Intersection Cost Comparison Spreadsheet User Manual

ROUNDABOUT GUIDANCE
VIRGINIA DEPARTMENT OF TRANSPORTATION

Version 2.5

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Section 1
Introduction

INTRODUCTION

The Intersection Cost Comparison Spreadsheet is a tool that compares the life cycle cost of a roundabout to that of a signalized or stop-controlled intersection. Within this manual and the spreadsheet, signalized and stop-controlled intersections are referred to as "traditional intersections". The purpose of the spreadsheet is to objectively consider roundabouts within the intersection planning process, and to consider multiple factors that will inform the selection of intersection control.

The spreadsheet analyzes costs associated with:

- Safety
- Vehicular delay
- Operations and maintenance
- Capital design and construction costs
- Right-of-way costs

Some costs are directly entered by the user, and others are computed by the spreadsheet based on typical costs in Virginia or nationwide.

The spreadsheet is not intended to be the only tool used to select intersection form. Public/stakeholder input, availability of capital funds, and availability of right-of-way are some of the many factors that also influence the selection of intersection form but are not directly incorporated into this spreadsheet.

This User Manual serves as a guide to the spreadsheet tool. Section 2 presents the concepts and methodologies used to compare intersection forms and compute costs. Section 3 presents step-by-step instructions for use of the spreadsheet. Section 4 presents three examples illustrating use of the spreadsheet.

This is version 2.5 of the User Manual, and it corresponds with version 2.5 of the spreadsheet.

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Section 2
Concepts Overview

CONCEPTS OVERVIEW

This section presents the scope of the spreadsheet's analysis procedures, the methodologies used to compare intersection forms, and the methodologies used to convert performance measures to dollar amounts.

SCOPE AND TYPES OF COMPARISON

The spreadsheet compares a roundabout to a traditional intersection alternative. At this time, the spreadsheet is only capable of comparing two alternatives, and one must be a roundabout.

The spreadsheet supports three types of comparisons, referred to as Cases 1, 2, and 3. The cases are intended to encompass the range of situations in which a roundabout might be considered. Users select the type of comparison (i.e., the case) they wish to conduct at the start of data entry. The differentiation between cases is based on the existing intersection control and options under consideration. Determining a case for analysis purposes primarily informs safety analysis methods. The three cases are defined below and explained in detail in the following sections.

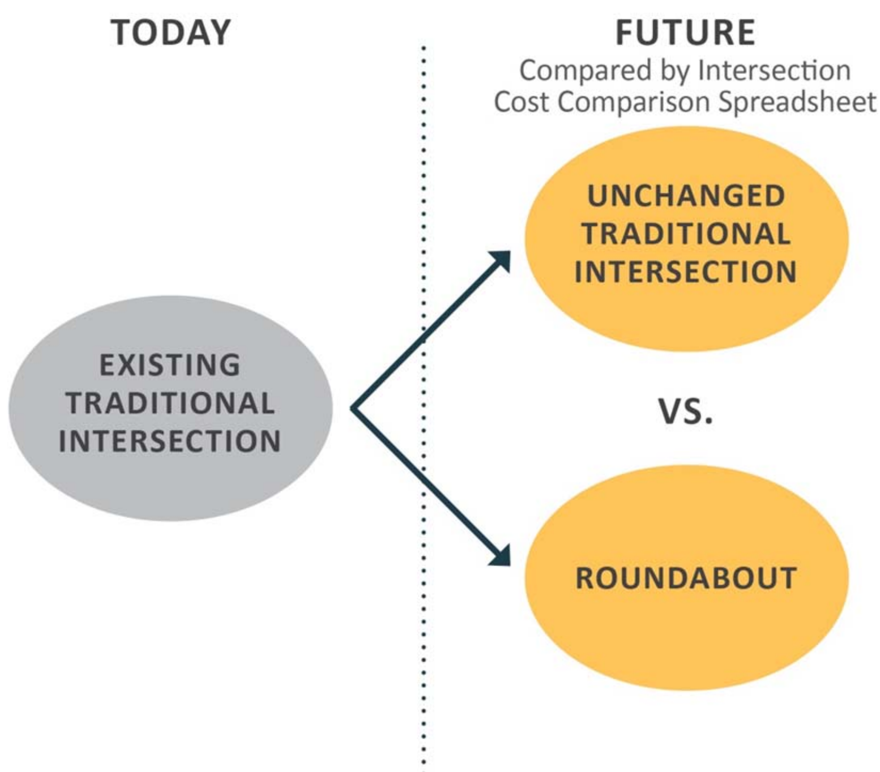
Case 1: an existing traditional intersection vs. a roundabout option

Case 2: a traditional intersection option vs. a roundabout option (at the site of an existing traditional intersection)

Case 3: a traditional intersection option vs. a roundabout option (at a site where there is currently no intersection)

Case 1 compares an existing traditional intersection (e.g., stop-controlled or signalized) to a roundabout option. In other words, an existing signalized or stop-controlled intersection is assumed to remain the same or to be converted to a roundabout. Case 1 may be used in a roundabout screening study in which a District or local jurisdiction either has available funds to construct one roundabout and is considering multiple sites. The right half of Figure 1 illustrates the two intersection forms in a Case 1 comparison.

Figure 1. Case 1 Comparison

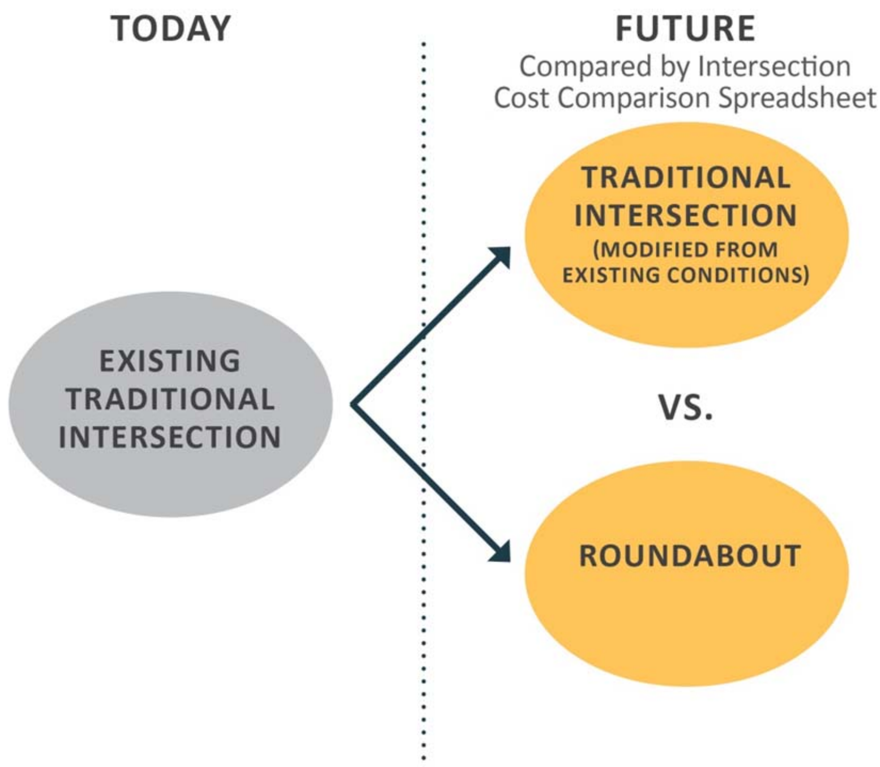


Case 2 compares a traditional intersection option to a roundabout option at the site of an existing traditional intersection. Two examples in which a Case 2 comparison may be applied are:

- A District plans to improve an existing stop-controlled intersection by converting to a signal or converting to a roundabout. The spreadsheet compares the signal operation to the roundabout.
- A District plans to improve an existing stop-controlled intersection by adding turn lanes (while maintaining stop control) or converting to a roundabout.

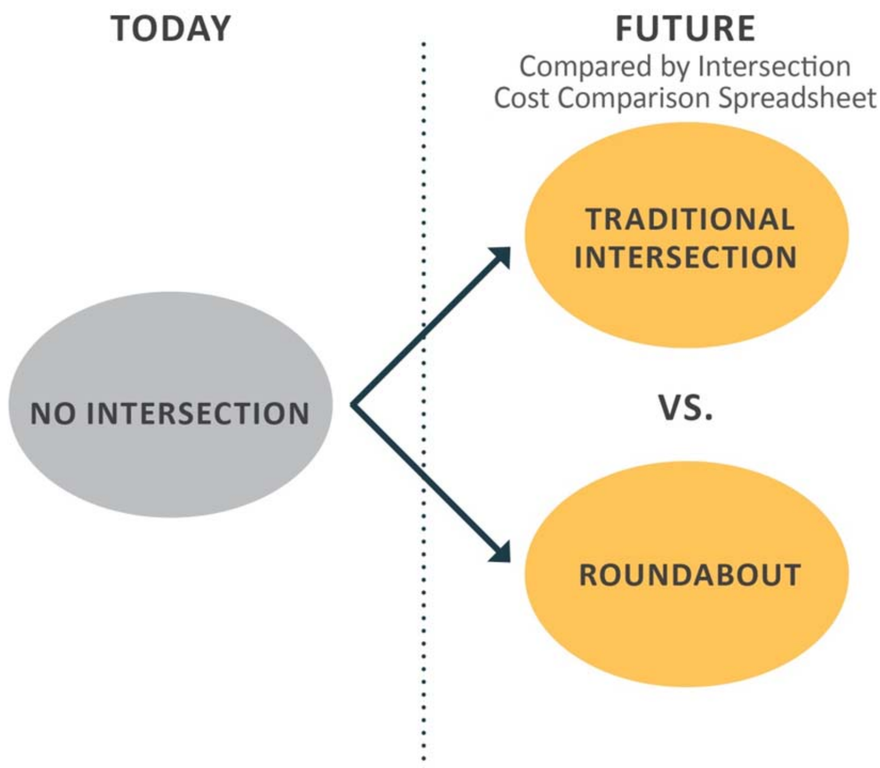
The right half of Figure 2 illustrates the two intersection forms in a Case 2 comparison.

Figure 2. Case 2 Comparison



Case 3 compares a traditional intersection option to a roundabout option at a site where there is currently no intersection. Case 3 comparisons may be applied to intersections along new roadways or new intersections on existing roadways, such as access points to developments. The right half of Figure 3 illustrates the two intersection forms in a Case 3 comparison.

Figure 3. Case 3 Comparison



COMPARISON PROCESSES AND METRICS

Throughout the comparisons, four metrics are utilized: safety, delay, operations and maintenance costs, and initial capital costs. The methodology used for each of these comparisons is described below. Of the four metric methodologies, the methodology pertaining to safety is the most complex and computationally intense.

Safety

The spreadsheet uses the crash prediction methodology from the Highway Safety Manual (HSM). Crash frequency and severity at traditional intersections is predicted using safety performance functions (SPFs). SPFs are regression equations that estimate the frequency and severity of crashes based on multiple factors, including intersection geometry, lane configuration, and traffic volume. SPFs in the HSM are based on national research and are intended to reflect a range of driver and roadway characteristics.

In the spreadsheet, crash frequency and severity for a roundabout is estimated by applying crash modification factors (CMFs) to the predicted crash frequency of the existing (traditional) intersection. CMFs are provided in Part D of the HSM for converting stop-controlled or signalized intersections to roundabouts. A range of CMFs are available to account for area type (rural, urban, or suburban) and number of lanes in the roundabout. The CMFs in the HSM were originally developed as part of NCHRP Report 572: Roundabouts in the United States. CMFs are multiplicative factors used to compute the expected number of crashes at a site after a given countermeasure is implemented. For example, if an intersection experienced an average of 20 crashes per year and a treatment with a CMF of 0.50 was installed, an average of 10 crashes per year would be expected at the intersection in future years.

