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A National Model for Predicting Life Cycle Costs and Benefits of Intersection Control Alternatives

Final Report

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EXECUTIVE SUMMARY

This project, NTC2016-MU-R-03: A National Model for Predicting Life Cycle Costs and Benefits of Intersection Control Alternatives provides a new method for analyzing the life cycle costs and benefits of converting two-way stop controlled (TWSC) intersections. TWSC intersections are often converted to other intersection control types to improve safety and operations, as well as other conditions. However, transportation agencies across the United States have historically lacked the tools and guidance needed to efficiently evaluate and select optimal control alternatives to TWSC intersections.

As a result, life cycle costs and benefits are often not the focus of planning-level conversion decision-making processes. Instead, short-term costs and gains, such as construction and reduced congestion can be given more weight. Each of these challenges can inhibit the ability of an agency to identify the most cost-effective conversion options and empirically support their selection. While progress in this area has been made with the introduction of computational tools such as NCHRP 03-110, a need for improved intersection conversion models that compare the life cycle costs of intersection control alternatives for TWSC remains. Accordingly, this research effort provides a model specifically designed to compare conversions options for TWSC intersections to enhance the effective allocation of public funds.

The model developed through this study combines enhanced Highway Capacity Manual 6th Edition methodologies and standard life cycle cost analysis methodologies to allow decision makers to efficiently evaluate the long-term net costs and benefits associated with converting a TWSC intersection to 1) all-way stop controlled, 2) signalized, and 3) roundabout intersection control types. The monetized results of this input-output model enable decision makers to identify the intersection control alternative that offers the greatest return on investment to citizens over a user-specified time period. To enable flexible application across the United States, this model allows users to incorporate their own unique inputs for values such as facility maintenance costs and crash reduction factors.

The model and associated findings of this project were integrated into a new computational tool called CostVAL. This Java-based computational engine is designed for use during the planning phase of potential intersection conversion projects. Unlike related tools used nationally, this tool calculates variables such as delay, safety, and related long-term costs and benefits within one platform. Such integration is aimed at saving transportation agencies valuable time and money, as intersection conversions can be time-consuming and expensive undertakings.

By developing an all-in-one computational tool, the research team aims to help transportation agencies nationwide reduce costs, staff time, and the potential for error. This unique, Java-based model could be more readily updated and expanded in the future compared to a traditional spreadsheet-based format. In addition, as transportation agencies share their state standards for construction and other standard values, the knowledge base of other agencies across the country will grow through exposure to approaches and data used by regions. Ultimately, savings and added efficiencies realized by the model may enhance the economic competitiveness of transportation agencies and their jurisdictions.

1.0 INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Many areas in the United States are growing, and with this growth, intersections that were previously adequate for area traffic may experience operational and safety issues that require interventions such as a facility type conversion. In particular, operations at Two-Way Stop Controlled (TWSC) intersections, which are often located in low volume or rural areas, may be improved with a conversion to an all-way stop controlled (AWSC), roundabout, or traffic signal control types. Each of these intersection control alternatives has advantages and disadvantages that can result in different long-term benefits and costs for public agencies like Department of Transportations (DOTs).

Life Cycle Cost Analyses (LCCAs) can help public agencies and lawmakers choose the project option that optimizes public funds by comparing the potential long-term costs and benefits of a project in monetary terms (Swiss, 2002). LCCAs are of value during intersection conversion decision-making processes because many of the costs and benefits associated with intersection reconfigurations may not be realized until after multiple years, sometimes decades, after an initial conversion. Consequently, in the absence of a LCCA, the most cost-effective alternative may not be selected and public funds may be inefficiently allocated (Litman, and Doherty, 2009).

However, conducting an LCCA that compares intersection control alternatives can be a time consuming and complex task, as currently multiple computation tools must be used for a single comparative analysis. Due to the time-consuming nature of such an analysis, intersection conversion decisions may often be made using limited data and short-term cost and benefit projections. As a result, the long-term costs and benefits of a conversion choice are often not the focus of the decision-making process, if they are evaluated at all (Misuraca, 2014). Consequently, intersection control options with minimal up-front costs, such as traffic signals, have historically been selected over more initially expensive alternatives such as roundabouts (NCHRP 03-110, 2016).

To address these issues, this research effort seeks to develop a model for evaluating the life cycle costs and benefits of intersection control alternatives to TWSC, and aims to integrate these findings into a spreadsheet-based computational tool that can be used across the United States to efficiently and uniformly compare the long-term impacts of conversion alternatives. This research aligns with the NTC theme of Economic Competitiveness because it provides transportation agencies with methods to make more fiscally sound intersection conversion decisions using minimal resources.

1.2 OBJECTIVES

The overarching goal of this research project is to develop new tool that help maximize the return on intersection transportation investments across the United States. The research team aims to accomplish this goal through two main objectives:

1. Support more informed decision-making and help transportation agencies across the nation more accurately project long-term conversion costs by outlining an intersection-specific LCCA methods and updating defaults for variables that impact these costs.
2. Streamline intersection LCCA processes by creating a web-based tool for evaluating the long-term impacts associated with converting a two-way stop controlled intersection to three different intersection options: 1) all-way stop controlled, 2) signalized, and 3) roundabout.

1.3 SCOPE

The model developed through this research employs site-specific user inputs as well as state and national standards to calculate the long-term costs and benefits of converting a specific intersection of interest. The final outputs of this model are the estimated long-terms costs of converting the existing TWSC intersection, considering construction and maintenance, user delay, and safety. The scope of the model is limited to TWSC intersections to AWSC, signal, and roundabout control types. In addition, environmental impacts and other possible factors of interest are not considered in this model, and the model is intended to be used in conjunction with additional sources of information such as stakeholder input, right-of-way availability, and funding flexibility.

1.4 APPROACH

This project focused on six key tasks:

1. Develop state of the practice review
2. Update existing framework to align with HCM 2015
3. Align methodology and system defaults with NCHRP 03-110
4. Develop national construction and maintenance costs defaults
5. Design a computational tool
6. Develop training materials and final report

The primary deliverable of this project is a web-based planning tool that compares the life cycle impacts of TWSC conversion options for four-legged intersections that can be utilized across the United States. Findings from the state of the practice review as well as the HCM 2015 will be integrated into the Java-based tool to ensure use of accurate and up-to-date methodologies. In addition, the LCCA-based model developed can help maximize returns on transportation investments nationwide by providing an efficient platform for calculating and comparing the long-term costs and benefits of conversion alternatives.

1.5 REPORT ORGANIZATION

This report is organized as follows. Section 2 outlines the state of practice review, including a background on intersection conversion LCCAs and their value. Section 3 explains the framework of the model developed through this study. Section 4 describes the computational tool development and process. Section 5 outlines the results of the study and related recommendations. Note that unanticipated compatibility challenges related to coding HCM 2015 methods into the model framework limited opportunities to focus efforts on Tasks 3 and 4 of the project. Therefore, the majority of this report will focus on Tasks 1-2 and 4-6.

