned that future efforts will add the analysis capabilities for other facility types.

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[1] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_715.pdf
[2] http://www.highwaysafetymanual.org/Pages/Training.aspx
[3] http://www.highwaysafetymanual.org/Pages/FHWAResourceCenterHSMWebinarSeries.aspx
[4] http://www.ltrc.lsu.edu/pdf/2015/FR_524.pdf

The product is developed on a GIS platform so that it may be fully integrated (in the future) with the other capabilities of the Signal Four System. Further, it is also useful to note that current HSM software (IHSDM4) is non-spatial and does not directly integrate with Geographic Information Systems. Given that the HSM methods relay on vast amounts of spatial data (roadway network and geometry, geo-coded crashes etc.), it would be immensely beneficial for the training material to be GIS-based so that these may further be developed into application tools for HSM-based safety analytics.

Report Organization

The rest of this report is organized as follows. Chapter 2 presents an overview of the Application Tool and gives details about the data used. Chapter 3 describes how a user may learn about the safety analysis of segments while Chapter 4 describes how a user may learn about the safety analysis of intersections. In each of Chapters 3 and 4, the procedures are illustrated with examples. The tool is developed to be interactive and to support exploration and self-learning. Therefore, it is envisioned that this document will be used as a “self-learning tutorial” which will instruct the user on functionalities of the tool and guide them on potential ways in which these may be used.

Chapter 2. APPLICATION TOOL OVERVIEW AND DATA

The HSM Part C Instructional Module is a web-based tool built using the same technology platform as Signal Four Analytics. As it is a web-based solution, nothing needs to be installed on the user's computer other than the Silverlight browser plug-in, a common web application technology which most users (including 100% of Signal Four Analytics users) will already have installed. If not, the user will be automatically re-directed to the Microsoft web site where they can download and install the Silverlight plug-in.

The tool is driven by the crash prediction engine built based on the HSM prediction methods. All of the calculation logic for SPFs, CMFs and Predicted Crashes is encapsulated in a class library that is designed to maximize re-use while easily supporting the expected expansion to additional facility types. Another important feature of the class library is the ability to plug in newer versions of the Highway Safety Manual and its myriad lookup tables as they become available. Using the object-oriented principle of inheritance, only those HSM tables that are changed would need to be overridden in the newer version, all others are simply inherited from the older version.

The visible user front-end of this module is map centric. The available facility types are shown on the map or on the aerial photography in their geographic context. The facility database includes a set of roadway segments and intersections. The users can select to apply the prediction tool on any of the available segments or intersections and create 'what if' prediction scenarios.

To start, point your web browser to https://s4.geoplan.ufl.edu/analytics-stride/ to open the application tool. Point the cursor on the image of the world and a drop-down menu with three items appears. The three items are Home, R2U Segments (Rural 2-lane Undivided Segments), and U4SG Intersections (Urban 4-leg Signalized Intersections). As already discussed, the current version of the software implements the predictive procedures for one facility type for each of segments and intersections. The addition of the procedures for the rest of the segment and intersection equations is identified as an area of future work.

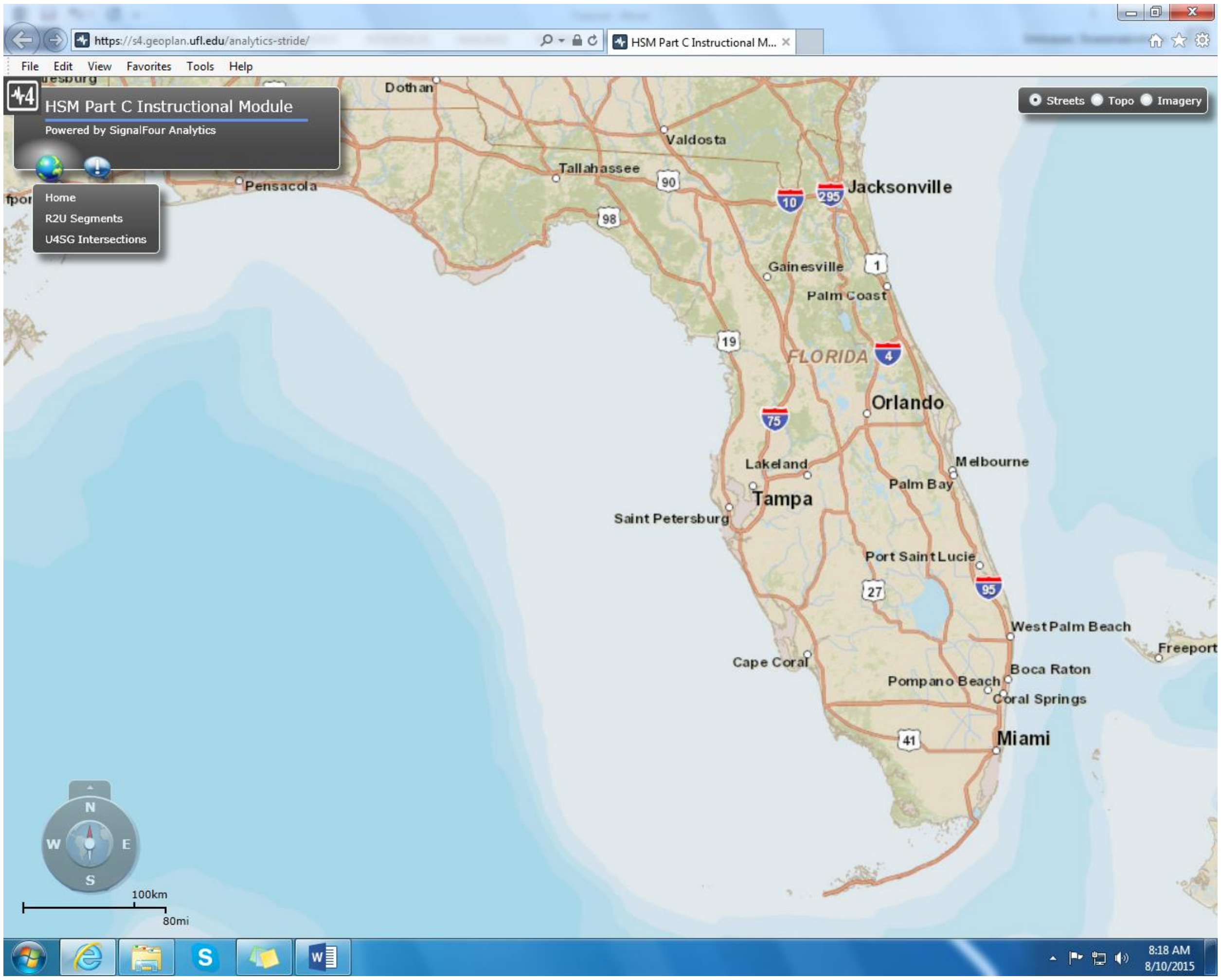


Figure 1 - Tool User Front-end

On clicking the R2U Segments, the map zooms into the Ocala region of Florida and six rural 2 lane undivided segments included as examples are shown in blue. In the next figure, these segments are highlighted for further clarity.

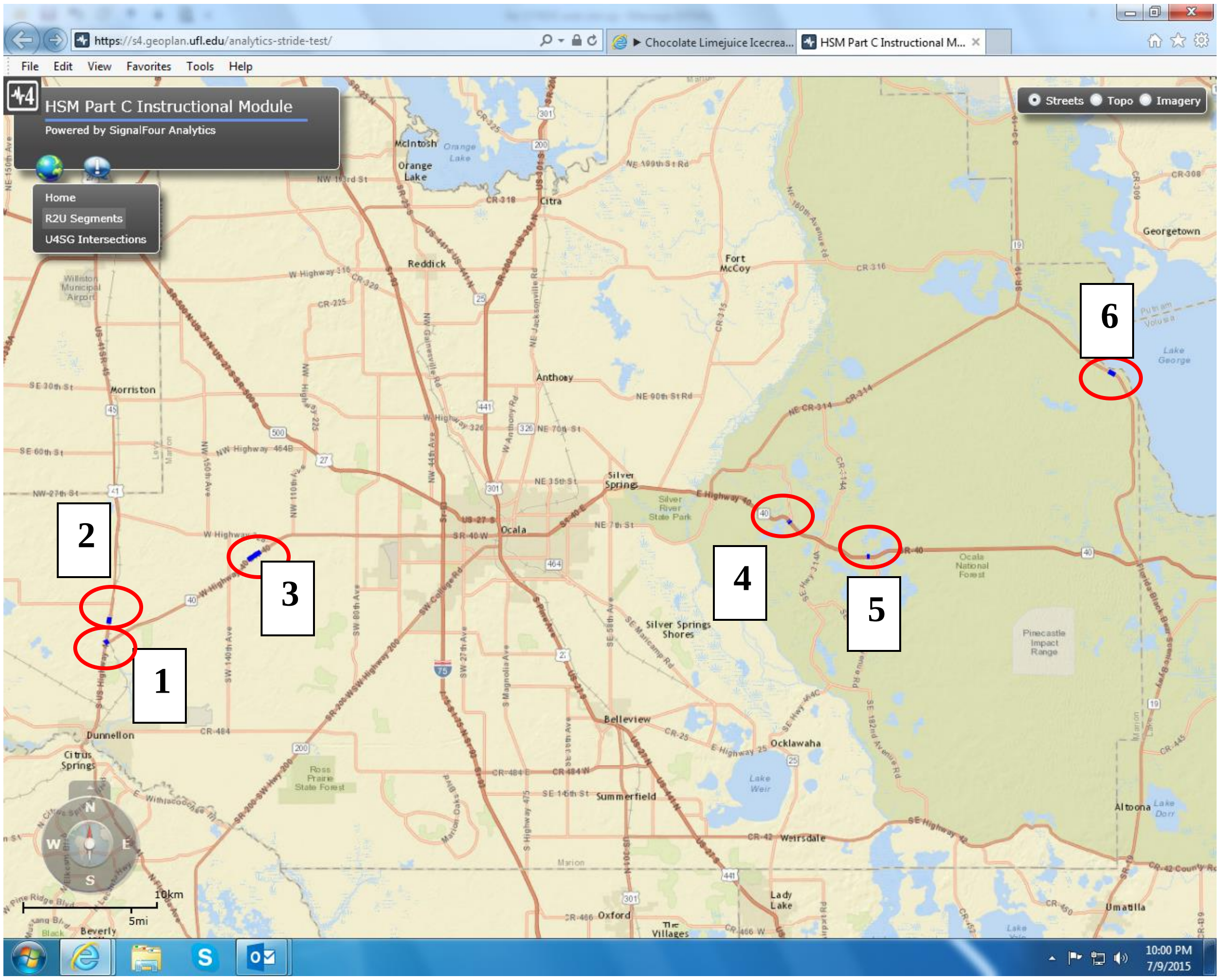


Figure 2 - Rural Two-Lane Two-Way Segments

The major characteristics of these segments are summarized in the following table. In addition to the attributes summarized in the table, there is no curvature on any of these segments and they are all at level grade. There is no lighting and no automated speed enforcement. These segments have a driveway density of 5 (driveways per mile) and a roadside hazard rating of 3 (a scale from 1 to 7) (both these conform to "base" conditions and so the corresponding CMFs are 1). These data were assembled from the Florida Roadway Characteristics Inventory (RCI) and Crash databases in a previous study on calibrating the HSM equations for Florida conditions[5].

[5] http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BDK77_977-06_rpt.pdf

Segment Number	AADT (Veh/day)	Length (miles)	Lane Width (feet)	Shoulder Width (feet)*	Shoulder Type	Shoulder Paved %
1	7700	0.2	10	0	-	-
2	9300	0.31	11	6	Composite	33
3	13700	0.71	10	8	Composite	25
4	12600	0.16	12	10	Composite	40
5	7800	0.14	12	10	Composite	40
6	1450	0.37	11	8	Composite	50

* Identical on Left and Right

Table 1- Segments Characteristics

Chapter 3 describes how predictive analysis of crashes on roadway segments may be performed using the software by taking one of the above segments as an example. The user may choose any of these six segments for further exploratory work. The software also allows the user to perform various "what if" analyses by changing the attributes of these segments. These are also described in Chapter 3.

On clicking the U4SG Intersections, the map zooms into the Miami region of Florida and five urban four-leg signal controlled intersections are included as examples are shown in red. In the next figure, these intersections are highlighted for further clarity.

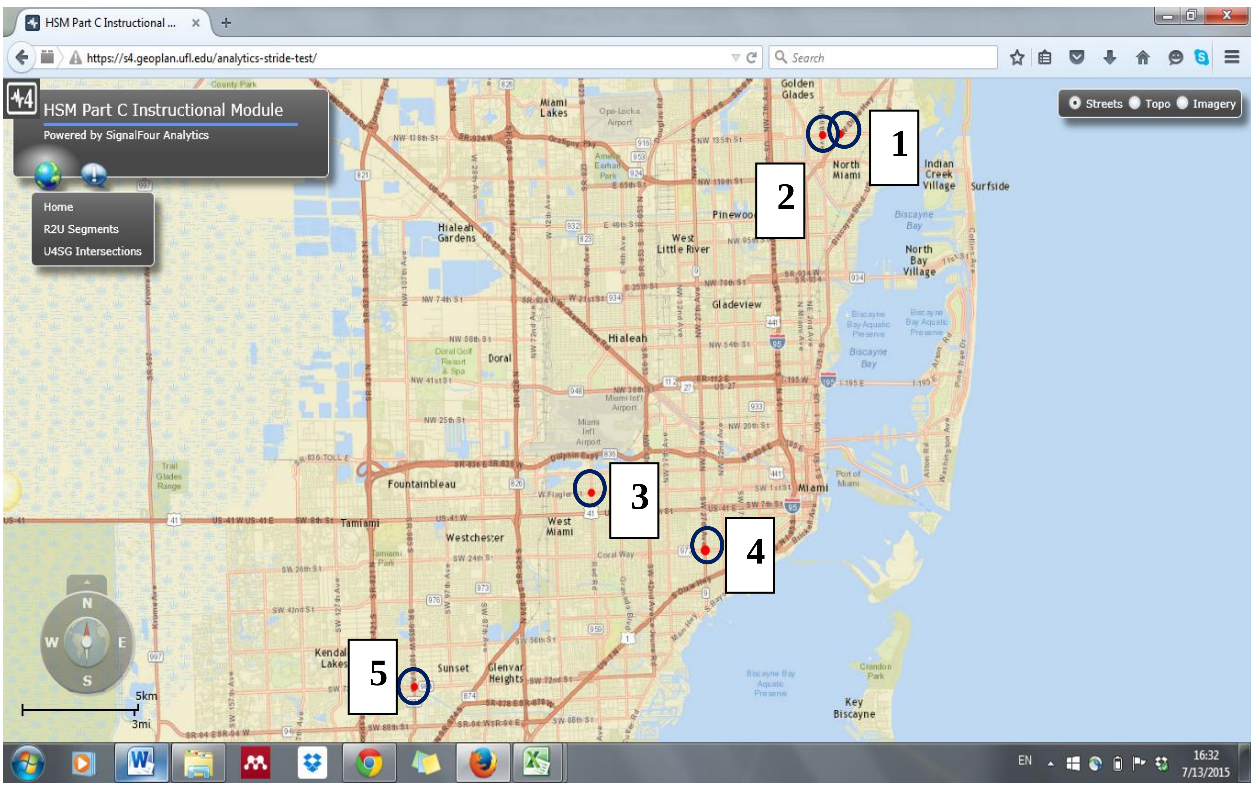


Figure 3 - Urban Four-leg Signalized Intersections

The major characteristics of these intersections are summarized in the following table. In addition to the attributes summarized in the table, these intersections have protected left turns and right-turn-on-red is permitted. There are no red-light cameras. These data were obtained from RCI and Google Maps in a previous study on calibrating the HSM equations for Florida conditions[6].

Intersection ID	AADT major (veh/day)	AADT minor (veh/day)	Pedestrian lane crossing #	Pedestrian crossing volume (ped_cross_all_legs/day)	Bus stops #	School present	Alcohol Est. #
1	26000	23500	5	50	8	N	2
2	46000	17900	5	240	7	Y	0
3	47500	26500	5	700	8	N	3
4	37000	23500	7	240	6	N	4
5	40000	34991	5	240	8	N	3

Table 2 - Intersections Characteristics

Chapter 4 describes how predictive analysis of crashes on intersections may be performed using the software by taking one of the above intersections as an example. The user may choose any of these five intersections for further exploratory work. The software also allows the user to perform various "what if" analyses by changing the attributes of these segments. These are also described in Chapter 4.