While the crash prediction methodology in the HSM is recognized as the best available, the First Edition of the HSM only includes SPFs for a limited number of intersection types. For situations in which SPFs are not available, the spreadsheet uses historical crash data to estimate future safety performance. The spreadsheet warns users when this occurs, because there is considerable uncertainty in the results for reasons related to regression to mean (discussed later in this manual).

When appropriate crash prediction models are not available to predict crash frequency for both the traditional intersection and the roundabout, safety is excluded from the overall intersection life cycle cost comparison.

Traditional Intersection Crash Prediction

Part C of the HSM provides SPFs for various intersection forms on three types of roadways: two-lane rural highways, multi-lane rural highways, and urban and suburban arterials. Table 1 lists the facility and intersection types for which SPFs are available. SPFs for other intersection forms will be included in future editions of the HSM.

The classification of an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population, and land uses, and is at the user's discretion. In the HSM, the definitions of "urban" and "rural" areas are based upon Federal Highway Administration (FHWA) guidelines, which classify "urban" areas as places inside urban boundaries where population is greater than 5,000 persons. "Rural" areas are defined as places outside urban areas where the population is less than 5,000. The HSM uses the term "suburban" to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area (Highway Safety Manual, 2010).

Table 1. SPF Availability for Traditional Intersections

	3 leg TWSC	4 leg TWSC	3 leg AWSC	4 leg AWSC	3 leg signal	4 leg signal
Rural Two-lane, Two-Way	SPF	SPF	No SPF	No SPF	No SPF	SPF
Rural Multi-Lane	SPF	SPF	No SPF	No SPF	No SPF	SPF
Urban and Suburban Arterials	SPF	SPF	No SPF	No SPF	SPF	SPF

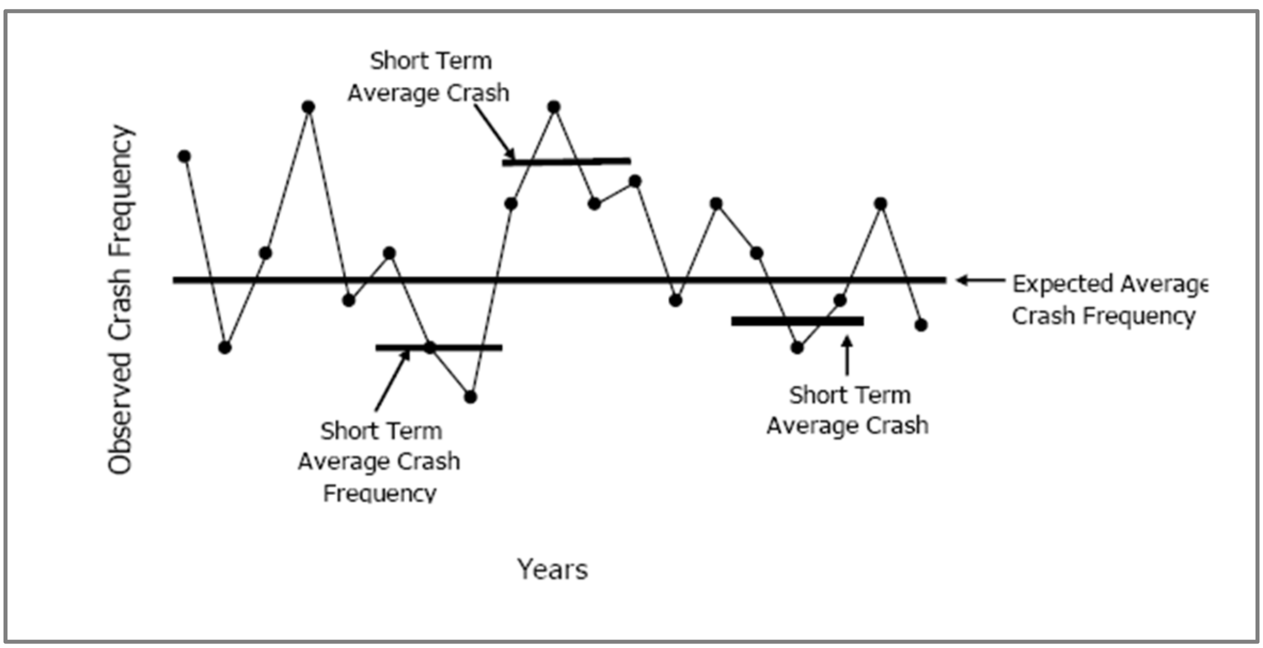
For each combination of facility and intersection type for which an SPF is available, the HSM predicts the expected number of Property Damage Only (PDO) crashes as well as the combined number of fatal and injury (FI) crashes.

The SPFs in the HSM assume certain base conditions related to lane configurations and geometry, as defined in Part C of the HSM. To account for variations between the study site and the SPF base conditions CMFs from Part C are applied in the spreadsheet. To avoid confusion with HSM Part D CMFs, Part C CMFs are generally referred to as “SPF Adjustments” in the spreadsheet.

In general, the HSM recommends that “default” SPFs in the manual be calibrated to local conditions or replaced with locally-derived SPFs. VDOT does not have calibration factors for HSM SPFs at present and uncalibrated SPFs from the HSM are used in the spreadsheet tool. The results of this spreadsheet should only be used in relative terms, to compare one alternative to another or one site to another.

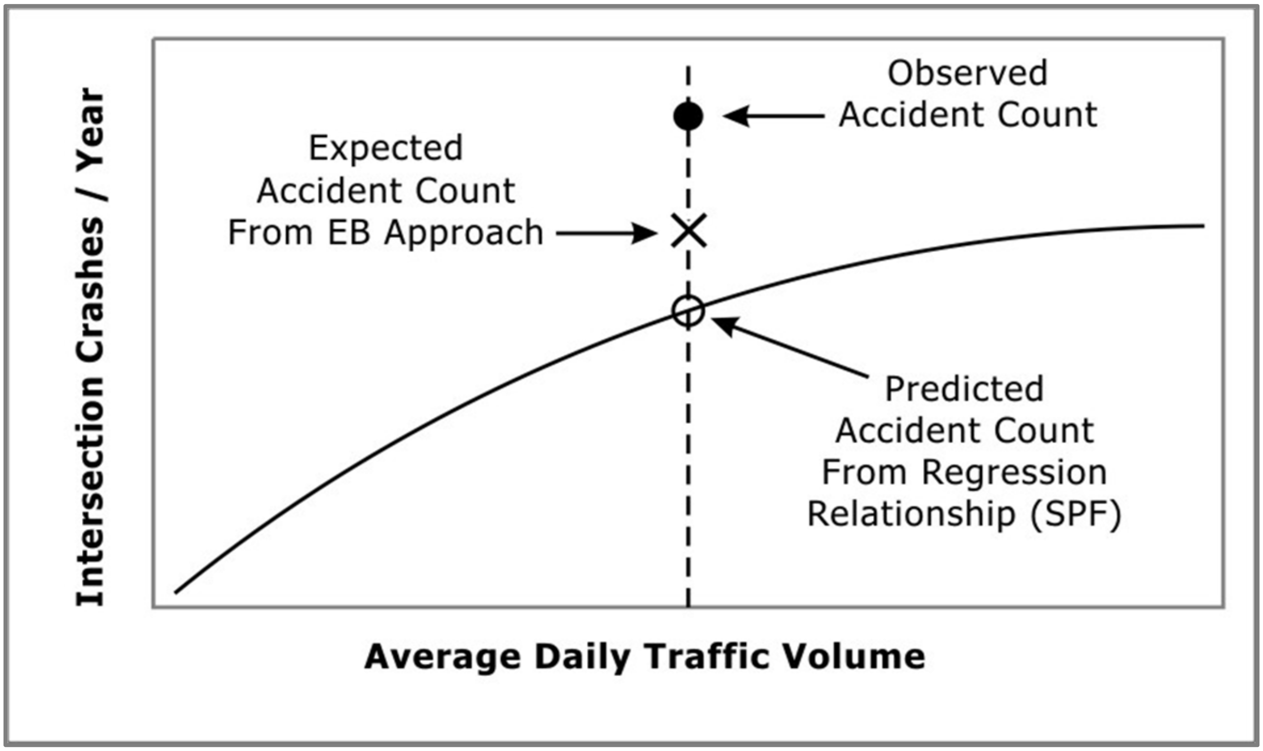
SPFs may not accurately predict future crash frequency, as they do not account for certain site-specific conditions that may influence safety. In addition, historical crash data may not accurately predict future crash frequency, as it may reflect a short-term average that is higher or lower than the long-term average, as shown in Figure 4.

Figure 4. Short-Term versus Long-Term Average Crash Frequency



When both SPF and historical crash data are available, the Empirical Bayes (EB) Method is applied. EB is a statistical inference method that modifies the predictive model to more accurately reflect site-specific conditions with the crash data provided. Essentially, the EB method provides a "weighted" average of historical crash frequency and crash frequency predicted by an SPF. The "weight" assigned to the results of the SPF and the historical data are determined by an over-dispersion parameter associated with the SPF. The EB method is conceptually depicted in Figure 5, and fully described in Appendix A of Volume 2 of the HSM.

Figure 5. Empirical Bayes Method



The spreadsheet's case-specific use of SPFs, historical data, and the EB method are described in a subsequent section of this manual.

Roundabout Crash Prediction

The spreadsheet uses CMFs to predict the change in crash frequency or severity at a roundabout relative to the crash frequency or severity that is estimated for the traditional intersection it is compared to. Table 2 below identifies the types of conversions for which CMFs are available. For conversion of an AWSC intersection to a roundabout, the spreadsheet estimates crash frequency the same for both intersection forms, as indicated in Table 2 by the CMF value of 1.0.

Table 2. CMF Availability for Conversion of Traditional Intersection to Roundabout

Convert from a _______ to a ____lane roundabout

	TWSC -> 1 ln	TWSC -> 2 ln	AWSC -> 1 ln	AWSC -> 2 ln	Signal -> 1 ln	Signal -> 2 ln
Rural	CMF	No CMF	Aggregated data indicates CMF ~1.0		No CMF	No CMF
Suburban	CMF	CMF			CMF	
Urban	CMF	CMF			CMF	

Case-Specific Safety Calculations

The sections below describe, for each case, the manner in which the spreadsheet uses SPFs, historical data, and CMFs to compute the expected number of crashes under the traditional intersection and roundabout options.

Case 1: Existing Traditional Intersection vs. Roundabout Option

Under Case 1, an existing traditional intersection remains the same or is converted to a roundabout. Future safety performance of the traditional intersection is predicted by an SPF, if one is available per Table 1. If historical crash data is available, the EB method is applied. If an SPF is not available but historical crash data is, then the future safety performance of the traditional intersection is assumed equivalent to historical performance. The spreadsheet provides a warning to users in this situation, because there is more uncertainty in results than if an SPF were applied.

The crash frequency or severity at a roundabout is calculated by applying a CMF (if available) to the estimated crash frequency of the existing traditional intersection, resulting in an estimate of the relative difference in crash frequency between traffic control options.

Table 3 lists scenarios that may occur under Case 1 comparisons with the corresponding type of calculations performed by the spreadsheet. Note that in some situations, there is insufficient data to predict crash frequency for both options. For these situations, safety is omitted from the overall life-cycle cost comparison of the two intersection forms.

Table 3. Case 1 Crash Prediction Scenario Methodologies

Scenario	Methodology Applied to Estimate Future Safety Performance		Method Reliability
	Traditional Intersection	Roundabout	
SPF available for traditional intersection, CMF available for conversion to roundabout	SPF, with EB applied if historical crash data available	CMF	HSM-Recommended Evaluation, Greatest Reliability
SPF not available for traditional intersection, but historical crash data available. CMF available for conversion to roundabout	Historical crash data	CMF applied to historical crash data	HSM Prediction Tools Applied, Moderate Reliability
SPF and historical crash data not available	No safety analysis		
CMF not available (except AWSC)	No safety analysis		
AWSC with historical crash data	Historical crash data	Same as traditional intersection (CMF = 1.0)	

Case 2: Traditional Intersection Option vs. Roundabout Option at site of existing traditional intersection

Under Case 2, an existing traditional intersection is improved in some manner and remains a traditional intersection, or it is converted to a roundabout. Improvements could retain the same control or change the control. For example, a TWSC intersection could remain TWSC with added turn lanes, or it could become a signalized intersection.