2.0 STATE OF THE PRACTICE REVIEW

A variety of research and data from both Life Cycle Cost Analysis (LCCA) and transportation literature is incorporated into this study. To enhance the research team's understanding of the challenges facing transportation agencies interested in TWSC conversion, preliminary research was conducted using journal articles, reports, expert opinion from transportation agencies, and other sources. This research showed that many transportation agencies lack guidance on LCCA models and the standardized inputs for the types of data needed to apply these models. Research showed that identifying standard analysis models and inputs could limit agency transaction costs and improve intersection conversion decision making over time (Misuraca, 2014; Litman and Doherty, 2009). Findings from this research were integrated into the design of the LCCA method developed through this study.

Additionally, the methodology developed through this study utilizes models from the Highway Capacity Manual (HCM), the Highway Safety Manual (HSM), and other reputable sources.

2.1 INTERSECTION CONVERSION DECISION-MAKING

Transportation agencies across the nation regularly convert two-way stop controlled TWSC intersections to other configurations, in particular roundabouts, traffic signals, and all-way controlled (AWSC) types. TWSC conversions typically occur because of traffic safety and operational problems at intersections that stem from increases in roadway volumes overtime. Each of these has advantages and disadvantages that result in unique costs and benefits to the public. For example, although roundabout, signal, and AWSC control types can each reduce collisions compared to TWSC, the degree of reduction can vary significantly not only by control type, but also by location type (urban, suburban, or rural) and state.

Conversion to an AWSC intersection can reduce collisions with only minimal construction and maintenance costs, but can result in increased delay as volumes increase. Signalization can reduce delay to side street movements, but may require higher construction, maintenance, and operational costs. Additionally, roundabouts often require significant initial construction costs but can effectively reduce delay under the right conditions (Han, Li, and Urbanik, 2008; Jiang, and Yu., 2012; Sides, Seals, and Walwork, 2005; FHWA, 2004; FHWA, 2010). As a result, the long-term costs associated with different conversion types can vary by tens of millions of dollars, which means choosing the best conversion can save millions of public funds annually (NCDOT 2015).

Choosing a more fiscally sound long-term option, can provide agencies savings in funds and man-hours that they can allocate elsewhere for projects that can increase an area's economic competitiveness. Additionally, installing the optimal intersection type can reduce congestion and collisions, which can make an area more attractive to businesses and consumers. However, transportation agencies are challenged to monetize and compare the life cycle impacts of alternatives to TWSC intersections because of the complexity of measuring resulting outcomes.

Consequently, public funds are often invested in the facility option that offers the fastest design at the lowest upfront cost instead of the option with the greatest return on investment (NCHRP 03-110), and the most cost-effective alternative may not be selected and public funds may be inefficiently allocated (Misuraca, 2014; Litman, and Doherty. 2009).

2.2 LIFE CYCLE COST ANALYSIS

Life Cycle Cost Analysis (LCCA), also known as benefit-cost analysis is a methodology that can enable analysis and comparison of the long-term financial impacts of investment alternatives. Because LCCA is an important methodology for systematically calculating and comparing transportation projects, and transportation agencies are increasingly being required to provide LCCA findings to policymakers as part of funding requests (NCHRP Report 483, 2003).

LCCAs are used to *monetize* variables of different types so that they can be compared using a common monetary unit like the dollar (United States Office of Management and Budget, 1992). Monetizing, or applying a monetary value to non-monetary variables, such as improved roadway safety, helps planners and policymakers account for both the social and fiscal costs and benefits of a project. This method is a useful technique for comparing project options because it allowed decision makers to directly compare the projected future costs and benefits of different alternative using consistent and measurable monetary units. (United States Office of Management and Budget, 1992; Swiss, 2002).

Because one of the core assumptions of the LCCA method is that money today will be worth less in the future because of its investment potential, LCCA models include a method called *discounting*(Jawad, and Ozbay, 2005). Similar to the idea of inflation, discounting adjusts monetized costs and benefits to reflect how their value will typically decline over time (Litman and Doherty, 2009). As shown the equation in Equation 1 below, in this model each cost and benefit is multiplied by a carefully selected anticipated rate of change, which compounds annually over the period of analysis selected by the user (United States Office of Management and Budget, 2015). This formula is the standard for discounting in LCCA literature.

Equation 1. Discounting

$$PV = \frac{AB_{y_f}}{(1+r)^{y_f - y_i}}$$

where:

PV = present value
AB (or AC) = annual benefit (or annual cost)
r = the discount rate
y_f = the final year in which the benefit or cost occurs
y_i = the initial year of analysis

In LCCA literature and in this model, after discounting the benefits are subtracted from costs for each option to identify its *Net Present Value (NPV)*, or total long-term benefits. The option with the highest NPV is that which would provide the greatest return on investment over time and is therefore the recommended conversion type for the site of interest (United States Office of Management and Budget, 1992).

Although widely used, LCCA has some limitations, in that the method does not address equity issues and standards for the valuation of certain variables may vary by organization, state, or even user preference (Swiss, 2002). To account for the latter limitation, this model and the associated computational tool allow users to override default values with inputs that may be more specific to the location and standards of their transportation agency.

2.3 CONVERSION TYPES

Innovative intersection designs such as Restricted Crossing U-turns are becoming more popular in the United States. However, TWSC intersections are most frequently converted to roundabouts, traffic signals, and all-way stop controlled types (FHWA, 2010). Compared to TWSC types, research shows that each of these configurations can reduce collisions (FHWA, 2010). The degree of crash reductions, however, can depend on the control type as well as the area type (urban, suburban, or rural), and other factors.

In addition, there are unique costs and benefits associated with each of these intersection control alternatives, which can accumulate at different rates over different time periods. Conversion to an AWSC intersection can reduce collisions with only minimal construction and maintenance costs but may result in increased delay as volumes increase. Signalization can reduce delay for side street movements but may require higher construction, maintenance, and operational costs. Conversely, roundabouts often require significant initial investment due to construction costs but can dramatically increase safety and effectively reduce delay under the right conditions (Han, Li, and Urbanik, 2008; Jiang, 2012; Sides, Seals, and Walwork, 2005; FHWA, 2004b; NCHRP Report 672, 2010).

2.4 COMPUTIONAL VARIABLES

Intersection conversion literature focuses on three categories of costs: 1) construction and maintenance, 2) user delay, and 3) safety (Sides, Seals, and Walwork, 2005; FHWA, 2010; Day, Hainen, and Bullock, 2013). Environmental impacts are often examined as well. However, environmental factors beyond consideration of fuel consumption due to idling are not included in this study (FHWA, 2010).

In this model, the monetization of each of the three primary variable types incorporates unique inputs, standard values, and adjustments for changes in these values overtime. Standardized, or default values are used in calculations throughout the developed model tool in order to both limit user input time and to enhance the uniformity of the LCCA processes.