[6] http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BDK77_977-06_rpt.pdf

Chapter 3. ANALYSIS OF SEGMENTS

This chapter presents an overview on how the software can be used for the predictive analysis of crashes on roadway segments. From the main window, click on R2U Segments and then click on Segment ID 3 (Figure on Chapter 2 indicates the location of Segment 3). A new “analysis” window pops up with the details about this segment. The title bar of this window identifies the roadway (Highway 40) and the start- and end- mile markers. The window comprises three vertical Expander controls. These are “Safety Performance Function”, Crash Modification Factors” and “Predicted Crashes”. Each of these may be expanded or collapsed using the arrow buttons.

Under the “Safety Performance Function” Expander, the segment length and traffic volumes are listed as the first two rows. These are the basic exposure variables needed for applying the safety performance function. The final row has the predicted crashes obtained by applying the SPF to the traffic volume and length identified in the previous rows.

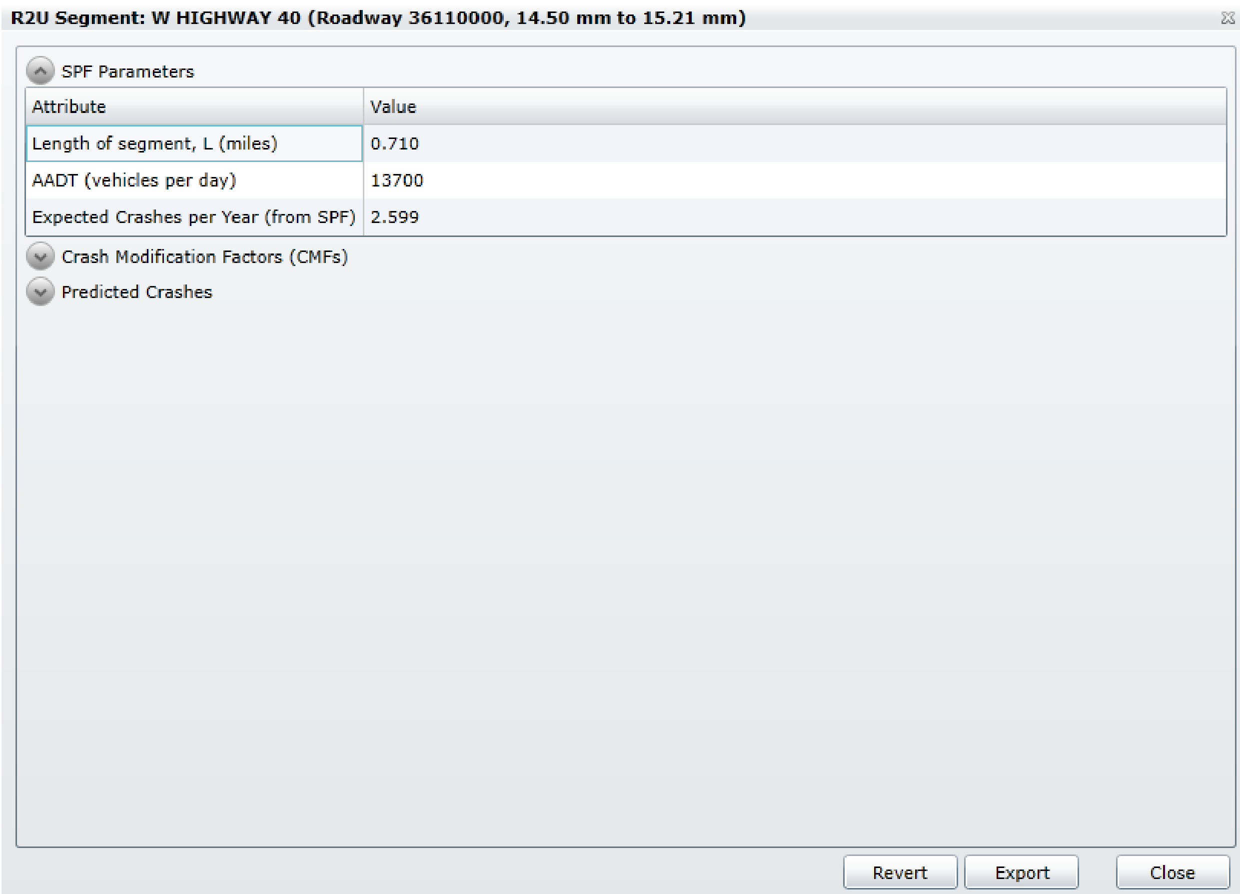


Figure 4 - SPF Expander_ Segment 3

Click on the final row (Expected Crashed per year from SPF) and a new window pops us showing the actual formula used in this calculation. Click on close to revert back to the analysis window.

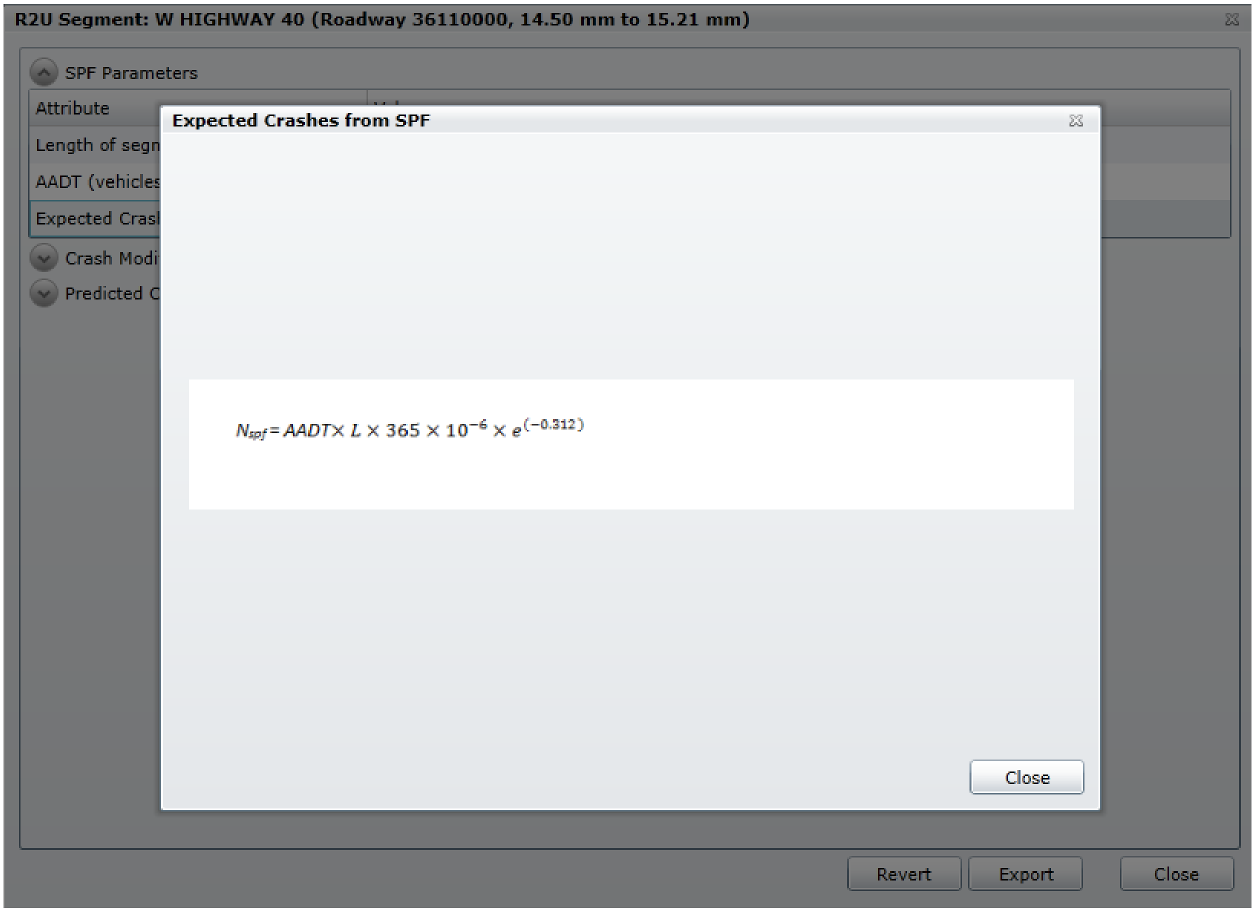
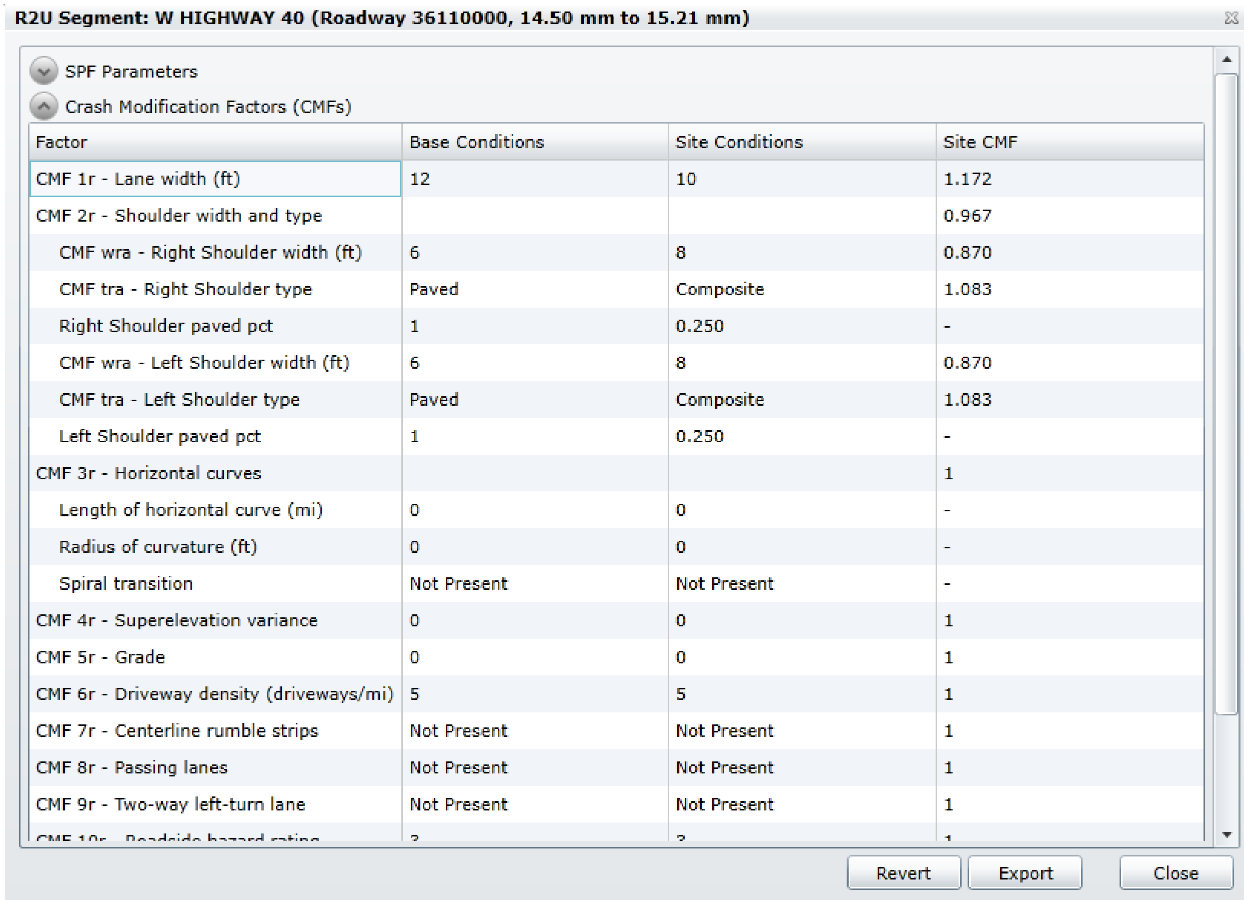


Figure 5 - Expected Crashed per year from SPF Formula_Segment3

Next, expand the “crash modification factors” Expander by clicking on the arrow button. This grid has four columns. The first column identifies the factors, the second defines the base condition for these factors as assumed in the SPF, the third shows data on the actual site conditions on these factors, and the final column presents the CMFs for each factor. Notice that the CMF is 1 if the site condition is the same as the base condition.



R2U Segment: W HIGHWAY 40 (Roadway 36110000, 14.50 mm to 15.21 mm)

SPF Parameters

Crash Modification Factors (CMFs)

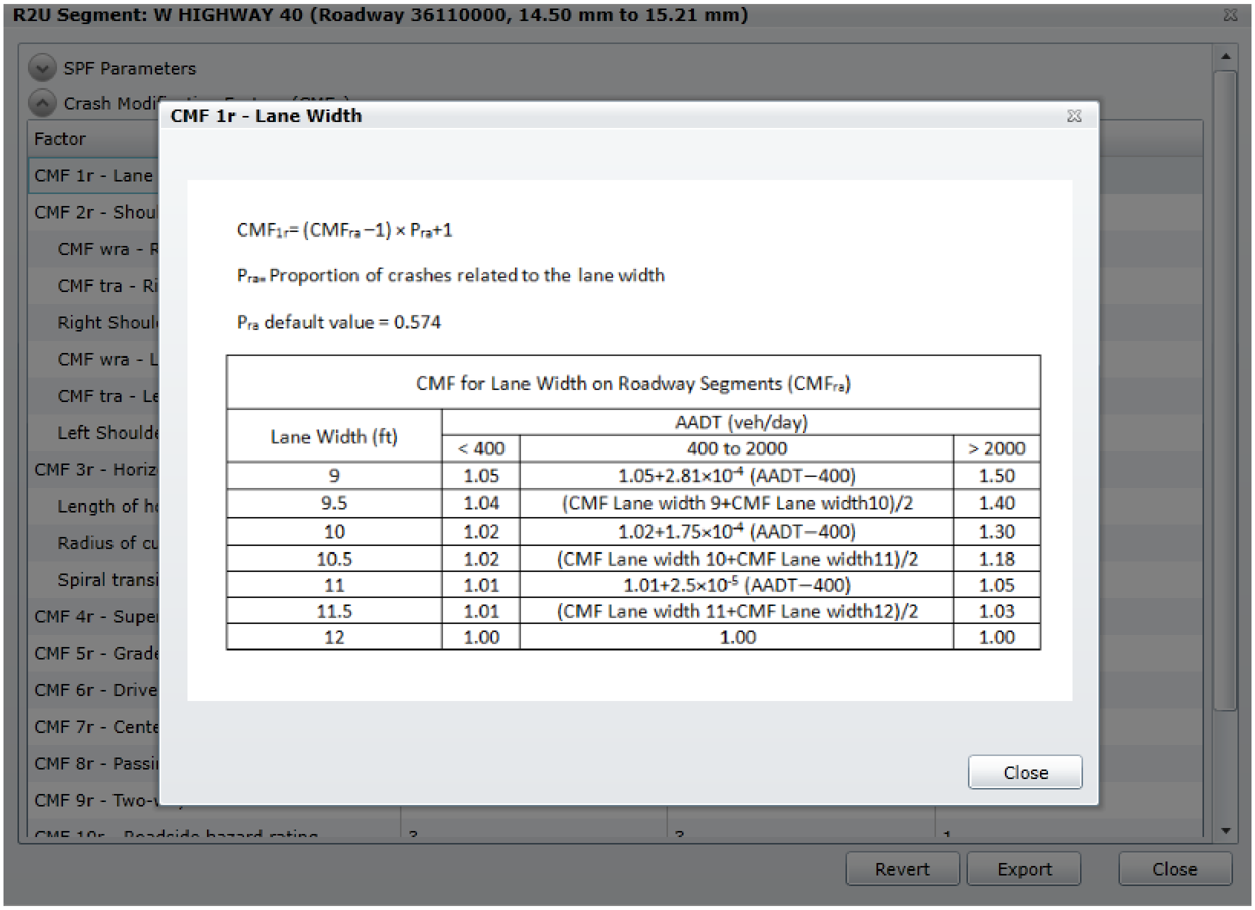
Factor	Base Conditions	Site Conditions	Site CMF
CMF 1r - Lane width (ft)	12	10	1.172
CMF 2r - Shoulder width and type			0.967
CMF wra - Right Shoulder width (ft)	6	8	0.870
CMF tra - Right Shoulder type	Paved	Composite	1.083
Right Shoulder paved pct	1	0.250	-
CMF wra - Left Shoulder width (ft)	6	8	0.870
CMF tra - Left Shoulder type	Paved	Composite	1.083
Left Shoulder paved pct	1	0.250	-
CMF 3r - Horizontal curves			1
Length of horizontal curve (mi)	0	0	-
Radius of curvature (ft)	0	0	-
Spiral transition	Not Present	Not Present	-
CMF 4r - Superelevation variance	0	0	1
CMF 5r - Grade	0	0	1
CMF 6r - Driveway density (driveways/mi)	5	5	1
CMF 7r - Centerline rumble strips	Not Present	Not Present	1
CMF 8r - Passing lanes	Not Present	Not Present	1
CMF 9r - Two-way left-turn lane	Not Present	Not Present	1
CMF 10r - Roadside hazard rating	3	3	1

Revert Export Close

Figure 6 - CMFs Expander_ Segment3

In the case of lane width, the CMF is calculated as 1.172. This value is greater than 1 because the base conditions assumed a lane width of 12 feet while the site only has 10 feet lanes. The site is "less safe" based on this attribute compared to base conditions and is therefore expected to have more crashes than under base conditions.