Safety performance of a traditional intersection option is predicted by an SPF if one is available. Otherwise, it is predicted by an SPF and/or historical crash data for the existing traditional intersection as well as by a Part D CMF for the conversion of the existing traditional intersection to the traditional intersection option.

Future safety performance of the roundabout is predicted both by knowledge of the future safety performance of the existing or optional traditional intersection (as detailed in Table 4) and by a CMF, if one is available. (See Table 2).

Table 4 lists scenarios that may occur under Case 2 comparisons with the corresponding type of calculations performed by the spreadsheet. Note that in some situations, there is insufficient data to predict crash frequency for both options. For these situations, safety is omitted from the overall life-cycle cost comparison of the two intersection forms.

Table 4. Case 2 Crash Prediction Scenario Methodologies (Assuming CMF for conversion of existing intersection to roundabout is available*)

Scenario	Methodology Applied to Estimate Future Safety Performance		Method Reliability
	Traditional Intersection Option	Roundabout	
SPF available for existing traditional intersection and traditional intersection option.	SPF for traditional intersection option	CMF applied to existing traditional intersection SPF	HSM Prediction Tools Applied, Moderate Reliability
SPF available for existing traditional intersection. SPF not available for traditional intersection option. HSM Part D CMF for conversion of existing traditional intersection to traditional intersection option.	SPF for existing traditional intersection is calculated and Part D CMF (for traditional intersection option) is applied	Roundabout CMF applied to traditional intersection SPF	HSM-Recommended Evaluation, Greatest Reliability
SPF available for existing traditional intersection. SPF not available for traditional intersection option. No Part D CMF for conversion of existing traditional intersection to traditional intersection option.	No safety analysis		N/A
SPF not available for existing traditional intersection. SPF available for traditional intersection option.	SPF for traditional intersection option	CMF applied to traditional intersection option SPF	HSM Prediction Tools Applied, Moderate Reliability
SPF not available for existing traditional intersection or traditional intersection option. Historical crash data available. Part D CMF for conversion of existing traditional intersection to traditional intersection option.	Part D CMF (for traditional intersection option) is applied to historical crash data	CMF applied to historical crash data.	HSM Prediction Tools Applied, Low Reliability
SPF not available for existing traditional intersection or traditional intersection option. Historical crash data not available. No Part D CMF for conversion of existing traditional intersection to traditional intersection option.	No safety analysis		N/A

* If a CMF for conversion of the existing traditional intersection to a roundabout is not available, no safety analysis is conducted. This applies to all scenarios listed in the table.

Case 3: Traditional Intersection Option vs. Roundabout Option at new site

Under Case 3, historical crash data is not available, and only SPFs are used to predict the safety performance of the traditional intersection. CMFs are applied to SPF results to predict the safety performance of the roundabout.

Table 5 lists scenarios that may occur under Case 3 comparisons with the corresponding type of calculations performed by the spreadsheet. Note that in some situations, there is insufficient data to predict crash frequency for both options. For these situations, safety is omitted from the overall life-cycle cost comparison of the two intersection forms.

Table 5. Case 3 Crash Prediction Scenario Methodologies

Scenario	Methodology Applied to Estimate Future Safety Performance		Method Reliability
	Traditional Intersection	Roundabout	
SPF available for traditional intersection, CMF available for conversion to roundabout	SPF	CMF	HSM Prediction Tools Applied, Moderate Reliability
SPF not available for traditional intersection, CMF available for conversion to roundabout	No safety analysis, but spreadsheet provides the CMF for the user's reference		N/A
SPF not available for traditional intersection and/or CMF not available for conversion to roundabout	No safety analysis		N/A

Delay

The spreadsheet does not compute intersection delays; users input delay data that has previously been computed with other software programs or analysis procedures.

Delay data can be entered for up to five weekday, time-of-day periods and up to five weekend, time-of-day periods. Delay data is usually available for only two or three time periods of the week (such as the a.m. peak, p.m. peak, weekday midday, and/or Saturday midday). The user may enter the number of hours of the day that each period represents. For example, p.m. peak delay data may be based on a one-hour traffic count, but it may be assumed that to approximate conditions over a two-hour period.

It is important to note that the effect of delay on the overall intersection cost comparison is directly influenced by the number of hours in a weekday and a weekend day that a user chooses to analyze. For example, analyzing four hours of weekdays and weekend days instead of two hours of weekdays and weekend days doubles the "weight" of delay relative to other metrics in the overall intersection cost comparison.

After selection of analysis periods and corresponding durations, the user enters delay values (seconds per vehicle) and the number of total entering vehicles for the roundabout and the traditional intersection option. The spreadsheet then multiplies these inputs to obtain total vehicle delay in an analysis period. Subsequent calculations determine vehicle delay for all weekday and weekend days analyzed, total person delay for all weekday and weekend days analyzed, and total person delay for a one-year period. The year consists of 260 weekdays and 105 weekend days.

All delay data is entered for the opening year and the design year of the intersection, and the spreadsheet uses linear interpolation to compute delay for all other years.

Occupants of vehicles are negatively impacted by delay time at intersections. The spreadsheet reports total person delay for the life cycle of the intersection, and uses a person delay unit cost.

Operations and Maintenance

Operations and maintenance costs are the ongoing costs associated with the intersection throughout the design life. Some types of operations and maintenance costs may be incurred at any intersection type, while others are only associated with specific intersection control types. Table 6 lists all of the operations and maintenance costs the spreadsheet considers.

Table 6. Operation and Maintenance Cost Elements by Intersection Control

Type of Operations and Maintenance Cost	Stop-Control	Traffic Signal	Roundabout
Luminaires – Electrical Consumption and Maintenance	Applicable	Applicable	Applicable
Electric Consumption by Traffic Signals	Not Applicable	Applicable	Not Applicable
Signal Retiming	Not Applicable	Applicable	Not Applicable
Signal Maintenance	Not Applicable	Applicable	Not Applicable
Roundabout Landscaping Maintenance	Not Applicable	Not Applicable	Applicable

As discussed in the next section of this manual, most operations and maintenance costs identified in Table 6 as “applicable” are automatically included in the life cycle cost of the intersection by the spreadsheet, and required user input is minimal.

Initial Capital Costs

The user may enter capital costs in three subtotals: preliminary engineering, right-of-way and utilities, and construction. Only the total capital cost is used in the spreadsheet’s calculations, and a user can enter a single total cost value into any of the three subtotal entry cells if desired. The spreadsheet assigns all capital costs to the opening year.

ECONOMIC ANALYSIS

Life Cycle Cost

Table 7 identifies the way in which costs are computed for each performance metric in each year of the intersection’s life cycle.

Table 7. Computation of Costs by Year

Cost Element	Opening Year	Design Year	Intermediate Years
Safety	Spreadsheet computes based on opening year AADT input, other inputs, and unit costs.	Spreadsheet computes based on design year AADT input, other inputs, and unit costs.	Linear interpolation of opening year and design year costs
Delay	Spreadsheet computes based on opening year delay inputs, other inputs, and unit costs.	Spreadsheet computes based on design year delay inputs, other inputs, and unit costs.	Linear interpolation of opening year and design year costs
Operations and Maintenance	Spreadsheet computes based on default values, unit costs, and minimal user input	Same as opening year	Same as opening year
Capital Elements	All entered capital costs are incurred in the opening year	None	None

To account for the multi-year nature of an intersection investment, the spreadsheet accounts for changes in the value of money over time. On the Results Tab, the total life-cycle cost of the intersection is reported in opening year dollars. Cash flows for years other than the opening year are converted to opening year dollars by applying a discount rate. A discount rate of 3% is used in the spreadsheet, which is typical for infrastructure projects. Thus, for a future year *n* and a discount rate *i*, costs for that year are converted to opening year dollars by applying a factor of *1/(1+i)^n*. The spreadsheet applies the factor to costs in each year beyond the opening year and then sums all costs for each year of the project's life cycle to provide the total life cycle cost of the roundabout and the traditional intersection option.

Benefit-Cost Ratio

In addition to providing the life-cycle cost of both intersection forms, the spreadsheet attempts to provide a benefit-cost ratio of the roundabout in comparison to the traditional intersection option. The benefit cost ratio is calculated as follows:

Safety benefit of roundabout = Life-cycle safety cost of traditional intersection option – life-cycle safety cost of roundabout

Delay reduction benefit of roundabout = Life-cycle delay cost of traditional intersection option – life-cycle delay cost of roundabout

Added operations and maintenance (O&M) cost of roundabout = Life-cycle O&M cost of a roundabout – life-cycle O&M cost of traditional intersection option

Added capital cost of roundabout = Capital cost of roundabout – capital cost of traditional intersection option

$$\frac{Benefit}{Cost} = \frac{safety\ benefit\ of\ roundabout + delay\ reduction\ benefit\ of\ roundabout}{added\ O\&M\ cost\ of\ roundabout\ +\ added\ capital\ cost\ of\ roundabout}$$

As seen in the calculations above, the spreadsheet makes the following assumptions:

- A roundabout has fewer crashes and less delay than the traditional intersection option

- A roundabout has greater operations and maintenance costs and greater capital costs than the traditional intersection option.

If both of these assumptions are true, the total benefit and total cost are positive numbers and the spreadsheet reports a life cycle benefit/cost ratio for the roundabout in comparison to the traditional intersection option. If the ratio is greater than 1.0, a roundabout is considered beneficial compared a traditional intersection. If the ratio is less than 1.0, a roundabout is not considered beneficial.

When one or more of the assumptions noted above are not true, benefit or cost values may be negative. The spreadsheet provides messages that notify the user of this condition; these outcomes are listed below in Table 8.

Table 8. Benefit/Cost Ratio Relationships

	Benefit of Roundabout as Compared to Traditional Intersection	Cost of Roundabout as Compared to Traditional Intersection	Result
1	More	More	Roundabout Potentially Preferred and Benefit/Cost Ratio is Calculated
2	More	Less	Roundabout Preferred
3	Less	More	Roundabout not Preferred
4	Less	Less	Unclear Relationship
5	Equivalent	Equivalent	No Data or No Preference
6	Equivalent	More	Roundabout not Preferred
7	Equivalent	Less	Roundabout Preferred
8	More	Equivalent	Roundabout Preferred
9	Less	Equivalent	Roundabout not Preferred

Row 1 of Table 8 describes the assumed condition under which a benefit-cost ratio is provided. If a roundabout provides benefit as compared to a traditional intersection and costs less (row 2 of Table 8), the roundabout is clearly preferred, but no ratio can be provided. If a roundabout does not provide benefit as compared to a traditional intersection and costs more (row 3 of Table 8), the roundabout is clearly not preferred. If a roundabout does not provide benefit as compared to a traditional intersection and costs less (row 4 of Table 8), it is unclear as to which intersection form is preferred. Rows 5 through 9 of the table describe unlikely situations in which benefits or costs of the intersection forms are equal.

HIGHWAY SAFETY IMPROVEMENT PROGRAM (HSIP) FUND ELIGIBILITY

Highway Safety Improvement Program (HSIP) funding may be applicable to roundabout projects on a case-by-case basis. The purpose of HSIP funding as dictated in MAP-21 §1112; 23 USC 130 and 148, is to achieve a significant reduction in traffic fatalities and serious injuries through the implementation of infrastructure-related highway safety improvements.