Extensive research was conducted to identify the most appropriate default values for monetizing the costs and benefits calculated by this tool, such as the average reduction in crashes expected for a specific conversion type and the average number of expected passengers per vehicle. Federal and state standards as well as state transportation data and findings from peer-reviewed research were gathered to inform the defaults in this tool. All of the monetary default variables used were converted to 2016 dollars for consistency. When available, standard values already established by reputable state and national sources were used to develop defaults for the variables in the model. All default values and their sources are outlined in later sections of this report, as well as Appendix A.

3.0 MODEL FRAMEWORK

This project is designed to help streamline conversion decisions across the nation by providing a framework for sound methodologies and defaults that can be used to compare alternatives in a standardized fashion. Utilizing standard LCCA methodologies and national transportation guidance, the inter-institutional research team developed model that compares the costs and benefits of each alternative uniformely. Two-way stop controlled (TWSC) intersection are considered the baseline, therefore the projected outcomes of the other three intersection control alternatives evaluated (all-way stop controlled, signalized, and roundabout) are compared against the projected long-term outcomes of the TWSC configuration. For the purpose of this study, a two-way stop controlled intersection is defined as a four-way intersection with no control mechanism for the main approach and stop signs positioned at the minor approach.

The model applies sound method to forecast outcomes, such as delay times, that would occur if the TWSC facility was not converted, and then subtracts these values from the projected outcomes of each alternative. Using LCCA methodologies, the difference between the projected outcomes of the TWSC option and those of each alternative are then monetized. This method accounts for only the costs and benefits that are expected to result from a given conversion option. For example, only the benefits of the potential reduction in crashes expected with a given conversion alternative are analyzed because the assumption is that without any conversion accident trends at the site will follow historical patterns.

Based on a methodology that considers the changing value of money over time, the model calculates site-specific construction and maintenance, user delay, and safety costs and benefits for each of the three conversion types by incorporating default values that can be customized by user when state-level or other more specific data is available. As discussed in Section 2, standard methodologies are used to calculate operational and safety data, as well as the changing value of money over time. Once the next long-term costs and benefits are calculated for each alternative, the results are compared to enable to identify the control type that will provide the greatest return on investment over time.

As discussed in Section 4, this model is integrated into a Java-based computational tool designed to be utilized during the planning phase of intersection conversion projects. Both the model and the computational tool build on the previous LCCA, engineering, and programming experience of the research team.

3.1 CONSTRUCTION AND MAINTENANCE

Construction and maintenance can be monetized by applying costs from similar historic projects. Most LCCA literature refers to the period of construction as “Year 0” because additional costs and benefits do not typically begin to accumulate until a facility is completed (Swiss, 2002). Additionally, construction costs are typically considered a one-time expenditure that occurs only during the period prior to project completion. Therefore, a discount rate is not applied to initial construction costs in LCCAs, and only costs and benefits that begin after Year 0 will be discounted (Minnesota Department of Transportation, 2015; Swiss, 2002). Maintenance costs, on the other hand, are typically discounted and are considered to accumulate annually (Minnesota Department of Transportation, 2015).

3.1.1 Construction Costs

For the purposes of this study, construction costs are the capital funds needed to convert an intersection from a two-way stop to another intersection type, including pre-construction (right-of-way purchases and preliminary engineering) and physical construction (utility moves/additions, infrastructure changes/additions, etc.). Defaults for the typical cost of converting a TWSC intersection to each alternative type were established by the research team by analyzing actual NCDOT intersection conversion costs for a five-year period. Although the research team made to gain additional construction cost data form other sources, this available data was insufficient for analysis given the level of resources allocated in this project. Thus, the construction values utilized are for North Carolina, although other states can input their own customized values into the model.

The NCDOT conversion projects analyzed for this model were funded through the Spot Safety Program. The dataset includes more than 700 projects, a third of which were identified as conversions from TWSC to one of the three alternatives of interest. Construction data, contracts, and before and after maps were analyzed for each conversion project. The projects were then categorized based on the characteristics of the re-configurations involved in the facility conversion, such as roadway realignment, utility movement, and right-of-way purchase. This method was applied with the consideration that the up-front costs needed to convert an intersection can vary greatly due to conversion type and site-specific characteristics.

Based on these characteristics, each project was categorized into one of three tiers of construction complexity (low, average, and high) for each of the three conversion types. The average cost for conversions of each category was then calculated to develop three tiers of typical construction costs (low, average, and high) for each alternative type, as shown in the User Manual in Appendix B. The three tiers of construction cost were developed to provide planners the flexibility to choose the best cost estimates based on the characteristics of the site of interest. For example, a conversion at an intersection that would require a realignment may be significantly costlier than one that does not and as a result, a user may chose a funding option higher than the lowest option. Model users can also opt to enter values other than those used for the cost tiers of this methodology.

3.1.2 Time from Analysis to Completion

Time to completion for an intersection conversion, or the time between the initiation of a conversion project and its opening, can vary by the intersection control alternative selected and other factors. For example, converting a TWSC intersection to a roundabout may require moving utilities while conversion to AWSC may require little more than adding additional stop signs to a location. In addition, projected benefits and costs of an intersection do not begin to accumulate until the standard construction period has concluded, which can vary by a month to years for different alternatives. For example, if the average signalized intersection takes six months to complete, benefits and costs do not begin until the first day of the seventh month from the day of the analysis because theoretically the signalized intersection does not exist until that time.

Consequently, this model allows for the application of unique periods to completion for each alternative to ensure more accurate life cycle cost comparisons.

Within the model, this variance in construction timeframes is considered by utilizing standards for average time to completion periods for each alternative type. These defaults, shown in Appendix A, were developed by based on past project data and the expertise of state DOT staff. In the model, costs and benefits are not considered until after the projected construction period is complete. As seen in Appendix A, “Year 0,” or the timeframe prior to construction, may actually be a period more or less than a year for some alternative intersection types. However, the time period of analysis will be the same for all alternatives, based on the timeframe selected by the model user. For example, if the timeframe of analysis is 25 years and the model assumes a roundabout will require 1.5 years for construction, then Year 1 for the roundabout alternative will begin after 1.5 years and only 23.5 years of costs and benefits will be analyzed for the facility.

3.1.3 Annual Maintenance Costs

In this model, maintenance costs include annual and incremental operations and upkeep costs, such as landscaping and signal timing, as well as the cost of revising an intersection at the end of its anticipated service life. Similar to construction costs, different facility types can have different maintenance costs, which should be considered in the monetization of the costs and benefits (FHWA, 2010: NCHRP Report 672, 2010).

When calculating maintenance costs, the model utilizes unique annual maintenance costs for the anticipated service life in years for each of the three intersection types. The annual maintenance costs applied for each intersection alternative are the standard defaults that were established by the NCDOT are based on existing national literature and local experience. These values are used because; similar to construction costs, available maintanence cost data from other sources was insufficient for analysis given the level of resources allocated in this project.

As shown in Appendix A, it is projected that both roundabouts and signalized intersections will incur a maintenance cost of $2,500 annually while AWSC types will require $0 in annual upkeep.