Click on the cell "Lane Width" and a new window pops up which presents the exact formula used for calculating the CMF. Click on close to revert back to the analysis window.



CMF for Lane Width on Roadway Segments (CMF_{ra})

Lane Width (ft)	AADT (veh/day)		
	< 400	400 to 2000	> 2000
9	1.05	$1.05+2.81\times10^{-4}$ (AADT−400)	1.50
9.5	1.04	(CMF Lane width 9+CMF Lane width10)/2	1.40
10	1.02	$1.02+1.75\times10^{-4}$ (AADT−400)	1.30
10.5	1.02	(CMF Lane width 10+CMF Lane width11)/2	1.18
11	1.01	$1.01+2.5\times10^{-5}$ (AADT−400)	1.05
11.5	1.01	(CMF Lane width 11+CMF Lane width12)/2	1.03
12	1.00	1.00	1.00

Figure 7 - CMF Formula for Lane Width

The CMF for shoulder width is 0.870. This value is less than 1 because the base condition assumed 6 feet shoulders while the site has 8 feet shoulders. The site is “more safe” based on this attribute compared to base conditions and is therefore expected to have fewer crashes than under base conditions. Notice that, the “net” CMF for shoulder width and type depends on both width and type and on both right- and left- side conditions. The user may click on cells such as “Right Shoulder Width” and “Right Shoulder Type” to see the CMF calculations for each of these aspects independently. Click on the cell “Shoulder Width and Type” and a new window pops up which presents the formula used for calculating the net CMF based on width and type on both the right- and left- sides.

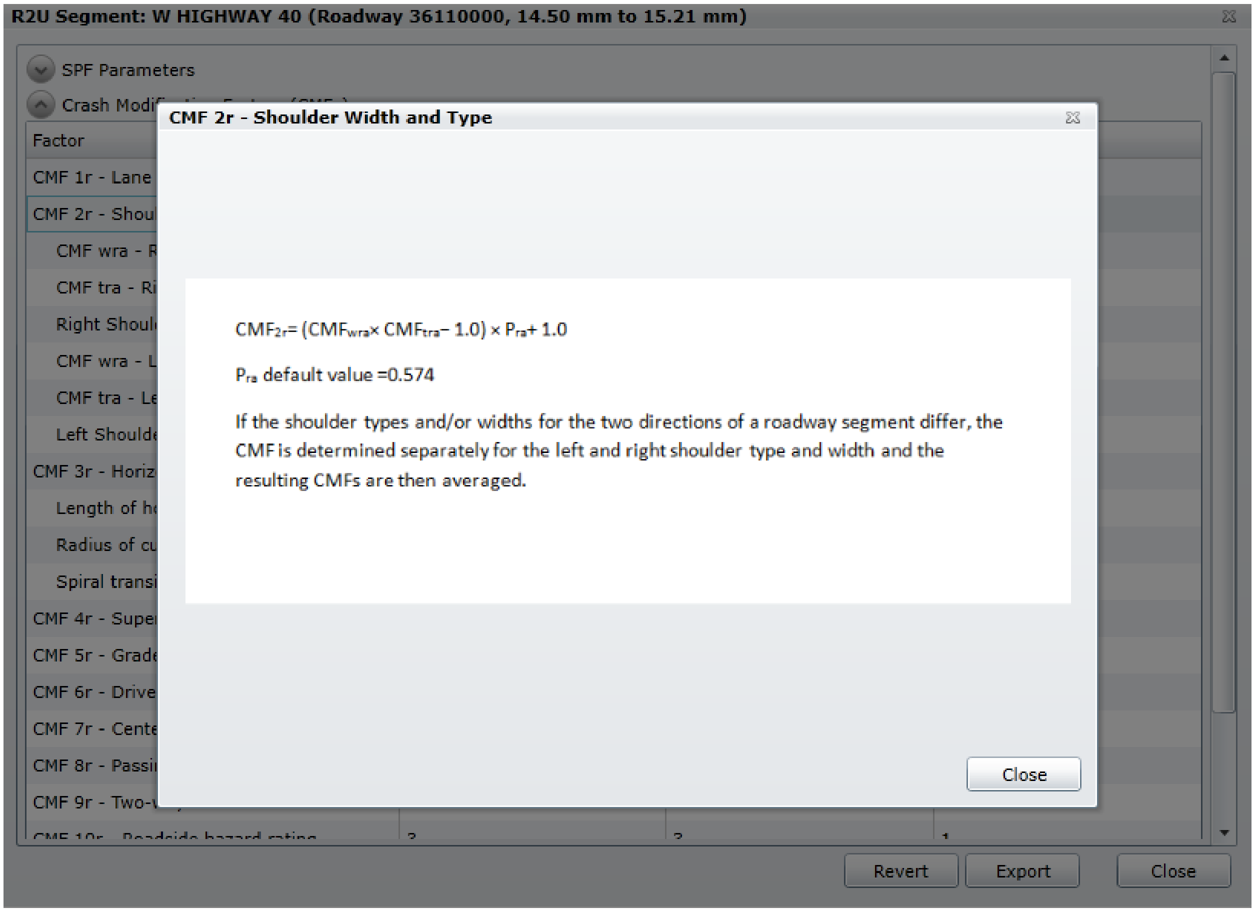
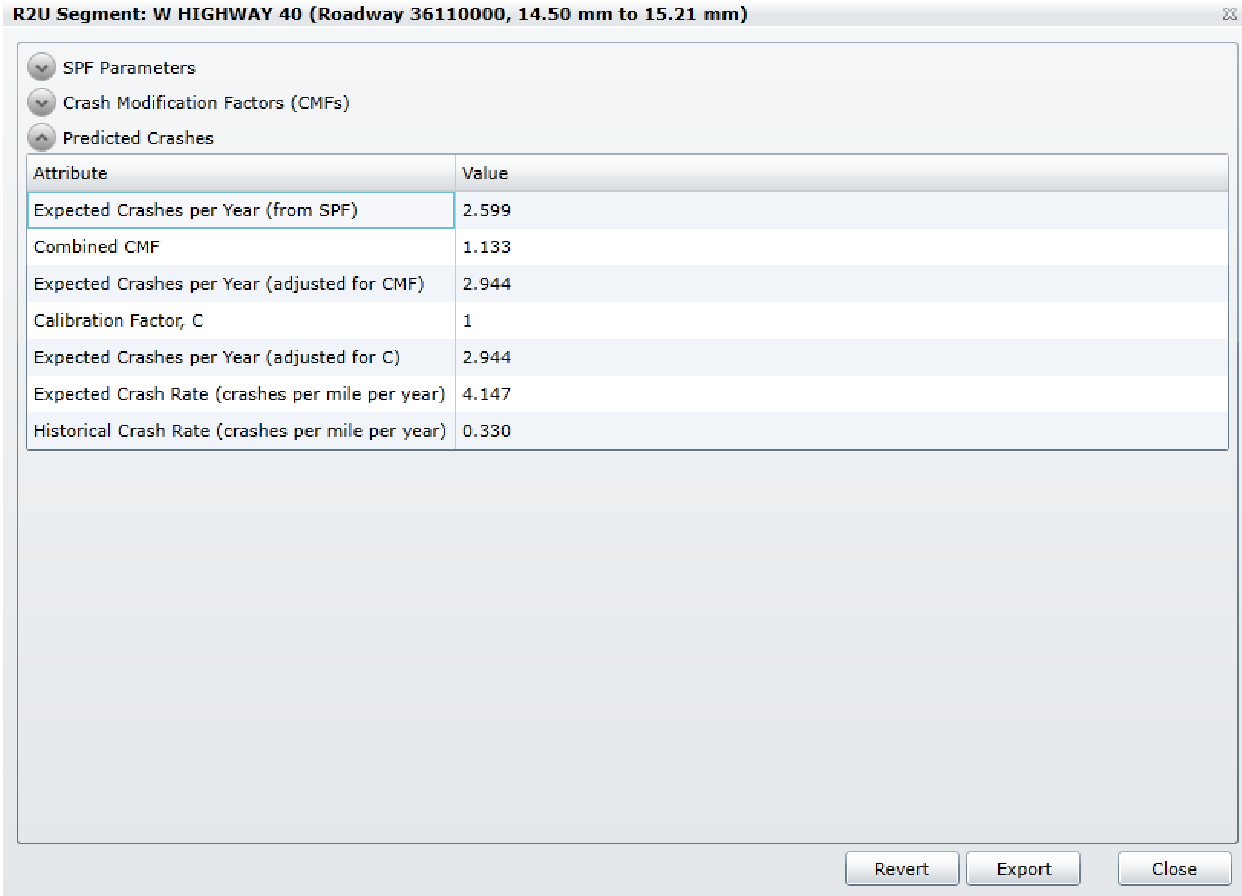


Figure 8- CMF Formula for Shoulder Width and Type

There are a total of 12 major factors (from lane with through presence of automated speed enforcement) for which CMF calculations are presented. Click on each of the cells under the Column titles Factor to see the formulas for each of the CMFs.

Finally, expand the Predicted Crashes Expander. The structure of this grid is similar to that of the “Safety Performance Functions” (the first tab) and has two columns, the attributes and the values.



Attribute	Value
Expected Crashes per Year (from SPF)	2.599
Combined CMF	1.133
Expected Crashes per Year (adjusted for CMF)	2.944
Calibration Factor, C	1
Expected Crashes per Year (adjusted for C)	2.944
Expected Crash Rate (crashes per mile per year)	4.147
Historical Crash Rate (crashes per mile per year)	0.330

Figure 9 - Predicted Crashes Expander _Segment3

The first row is simply the predicted crashes obtained by applying the SPF to the traffic volume and length (also shown in the “Safety Performance Functions” expander. The next row presents the composite CMF for this segment which is simply the product of all the 12 individual CMFs (click on the cell “Combined CMF” to see the formula). The third row presents the predicted crashes from SPF after it is scaled by applying the combined CMF (again click on the corresponding cell to see the formula).

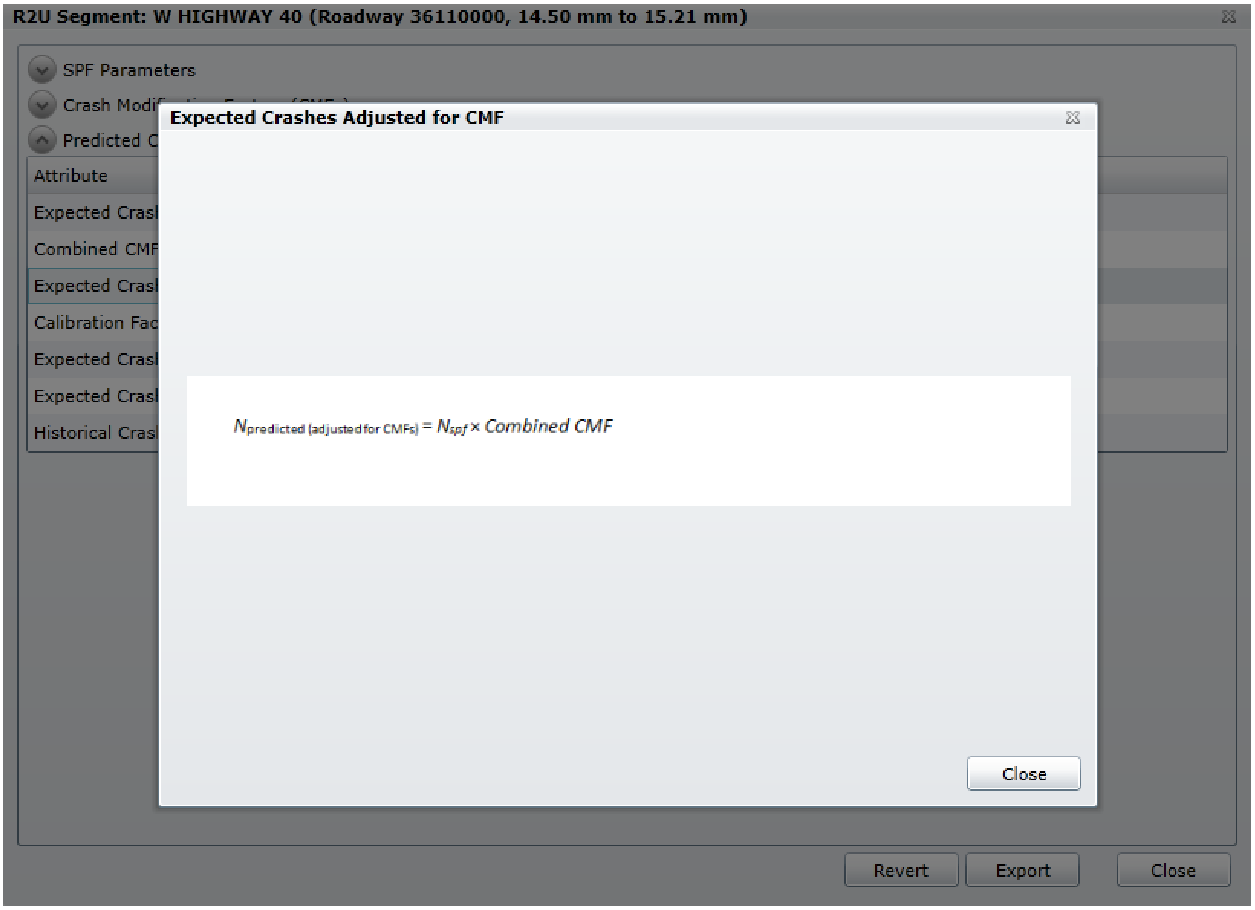


Figure 10 - Formula for Expected crashes adjusted for CMFs

The fourth row is the calibration factor. While the default value is set to 1, the user may modify based on local conditions. Florida-specific calibration factors by facility type and location are also available[7]. The fifth row presents the predicted crashes from SPF after it is scaled by applying the combined CMF and the calibration factor. The sixth row presents predicted crashes per mile obtained by simply scaling the predicted crashed by segment length (click on the cell to see the formula). The final row presents the observed crash rate for this segment. The last two rows of data can be used for Empirical Bayes Analysis to be implemented in future versions of the module.

In the rest of this section, we will examine how the software can be used to perform several "what if" analysis. Prior to making any changes, click on the "Export" tab at the bottom of the analysis window to save the details "as is" locally. Provide a file name and the details seen in the analysis window are saved as a CSV file.