Section 3
Using the Spreadsheet

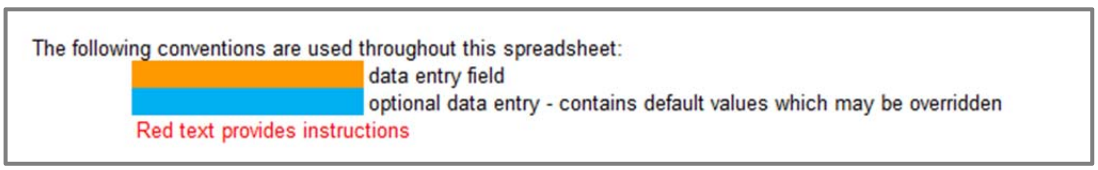
USING THE SPREADSHEET

The Intersection Cost Comparison Spreadsheet was designed to assess the life cycle cost of a roundabout as compared to a traditional intersection alternative. A traditional intersection is defined as a stop-controlled or signalized intersection.

The spreadsheet tool evaluates comparative capital, operation, and maintenance costs as well as costs associated with safety and delay for all intersection types evaluated. A summary of the cost comparison may be found on the Results Tab following the input of conditional variables.

The User Manual serves as a step-by-step guide throughout the assessment of build scenarios. Brief instructional overview is additionally presented on the Introduction Tab of the Intersection Cost Comparison Spreadsheet. Throughout the spreadsheet tool, orange cells represent required fields, and blue cells denote optional inputs that are initially filled with default values. Red text provides instruction on each of the tabs.

Figure 6. Introduction Tab Field Entry Color Reference



Generally, progression through the spreadsheet is as follows:

1. To begin, open the Introduction Tab and read the instructions provided.
2. Move from the Introduction Tab to the MainENTRY Tab and enter the required information into the orange cells.
3. Move to the AdjustSPF Tab to enter roadway and intersection geometry information that is used in safety calculations.
4. Move to the DelayENTRY Tab to enter delay information.
5. Move to the Results Tab – Life Cycle Costs Tab to view results.

The last three tabs (O_SafetyCalculation, D_SafetyCalculation, and CostCalculation) only perform calculations and do not need to be viewed or modified.

If the user desires to omit certain cost considerations such as delay or safety, the corresponding spreadsheet tool sections may be left blank.

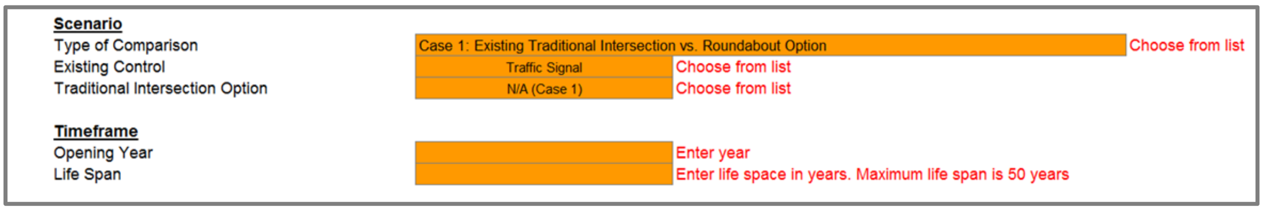
MAINENTRY TAB

The MainENTRY Tab has several sections, each of which are described below.

Scenario

Scenario inputs are the basis for analysis throughout the spreadsheet tool and should be selected based upon the conditions that best apply to the user's project. The scenarios correspond to differing methodologies of safety calculations. That is, the "Existing Control" field applies to Case 1 and Case 2, and the only option available for the field is "N/A" when Case 3 is selected. Similarly, the "Traditional Intersection Option" field applies to Case 3 and Case 2 only, and will display "N/A" with the selection of Case 1. Figure 7 below shows the layout of this section.

Figure 7. MainENTRY Tab Scenario Selection



In the Scenario section of the MainENTRY Tab, select the type of comparison to be analyzed. Three cases are available for selection:

- Case 1: Existing Traditional Intersection vs. Roundabout Option
- Case 2: Traditional Intersection Option vs. Roundabout Option at site of existing traditional intersection
- Case 3: Traditional Intersection Option vs. Roundabout Option at new site

Case 1 compares the life cycle cost of a new roundabout to an existing traditional intersection. Case 1 should be selected if a roundabout is the only option under consideration for an intersection, and the intersection will remain unchanged if a roundabout is not constructed.

Case 2 compares the life cycle cost of a new roundabout with a traditional intersection option at the site of an existing intersection. Case 2 should be selected if the user is comparing the replacement of an existing intersection with either a roundabout or a modified traditional intersection. For example, Case 2 should be selected in the following scenarios:

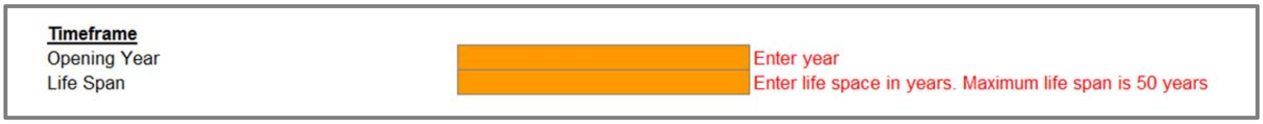
- A two-way stop-control (TWSC) intersection will be converted to a traffic signal or a roundabout
- A TWSC intersection will have improvements (addition of a turn lane, removal of skew, addition of illumination, etc.) or be converted to a roundabout

Case 3 compares the life cycle cost of a roundabout option with a traditional intersection option at a new site. Case 3 should be selected if the intersection is yet to be built.

Timeframe

Under Timeframe (Figure 8), enter the opening year of the proposed project. Then enter the life span of the proposed project in years. The life span is used to calculate the life cycle costs associated with the project.

Figure 8. MainENTRY Tab Timeframe Input



Safety Inputs

The safety input section of the MainEntry tab is shown in Figure 9. The user has the option of omitting safety input with the selection of "No" on the first drop down list under the section. If "No" is selected, inapplicable sections of the spreadsheet, including all entries on the AdjustSPF Tab, will be grayed out and safety costs will not be reflected in the life cycle costs computed by the spreadsheet.

Figure 9. MainENTRY Tab Safety Inputs

Should the user choose to consider safety costs, select the number of legs at the intersection. The spreadsheet accommodates intersections with 3, 4, or 5+ legs, although no safety analysis is performed for intersections with 5+ legs due to a lack of SPFs and CMFs for this condition. Next, enter the Annual Average Daily Traffic (AADT) for the major road and minor road for both the opening year and the design year.

The facility type input under this section is used to select an SPF for the site. The facility types are in accordance with the predictive methods (Part C) of the Highway Safety Manual as follows:

- Rural Two-Lane, Two-Way Roads (HSM Chapter 10)

- Rural Multilane Highways (HSM Chapter 11)
- Urban and Suburban Arterials (HSM Chapter 12)

For more information on each of the facility types, please see the Comparison Processes and Metrics section of the Concepts Overview in this manual or Part C of the Highway Safety Manual.

Next, the number of lanes in the roundabout option is selected because the HSM provides separate CMFs for conversion to one-lane and two-lane roundabouts. The spreadsheet does not accommodate roundabouts with three or more lanes. However, the number of lanes in the roundabout is only used for safety analysis so a user could analyze a three-lane roundabout by choosing “no” in the “Consider Safety Costs?” field.

If the facility type is an urban or suburban arterial, the Area Type drop down list allows for the selection of either “Urban” or “Suburban”. Choose the relevant area type. The “Urban and Suburban Arterials” facility type requires more inputs than either “Rural Two-Lane, Two-Way Roads” or “Rural Multilane Highways.” When the “Urban and Suburban Arterials” selection is made, additional input cells are exposed, as shown in the boxed area at the bottom of Figure 10:

- Enter the maximum number of lanes to be crossed by a pedestrian on the urban or suburban arterial. Each stage of a multi-stage crossing is counted separately, and maximum number of lanes crossed in a single stage is entered. For example, a pedestrian would be considered to cross a maximum of four lanes at an intersection on an undivided four-lane major road. The maximum number of lanes crossed would reduce to two, however, if a median or raised island divided the roadway at the intersection.
- Enter the daily pedestrian volume, defined in the HSM as the sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs.

Figure 10. MainENTRY Tab Urban and Suburban Arterial Facility Type

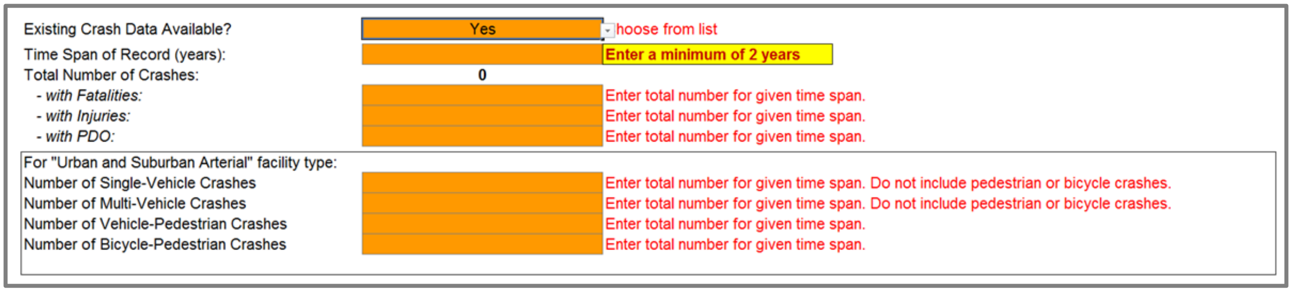
For "Urban and Suburban Arterial" facility type:		
Max. number of lanes crossed by pedestrian		For any crossing at intersection. If raised island/median, count stages seperately.
Daily Pedestrian Volume		Sum of all legs crossed

Crash Data

Crash data may be entered under the Safety Inputs section of the MainENTRY Tab. As explained in Section 2 of this manual, use of historical crash data improves the accuracy of the prediction of future crash frequency, and it should be entered when available.

If crash data is available, enter the time span for which crash history is considered, as shown in Figure 11. A minimum of two years of data is necessary. Then enter the total number of crashes across the timespan for each crash type: fatal crashes, injury crashes, and property damage only (PDO) crashes.

Figure 11. MainENTRY Tab Urban and Suburban Arterials Crash Inputs



Existing Crash Data Available?	Yes	hoose from list
Time Span of Record (years):		Enter a minimum of 2 years
Total Number of Crashes:	0	
- *with Fatalities:*		Enter total number for given time span.
- *with Injuries:*		Enter total number for given time span.
- *with PDO:*		Enter total number for given time span.
For "Urban and Suburban Arterial" facility type:		
Number of Single-Vehicle Crashes		Enter total number for given time span. Do not include pedestrian or bicycle crashes.
Number of Multi-Vehicle Crashes		Enter total number for given time span. Do not include pedestrian or bicycle crashes.
Number of Vehicle-Pedestrian Crashes		Enter total number for given time span.
Number of Bicycle-Pedestrian Crashes		Enter total number for given time span.

If the facility type is an urban or suburban arterial, a dialog box, shown at the bottom of Figure 11, will appear that requests additional crash data. The additional inputs are variables in the sub-models specific to this facility type, and are needed to apply the EB method to each sub-model. In the box, enter the total number of crashes each for single-vehicle crashes, multi-vehicle crashes, pedestrian crashes, and bicycle crashes. Pedestrian crashes are defined in the HSM as crashes involving a vehicle and a pedestrian, and bicycle crashes are defined as crashes involving a vehicle and a bicycle. For example, a crash involving one vehicle and one pedestrian is considered a pedestrian crash, not a single-vehicle crash.

The sum of fatal, injury, and PDO crashes should equal the sum of single-vehicle, multi-vehicle, pedestrian, and bicycle crashes. If the sums are not equal, the spreadsheet ignores the entered data and does not apply the EB method. In situations where no SPF is available and historical crash data is used as the sole predictor of future safety performance (i.e. AWSC intersections on urban and suburban arterials), only the number of fatal, injury, and PDO crashes are used by the spreadsheet and the number of single-vehicle, multi-vehicle, pedestrian, and bicycle crashes may be omitted if it is not known.