3.1.4 Facility Service Life

Each of the three intersection alternatives also has a unique end of service life, or life expectancy, at the end of which it is anticipated that the facility will need significant revision(s). The LCCA model of this study uses default values for the facility service life period that were developed via expert panels and historical data. These values are shown in Appendix A. In the year following an intersection type’s anticipated end of service life period, the tool applies the cost of the lowest construction tier for that type instead of that year’s annual maintenance cost, with the assumption that facilities will need to be upgraded at that time.

In consideration of these varied service life periods and national defaults for analysis periods, the model is designed to analyze projects only between 10 and 25 years into the future. In the United States, the typical period of analysis used for transportation improvement projects is 20 years

(Minnesota Department of Transportation, 2015). The 10 to 25 year range aligns with the literature, and allows time for some benefits to accumulate for each alternative in addition to allowing planners the flexibility to select a timeframe that is appropriate for the intersection of interest.

For example, users may want to select a timeframe closer to 10 years in cases where decision-makers plan to use a conversion as a temporary solution due to a longer-range plan for the area of interest. For cases in which the user makes input choices based on future plans or insights about an area, users can explain plans in the comment sections of the tool's printable report. This report, explained further in the *Print Report* section below, includes details from the analysis and provides a space users can use to comment on inputs and other factors of the analysis, as they desire.

3.2 USER DELAY

User, or passenger, delay is an important measure for evaluating an intersection (Han, Li, and Urbanik, 2008). In alignment with findings from multiple peer-reviewed studies, this model applies a user delay analysis based on the assumption that conversion from a two-way stop controlled intersection to a more complex type will decrease delay (Sides, Seals, and Walwork, 2005). To align with the standards used nationally, delay calculations apply HCM 2015 methods. Note that delay calculations in this methodology focus solely on vehicle demand and do not account for pedestrian or bike usage.

Congestion and related traffic delays are important factors to consider when comparing intersection control alternative because they can come at a high price for roadway users (Virginia Department of Transportation, 2013). Typically, these costs occur due to time lost waiting in traffic, increased vehicle wear and tear, fuel lost due to idling, and other factors. Instead of approaching user delay as a cost, the methodology of this study treats conversion-related reductions in delay as a benefit by subtracting delay outcomes expected with the current TWSC from that projected for an alternatives and monetizing the difference.

This model monetizes delay using two key variables: the value of fuel consumed while idling and the value of travel time. Other variables that can influence delay costs were not considered due to their complex and variable nature.

3.2.1 Calculating Delay

The Highway Capacity Manual (HCM) is one of the widely used references in transportation engineering. In this research project, the 6th edition of the HCM is used to estimate delay for different intersection types. Analytical methods described in chapters 19, 20, 21, and 22 are used in the model to compute estimated delay for signalized, two-way-stopped, four-way-stopped and roundabout intersections respectively. Described methods, along with methodological details in HCM Volume IV, are coded within the computational engine to allow for a robust analysis.

3.2.2 Fuel Consumption

This model also considers the impact of different intersection control alternative on fuel costs because user delay and idling are positively correlated in that when user delay decreases it is anticipated that idling will decrease, and vice versa (FHWA, 2005; HCM, 2015). The Argonne National Laboratory estimates that in the United States idling results in more than 6 billion gallons of wasted fuel at a cost of more than $20 billion each year (United States Department of Energy, 2013).

The idling cost per second used is calculated in the model by multiplying the cost of fuel per gallon by the average number of gallons expected to be consumed per second respective to vehicle type. Unleaded fuel for passenger vehicles and diesel fuel for heavy vehicles are calculated separately to account for the difference in pricing. To increase the precision of idling cost and benefit estimations, model users input the cost per gallon of unleaded (for passenger vehicles) and diesel (for heavy vehicles) fuel on the day of analysis for the state in which the intersection is located. The U.S. Department of Energy's standards for the average amount of fuel consumed per hour by passenger and heavy vehicles, shown in Appendix A is then applied and resulting values are divided by 3600 to identify the average amount of fuel consumed per second due to idling.

In order to determine the total cost of delay for the specific intersection of interest, the costs of idling per second for both passenger and heavy vehicles are then multiplied separately by the control delay per second for each roadway approach. These calculations provide the unique idling cost per second per vehicle for each of the approaches specific to the intersection of interest.

In addition to increased fuel costs, delay can come at a financial cost to drivers in the form of increased vehicle maintenance, decreased vehicle life span, and increased pollution (United States Department of Energy, 2013). However, changes in vehicle maintenance costs, vehicle life spans, and environmental ramifications can be challenging to monetize accurately. Therefore, this model focuses on the value of fuel to monetize idling projected to occur due to various intersection conversions.

3.2.3 Value of Travel Time

Value of travel time, a commonly applied LCCA monetization approach is also considered in delay monetization methods within the model. Applying a value to travel time follows the logic that the time of all roadway users has a monetary value, and as a result, increased delay results in a cost to users. For the purposes of this study, value of travel time is calculated using valuation standards released by the Texas A&M Transportation Institute, which estimates the value of an hour of time for passenger and heavy vehicles (Schrank, Eisele, Lomax, and Bak, 2015). These figures are shown in Appendix A.

These values are divided by 3600 to identify the cost of delay to each passenger per second. Because it cannot be assumed that only one person is occupying each vehicle at an intersection, this cost is multiplied by the default of 1.25 persons per vehicle produced the Texas A&M

Transportation Institute to develop the cost per second per vehicle (Eisele, Schrank, Lomax, and Bak, 2015).

The cost of idling per second per vehicle is then added to the cost of each second of travel time per vehicle to bring the fuel cost per vehicle and the user travel time cost together. These figures, which are calculated separately for passenger and heavy vehicles types, account for the total cost of delay by vehicle type.

The total cost of delay for a vehicle is then multiplied by the peak volume of vehicles per hour for each individual approach to produce the total cost per vehicle. These values are then divided by a K factor and multiplied by 365 days a year to identify the total annual cost for vehicles at each approach. Finally, all of the values for all of the approaches are added to calculate the total costs for all vehicles annually at the given intersection.

3.2.4 Annual Volume Growth

For each year of analysis, this model applies an annual volume growth factor in order to adjust future projected delay times. Similar to discounting, the resulting percentage increases in traffic demand compound over time, as shown in the equation in Equation 2 below.

Equation 2. Volume Growth

$$\textit{Volume Growth} = (T_2/T_1)^{1/(Y2-Y1)}$$

where:

T1 = traffic flow in year Y1
T2 = traffic demand in year Y2
With the annual traffic growth compounding

Source: FHWA, 2007

Defaults for volume growth factors are not included in this model, as growth factors will vary from site to site based on a variety of variables such as anticipated area population growth and business development.

3.3 SAFETY

Safety can be a key factor in TWSC intersection conversion decisions. Research shows that a conversion from TWSC to each of the three types examined in this model (AWSC, signalized and roundabouts) can reduce the number of collisions at an intersection (Sides, Seals, and Walwork, 2005; FHWA, 2004b; FHWA, 2010).