[7] http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BDK77_977-06_rpt.pdf

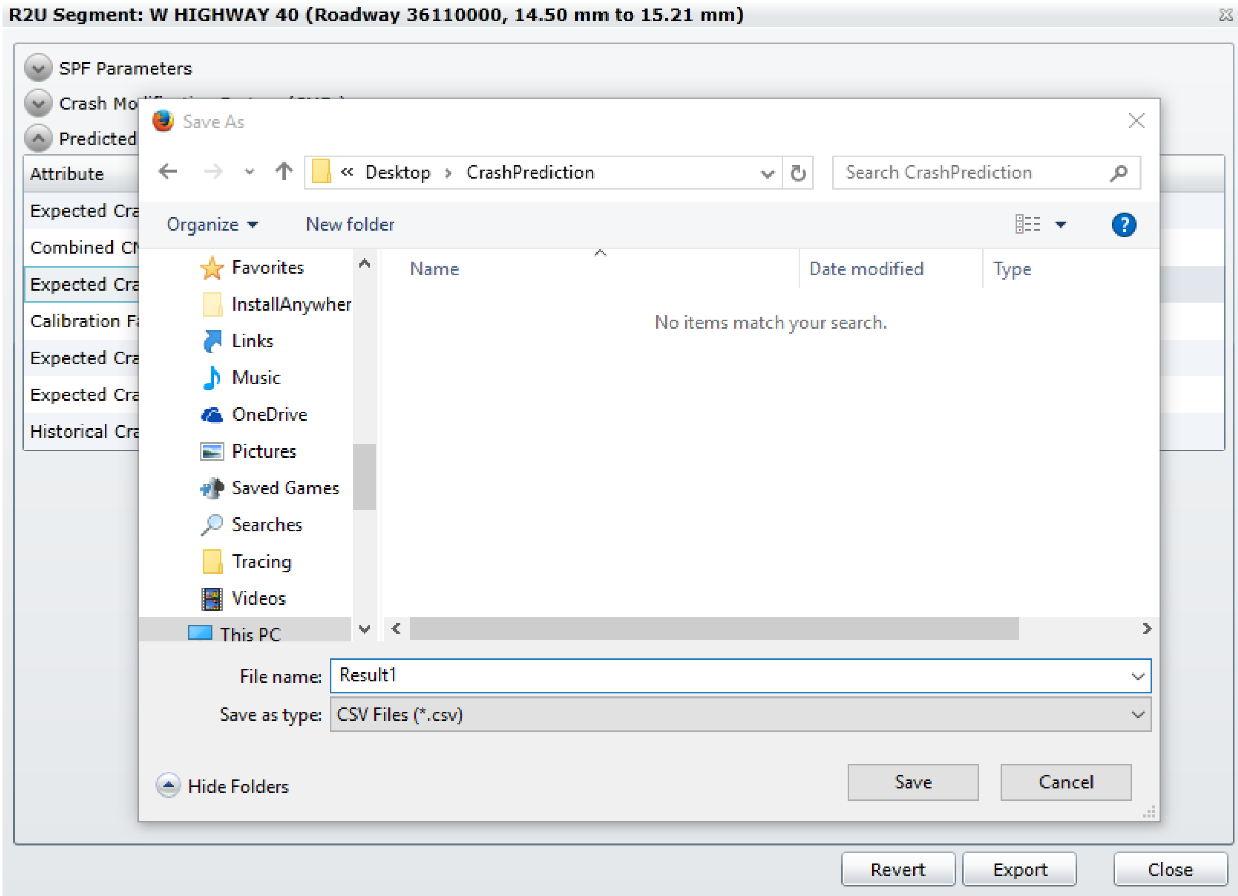


Figure 11 - Save the Results in CSV Format

The following figure details the structure of the saved CSV file. Note that the data are saved in the same format as seen in the analysis window.

	A	B	C	D	E
1	SPF Parameters				
2	Attribute	Value			
3	Length of segment, L (miles)	0.71			
4	AADT (vehicles per day)	13700			
5	Expected Crashes per Year (from SPF)	2.598794279			
6					
7	CMFs				
8	Factor	Base Conditio	Site Condition	Site CMF	
9	CMF 1r - Lane width (ft)	12	10	1.1722	
10	CMF 2r - Shoulder width and type			0.9666	
11	CMF wra - Right Shoulder width (ft)	6	8	0.87	
12	CMF tra - Right Shoulder type	Paved	Composite	1.0825	
13	Right Shoulder paved pct	1	0.25	-1	
14	CMF wra - Left Shoulder width (ft)	6	8	0.87	
15	CMF tra - Left Shoulder type	Paved	Composite	1.0825	
16	Left Shoulder paved pct	1	0.25	-1	
17	CMF 3r - Horizontal curves			1	
18	Length of horizontal curve (mi)	0	0	-1	
19	Radius of curvature (ft)	0	0	-1	
20	Spiral transition	Not Present	Not Present	-1	
21	CMF 4r - Superelevation variance	0	0	1	
22	CMF 5r - Grade	0	0	1	
23	CMF 6r - Driveway density (driveways/mi)	5	5	1	
24	CMF 7r - Centerline rumble strips	Not Present	Not Present	1	
25	CMF 8r - Passing lanes	Not Present	Not Present	1	
26	CMF 9r - Two-way left-turn lane	Not Present	Not Present	1	
27	CMF 10r - Roadside hazard rating	3	3	1	
28	CMF 11r - Segment lighting	Not Present	Not Present	1	
29	CMF 12r - Auto speed enforcement	Not Present	Not Present	1	
30					
31	Predicted Crashes				
32	Attribute	Value			
33	Expected Crashes per Year (from SPF)	2.598794279			
34	Combined CMF	1.133023728			
35	Expected Crashes per Year (adjusted for C	2.944495582			
36	Calibration Factor, C	1			
37	Expected Crashes per Year (adjusted for C	2.944495582			
38	Expected Crash Rate (crashes per mile pe	4.147176876			
39	Historical Crash Rate (crashes per mile per	0.33			

Figure 12-Results for Segment 3 in CSV Format

None of the changes made by the user are automatically saved. Therefore, the "export" button should be used to save a copy of the results for any of the revised cases locally if so desired. The default data stored internally in the software is never overwritten even if changes are made via the User Interface. The data displayed can quickly be reset to the original site conditions by clicking the Revert button at the bottom left of the analysis window.

Let us first examine what happens to the predicted crashes when the traffic volumes are changed. Under the "Safety Performance Function" Expander, the AADT observed on the segment is listed as 13,700 veh/day. For this AADT, the expected crashes (from SPF) on the segment is 2.599. Now click on the cell which has the AADT value and change it to 14,700 (AADT increased by 1000). Notice that the expected crashed from SPF now increases to 2.788 and this was calculated by using the new AADT value in the SPF equation. The increase is 2.788-2.599 = 0.189.

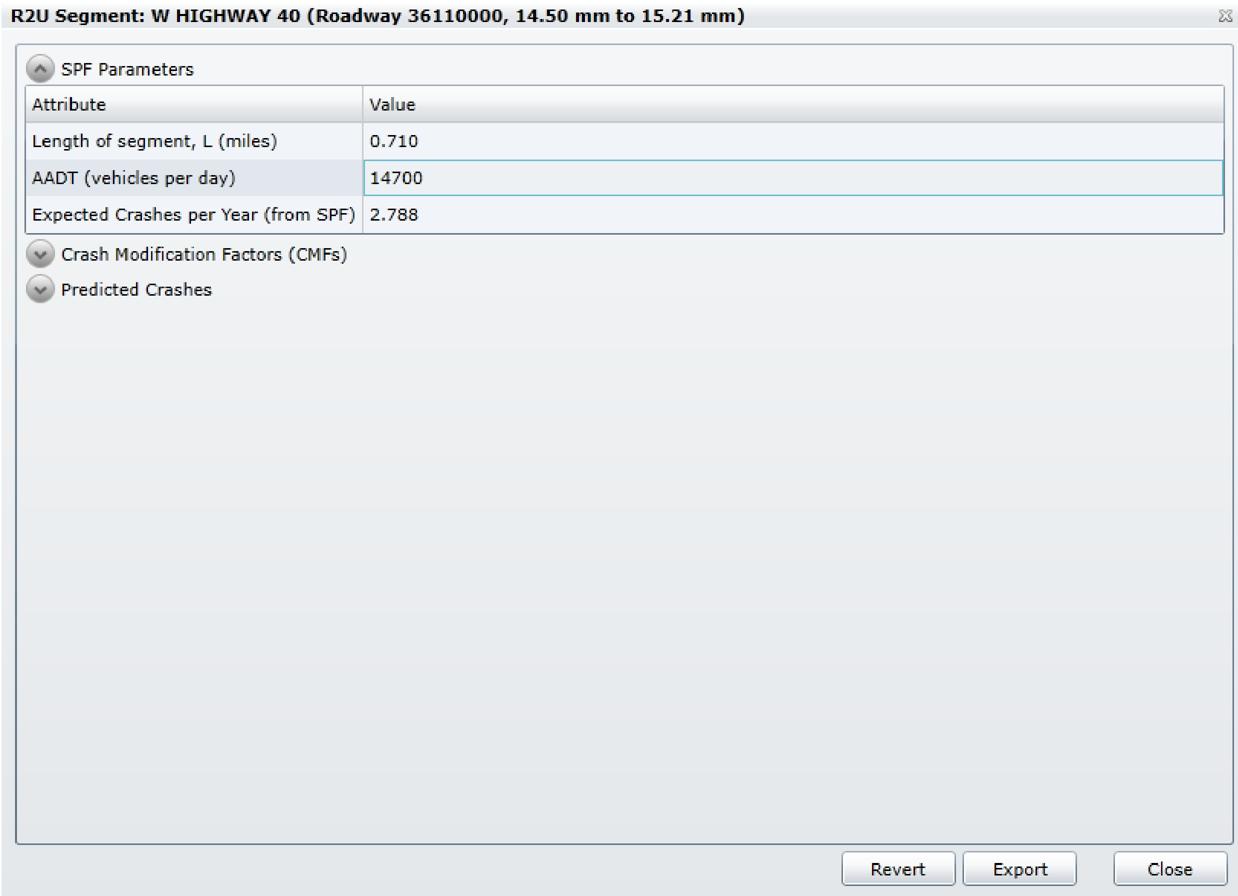


Figure 13 - SPF resulted from Increasing AADT_Segment3

Now consider the effect of decreasing the AADT by 1000 from the original site conditions by inputting 12,700 as the AADT value. Notice that the expected crashes from SPF is now 2.409. The decrease is 2.599-2.409 = 0.19.

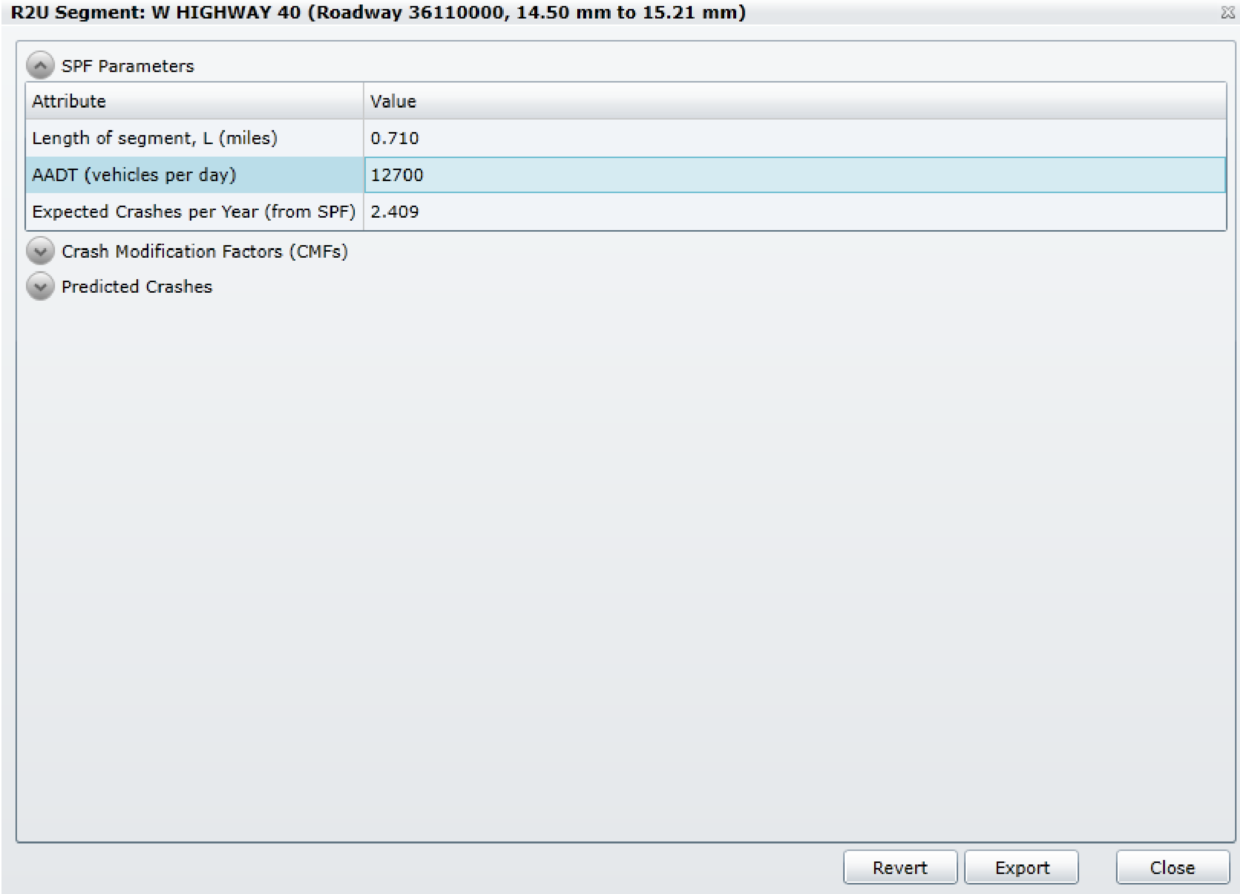


Figure 14 - SPF resulted by Decreasing AADT_Segment3

As such the impact of an increase of 1000 AADT is not the same as the impact of a reduction in AADT by the same amount. This is because of the non-linear relationship between the AADT and the crashes.

Let us now examine the impacts of changing roadway conditions. First, click on the “revert” button to rest all values (i.e., the AADT values in this case) to the original default conditions. Open the “Predicted Crashes” expander. Notice that the combined CMF is 1.133 (second row in Predicted Crashes expander) and the expected crashes adjusted for CMF is 2.944 for this segment.