Use of Part D CMFs for Traditional Intersection Conversion in Case 2

In two situations, the spreadsheet uses a Part D CMF to estimate the safety performance of the traditional intersection option. In both situations, there is no SPF for the traditional intersection option. The situations are:

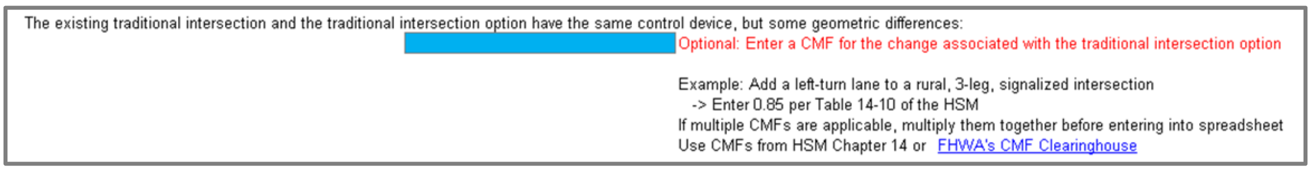
- Conversion of a rural, three-leg, TWSC intersection to a signal
- Conversion of a rural TWSC intersection to AWSC.

The CMFs applied by the spreadsheet for these situations are 0.56 and 0.52, respectively.

Case 2 Manual CMF Input

Case 2 scenarios involve three intersection designs (one existing, and two proposed options), making the comparison of intersection forms more complex than Case 1 or Case 3 and, in some situations, requiring the user manually to enter a CMF to quantify expected changes in safety performance. If the existing traditional intersection and the traditional intersection option have the same control device, and there is an SPF and/or crash data for the existing intersection, the user should enter a CMF. For example, if an existing urban, three-leg, TWSC intersection is proposed to remain TWSC but have a left turn lane added on the major roadway (or become a roundabout_, the user should enter a CMF of 0.67 based Table 14-10 of the HSM to quantify the expected change in safety with the addition of the left turn lane. For the roundabout option, the spreadsheet still automatically applies a CMF. CMFs entered by the user should come from Chapter 14 of the HSM or other sources such as FHWA's online CMF Clearinghouse. The option to enter a CMF for total crashes at the site of the traditional intersection option is displayed in Figure 12.

Figure 12. MainENTRY Tab Manual CMF Input for Case 2



Additional Safety Inputs

For ease of use, additional safety inputs are located on a subsequent tab.

Vehicle Delay

The Vehicle Delay section on the MainENTRY Tab refers the user to the DelayENTRY Tab to input information required for the consideration of delay costs.

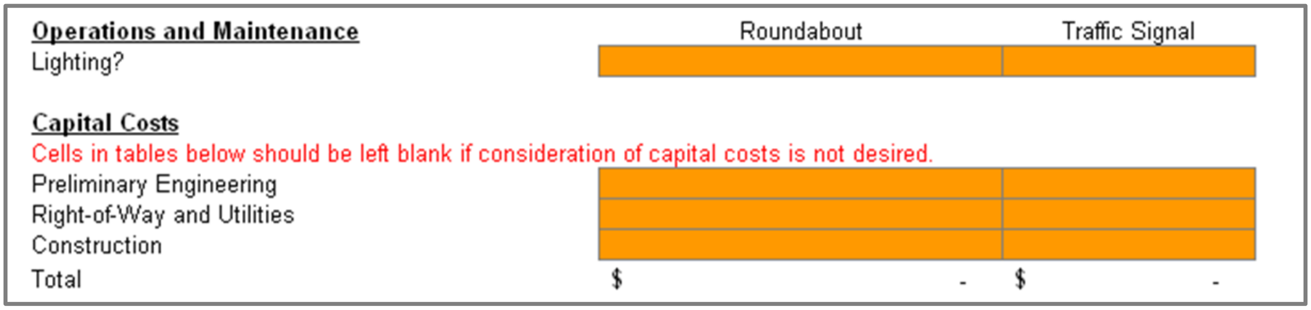
Operations and Maintenance

Operations and maintenance costs are the ongoing costs associated with the intersection throughout the design life. The spreadsheet tool considers the following operations and maintenance costs:

- electrical consumption by and maintenance of luminaires,
- electricity consumption by traffic signals,
- signal retiming,
- signal maintenance, and
- roundabout landscaping maintenance.

To compute electrical consumption and maintenance of luminaires, users specify if an intersection has lighting as shown at the top of Figure 13. This is a relatively small component of the overall intersection cost comparison. Other operations and maintenance-related costs are automatically applied by the spreadsheet based on the form of the intersection. For example, roundabout landscaping maintenance costs are always included in the life cycle cost of the roundabout.

Figure 13. MainENTRY Tab Operations, Maintenance, and Capital Costs



Capital Costs

Capital costs are entered in the cells shown at bottom of Figure 13. Capital cost entry is broken down in to four subtotals: preliminary engineering, right-of-way and utilities, and construction. Only the total capital cost is used in the spreadsheet's calculations, and a user can enter a single total cost value into any of the three subtotal entry cells if desired.

Unit Costs

At the bottom of the MainENTRY Tab are blue entry fields for unit costs that are populated with values from VDOT and other sources. There is no need to change these values, and VDOT will periodically re-lease new versions of this spreadsheet as unit costs change over time. The basis of each unit cost is de-scribed below.

Crashes

VDOT has cost values for five severities of crashes and they are listed below in Table 10.

Table 9. Cost of Fatal-Injury Crashes

Severity	Cost	Percent of Statewide Total of Crashes
Fatality	$5,000,000	1.6%
Major Injury	$275,000	17.9%
Moderate Injury	$98,000	10.1%
Minor Injury	$55,000	13.8%
Property Damage Only	$9,000	56.6%

The HSM only predicts a total number of fatal-injury crashes. To obtain the typical cost of a fatal-injury crash, a weighted average value of the first four costs listed in Table 10 was computed. The weights were the statewide percentages of each fatal-injury crash severity category. The resulting cost is $338,048; this is the cost assigned to a fatal-injury crash in the spreadsheet. The VDOT cost value of a PDO crash is $9,000; this is the cost assigned to a PDO crash in the spreadsheet.

Vehicle-Hour Delay

The cost of an hour of delay is $16.79. This value is from the Texas Transportation Institute's 2012 Urban Mobility Report. This report quantifies the amount of congestion in cities across the US, and provides a number of cost-related impacts of congestion.

Retiming

Traffic signals are typically retimed every few years to account for changes in volume. The spreadsheet assigns a $5,000 retiming cost to a signal once every three years. This cost reflects a typical timing plan developed by consultants and does not include any costs incurred by agency staff.

Power to Signal

The estimated annual cost of power supply to a signal is $750. This value is based on VDOT experience. Costs at specific intersections will vary based on the number of signalheads and the type of blubs (i.e. incandescent versus LED)

Luminaires

The annual cost of lighting an intersection includes maintenance and power supply. This cost is set at $750 based on VDOT experience.

Signal Maintenance

The typical annual maintenance cost for a signal in Virginia is $3,750.

Roundabout Landscaping

The typical annual maintenance cost is $2,000. This value is based on data provided by Bend, Oregon, which has over 25 roundabouts. A typical value for VDOT roundabouts is not available at this time.

Discount Rate

The discount rate, or the opportunity cost of investing in the intersection, is set at 3.0%. This is a typical value for infrastructure projects.

Unit Cost Summary

Table 10 summarizes the cost values described above.

Table 10. Unit Cost Default Values (2013)

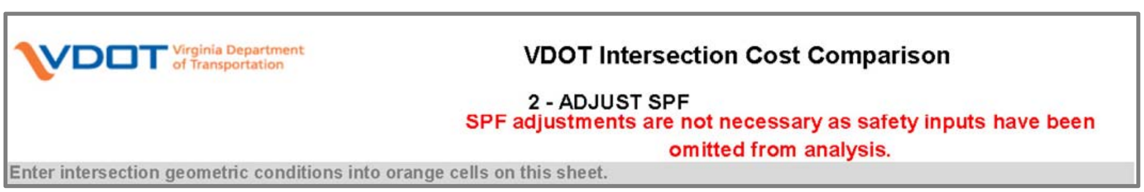
Unit Cost	Default Value*	Source
Cost per Fatal-Injury Crash	$338,048	Weighted average of VDOT values for various fatal-injury severity levels
Cost per PDO Crash	$9,000	VDOT standard value
Cost per Vehicle-Hour Delay	$16.79	2012 Texas Transportation Inst. Urban Mobility Report
Retiming Cost Every Five Years	$5,000**	VDOT
Annual Power Cost for Signal	$750**	VDOT
Annual Illumination Cost	$750	VDOT
Annual Signal Maintenance Cost	$3,750**	VDOT
Annual Roundabout Landscaping Cost	$2,000	Typical cost
Discount Rate	3.0%	Typical for infrastructure projects
* 2013 Values ** $0 for stop-controlled intersection or roundabout		

ADJUSTSPF TAB

The AdjustSPF Tab is used to enter data that selects and computes HSM Part C Crash Modification Factors (CMFs). These CMFs are used to adjust the safety performance function (SPF) to predict more accurately the traditional intersection's average crash frequency in future years. For more information regarding these CMFs and the degree with which they influence the results of the SPF, refer to Safety under the Concepts Overview section of the User Manual or to Part C of the HSM.

If safety costs are omitted from analysis, input fields on the AdjustSPF Tab will be hidden and the message shown in Figure 14 will appear. If the message does not appear, the user should ensure that "No" is selected from drop-down menu under the Safety Inputs section of the MainENTRY Tab.

Figure 14. AdjustSPF Tab Safety Input Omission Message



If the user chose to consider safety costs on the MainENTRY Tab, the facility type will appear at the top of the AdjustSPF Tab, and the facility type's corresponding inputs will appear below. For example, if the user selects Rural Two-Lane, Two-Way Roads under facility type on the MainENTRY Tab, "Rural Two-Lane, Two-Way Roads" will appear at the top of the AdjustSPF Tab and applicable input fields will display on the screen. Input fields for other facility types will be hidden.

Inputs for each of the HSM's 3 facility types are discussed below.

Rural Two-Lane, Two-Way Roads

Figure 15 shows input fields for CMFs used in the HSM's Rural Two-Lane, Two-Way Roads procedure. Note that entry fields for both a TWSC intersection and a signalized intersection are displayed. Users only need to enter data into the fields for the applicable control device if a Case 1 or Case 3 comparison is being conducted. Both sets of entry fields are displayed for Case 2 comparisons in which a TWSC intersection currently exists and a signal is an option (or vice versa). In this situation, the user should enter data for both the TWSC and signalized intersection. Guidance on entry field input is provided below.

Figure 15. AdjustSPF Tab Rural Two-Lane, Two-Way Roads Inputs

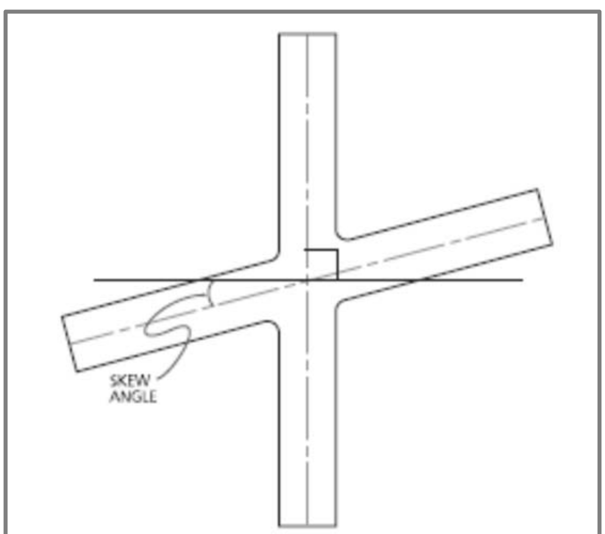
Enter intersection geometric conditions into orange cells on this sheet.