3.3.1 Crash Reduction Factors

The potential safety impacts of intersection control alternatives calculated in the model by applying Crash Reduction Factors (CRFs). CRFs express the percent amount crashes are expected to decrease when a countermeasure is implemented (FHWA, 2014). CRFs are the inverse of Crash Modification Factors, also called Accident Modification Factors, which are multiplicative factors used to calculate the number of crashes that are projected to occur with the implementation of a countermeasure (FHWA, 2016).

For example, an intersection conversion that is expected to reduce crashes by 20% would have a CMF of .80. This means that if a site had 100 crashes annually prior to the conversion, the projected number of crashes would be reduced to 80 each year after the conversion. Alternatively, the CRF for a conversion option expected to reduce crashes by 20% would be 20. Both CRFs and CMFs can be applied to existing crash frequency data as a ratio of change expected to occur with the installation of a countermeasure (HSM, 2010). The research team incorporated CRFs into this model because this method can be more easily understood by tool users and decision-makers.

All CRF defaults used in this model transportation were developed through peer-reviewed studies and are the most reliable figures identified in the FHWA's CMF Clearinghouse (http://www.cmfclearinghouse.org/). Unique CRFs are used for rural, urban, and suburban locations, shown in Appendix A. However, transportation agencies can opt to override default CRFs with those of their own choosing.

3.3.2 Crash Costs

The benefits of increased safety are monetized by applying NCDOT annual KABCO costs, based on injury by severity, and can be adapted by users to align with the values used by their transportation agency. The CostVAL User Manual in Appendix B includes descriptions of KABCO severity categories and the standard costs associated with each crash category are shown in Appendix A.

In the developed model, *the* proportional reduction in crashes is multiplied by the KABCO costs that would be anticipated to occur on average each year if the intersection of interest remained a TWSC type. For example, if the annual collision cost expected at a TWSC control intersection is $5 million, then a conversion with CRF of 20 would be result in a benefit of $1 million annually due to a 20% reduction in crashes. These crash costs are monetized using three different crash categories and associated tiers of costs: 1) K + A injuries, 2) B + C injuries, and 3) PDO injuries.

This study uses a 3% discount rate. This rate is within the 3-5% standard recommended by the FHWA (FHWA, 2004a), and is also in alignment with the standards released in 2016 by the United States Office of Management and Budget (United States Office of Management and Budget, 2016). As discussed earlier, it should be noted that not all costs and benefits begin accumulating in Year 1 of a project and are therefore discounted based on the year that they begin. For example, if a onetime cost occurs in Year 5, it will be discounted based on five years of a 3% rate compounded. For additional information, see the discounting formula (Formula 1) in Section 2.1.

4.0 COMPUTATIONAL TOOL

4.1 STRUCTURE OF PROCESS

The model developed through this study was integrated into a Java-based computational tool to optimize efficiency and user-friendliness. Within the tool, called CostVAL, the model process is broken into an 8-step process for the user. The steps are as follows:

1) Global Inputs
2) Traffic Demand
3) Crash Data
4) Roundabout Configuration
5) All-Way Stop Configuration
6) Signal Configuration
7) Review and Summary
8) Print Report

The methods and unique inputs used for each of these steps are explained in the following sections, and are detailed in the CostVAL User Manual in Appendix B. Within the tool, dynamic graphic user interfaces are included for many steps to optimize the accuracy of inputs and user understanding.

The CostVAL computational engine is designed to help transportation agencies to more effectively compare variables such as delay, safety, and other long-term costs and benefits within one platform. Transportation agencies will be able to use the resulting data to make better funding decisions and to meet the funding requirements of policymakers. To optimize tool usage, the research team developed training materials, including the User Manual in Appendix B.

Users of similar platforms currently must calculate variable such as delay independently and then input these figures in order to evaluate the life cycle costs of intersection alternatives. Running such calculations in other platforms cannot only be time consuming, but can produce varying results depending on the platform and configurations used. Consequently, the tool proposed by this inter-institutional research team will not only help transportation agencies make better informed decisions about projects involving public funds, but can also reduce the staff time needed to evaluate alternatives and potential for error.

4.2 NET PRESENT VALUE

The tool breaks down the long-term, discounted costs and benefits of each alternative based on variable type, and most importantly, provides the ultimate deliverable of the analysis: the Net Present Values (NPV) for each option. In Life Cycle Cost Analysis methodology, the NPV of an alternative is present value (PV) of the total long-term benefits minus the PV of the total long-term costs, NPV = Σ PV (Benefits) - Σ PV (Costs), described further in Equation 3 below.

Equation 3. Net Present Value

$$NPV = \sum_{t=0}^{n} \frac{(\text{Benefits} - \text{Costs})_t}{(1 + r)^t}$$

where:

NPV = net present value
t = year
r = the discount rate
n = analysis period (in years

In the tool, the Total Long-Term Benefits (Net Present Value) present the total benefits minus the costs expected for each alternative over the course of the analysis period, which are the values that should be compared in order to identify the best intersection option based on the time frame identified by the user. The NPVs represent the benefits that the transporation agency can expect to gain from an intersection option. Therefore, the intersection type with the highest NPV is considered the best option because it will provide the greatest value long-term. Additional details are in and are detailed in the CostVAL User Manual in Appendix B.

4.3 SENSITIVITY ANALYSIS

Most LCCA literature advises that sensitivity analyses, or checks on the degree to which outcomes may change due to changes in variables, be performed to ensure the accuracy of results (Swiss, 2012). Conducting a sensitivity analysis for LCCA results involves applying extreme values on the high and low end to determine if a model's methodological assumptions and variable choices are sound.

4.3.1 Safety

In this study, much of the sensitivity analysis focused on the relationship between safety and delay. These two variable categories consistently dominated the outcomes of analysis tests on the model. For example, high volume inputs can result in high delay costs due to excessive facility congestion and high crash frequency can result in significant safety benefits, and vice versa. As a result, the Net Present Values can be valued at billions of dollars in some cases.

In spite of the strength of these two types of variables, the research team decided not to apply factors in the model to adjust outcomes for several reasons. First, the methodologies of other intersection analysis tools and studies around the country do not include adjustment factors. Second, the study's model incorporates sound data and models from reputable sources such as the HCM 2015 and applying adjustment factors would alter the value and models, potentially reducing the accuracy of analysis findings. Second, many states currently monetizes safety outcomes for internal analysis using the same methodology as this tool. Third, it would be time consuming to develop adjustment factors that are appropriate for the diverse intersections that can be analyzed using the methodology of this study.

4.3.2 Delay

The HCM 6th edition uses a macroscopic approach for any analytical analysis. As such, the delay estimation within this research includes the inherit benefits and limitations of the macroscopic approach. While the macroscopic approach requires considerably less input values to perform mobility analysis compared to simulation, when these models are pushed into boundary conditions the results may not be accurate. This is due to the use of regression in the majority of the macro models in the HCM. Apart from the accuracy issues related to the necessity to push into boundary conditions, the generic format of the models provides limitations to specifying the geometric details of intersections.

4.3.3 Accuracy of Inputs

Outputs in the model have a strong relationship to user inputs. Consequently, care should be taken when inputting data into the model, erroneous entries can result in outputs that do not reflect the true long-term costs and benefits of alternatives. For this reason, the key inputs applied by the user are included in the tool’s printable report. In addition, users are advised collect data for inputs prior to starting the analysis process.