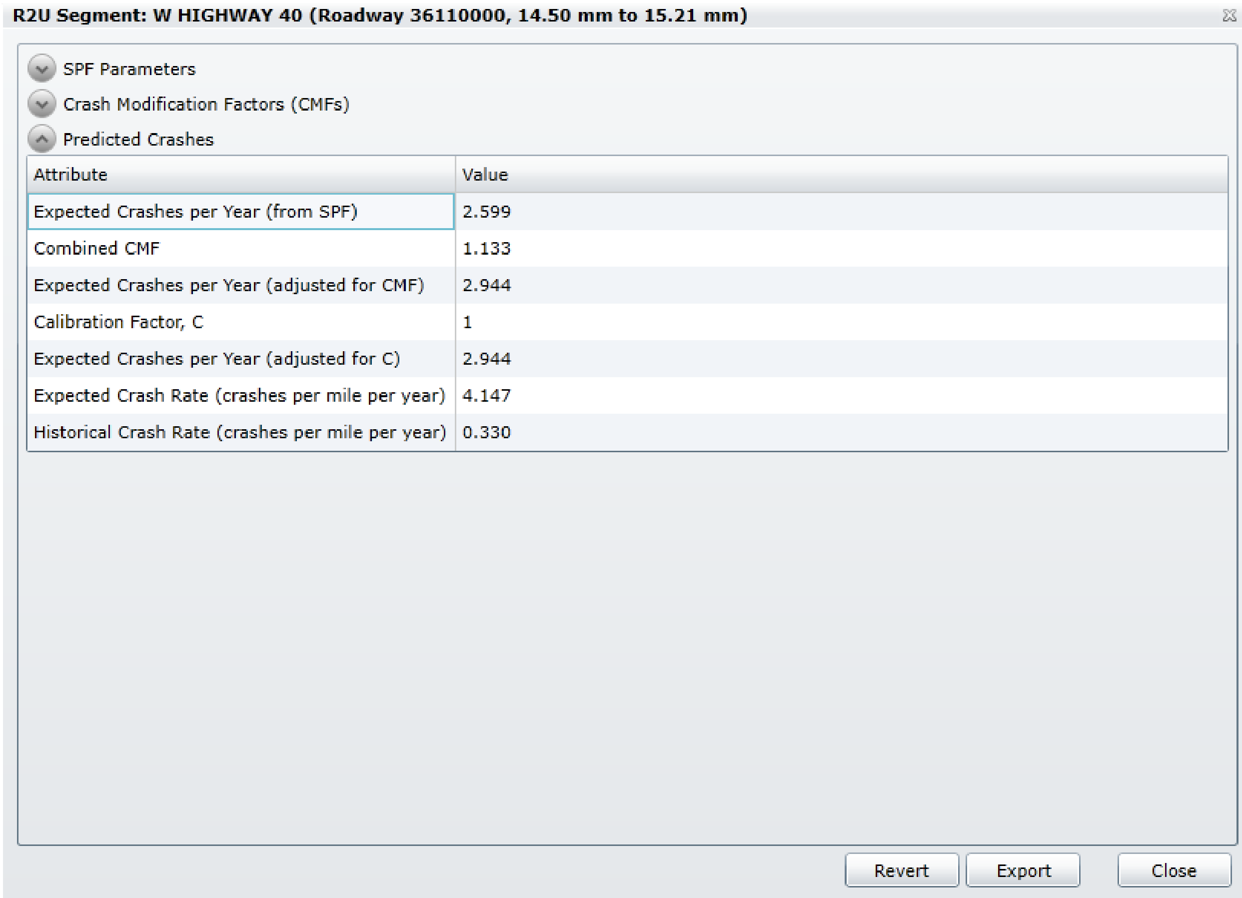
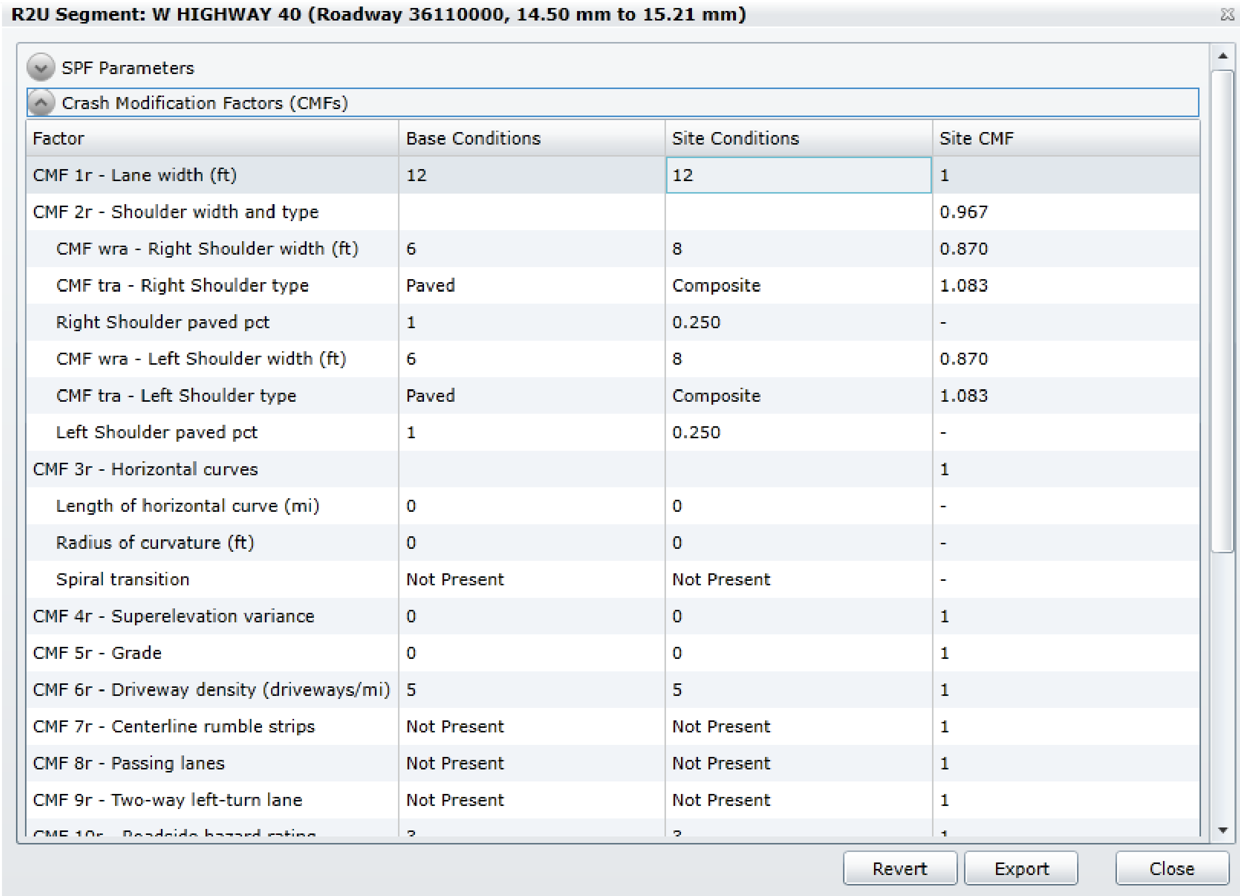


Figure 15 - Predicted Crashes Expander_Segment3

Under the Crash Modifications Factors expander, click on the cell in row “lane width” under column “site conditions” and change the value from 10 to 12 (feet). Notice that the CMF changes from 1.172 to 1. The decrease in CMF indicates that the increase in lane width from 10 to 12 feet is associated with a decrease in crashes (reduction in CMF). Further, the value of the new CMF is one as a 12 feet lane width is the “base condition” assumed in developing the SPF.


R2U Segment: W HIGHWAY 40 (Roadway 36110000, 14.50 mm to 15.21 mm)

SPF Parameters

Crash Modification Factors (CMFs)

Factor	Base Conditions	Site Conditions	Site CMF
CMF 1r - Lane width (ft)	12	12	1
CMF 2r - Shoulder width and type			0.967
CMF wra - Right Shoulder width (ft)	6	8	0.870
CMF tra - Right Shoulder type	Paved	Composite	1.083
Right Shoulder paved pct	1	0.250	-
CMF wra - Left Shoulder width (ft)	6	8	0.870
CMF tra - Left Shoulder type	Paved	Composite	1.083
Left Shoulder paved pct	1	0.250	-
CMF 3r - Horizontal curves			1
Length of horizontal curve (mi)	0	0	-
Radius of curvature (ft)	0	0	-
Spiral transition	Not Present	Not Present	-
CMF 4r - Superelevation variance	0	0	1
CMF 5r - Grade	0	0	1
CMF 6r - Driveway density (driveways/mi)	5	5	1
CMF 7r - Centerline rumble strips	Not Present	Not Present	1
CMF 8r - Passing lanes	Not Present	Not Present	1
CMF 9r - Two-way left-turn lane	Not Present	Not Present	1
CMF 10r - Roadside hazard rating	3	3	1

Revert Export Close

Figure 16 - CMF resulted from Increasing Lane Width_Segment3

Open the “Predicted Crashes” expander, the value of the combined CMF is 0.967 (Second row) and the expected crashes adjusted for CMF is 2.512(third row).

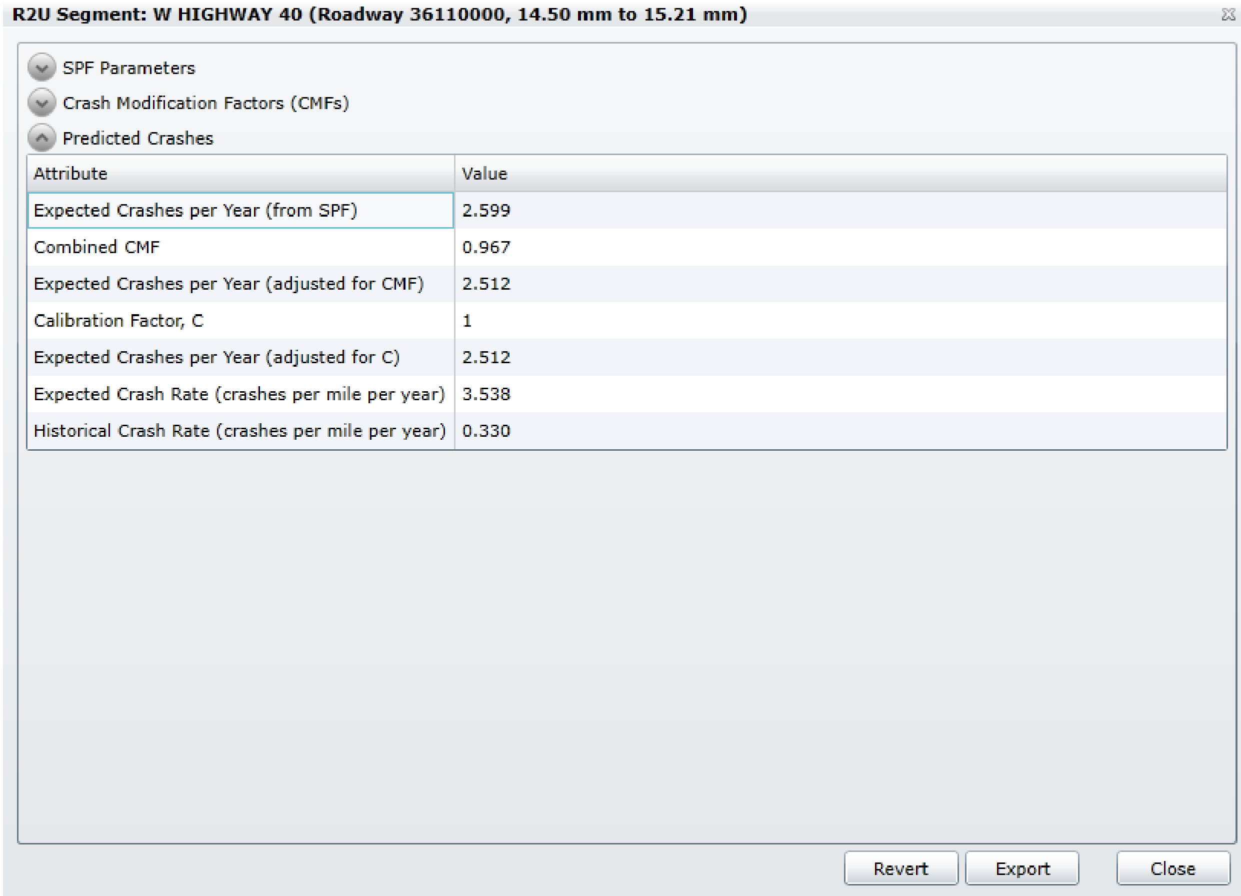
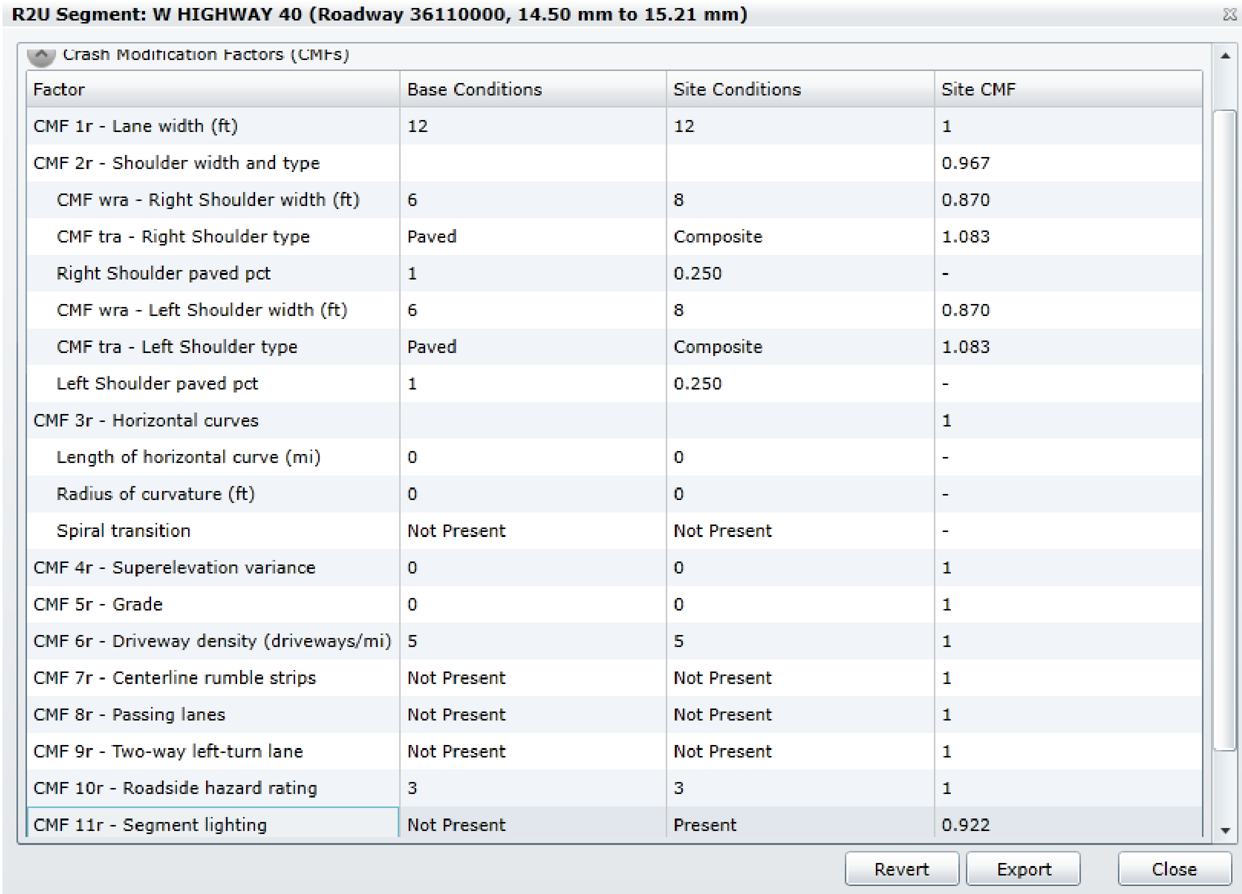


Figure 17 - Predicted Crashes resulted from Increasing Lane width

Recall that, before changing the lane width, the combined CMF was 1.133 (second row in Predicted Crashes expander) and the expected crashes adjusted for CMF is 2.944 for this segment. Therefore, the net reduction in crashes because changing lane width on this segment = (1.133 – 0.967)/1.133 = 14.65 % or a reduction of 0.431 crashes from 2.944 to 2.512 crashes.

Next, let us examine the further effect of changes to lighting conditions. Keep the lane width at the new value if 12 feet, under the Crash Modifications Factors expander, click on the cell in row “segment lighting” under column “site conditions” and change the value from “Not Present” to “Present”. Notice that the CMF changes from 1 to 0.922. The decrease in CMF indicates that the adding lighting is associated with a decrease in crashes (reduction in CMF). Since the “no lighting” is the base condition the CMF corresponding to this original state is 1.



R2U Segment: W HIGHWAY 40 (Roadway 36110000, 14.50 mm to 15.21 mm)

Crash Modification Factors (CMFs)

Factor	Base Conditions	Site Conditions	Site CMF
CMF 1r - Lane width (ft)	12	12	1
CMF 2r - Shoulder width and type			0.967
CMF wra - Right Shoulder width (ft)	6	8	0.870
CMF tra - Right Shoulder type	Paved	Composite	1.083
Right Shoulder paved pct	1	0.250	-
CMF wra - Left Shoulder width (ft)	6	8	0.870
CMF tra - Left Shoulder type	Paved	Composite	1.083
Left Shoulder paved pct	1	0.250	-
CMF 3r - Horizontal curves			1
Length of horizontal curve (mi)	0	0	-
Radius of curvature (ft)	0	0	-
Spiral transition	Not Present	Not Present	-
CMF 4r - Superelevation variance	0	0	1
CMF 5r - Grade	0	0	1
CMF 6r - Driveway density (driveways/mi)	5	5	1
CMF 7r - Centerline rumble strips	Not Present	Not Present	1
CMF 8r - Passing lanes	Not Present	Not Present	1
CMF 9r - Two-way left-turn lane	Not Present	Not Present	1
CMF 10r - Roadside hazard rating	3	3	1
CMF 11r - Segment lighting	Not Present	Present	0.922

Revert Export Close

Figure 18 - CMF resulted from Adding Lighting_Segment3

Now open the "Predicted Crashes" expander, the value of the combined CMF is 0.891 (Second row) and the expected crashes adjusted for CMF is 2.315 (third row).