Selected Facility Type from MainEntry tab: Rural Two-Lane, Two-Way Roads

<u>Rural Two-lane, Two-Way Roads</u> - Two-Way Stop-Control Intersection (3 or 4 legs)		
Intersection Skew Angle	0	Enter Angle (positive number). See figure.
Major Street Approaches With Left-Turn Lanes	0	Choose from list
Major Street Approaches With Right-Turn Lanes	0	Choose from list
Lighting	No	Choose from list
<u>Rural Two-lane, Two-Way Roads</u> - Signalized Intersection (4 legs)		
Approaches With Left-Turn Lanes	0	Choose from list
Approaches With Right-Turn Lanes	0	Choose from list
Lighting	No	Choose from list

- Enter the intersection skew angle. Skew angle is defined as the deviation from an intersection angle of 90 degrees and is illustrated in Figure 16. For use in the spreadsheet tool, the skew angle carries a positive sign indicating the acute angle at which the minor road intersects the major road. The skew angle is zero if the intersection is perpendicular.

Figure 16. Skew Angle



Skew Angle is 0 if intersection is perpendicular.

- The number of approaches with left-turn and right-turn lanes from the drop-down list as applicable under each section. For TWSC intersections, the number of approaches with turn lanes pertains to the major street approaches only.
- Specify if lighting (illumination) is present.

Rural Multilane Highways

Figure 17 shows the entry fields for Rural Multilane Highways. Inputs are similar to Rural Two-Lane Two-Way Highways.

Figure 17. AdjustSPF Tab Rural Multilane Highway Inputs

Enter intersection geometric conditions into orange cells on this sheet.

Selected Facility Type from MainEntry tab: Rural Multilane Highways

Rural Multilane Highways - Two-Way Stop-Control Intersection (3 or 4 legs)

Intersection Skew Angle	0	Enter Angle (positive number). See figure.
Major Street Approaches With Left-Turn Lanes	0	Choose from list. Do not choose "2" for a 3-leg intersection
Major Street Approaches With Right-Turn Lanes	0	Choose from list. Do not choose "2" for a 3-leg intersection
Lighting	No	Choose from list

Rural Multilane Highways - Signalized Intersection (4 legs)

No crash modification factors for this safety performance function

Urban and Suburban Arterials

Figure 18 shows the entry fields for Urban and Suburban Arterials. Inputs for TWSC intersections are similar to Rural Two-Lane Two-Way Highways. For signalized intersections, the HSM requires additional inputs for the Urban and Suburban Arterial facility type. These additional inputs are:

- Number of approaches with protected/permissive or permissive/protected signal phasing for left turns
- Number of approaches with protected signal phasing for left turns
- Number of approaches on which right-turn-on-red is prohibited
- Presence/absence of red light running cameras
- Number of bus stops within 1000 feet of the intersection. Multiple bus stops at the same intersection (for example, an intersection with stops on the north leg and east leg) are count-

ed separately. This CMF only adjusts the number of pedestrian crashes predicted by the vehicle-pedestrian crash sub-model. If the user did not enter the pedestrian volume on the MainEntry Tab, the predicted number of vehicle-pedestrian crashes is zero and this CMF will have no effect on the predicted number of vehicle-pedestrian or total crashes at the intersection.

- Presence/absence of schools within 1000 feet of the intersection. A school is considered present if any portion of the grounds is within 1000 feet of the intersection. This CMF only adjusts the number of pedestrian crashes, and has no effect on results if the user did not enter the pedestrian volume on the MainEntry Tab.
- Number of alcohol sales establishments within 1000 feet of the intersection. This includes liquor stores, bars, restaurants, convenience stores, and grocery stores. This CMF only adjusts the number of pedestrian crashes, and has no effect on results if the user did not enter the pedestrian volume on the MainEntry Tab.

Figure 18. AdjustSPF Tab Urban and Suburban Arterial Inputs

Urban and Suburban Arterials - Two-Way Stop-Control Intersection (3 or 4 legs)		
Major Street Left-Turn Lanes	0	Choose from list
Major Street Right-Turn Lanes	0	Choose from list
Lighting	No	Choose from list
Urban and Suburban Arterials - Signalized Intersection (3 or 4 legs)		
Approaches with Left-Turn Lanes	0	Choose from list
Approaches with Protected/Permissive or Permissive/Protected left-turn phasing	2	Choose from list
Approaches with protected phasing	0	Choose from list
Approaches with Right-Turn Lanes	0	Choose from list
Approaches with RTOR Prohibited	0	Choose from list. RTOR is Right-Turn-on-Red
Lighting	Yes	Choose from list
Red-Light Cameras	No	Choose from list
Bus Stops within 1000 feet of Intersection	0	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes
Presence of Schools within 1000 feet of Intersection	No school present	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes
Number of Alcohol Sales Establishments within 1000 feet of Intersection	1 to 8	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes

DELAYENTRY TAB

The DelayEntry Tab is used to input the results of traffic analysis previously conducted by the user. If the user chooses to omit delay costs from analysis, select "No" from the drop-down list at the top of the DelayENTRY Tab, shown in Figure 19. If "No" is selected, the remaining dialog boxes on the DelayENTRY Tab will be grayed out, and no further input is necessary.

Figure 19. DelayENTRY Tab Input Omission Message

VDOT Virginia Department of Transportation

VDOT Intersection Cost Comparison

3 - DELAY ENTRY

Enter delay data into orange cells on this sheet.

Consider delay costs? No Choose from list

Should the user choose to consider delay costs, select “Yes” from the dropdown menu shown above, and proceed to the vehicle occupancy dialog box on the DelayENTRY Tab. Each group of inputs on the Tab is described below.

Vehicle Occupancy

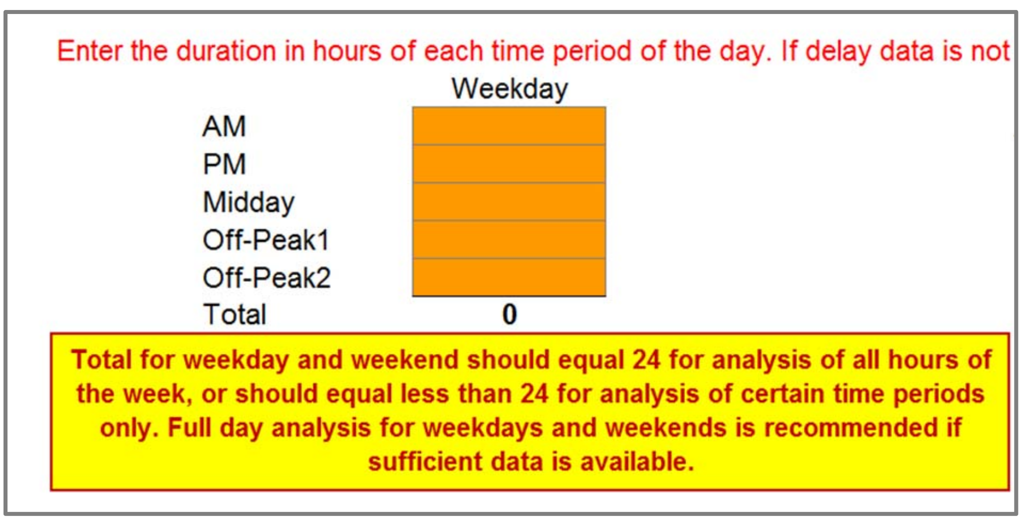
Enter the average occupancy of vehicles at the intersection. This value will generally be unknown, and users will need to input an assumed value. The spreadsheet has a default value of 1.1 persons per vehicle, which may be overridden. According to the US Department of Energy, national average vehicle occupancy is 1.59 persons per vehicle.

Vehicle occupancy directly “weights” delay costs in the overall intersection cost comparison. For example, an intersection with $1 million of life cycle delay and an average vehicle occupancy of 1.0 will have $2 million of life cycle delay if average vehicle occupancy is set at 2.0.

Duration of Analysis Periods

Enter the corresponding time period duration (in hours) for weekday and weekend design year and opening year, as necessary. If delay data is not available for a particular time period, enter a duration of “0” hours in the corresponding cell, and a period of less than 24 hours will be analyzed. If a period of less than 24 hours is entered, a message, shown in Figure 20, will display that advises the user to use 24-hour data. While preferred, 24-hour data is not necessary to continue with analysis.

Figure 20. DelayENTRY Tab 24-Hour Time Period Message



Hourly Volume

The total number of vehicles entering the intersection during each analysis period is entered into the cells shown in Figure 21. These volumes are used to convert average delay per vehicle (entered further down on the Tab) into total delay for all vehicles entering the intersection. They are not used for any other purpose

Users may omit certain analysis periods for which data is unavailable or analysis is not desired by leaving entry fields blank. Often, only weekday a.m. and p.m. traffic analysis is conducted. In this case, weekday midday, off-peak1, and off-peak2 field, and all weekend fields should be left blank.

Figure 21. DelayENTRY Tab Hourly Volume Inputs

Enter the hourly volume (total entering vehicles) for each time period of the day. This is used to convert average delay per vehicle to total delay.
If analysis of certain time periods is not desired, leave cells for that time period blank

	Weekday			Weekend		
	Opening Year	Design Year		Opening Year	Design Year	
AM			AM			
PM			PM			
Midday			Midday			
Off-Peak1			Off-Peak1			
Off-Peak2			Off-Peak2			
ADT	**Requires 24**	**hour data**	ADT	**Requires 24**	**hour data**	ADT calculated from the hourly volumes above time period durations below. Provided for informational purposes and not used in subsequent calculations.

Delay

Enter the delay by time period (in seconds per vehicle). Enter the roundabout delay in the first of the two rows of tables, and the traditional intersection delay in the second of the two rows of tables. (Figure 22) Roundabout and traditional intersection delay must be determined prior to use of this spreadsheet with the methodologies of the Highway Capacity Manual. It is recommended that Highway Capacity Software (HCS) or SYNCHRO be used to compute delay at traditional intersections, and HCS or the "HCM 2010" model within SIDRA be used to compute delay at roundabouts.

As with previous sections on the DelayENTRY Tab, fields associated with time periods the user chooses to omit are left blank.

Figure 22. DelayENTRY Tab Time Period Delay Inputs

Orange cells in tables below can be left blank if consideration of time period is not desired.
For example, if it is desired to only analyze peak hours, delay entries for midday and off-peak may be left blank.

Weekday

Roundabout

	AM	**PM**	**Midday**	**Off-Peak1**	**Off-Peak2**
	Delay	**Delay**	**Delay**	**Delay**	**Delay**
	sec/veh	sec/veh	sec/veh	sec/veh	sec/veh
2015					
2035					

Traffic Signal

	AM	**PM**	**Midday**	**Off-Peak1**	**Off-Peak2**
	Delay	**Delay**	**Delay**	**Delay**	**Delay**
	sec/veh	sec/veh	sec/veh	sec/veh	sec/veh
2015					
2035					

The tables at the bottom of the DelayENTRY Tab calculate and display “daily” delay totals, which represent less than 24 hours of the day if the user did not enter data for 24 hours of the day. No user entry is required in this section.

RESULTS TAB

The Results Tab displays the following:

- Annual costs for both intersection forms,
- Life-cycle costs for both intersection forms,
- A benefit-cost ratio for the roundabout in comparison to the traditional intersection, and

There are no inputs on this Tab.

Annual Costs and Life-Cycle Costs

The first of the two tables on the Results Tab display safety, delay, operations and maintenance, and capital costs for the roundabout and the traditional intersection. The total life cycle cost, in opening year dollars, is displayed in the green row at the bottom of the second table.