4.4 LIMITATIONS

The computational engine developed in this research uses STREETVAL as the base model to evaluate the operational condition of the signalized intersections. The HCM method used to evaluate urban streets with signalized intersections is by far the most complex method in the HCM. Coding a specific version of the signalized methodology for the purpose of this research was not feasible due to the amount of available funding in this project. Therefore, the research team used the existing STREETVAL model to efficiently integrate the HCM signalized methodology used to estimate delay. As such, any computational and accuracy issues related to the original STREETVAL tool were inherent in CostVAL, in spite of the efforts of the research team to resolve such issues.

In order to address any upcoming bug-report and issues within STREETVAL and this projects computational tool (CostVAL), the research team has used a direct GitHub “branch” out of original STREETVAL. This approach will enable future bug fixes to be automatically integrated into the CostVAL tool.

5.0 RESULTS AND RECOMMENDATIONS

5.1 RESULTS

This research resulted in the development of a model for quantifying the life cycle costs of converting a two-way stop controlled intersection to three alternative facilities. These alternatives included all-way stop, signalized and roundabout control types. The developed methodology was integrated into an input-output based spreadsheet-based computational tool that requires minimal time and inputs, called CostVAL. This tool is designed to be used by transportation agencies during the planning phase of intersection projects to evaluate and compare the long-term costs and benefits of intersection conversions. As an added benefit, the tool can generate reports for easy information sharing with stakeholders involved in the decision-making processes.

The method developed through this project contributes to existing transportation and Life Cycle Cost Analysis literature. Three categories of variables are monetized in the model: 1) Construction & Maintenance, 2) User Delay, and 3) Safety. The final product of the analysis is the long-term costs, or Net Present Value, for each alternative. These outputs can be compared easily by decision-makers to identify the intersection control alternative that may provide the greatest return on investment for a transportation agency, with the goal of saving public funds.

Overall, the computational engine developed through this project is unique compared to other conversion comparison tools because it requires limited inputs and calculates outputs within one single platform. These efficiencies can reduce agency time to analysis and reduce user error and potential for bias.

5.2 RECOMMENDATIONS

As transportation agencies continue to be challenged to provide quantitative evidence to support decision-making, better data will be needed. The research team found that may agencies across the country continue to lack state-specific data for some variables essential to analyzing the life cycle costs of intersection alternatives. Consequently, the research team recommends that further studies should be conducted to develop standard inputs that can be used at the state and national level for LCCAs such as the type outlined in this study. Identifying better data and standards can ultimately improve the accuracy of LCCAs and resulting decisions. Examples include the development of additional CRFs and ranges for inputs including PHF and PHV.

5.2.1 Data Updates

The majority of the variables and figures utilized in the methodology developed through this study to are updated annually by the data providers because they are sensitive to changes in human behavior and/or the economy. This is especially true for figures used to monetize such as the value of travel time. Consequently, many of the variables and figures used as inputs in

CostVAL will need to be updated regularly in order to ensure that the results are as accurate as possible.

Most new data is released on an annual schedule. However, updates to defaults for some variables in the model, such as Crash Reduction Factors, may be released more frequently without a clear schedule. Because there is no ongoing funding to update the tool regularly, As such, the research team suggests that tool users contact them (main menu in the tool "Help → about" email list) with updates to data that will be beneficial at the state or national level. Updates to HCM or significant changes to other core methodologies used in the model will also pose challenges to tool accuracy overtime.

5.2.2 Future Research

The methodology developed through this project provides many opportunities for future research. In addition to the LCCA model established, this an object-oriented code was developed through this project to replicate TWSC, AWSC and roundabout analysis. These modules are flexible and can be embed in future intersection control conversion tools. Additionally, the methodology and the tool framework can be expanded to analyze other intersection types or can be adapted to analyze other types of construction projects. Examples include applications and LCCAs for intersection configurations beyond those examined in this study.

Overall, the computational tool developed through this project serves as an interim tool to help practitioners evaluate their alternatives for intersections. However, it is not a commercial grade product and as such, it is limited in terms of support and technical challenges to the user remain. User report of any bugs observed in the computational engine (main menu in the tool "Help → about" email list) will help generate opportunities for future research as well as tool optimization.

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APPENDIX A

Default Values Applied in Tool

Type	Details	Default Value	Source
Crash Costs	K & A Injury Types	$4,544,000	NCDOT annual crash cost estimates (2013)
	B & C Injury Types	$134,000	
	Property Damage Only	$6,700	
Value of User Travel Time	Per Passenger Vehicle (per hour)	$17.67	TTI Annual Urban Mobility Report (Schrank, Eisele, Lomax, and Bak. 2015. 2015 Urban Mobility Report. Appendix A Methodology for the 2015 Urban Mobility Scorecard. College Station, TX: Texas A&M Transportation Institute.)
	Per Heavy Vehicle (per hour)	$94.04	
Number of Riders Per Vehicle	Passenger Vehicle	1.25	TTI Annual Urban Mobility Report (Schrank, Eisele, Lomax, and Bak. 2015. 2015 Urban Mobility Report. Appendix A Methodology for the 2015 Urban Mobility Scorecard. College Station, TX: Texas A&M Transportation Institute.)
	Heavy Vehicle	1.25	
Fuel Burnt Per Hour of Idling	Passenger Vehicle (gallons)	0.39	U.S. Department of Energy (2014)
	Heavy Vehicle (gallons)	0.69	

Type	Details	Default Value			Source
		Roundabout	AWSC	Signal	
Construction Cost	Low	$500,000	$10,000	$60,000	NCDOT Spot Safety Program data (2008-13)
	Medium	$750,000	$25,000	$90,000	
	High	$1,000,000	$75,000	$300,000	
Incremental Costs	Minimum Facility Replacement	$500,000	$10,000	$60,000	
	Annual Maintenance	$2,500	$0	$2,500	NCDOT Project Development Crash Reduction Information (April 2015)
Time	Analysis to Facility Opening (years)	1.5	0.2	0.5	NCDOT expert panel (2015)
	Service Life (years)	25	6	10	NCDOT Project Development Crash Reduction Information (April 2015)
Crash Reduction Factors	K & A Injury Crashes (Urban)	29%	71%	23%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; Mcgee et al., 2003
	K & A Injury Crashes (Suburban)	78%	71%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	K & A Injury Crashes (Rural)	71%	71%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	B & C Injury Crashes (Urban)	29%	71%	23%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; Mcgee et al., 2003
	B & C Injury Crashes (Suburban)	78%	71%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	B & C Injury Crashes (Rural)	71%	71%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	PDO Crashes (Urban)	29%	61%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	PDO Crashes (Suburban)	78%	61%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008
	PDO Crashes (Rural)	71%	61%	44%	NCHRP Report 572, 2007; Simpson and Hummer, 2010; NCHRP Report 617, 2008

APPENDIX B

CostVAL
Intersection Control Life Cycle Cost Analysis Computational Tool
User Manual

Version 1.0

TABLE OF CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

The CostVAL Intersection Control Life Cycle Cost Analysis Computational Tool User Manual was developed as part of NTC2016-MU-R-03: A National Model for Predicting Life Cycle Costs and Benefits of Intersection Control Alternatives.