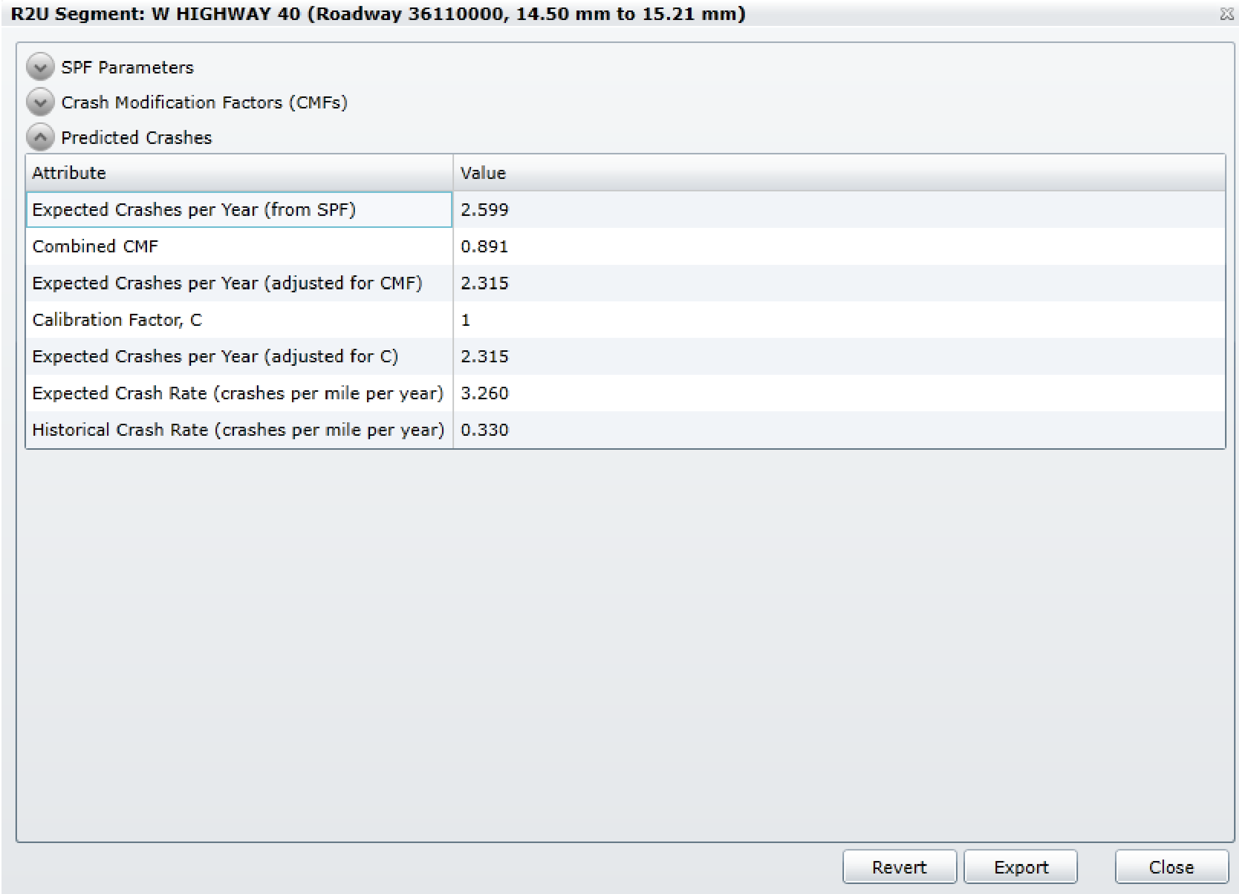


Figure 19 - Predicted Crashes resulted from Adding Lighting and Increasing Lane Width_Segment3

Recall that, before changing the lane width and lighting, the combined CMF was 1.133 (second row in Predicted Crashes expander) and the expected crashes adjusted for CMF is 2.944 for this segment. Therefore, the net reduction in crashes because of both changes = (1.133 – 0.891)/1.133 = 21.35% or a reduction of 0.63 crashes from 2.944 to 2.315 crashes.

We encourage you to explore the methods further by changing more site condition variables and/or using a different site to do the analysis. The list of possible values that the site condition variables can take for each attribute representing a CMF is presented below. The list of all segments included in this tool has been described in Section 2. You can use the export button to save a copy of any analysis locally and the revert button to rest the window to the default conditions of the site.

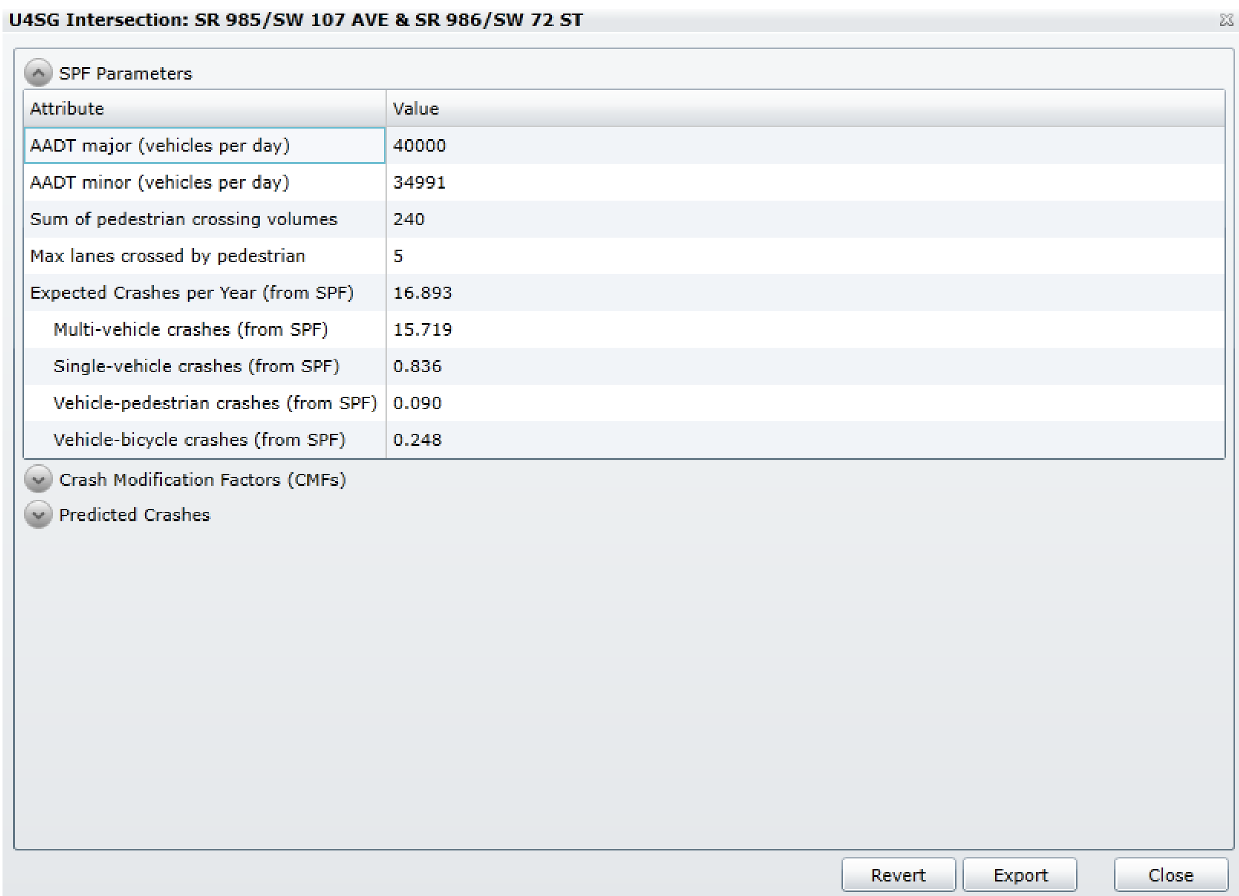
Identifier	Factor	Possible Values of Site Conditions
CMF 1r	Lane Width	9 to 12
CMF 2r	Shoulder Width& Type	-
CMF wra	Shoulder Width	Non negative, maximum effective sets to 8
CMF tra	Shoulder Type	Non, Paved, Gravel, Composite, Turf
	Shoulder paved ratio	0 to 1
CMF 3r	Horizontal Curves	-
	Length of Horizontal Curves	Non negative, if present the minimum sets to 100ft(0.019mi)
	Radius of Curvature	Non negative, if present the minimum sets to 100ft(0.019mi)
	Spiral Transition	Not present, present one end, present both ends
CMF 4r	Super Elevation Variance	-
CMF 5r	Grade	Non negative
CMF 6r	Driveway Density	Non negative
CMF 7r	Centerline Rumble Strips	Not present, present
CMF 8r	Passing Lanes	Not present, present one lane, present two lanes
CMF 9r	Two-Way Left-Turn Lane	Not present, present
CMF 10r	Roadside Hazard Rating	1 to 7
CMF 11r	Segment Lighting	Not present, present
CMF 12r	Auto Speed Enforcement	Not present, present

Table 3 - CMFs Possible Values for Segments

Chapter 4. ANALYSIS OF INTERSECTIONS

This chapter presents an overview on how the software can be used for the predictive analysis of crashes on intersections. From the main window, click on U4SG Intersections and then click on Intersection ID 5 (Figure on Chapter 2 indicates the location of Intersection 5). A new "analysis" window pops up with the details about this intersection. The title bar of this window identifies the intersection (SR 985 and SR 986 or SW 107 Ave and SW 72 Street). As in the case of Segments, The window comprises three vertical Expander controls. These are "Safety Performance Function", Crash Modification Factors" and "Predicted Crashes". Each of these may be expanded or collapsed using the arrow buttons

Under the "Safety Performance Function" Expander, the traffic volumes on the major and minor approaches are listed as the first two rows. The pedestrian volume and the maximum number of lanes that a pedestrian has to cross are presented in the next two rows. These are the basic exposure variables needed for applying the safety performance function.



Attribute	Value
AADT major (vehicles per day)	40000
AADT minor (vehicles per day)	34991
Sum of pedestrian crossing volumes	240
Max lanes crossed by pedestrian	5
Expected Crashes per Year (from SPF)	16.893
Multi-vehicle crashes (from SPF)	15.719
Single-vehicle crashes (from SPF)	0.836
Vehicle-pedestrian crashes (from SPF)	0.090
Vehicle-bicycle crashes (from SPF)	0.248

Figure 20 - SPF Expander _Intersection5

The crashes on urban 4-leg signal controlled intersections are obtained by summing up four components (represented on four separate rows preceded by the total crashes): single vehicle crashes, multi-vehicle crashes, vehicle-pedestrian crashes and vehicle-bicycle crashes. Each of these types of crashes have separate equations. Click on the corresponding row and a new window pops us showing the actual formula used in these calculation. Click on close to revert back to the analysis window.

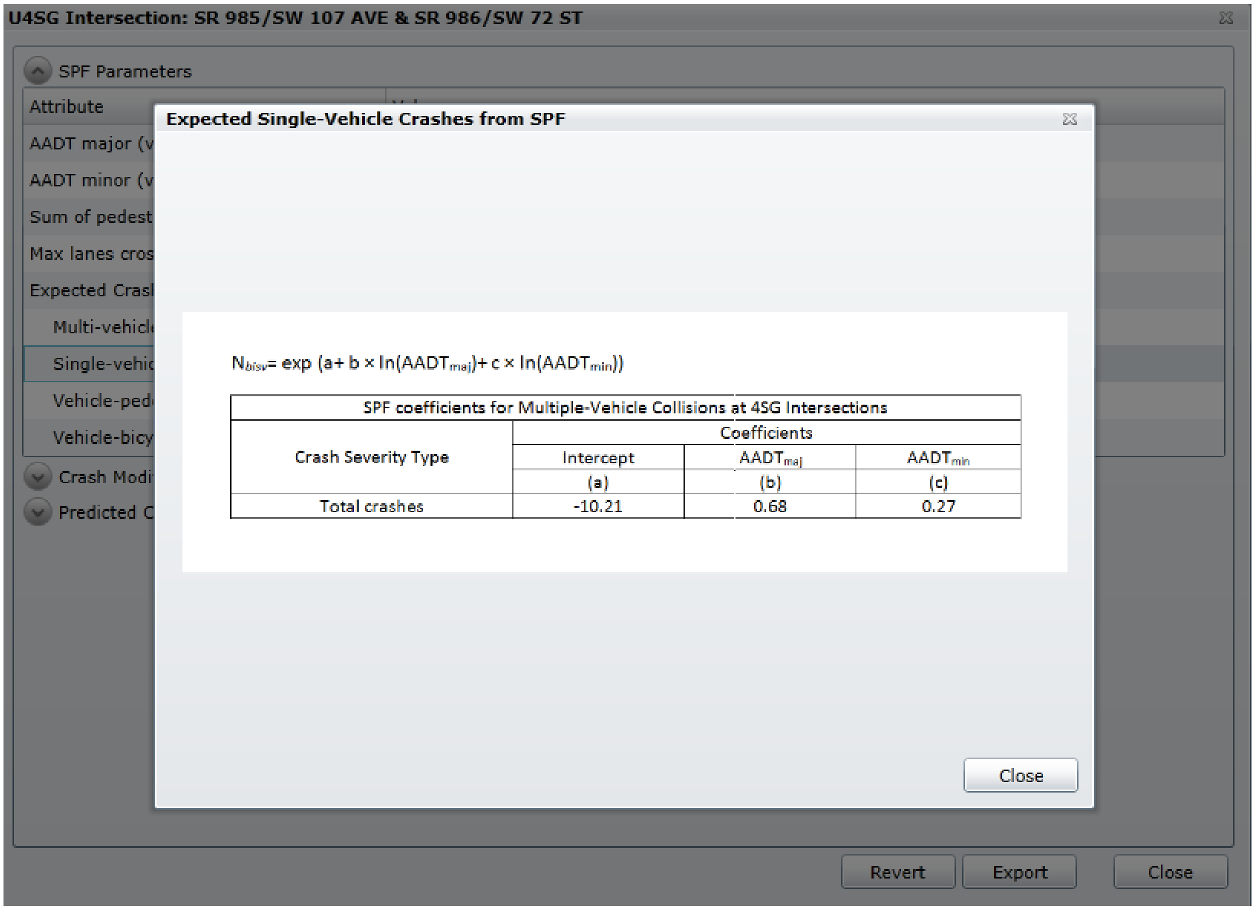
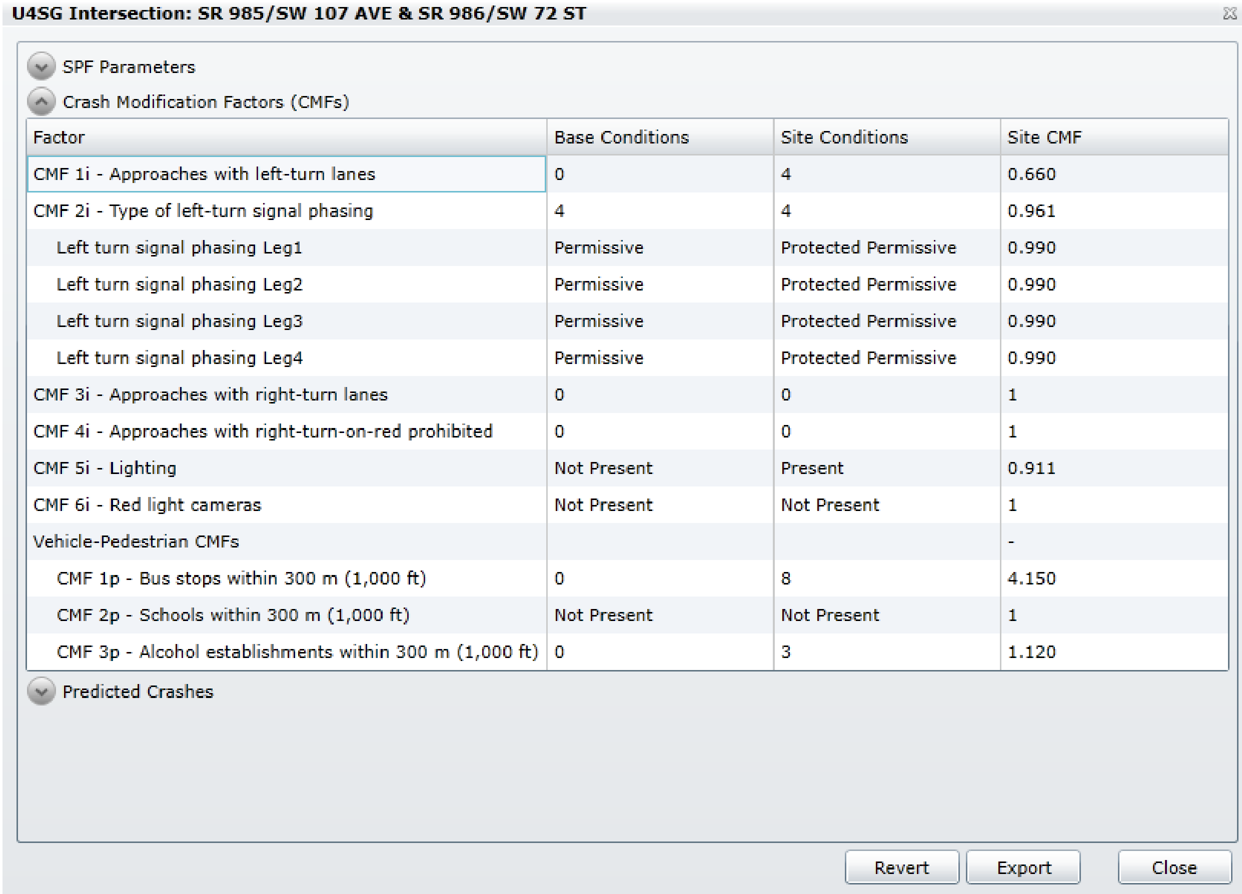


Figure 21 - SPF Formula for Single-Vehicle Crashes

Next, expand the "crash modification factors" Expander by clicking on the arrow button. This grid has four columns. The first column identifies the factors, the second defines the base condition for these factors as assumed in the SPF, the third shows data on the actual site conditions on these factors, and the final column presents the CMFs for each factor. Notice that the CMF is 1 if the site condition is the same as the base condition.