VDOT Intersection Cost Comparison

Annual Costs	Roundabout		Traffic Signal	
Safety	**Predicted Annual Crashes**	**Safety Cost**	**Predicted Annual Crashes**	**Safety Cost**
Predicted Fatal/Injury Crashes	0.16	$ 52,613	0.36	$ 121,748
Predicted PDO Crashes	0.24	$ 2,178	0.71	$ 6,400
	Annual Costs of Predicted Crashes	$ 54,791	*Annual Costs of Predicted Crashes*	$ 128,148
Delay	**Annual Intersection Delay (person-hrs)**	**Delay Cost**	**Annual Intersection Delay (person-hrs)**	**Delay Cost**
Average Annual Person (in Vehicle) Delay	1903	$ 23,155	1257	$ 15,631
Operation and Maintenance	**Operation and Maintenance**	**O&M Cost**	**Operation and Maintenance**	**O&M Cost**
Annualized Cost of Signal Retiming		$ -	Signal Retiming Every 3 Years	$ 1,667
Annual Cost of Power for Signal		$ -	Power for Signal	$ 750
Annual Cost of Illumination	Intersection Illumination	$ 750	Intersection Illumination	$ 750
Annual Cost of Maintenance	Landscaping Costs	$ 2,000	Signal Maintenance Costs (power outage, detection, etc.)	$ 3,750
	Total Annual Operation and Maintenance Costs	$ 2,750	*Total Annual Operation and Maintenance Costs*	$ 6,917
Initial Capital Costs	**Total Capital Costs**	**Cost**	**Total Capital Costs**	**Cost**
Preliminary Engineering		$ 1,000,000		$ 600,000
Right-of-way and Utilities		$ -		$ -
Construction		$ -		$ -

*Delay cost is based upon a 2 hour analysis period.

Total Discounted Life Cycle Costs (2013 - 2033)	Roundabout		Traffic Signal	
Safety	**Total Predicted Crashes**	**Safety Cost**	**Total Predicted Crashes**	**Safety Cost**
Predicted Fatal/Injury Crashes	3.11	$ 782,742	7.20	$ 1,811,300
Predicted PDO Crashes	4.84	$ 32,407	14.22	$ 95,219
	Total Costs of Predicted Crashes	$ 815,149	*Total Costs of Predicted Crashes*	$ 1,906,519
Delay	**Total Intersection Delay (person-hrs)**	**Delay Cost**	**Total Intersection Delay (person-hrs)**	**Delay Cost**
Total Person (in Vehicle) Delay	39955	$ 486,263	26402	$ 328,243
Operation and Maintenance	**Operation and Maintenance**	**O&M Cost**	**Operation and Maintenance**	**O&M Cost**
Annualized Cost of Signal Retiming		$ -	Signal Retiming Every 3 Years	$ 24,796
Annual Cost of Power for Signal		$ -	Power for Signal	$ 11,158
Annual Cost of Illumination	Intersection Illumination	$ 11,158	Intersection Illumination	$ 11,158
Annual Cost of Maintenance	Landscaping Costs	$ 29,755	Signal Maintenance Costs (power outage, detection, etc.)	$ 55,791
	Total Annual Operation and Maintenance Costs	$ 40,913	*Total Annual Operation and Maintenance Costs*	$ 102,903
Initial Capital Costs	**Total Capital Costs**	**Cost**	**Total Capital Costs**	**Cost**
Preliminary Engineering		$ 1,000,000		$ 600,000
Right-of-way and Utilities		$ -		$ -
Construction		$ -		$ -
	Total Initial Capital Costs	$ 1,000,000	*Total Initial Capital Costs*	$ 600,000
Total Life Cycle Costs (Opening Year $)	**Net Present Value**	**$ 2,342,325**	**Net Present Value**	**$ 2,937,664**
		Roundabout		Traffic Signal

*Delay cost is based upon a 2 hour analysis period.

Life Cycle Benefit/Cost Ratio		
Safety Benefit of a Roundabout	$ 1,091,370	
Delay Reduction Benefit of a Roundabout	$ (158,020)	
Total Benefits	$ 933,350	
Added Operations&Maintenance Costs of a Roundabout	$ (61,989)	
Added Capital Costs of a Roundabout	$ 400,000	
Total Costs	$ 338,011	
Life Cycle Benefit/Cost Ratio	**2.8**	**Roundabout Compared to Traffic Signal**
	Roundabout Preferred	

Figure 23. Intersection Cost Comparison

Life Cycle Benefit/Cost Ratio

The life cycle benefit/cost ratio table near the bottom of the Results Tab is configured with the following assumptions:

- A roundabout has fewer crashes and less delay than the traditional intersection option
- A roundabout has greater operations and maintenance costs and capital costs than the traditional intersection option.

The spreadsheet computes the safety and delay benefits of a roundabout (compared the traditional intersection option), as well as the added operations and maintenance costs and capital costs of a roundabout (compared to the traditional intersection option). When the assumptions listed above are true, the total benefit and total cost are positive numbers and the spreadsheet reports a life cycle benefit/cost ratio for the roundabout in comparison to the traditional intersection option. When one or more the assumptions noted above are not true, benefit or cost values may be negative. The spreadsheet provides messages notifying the user of this condition; refer to the Concepts Overview section of the User Manual for a full discussion of these messages.

Figure 24. Results Tab Life Cycle Benefit/Cost Ratio

Life Cycle Benefit/Cost Ratio		
Safety Benefit of a Roundabout	$ -	
Delay Benefit of a Roundabout	$ -	
Total Benefits	**$ -**	
Added Operations&Maintenance Costs of a Roundabout	$ -	
Added Capital Costs of a Roundabout	$ -	
Total Costs	**$ -**	
Life Cycle Benefit/Cost Ratio	**0.0**	**Roundabout Compared to Traffic Signal**
	No Data or No Preference Costs and Benefits are Zero	

Section 4
Spreadsheet Example

SPREADSHEET EXAMPLES

The following example shows application of the spreadsheet on an actual project. Screenshots of the spreadsheet for this example are included in Appendix 1.

Scenario

The installation of a single-lane roundabout was proposed at the four-leg intersection of Hopkins Road and Kingsland Road in Richmond, Virginia. The major road is an urban and suburban arterial in a suburban area, and is currently two-way stop-controlled. The major road ADT is 7,750 and the minor road ADT is 1,840, with growth anticipated over the 20 year life span of the project.

This is a Case 2 comparison. A single-lane roundabout will be installed or the intersection will be signalized.

Results

On the Results tab, the spreadsheet indicates that the roundabout produces fewer predicted crashes than the TWSC intersection with a lower safety cost as a result. Additionally, the TWSC yields less predicted delay because through traffic on the major street is uncontrolled and never stops. Delay analysis was conducted for four hours of weekday days.

While the roundabout yields lower safety and delay costs than the TWSC intersection, operating and maintenance costs were determined to be higher in this example. Construction costs also contributed to the increased cost of the roundabout as the TWSC intersection is existing.

Overall, the roundabout total discounted life cycle cost was determined to be less than that of the TWSC intersection. The life cycle benefit/cost ratio of installing a roundabout is 1.9, indicating that the roundabout is preferred. This is primarily due to crash reduction.

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Section 6
References

REFERENCES

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Appendix 1
Spreadsheet Example Screen Shots

VDOT Intersection Cost Comparison

This spreadsheet tool compares the cost of a roundabout to the cost of a traditional intersection, as specified by the user. A traditional intersection is defined as a stop-controlled or signalized intersection and serves as the basis for comparison to the roundabout.

A User Manual for this tool is available from the VDOT Roundabout Group

For the purpose of safety analysis, the spreadsheet tool requires variable input for Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs). The Highway Safety Manual (HSM) defines SPFs as equations that estimate expected average crash frequency and allow for the correction of short-term crash counts. Similarly, CMFs are factors that estimate the potential changes in crash frequency or severity due to the installation of particular treatments.

The following costs are incorporated into the spreadsheet tool comparison:

- Safety
- Delay to persons in vehicles
- Operations and Maintenance
- Capital Construction Costs

Safey and Delay may be excluded from the analysis through use of a drop-down menu. Capital Construction Costs may be excluded from the analysis by not entering them.

The following conventions are used throughout this spreadsheet:

(orange)	data entry field
(blue)	optional data entry - contains default values which may be overridden

Red text provides instructions

1 To begin, move to the MainENTRY tab and enter the required information into the the orange cells. Most information is entered on the MainENTRY Tab.

2 Move to the AdjustSPF tab to enter roadway and intersection geometry information that is used in safety calculations.

3 Move to the DelayENTRY tab to enter delay information.

4 Move to the RESULTS-Life Cycle Costs tab to view results.

5 The last three tabs (O_SafetyCalculation, D_SafetyCalculation, and CostCalculation) only perform calculations and do not need to be viewed or modified.

For questions or to obtain the User Manual, please contact one of the following

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VDOT Intersection Cost Comparison

1 - MAIN ENTRY

Enter project-specific data into orange cells on this sheet.

Scenario

Type of Comparison	Case 2: Traditional Intersection Option vs. Roundabout Option at site of existing traditional intersection	Choose from list
Existing Control	Two-Way Stop Control	Choose from list
Traditional Intersection Option	Traffic Signal	Choose from list

Timeframe

Opening Year	2013	Enter year
Life Span	20	Enter life space in years. Maximum life span is 50 years

Safety Inputs

Consider safety costs?	Yes	Choose from list	
Number of Legs	4	Choose from list	
	Major Road	Minor Road	
Opening Year AADT	7,750	1,840	Enter volumes
Design Year AADT	11,290	2,120	Enter volumes
Facility Type (for SPFs)	Urban and Suburban Arterials	Choose from list	
Area Type (for roundabout CMFs)	Suburban	Choose from list	
Number of Lanes in Roundabout	1	Choose from list	

For "Urban and Suburban Arterial" facility type:

Max. number of lanes crossed by pedestrian	4	For any crossing at intersection. If raised island/median, count stages seperately.
Daily Pedestrian Volume	50	Sum of all legs crossed

Existing Crash Data Available?	Yes	Choose from list
Time Span of Record (years):	3	Enter a minimum of 2 years
Total Number of Crashes:	**15**	
- *with Fatalities:*	1	Enter total number for given time span.
- *with Injuries:*	5	Enter total number for given time span.
- *with PDO:*	9	Enter total number for given time span.

For "Urban and Suburban Arterial" facility type:

Number of Single-Vehicle Crashes	2	Enter total number for given time span. Do not include pedestrian or bicycle crashes.
Number of Multi-Vehicle Crashes	13	Enter total number for given time span. Do not include pedestrian or bicycle crashes.
Number of Vehicle-Pedestrian Crashes	0	Enter total number for given time span.
Number of Vehicle-Bicycle Crashes	0	Enter total number for given time span.

The existing traditional intersection and the traditional intersection option have the same control device, but some geometric differences:

Optional: Enter a CMF for the change associated with the traditional intersection option

Example: Add a left-turn lane to a rural, 3-leg, signalized intersection
-> Enter 0.85 per Table 14-10 of the HSM
If multiple CMFs are applicable, multiply them together before entering into spreadsheet
Use CMFs from HSM Chapter 14 o FHWA's CMF Clearinghouse

Additional safety inputs are located on the "2 - Adjust SPF" tab.

Vehicle Delay

Enter this information on the "3 - DelayENTRY" tab.

Operations and Maintenance	Roundabout	Traffic Signal
Lighting?	Yes	Yes

Capital Costs

Cells in tables below should be left blank if consideration of capital costs is not desired.

	Roundabout	Traffic Signal
Preliminary Engineering		
Right-of-Way and Utilities		
Construction	$ 1,000,000	$ 600,000
Total	**$ 1,000,000**	**$ 600,000**

Unit Costs are listed below. In general, there is no need to change these and default values should be used. Changes, if made, should be made in blue cells.