This Java-based computational engine is designed to analyze the long-term costs and benefits of conversions of two-way stop controlled intersections to other intersection types. It is designed to be used during the planning phase of potential intersection conversion projects to help stakeholders identify the most cost-effective conversion configuration option.

This user-friendly tool combines enhanced 2015 Highway Capacity Manual methodologies and standard cost benefit analysis methodologies to calculate the long-term net benefits of converting a two-way stop controlled intersections to three different alternatives: 1) all-way stop controlled, 2) signalized, and 3) roundabout types. For the purpose of tool, a two-way stop controlled (TWSC) intersection is defined as a four-way intersection with no control mechanism for the main approach and stop signs positioned at the minor approach.

Based on user inputs and standard state and national data, site-specific construction and maintenance, user delay, and safety costs and benefits are calculated for each of the three conversion types. These costs and benefits are projected into the future using a methodology that considers the changing value of money over time. The resulting dollar figures can be compared to identify the intersection type that offers the greatest return on investment to citizens over a user-specified time period.

2. OVERVIEW OF TOOL

The future costs and benefits of conversion alternatives are projected using a method called Life Cycle Cost Analysis (LCCA). Using LCCA, variables that may not have clear financial value, such as reduced pollution, are given a monetary value so that they can be calculated and then compared using common units. The LCCA method is used because many of the costs and benefits associated with intersection reconfigurations may not be realized until years, sometimes decades, after an initial conversion. Analyzing each intersection project with a LCCA can help ensure that state funds are allocated as effectively as possible.

“Monetizing,” or applying a monetary value to non-monetary variables such as improved roadway safety, helps planners and policymakers account for both the social and fiscal costs and benefits of a project. Consequently, the final outputs of this tool are the monetized costs and benefits of installing each alternative intersection type. The difference between the outcomes that would be expected if the TWSC intersection was not converted are subtracted from the monetized outcomes projected for alternatives to produce an estimation of the long-term costs and benefits of implementing each option. These final values are referred to as the “Net Present Value,” or NPV for each intersection option.

Each monetized figure is projected into the future using an LCCA method called discounting. Similar to the idea of inflation, discounting adjusts monetized costs and benefits to reflect how their value will typically decline over time. The discount rate applied in this tool is 3% per year. As with inflation, this rate is assumed to compound each year until the end of the period of analysis. Three categories of variables are used to calculate the costs and benefits of each option: 1) Construction & Maintenance, 2) User Delay, and 3) Safety. Monetizing each of these involves a combination of unique user inputs and standardized, or “default,” values which are applied throughout the tool.

These three larger variable types are monetized into the future using the following sub-variables:

1) **Construction & Maintenance**
    - *Construction Costs*: The up-front funds needed to convert the TWSC intersection including pre-construction (right-of-way purchases and preliminary engineering) and physical construction (utility moves/additions, infrastructure changes/additions, etc.)
    - *Annual Maintenance Costs*: Annual and incremental operations and upkeep costs for a facility option, such as landscaping and signal timing
2) **User Delay**
    - *Fuel Burned during Idling*: Based on fuel costs for the day of analysis and delay projections for each alternative
    - *Value of User Travel Time*: Estimation of the monetary value of an hour of time for roadway users
3) **Safety**
    - *Crash Costs:* Broken down by crash type, based on the NCDOT annual KABCO cost estimations, projected for each alternative option using historic crash numbers for the site and applying well-researched crash reduction factors

The steps of this tool are broken into eight steps organized by input and variable type. These include:

9) **Global Inputs**: Site-specific data and user details
10) **Traffic Demand:** Demand data for current TWSC site
11) **Historic Crash Data**: Crash data for current TWSC site
12) **Roundabout Configuration**: Projections for roundabout construction costs and configurations at site of interest
13) **All-Way Stop Configuration**: Projections for AWSC construction costs and configurations at site of interest
14) **Signal Configuration**: Projections for signal construction costs and configurations at site of interest
15) **Review and Summary**: Tool outputs including informational tables comparing different intersection options
16) **Print Report**: Print automatically generated PDF report including details of the tool analysis that can be easily printed and shared with decision-makers

IMPORTANT NOTES:

1) **Units**: All the units (if applicable) are shown in the parenthesis next to each input/output field.

2) **Process Order**: All steps should be completed by the user in the order that they occur. The user must click the appropriate button to move to the next step in the tool. A failure to follow steps in order could result in miscalculations or data loss.
3) **Data Collection:** Users are strongly encouraged to collect/calculate the site-specific data needed for the inputs before beginning the analysis process to reduce the risk of error. In this user guide, the data required for the steps of this tool is listed at the beginning of the instructions for each step.
4) **Saving Project**: Users will save the project with the analysis data and site name immediately upon beginning an analysis to prevent calculation errors. Projects should be re-saved after performing any additional analyses or revising inputs.

3. STEP 1: GLOBAL INPUTS

To begin a project, open the CostVAL tool, click on "Project" in the left corner, click "New Project," and then name the project and click "Next." Once beginning the project, several site-specific details are required in *Step 1: Global Inputs* of the tool. To begin the intersection option comparison process, input basic information about the intersection in first tab.

➔ ***<u>What you need for Step 1</u>*:**

1) ***Major and Minor Approach Names:*** Names of the intersecting roadways of interest.
2) ***County:*** Name of county where intersection is located.
3) ***Analyst Name:*** Name of the person using the tool.
4) ***Major Approach Orientation:*** Ordinal direction of the minor approach roadway, either "North-South" or "East-West."
5) ***Analysis Date:*** Analysis date in the form MM/DD/YYYY.
6) ***Operation Analysis Period (Years)***: Number of years desired into the future that the tool will consider when calculating Life Cycle Costs. The methodology is designed to analyze periods of time only between 10 and 25 years. Note: The analysis period begins on the data the model is applied, the *Analysis Date*.
7) ***Current TWSC Configuration:*** Select either "One Stage" or "Two Stage," based on the configuration of the TWSC intersection.
8) ***Volume Growth Factor Per Year (Anticipated):*** Percent of traffic volume growth that the intersection is expected to experience annually (recommend 2-3%).
9) ***Current Percent Heavy Vehicle (%):*** Percentage of the vehicles as the intersection that are considered heavy vehicles.
10) ***Peak Hour Factor (PHF):*** Input the ratio of the total hourly traffic volume against the busiest 15-minute interval.
11) ***Area Type:*** Type of location (Rural, Urban, or Suburban) at which the intersection is located.
12) ***Current Unleaded and Diesel Fuel Costs:*** Current unleaded and diesel fuel prices for the U.S. state the intersection is in, which can be obtained via the American Automobile Association's website.

Exhibit 1 below shows what the input entry table within the spreadsheet tool looks like.