U4SG Intersection: SR 985/SW 107 AVE & SR 986/SW 72 ST

SPF Parameters

Crash Modification Factors (CMFs)

Factor	Base Conditions	Site Conditions	Site CMF
CMF 1i - Approaches with left-turn lanes	0	4	0.660
CMF 2i - Type of left-turn signal phasing	4	4	0.961
Left turn signal phasing Leg1	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg2	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg3	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg4	Permissive	Protected Permissive	0.990
CMF 3i - Approaches with right-turn lanes	0	0	1
CMF 4i - Approaches with right-turn-on-red prohibited	0	0	1
CMF 5i - Lighting	Not Present	Present	0.911
CMF 6i - Red light cameras	Not Present	Not Present	1
Vehicle-Pedestrian CMFs			-
CMF 1p - Bus stops within 300 m (1,000 ft)	0	8	4.150
CMF 2p - Schools within 300 m (1,000 ft)	Not Present	Not Present	1
CMF 3p - Alcohol establishments within 300 m (1,000 ft)	0	3	1.120

Predicted Crashes

Revert Export Close

Figure 22 - CMF Expander_ Intersection5

There are two categories of factors / CMFs in this expander window. Those that are applicable only to vehicle-pedestrian crashes are listed at the bottom (CMF 1p, CMF 2p and CMF 3p) and these include bus stops, schools, and alcohol establishments. Notice that in the “base conditions” it is assumed that there are no schools, bus stops, or alcohol establishments nearby. If any are present, the corresponding CMFs are greater than 1 indicating the increasing frequency of vehicle-pedestrian crashes with greater exposure to pedestrians. Click on the cell “Bus Stops” and a new window pops up which presents the exact formula used for calculating the CMF. Click on close to revert back to the analysis window.

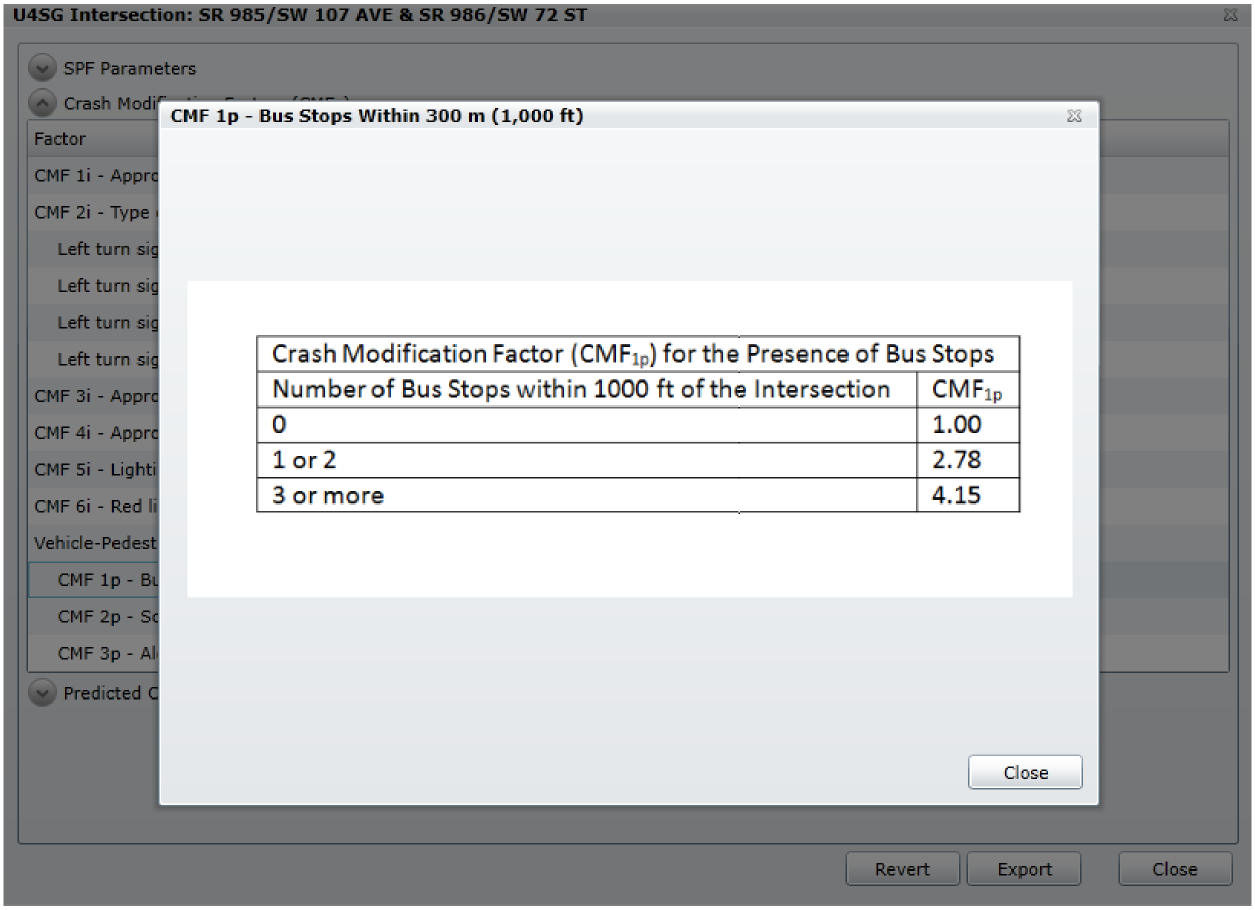


Figure 23 - CMF Formula for Bus Stops _Intersection 5

The factors and CMFs included in the top portion of the window (CMF 1i through CMF 6i) are applicable for the other three types of crashes (single vehicle, multi-vehicle, and vehicle-bicycle). For instance, the first factor is number of left-turn lanes. The base-conditions in which the SPFs were derived assume no approach has left turn lanes – therefore the corresponding CMF is 1. In this intersection, all approaches have left turn lanes resulting in a CMF of 0.66 indicating the safety benefits of left-turn lanes. Note that you can see the formula for calculating the CMFs associated with left turn lanes by clicking on the cell “Approaches with Left Turn Lanes”. As always click close to revert back to the analysis window.

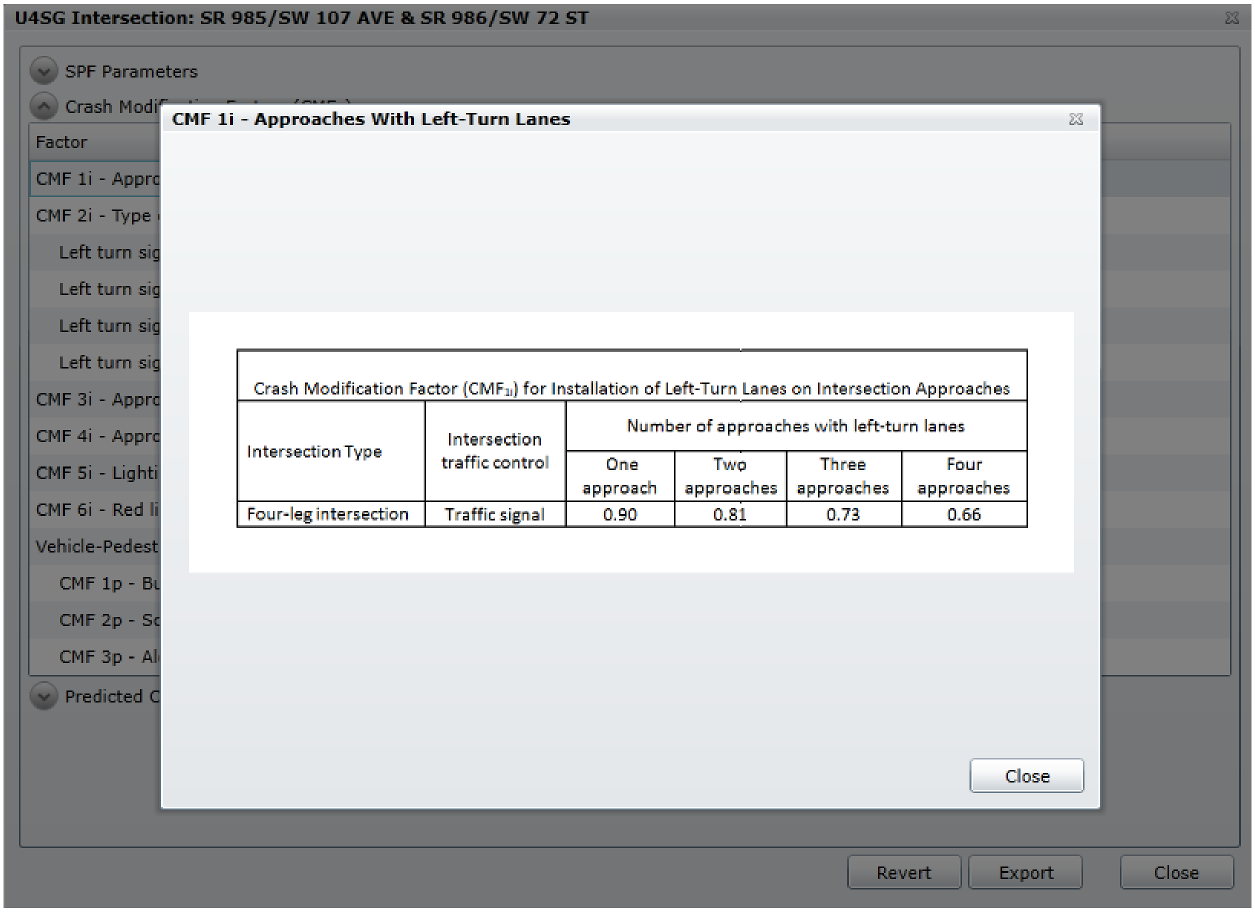


Figure 24 - CMF Formula for Left-Turn lanes on Intersection Approaches

Finally, expand the Predicted Crashes Expander. The structure of this grid is similar to that of the "Safety Performance Functions" (the first tab) and has two columns, the attributes and the values.

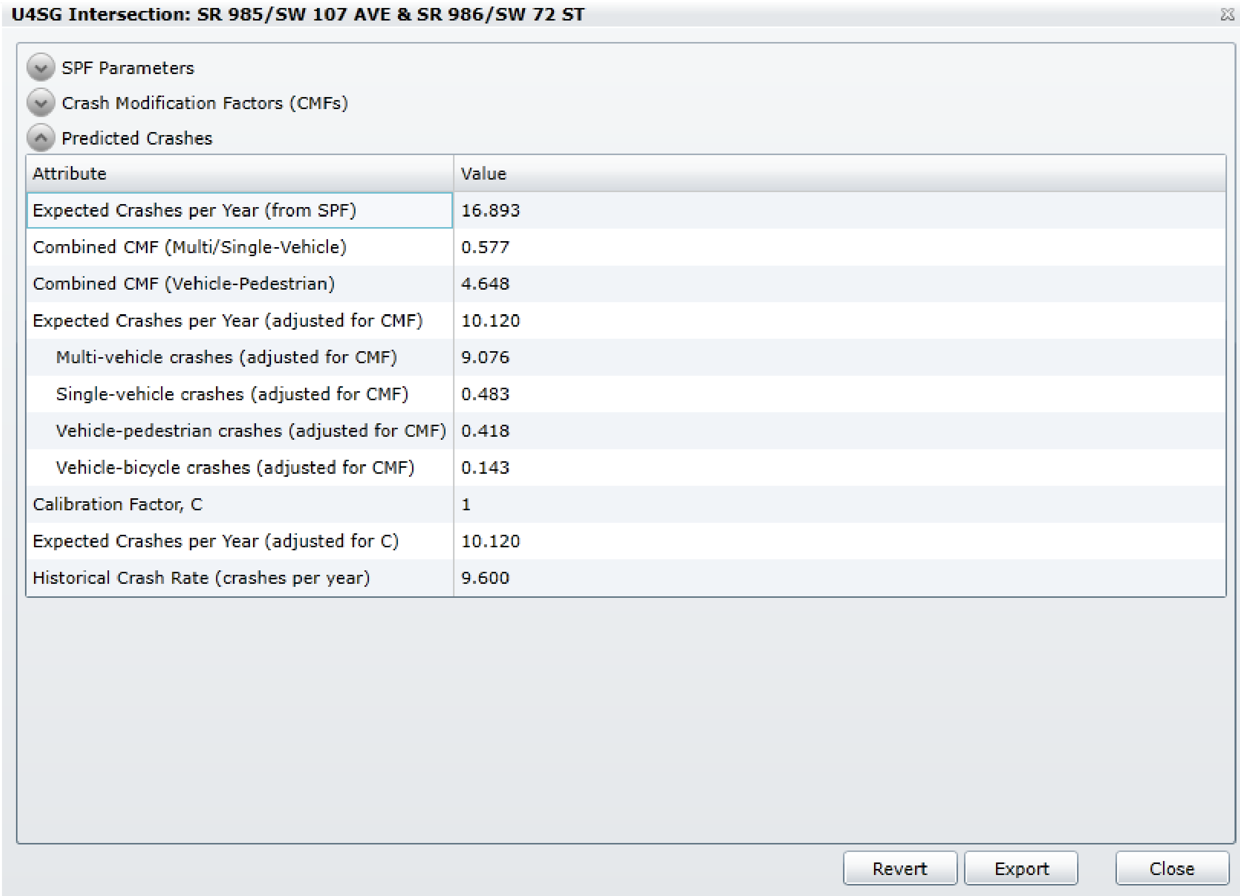


Figure 25 - Predicted Crashes Expander _Intersection 5

The first row is simply the total predicted crashes obtained by applying and summing the four (one for each type of crashes) SPFs (also shown in the "Safety Performance Functions" expander. As already indicated, some CMF apply only for vehicle-pedestrian crashes and others apply for the other –three types of crashes. Therefore, there are two values of "combined CMFs" presented. The first (applicable for non-pedestrian crashes) is the product of 6 individual CMFs and the second (applicable only for vehicle-pedestrian crashes) is a product of 3 individual CMFs. Subsequently, expected crashes of each type are scaled by the appropriate combined CMFs. The ninth row is the calibration factor. While the default value is set to 1, the user may modify based on local conditions. Florida-specific calibration factors by facility type and location are also available[8]. The tenth row presents the predicted crashes from SPF after it is scaled by applying the combined CMF and the calibration factor. The final row presents the observed crash rate for this segment (for use in Empirical Bayes Analysis to be implemented in future versions of the module).

Let us now perform some what-if analysis. Recall that none of the changes made by the user are automatically saved. Therefore, the "export" button should be used to save a copy of the results

[8] http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BDK77_977-06_rpt.pdf

for any of the revised cases locally if so desired. The default data stored internally in the software is never overwritten even if changes are made via the User Interface. The data displayed can quickly be reset to the original site conditions by clicking the Revert button at the bottom left of the analysis window.

First, let us change an attribute that impacts only vehicle-pedestrian crashes. Under the normal conditions of the site, there are no schools near the intersection and, hence the corresponding CMF is 1. The combined CMF-for vehicle-pedestrian crashes is 4.648 and the expected vehicle-pedestrian crashes (adjusted for CMFs) is 0.418.

In the Crash Modifications Factors expander, click on the cell in row "schools within 300m" under column "site conditions" and change the value from "Not Present" to "Present". Notice that the CMF changes from 1 to 1.350. The increase in CMF indicates that presence of schools is associated with an increase in crashes. Since the "no school" is the base condition, the CMF corresponding to this original state was 1.