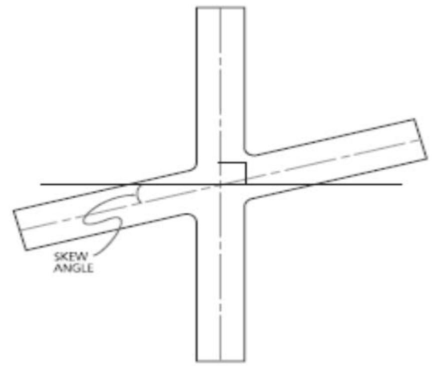
Item	**Cost**	**Typ. Cost**	**Typ. Cost Source**
Cost/Fatal-Injury Crash	$ 338,048	$ 338,048	Weighted average ofVDOT fatal-injury crash costs based on statewide proportion of fatal and all types of injury crashes
Cost/PDO Crash	$ 9,000	$ 9,000	VDOT
Cost/Vehicle-Hour Delay	$ 16.79	$ 16.79	2012 Urban Mobility Report by Texas Transportation Institute
Retiming Cost Every 3 Years	$ 5,000	$ 5,000	VDOT. *Equals $5000 for signal and $0 for stop-control*
Annual Power Cost for Signal	$ 750	$ 750	VDOT. *Equals $750 for signal and $0 for stop-control*
Annual Lighting Cost	$ 750	$ 750	VDOT. *Equals $750 if illumination present*
Annual Signal Maintenance Cost	$ 3,750	$ 3,750	VDOT. *Equals $2000 for signal and $0 for stop control*
Annual Roundabout Landscaping Cost	$ 2,000	$ 2,000	Typical cost
Discount Rate	3.0%	3.0%	Typical for Infrastructure Projects. Opportunity cost of investing in intersection. *Discount rate cannot be zero.*

VDOT Intersection Cost Comparison

2 - ADJUST SPF

Enter intersection geometric conditions into orange cells on this sheet.

Selected Facility Type from MainEntry tab: Urban and Suburban Arterials



Rural Two-lane, Two-Way Roads - Two-Way Stop-Control Intersection (3 or 4 legs)

Intersection Skew Angle	0	Enter Angle (positive number between 0 and 90). See figure.
Major Street Approaches With Left-Turn Lanes	0	Choose from list
Major Street Approaches With Right-Turn Lanes	0	Choose from list
Lighting	No	Choose from list

Rural Two-lane, Two-Way Roads - Signalized Intersection (4 legs)

Approaches With Left-Turn Lanes	0	Choose from list
Approaches With Right-Turn Lanes	0	Choose from list
Lighting	No	Choose from list

Rural Multilane Highways - Two-Way Stop-Control Intersection (3 or 4 legs)

Intersection Skew Angle	0	Enter Angle (positive number). See figure.
Major Street Approaches With Left-Turn Lanes	0	Choose from list. Do not choose "2" for a 3-leg intersection
Major Street Approaches With Right-Turn Lanes	0	Choose from list. Do not choose "2" for a 3-leg intersection
Lighting	No	Choose from list

Rural Multilane Highways - Signalized Intersection (4 legs)

No crash modification factors for this safety performance function

Urban and Suburban Arterials - Two-Way Stop-Control Intersection (3 or 4 legs)

Major Street Left-Turn Lanes	2	Choose from list
Major Street Right-Turn Lanes	2	Choose from list
Lighting	Yes	Choose from list

Urban and Suburban Arterials - Signalized Intersection (3 or 4 legs)

Approaches with Left-Turn Lanes	4	Choose from list
Approaches with Protected/Permissive or Permissive/Protected left-turn phasing	2	Choose from list
Approaches with protected phasing	0	Choose from list
Approaches with Right-Turn Lanes	4	Choose from list
Approaches with RTOR Prohibited	0	Choose from list. RTOR is Right-Turn-on-Red
Lighting	Yes	Choose from list
Red-Light Cameras	No	Choose from list
Bus Stops within 1000 feet of Intersection	0	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes
Presence of Schools within 1000 feet of Intersection	No school present	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes
Number of Alcohol Sales Establishments within 1000 feet of Intersection	0	Choose from list. This CMF only affects the number of vehicle-pedestrian crashes

VDOT Intersection Cost Comparison

3 - DELAY ENTRY

Enter delay data into orange cells on this sheet.

Consider delay costs? | Yes | Choose from list

Enter average vehicle occupancy. This is used to convert vehicle delay to person delay.

Vehicle Occupancy | 1.1 | Average car rate is 1.59 per US Dept. of Energy http://www1.eere.energy.gov/vehiclesandfuels/facts/2010_fotw613.html

Enter the duration in hours of each time period of the day. If delay data is not available for a time period, enter a duration of 0 hours and analyze less than all 24 hours of the day

	Weekday		Weekend	
AM	1	AM		
PM	1	PM		
Midday		Midday		
Off-Peak1		Off-Peak1		This could be used for hours before the AM Peak or in the evening after the PM Peak
Off-Peak2		Off-Peak2		This could be used for overnight hours
Total	**2**	Total	**0**	

Total for weekday and weekend should equal 24 for analysis of all hours of the week, or should equal less than 24 for analysis of certain time periods only. Full day analysis for weekdays and weekends is recommended if sufficient data is available.

Enter the hourly volume (total entering vehicles) for each time period of the day. This is used to convert average delay per vehicle to total delay.
If analysis of certain time periods is not desired, leave cells for that time period blank

	Weekday Opening Year	Weekday Design Year		Weekend Opening Year	Weekend Design Year
AM	859	1180	AM		
PM	959	1341	PM		
Midday			Midday		
Off-Peak1			Off-Peak1		
Off-Peak2			Off-Peak2		
ADT	**Requires 24**	**hour data**	ADT	**Requires 24**	**hour data**

ADT calculated from the hourly volumes above time period durations below.
Provided for informational purposes and not used in subsequent calculations.

Orange cells in tables below can be left blank if consideration of time period is not desired.
For example, if it is desired to only analyze peak hours, delay entries for midday and off-peak may be left blank.

Orange cells in tables below can be left blank if consideration of time period is not desired.
Leave all cells in weekend tables below blank if consideration of weekend delay is not desired.

Weekday

Roundabout

	AM Delay sec/veh	PM Delay sec/veh	Midday Delay sec/veh	Off-Peak1 Delay sec/veh	Off-Peak2 Delay sec/veh
2013	7.7	8.5			
2033	11.6	14.5			

Traffic Signal

	AM Delay sec/veh	PM Delay sec/veh	Midday Delay sec/veh	Off-Peak1 Delay sec/veh	Off-Peak2 Delay sec/veh
2013	7.3	6.8			
2033	7.8	7.2			

Weekend

Roundabout

	AM Delay sec/veh	PM Delay sec/veh	Midday Delay sec/veh	Off-Peak1 Delay sec/veh	Off-Peak2 Delay sec/veh
2013					
2033					

Traffic Signal

	AM Delay sec/veh	PM Delay sec/veh	Midday Delay sec/veh	Off-Peak1 Delay sec/veh	Off-Peak2 Delay sec/veh
2013					
2033					

These cells calculate daily totals. No data entry here.

Roundabout

Weekday Total - Entire Day OR Sum of Hours Entered Vehicle Delay	Weekday Total Person Delay
(in sec)	(in sec)
14,766	16,242
33,133	36,446

Traffic Signal

Weekday Total - Entire Day OR Sum of Hours Entered Vehicle Delay	Weekday Total Person Delay
(in sec)	(in sec)
12,792	14,071
18,859	20,745

These cells calculate daily totals. No data entry here.

Roundabout

Weekend Total - Entire Day OR Sum of Hours Entered Vehicle Delay	Weekend Total Person Delay
(in sec)	(in sec)
0	0
0	0

Traffic Signal

Weekend Total - Entire Day OR Sum of Hours Entered Vehicle Delay	Weekend Total Person Delay
(in sec)	(in sec)
0	0
0	0

VDOT Intersection Cost Comparison

Annual Costs	Roundabout		Traffic Signal	
Safety	**Predicted Annual Crashes**	**Safety Cost**	**Predicted Annual Crashes**	**Safety Cost**
Predicted Fatal/Injury Crashes	0.16	$ 52,613	0.35	$ 117,549
Predicted PDO Crashes	0.24	$ 2,178	0.71	$ 6,400
	Annual Costs of Predicted Crashes	**$ 54,791**	***Annual Costs of Predicted Crashes***	**$ 123,949**
Delay	**Annual Intersection Delay (person-hrs)**	**Delay Cost**	**Annual Intersection Delay (person-hrs)**	**Delay Cost**
Average Annual Person (in Vehicle) Delay	1903	**$ 23,155**	1257	**$ 15,631**
Operation and Maintenance	**Operation and Maintenance**	**O&M Cost**	**Operation and Maintenance**	**O&M Cost**
Annualized Cost of Signal Retiming		$ -	Signal Retiming Every 3 Years	$ 1,667
Annual Cost of Power for Signal		$ -	Power for Signal	$ 750
Annual Cost of Illumination	Intersection Illumination	$ 750	Intersection Illumination	$ 750
Annual Cost of Maintenance	Landscaping Costs	$ 2,000	Signal Maintenance Costs (power outage, detection, etc.)	$ 3,750
	Total Annual Operation and Maintenance Costs	**$ 2,750**	***Total Annual Operation and Maintenance Costs***	**$ 6,917**
Initial Capital Costs	**Total Capital Costs**	**Cost**	**Total Capital Costs**	**Cost**
Preliminary Engineering		$ -		$ -
Right-of-way and Utilities		$ -		$ -
Construction		$ 1,000,000		$ 600,000

*Delay cost is based upon a 2 hour analysis period.

Total Discounted Life Cycle Costs (2013 - 2033)	Roundabout		Traffic Signal	
Safety	**Total Predicted Crashes**	**Safety Cost**	**Total Predicted Crashes**	**Safety Cost**
Predicted Fatal/Injury Crashes	3.11	$ 782,742	6.95	$ 1,748,836
Predicted PDO Crashes	4.84	$ 32,407	14.22	$ 95,219
	Total Costs of Predicted Crashes	**$ 815,149**	***Total Costs of Predicted Crashes***	**$ 1,844,055**
Delay	**Total Intersection Delay (person-hrs)**	**Delay Cost**	**Total Intersection Delay (person-hrs)**	**Delay Cost**
Total Person (in Vehicle) Delay	39955	**$ 486,263**	26402	**$ 328,243**
Operation and Maintenance	**Operation and Maintenance**	**O&M Cost**	**Operation and Maintenance**	**O&M Cost**
Annualized Cost of Signal Retiming		$ -	Signal Retiming Every 3 Years	$ 24,796
Annual Cost of Power for Signal		$ -	Power for Signal	$ 11,158
Annual Cost of Illumination	Intersection Illumination	$ 11,158	Intersection Illumination	$ 11,158
Annual Cost of Maintenance	Landscaping Costs	$ 29,755	Signal Maintenance Costs (power outage, detection, etc.)	$ 55,791
	Total Annual Operation and Maintenance Costs	**$ 40,913**	***Total Annual Operation and Maintenance Costs***	**$ 102,903**
Initial Capital Costs	**Total Capital Costs**	**Cost**	**Total Capital Costs**	**Cost**
Preliminary Engineering		$ -		$ -
Right-of-way and Utilities		$ -		$ -
Construction		$ 1,000,000		$ 600,000
	Total Initial Capital Costs	**$ 1,000,000**	***Total Initial Capital Costs***	**$ 600,000**
Total Life Cycle Costs (Opening Year $)	**Net Present Value**	**$ 2,342,325**	**Net Present Value**	**$ 2,875,200**
		Roundabout		Traffic Signal

*Delay cost is based upon a 2 hour analysis period.

Life Cycle Benefit/Cost Ratio		
Safety Benefit of a Roundabout	$ 1,028,906	
Delay Reduction Benefit of a Roundabout	$ (158,020)	
Total Benefits	**$ 870,886**	
Added Operations&Maintenance Costs of a Roundabout	$ (61,989)	
Added Capital Costs of a Roundabout	$ 400,000	
Total Costs	**$ 338,011**	
Life Cycle Benefit/Cost Ratio	**2.6**	**Roundabout Compared to Traffic Signal**
	Roundabout Preferred	