U4SG Intersection: SR 985/SW 107 AVE & SR 986/SW 72 ST

SPF Parameters

Crash Modification Factors (CMFs)

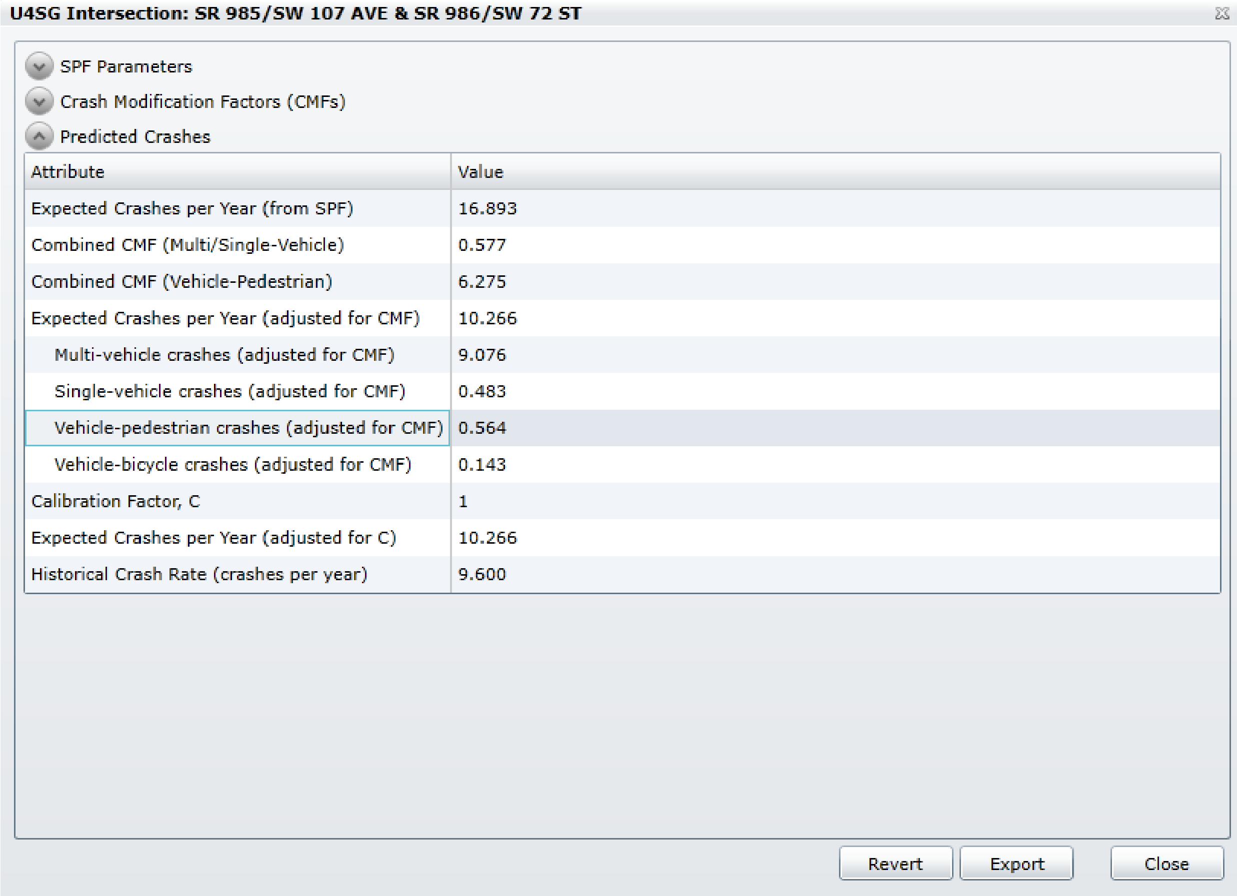
Factor	Base Conditions	Site Conditions	Site CMF
CMF 1i - Approaches with left-turn lanes	0	4	0.660
CMF 2i - Type of left-turn signal phasing	4	4	0.961
Left turn signal phasing Leg1	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg2	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg3	Permissive	Protected Permissive	0.990
Left turn signal phasing Leg4	Permissive	Protected Permissive	0.990
CMF 3i - Approaches with right-turn lanes	0	0	1
CMF 4i - Approaches with right-turn-on-red prohibited	0	0	1
CMF 5i - Lighting	Not Present	Present	0.911
CMF 6i - Red light cameras	Not Present	Not Present	1
Vehicle-Pedestrian CMFs			-
CMF 1p - Bus stops within 300 m (1,000 ft)	0	8	4.150
CMF 2p - Schools within 300 m (1,000 ft)	Not Present	Present	1.350
CMF 3p - Alcohol establishments within 300 m (1,000 ft)	0	3	1.120

Predicted Crashes

Revert Export Close

Figure 26 - CMF resulted from Adding School_Intersection5

Now open the predicted crashes expander. Notice that the combined CMF for vehicle-pedestrian crashes is now 6.275 (up from 4.64 in the original case). The expected vehicle-pedestrian crashes adjusted for CMFs is now 0.564 (up from 0.418). Notice that the combined CMF single/multi-vehicle crashes does not change.



Attribute	Value
Expected Crashes per Year (from SPF)	16.893
Combined CMF (Multi/Single-Vehicle)	0.577
Combined CMF (Vehicle-Pedestrian)	6.275
Expected Crashes per Year (adjusted for CMF)	10.266
Multi-vehicle crashes (adjusted for CMF)	9.076
Single-vehicle crashes (adjusted for CMF)	0.483
Vehicle-pedestrian crashes (adjusted for CMF)	0.564
Vehicle-bicycle crashes (adjusted for CMF)	0.143
Calibration Factor, C	1
Expected Crashes per Year (adjusted for C)	10.266
Historical Crash Rate (crashes per year)	9.600

Figure 27 - Predicted Crashes resulted from Adding School

Next, let us examine an attribute that impacts non-pedestrian crashes. Click on the revert button to reset the data to original site conditions. In the Crash Modifications Factors expander, click on the cell in row “approaches with right turn on red prohibited” under column “site conditions” and change the value from “0” to “4”. Notice that the CMF changes from 1 to 0.656 (The user may click on the cell “approaches with right turn on red prohibited” to see the actual formula used to produce this change. The decrease in CMF indicates that prohibiting right turn on red is associated with a decrease in crashes.

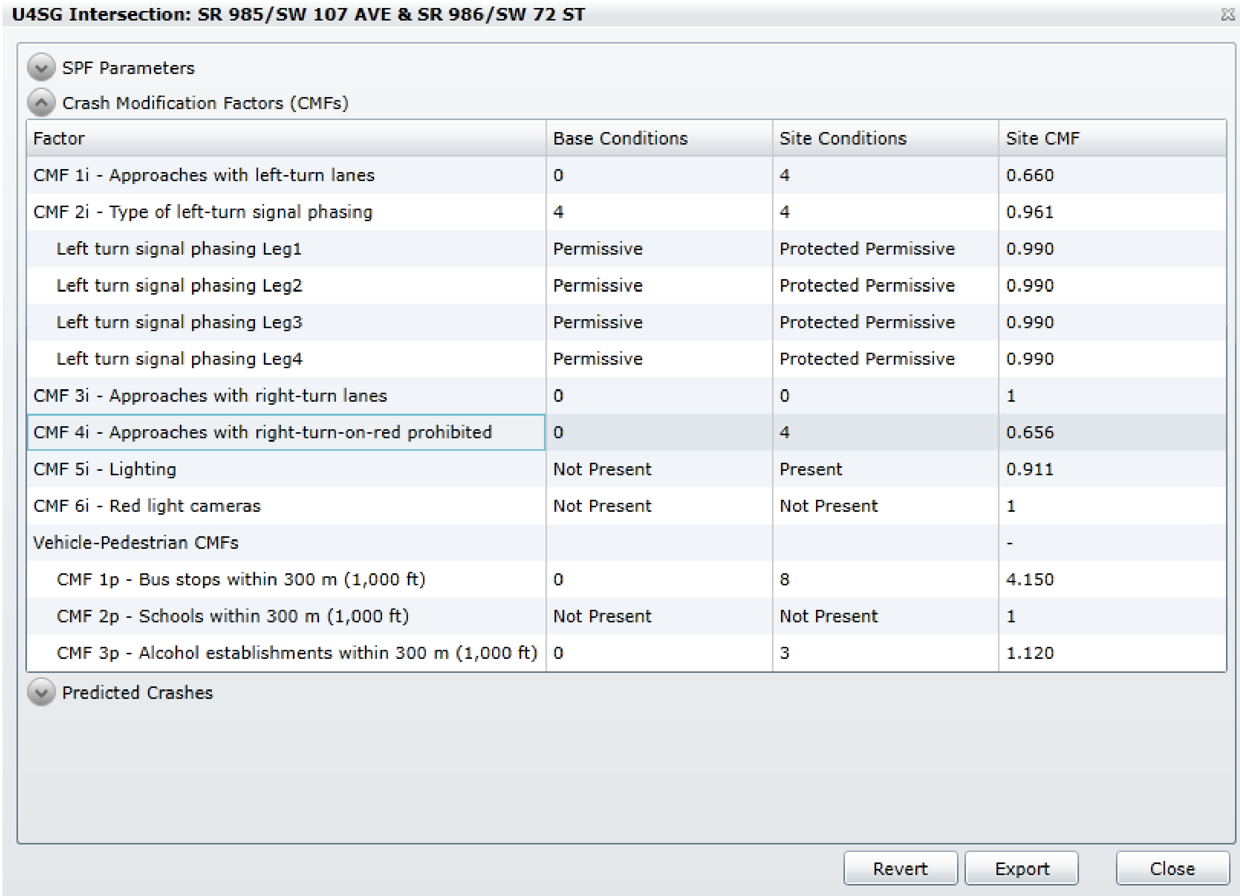
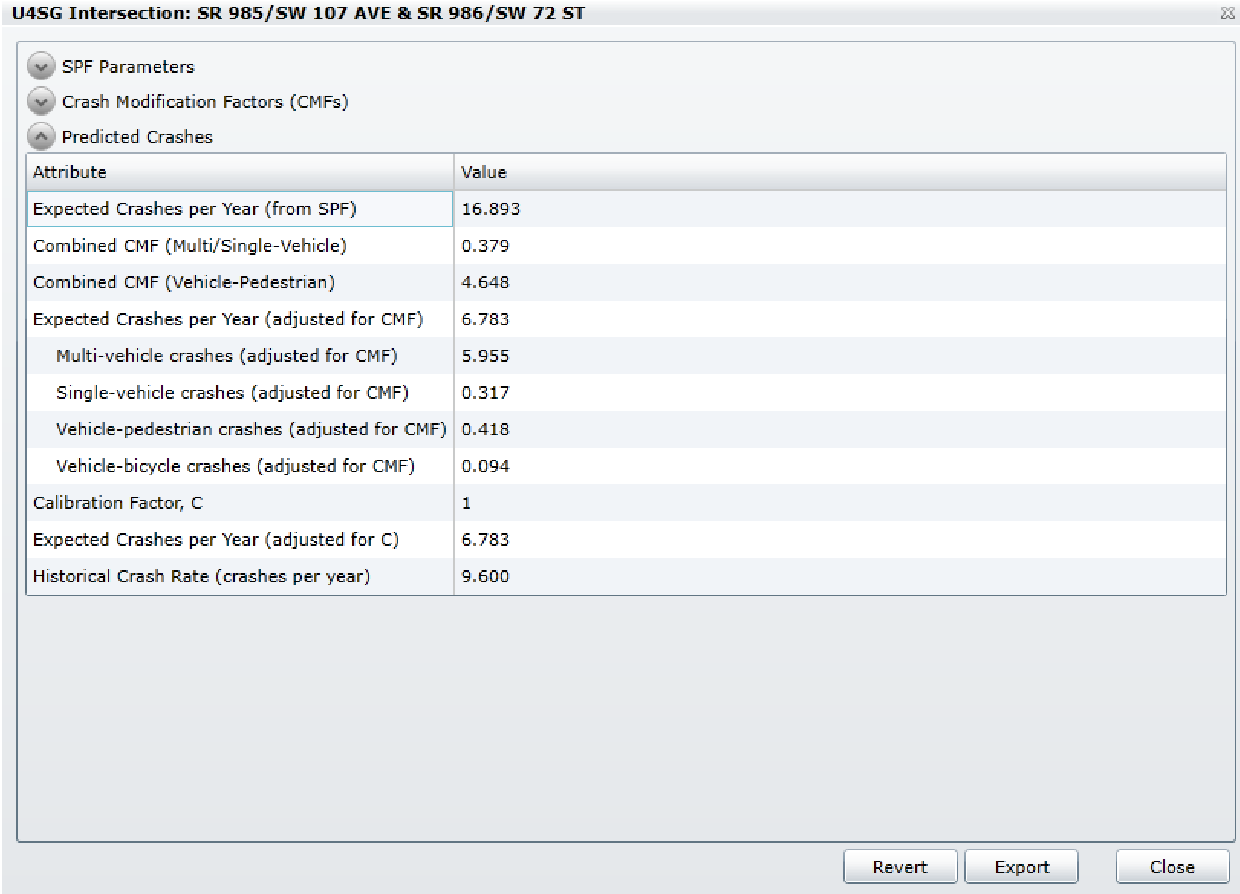


Figure 28 - CMF resulted from Adding 4 approaches with Right-Turn-on-Red Prohibited_ Intersection 5

Now open the predicted crashes expander. Notice that the combined CMF for single/multi-vehicle crashes is now 0.379 (down from 0.577 in the original case). Notice that the combined CMF for vehicle-pedestrian crashes does not change.



U4SG Intersection: SR 985/SW 107 AVE & SR 986/SW 72 ST

SPF Parameters

Crash Modification Factors (CMFs)

Predicted Crashes

Attribute	Value
Expected Crashes per Year (from SPF)	16.893
Combined CMF (Multi/Single-Vehicle)	0.379
Combined CMF (Vehicle-Pedestrian)	4.648
Expected Crashes per Year (adjusted for CMF)	6.783
Multi-vehicle crashes (adjusted for CMF)	5.955
Single-vehicle crashes (adjusted for CMF)	0.317
Vehicle-pedestrian crashes (adjusted for CMF)	0.418
Vehicle-bicycle crashes (adjusted for CMF)	0.094
Calibration Factor, C	1
Expected Crashes per Year (adjusted for C)	6.783
Historical Crash Rate (crashes per year)	9.600

Revert Export Close

Figure 29- Predicted Crashes resulted from Adding 4 approaches with Right-Turn-on-Red Prohibited Intersection 5

We encourage you to explore the methods further by changing more site condition variables and/or using a different site to do the analysis. The list of possible values that the site condition variables can take for each attribute representing a CMF is presented below. The list of all segments included in this tool has been described in Section 2. You can use the export button to save a copy of any analysis locally and the revert button to rest the window to the default conditions of the site.

Identifier	Factor	Possible Values of Site Conditions
CMF 1i	Approaches with Left Turn Lanes	0,1,2,3,4
CMF 2i	Type of Left Turn Signal Phasing	
	Left Turn Signal Phasing leg_i	None, Permissive, Protected, Protected Permissive, Permissive Protected
CMF 3i	Approaches with Right Turn Lanes	0,1,2,3,4
CMF 4i	Approaches with Right Turn on Red Prohibited	0,1,2,3,4
CMF 5i	Lighting	Not present, Present
CMF 6i	Red Light Camera	Not present, Present
CMF 1p	Bus Stops within 300m	None negative
CMF 2p	Schools within 300m	Not present, Present
CMF 3p	Alcohol sales establishments within 300 m	None negative

Table 4 - CMFs Possible Values for Intersections

Chapter 5. CONCLUSIONS AND FUTURE WORK

The effort in this study resulted in two outcomes: a) Developed an architectural software framework that implements HSM Part C methods in a GIS context and b) Implemented this framework into a functional self-learning instructional tool. The instructional tool is operational and available at **https://s4.geoplan.ufl.edu/analytics-stride/**. Users can simply access the tool's website and use it to explore and understand the HSM-based predictive methods currently applied to rural two-lane undivided highways and to urban four-leg signalized intersections, using selected segments and intersections in Florida. The directions for a self-learning tutorial are provided in Chapters 3 and 4.

We acknowledge a few shortcomings of the study which mostly are a reflection of the limited scope of this work. Nevertheless, we made an effort to design this work in such a way that these limitations can be turned into opportunities to expand the tool in the future:

First, at this time, the tool can be used to explore a limited number of facilities. This presents the opportunities for one of the future work items: expand the tool to implement all the HSM Part C methods. The software architectural framework is intentionally designed to support this expansion relatively easily. We envision gradually adding or "plugging" the rest of the HSM Part C methods.

Second, at present the tool cannot be used as a safety assessment tool. Although this limitation was "by design" due to limited scope, we considered this need during the design of the software architecture in such a way that this capability can be easily added in the future without requiring a rewrite or major modifications of the software. The computational engine of the tool is modular and insulated from the user interface. As such, a front-end user interface can be added for project evaluation without making changes to the computational engine, but rather, easily using it to evaluate any segment or combination of segments or intersections on the network. Obviously, this will require the supporting network data to allow the user to select segments of choice rather than be limited to pre-packaged instructional data provided at present. And, as the tool transition from its instructional scope to a project evaluation scope, additional functions and supporting data should be considered. Additional reference data of interest could include site conditions (e.g. alcohol establishments, left turn lanes, driveways), historic crashes etc.

Other improvements that can make the tool more robust is to replace free text variables with drop down menus (Permissive, Protected etc.), addition of a graph or other functions to visualize predicted crashes, inclusion of historic crashes etc.

Another future improvement could add formal instructional plans and a sample application and associated discussion.