Exhibit 1. Global Inputs Table Example

Major Approach Name:	Major Approach for Site 1-28
Minor Approach Name:	Minor Approach for Site 1-28
County:	Wake
Analyst Name:	Caleb Gellert
Major Approach Orientation:	East-West
Analysis Date (MM/DD/YYYY):	03/26/2018
Operation Analysis Period (Years, min=2, max=25):	25
Current TWSC Configuration:	One Stage (The median width is less than 25 ft)
Volume Growth Factor Per Year (Anticipated) (%):	3 %
Current Percent Heavy Vehicle (%):	5 %
Peak Hour Factor (PHF):	1
Area Type:	Rural
Current Unleaded Fuel Cost ($/gal):	$ 2.46
Current Diesel Fuel Cost ($/gal):	$ 2.7

After completing the inputs, the user can either choose to move forward with the next steps by clicking “Next” or can choose to view the default values used in calculations by clicking “Defaults Applied,” which will take them to a separate window.

Changes can be made to defaults as necessary. The defaults in the tool are based on federal standards as well as state transportation data and findings from peer-reviewed research. All default monetary variables used have been converted to 2016 dollars for consistency. Explanations of each default value and its source are outlined in Appendix A of the project final report.

4. STEP 2: TRAFFIC DEMAND

For *Step 2: Traffic Demand*, the user will enter the demand data for the TWSC intersection being analyzed. In this step, the user will input information about the traffic demand that is currently observed at the intersection, which will be used in the underlying methodologies used to evaluate delay.

➔ ***<u>What you need for Step 2</u>*:**

Demand Data: Demand/volume information for the current intersection in **ONE** of these three forms, including these specific sets of data:

1) Hourly counts
   - 13 or more hours of turning movement counts for each approach
2) Peak hour counts
   - 12 hours or less of turning movement count data for each approach
   - An idea of the hourly demand distribution of traffic at the TWSC site OR actual hourly demand distribution percentages for the TWSC site
3) AADT

- Two-directional average annual daily traffic (AADT) data for each approach
- Percent distributions of left, through, and right movements for each approach
- An idea of the hourly demand distribution of traffic at the TWSC site OR actual hourly demand distribution percentages for the TWSC site

The model allows the flexibility to provide one of following three methods for characterizing traffic demand: 1) Hourly Counts 2) Peak Hour Count, or 3) AADT. The user only needs to provide data using one of these options. Each of these three methods is explained below. To select the most appropriate demand data option based on the details below, the user will click the aerial button beside their selection.

Hourly Counts - 13 or More Hours of Turning Movement Counts

To ensure the accuracy of delay calculations, users are advised to use the hourly count method only when 13 or more hours of turning movement count data is available. This correlates with the recommended practice in the MUTCD for considering signal timing devices.

To begin entering data using this option, enter available counts into "Detailed Volume Counts" table. The user must provide turning movement counts for vehicles per hour for left, through, and right at each of the four approaches. The tool will apply a value of zero for each count in each hour for which the user does not provide data because the delay incurred outside those time periods is assumed to be minimal compared to that incurred during the count. For example, if only 13 hours of turning movement counts are provided it will be assumed that all of the counts for the remaining 11 hours of the 24-hour period are zero.

After entering turning movement count data, the user has finished Step 2 and can choose to move forward to the next step by clicking "Next" or clicking "Previous" to modify previous entries.

Peak Hour Count - 12 or Less Hours of Turning Movement Counts

In some cases, sufficient turning movement count data for the peak periods of the day may not be available. In this case, the "Peak Hour Count" option can be selected for demand data entry. It is recommended that this option be chosen when 12 hours or less of turning movement count data is available.

To begin entering data using this option, the user must first select one hour of turning movement count data to enter into the tool for analysis, most likely a peak hour. This single hour of count data will be used to model a traffic distribution for a full day within the tool's calculations. After the radial button beside "Peak Hour Count" has been selected, the user can enter the hour for which the turning movement count data will be provided into the "Specified Analysis Period" table. For example, if counts for the hour starting at 5PM will be used, then the user can choose the "5PM" option from the dropdown box in the table.

Next, the user can begin entering the turning movement counts for vehicles per hour for left, through, and right turn lanes for each approach in to the "Demand Flow Rate Data" table. Again, these counts should be for the specific hour of analysis selected in the "Specified Analysis Period" table. Finally, the user must populate the "Hourly Demand Distribution" table with

percent of traffic at the current TWSC intersection each hour compared to the total for an entire day, as shown in
Exhibit 2.

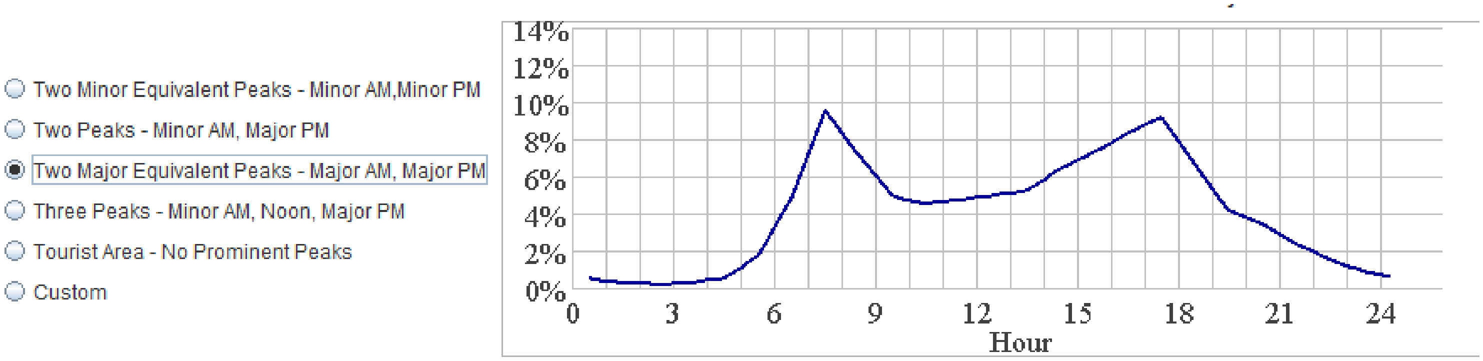
Exhibit 2. Hourly Demand Distribution Input Table Example

Hour From	Hour To	% AADT
12AM	1AM	0.53 %
1AM	2AM	0.28 %
2AM	3AM	0.21 %
3AM	4AM	0.26 %
4AM	5AM	0.56 %
5AM	6AM	1.71 %
6AM	7AM	4.84 %
7AM	8AM	9.55 %
8AM	9AM	7.17 %
9AM	10AM	4.96 %
10AM	11AM	4.54 %
11AM	12PM	4.76 %
12PM	1PM	5.01 %
1PM	2PM	5.26 %
2PM	3PM	6.46 %
3PM	4PM	7.33 %
4PM	5PM	8.37 %
5PM	6PM	9.21 %
6PM	7PM	6.6 %
7PM	8PM	4.14 %
8PM	9PM	3.42 %
9PM	10PM	2.39 %
10PM	11PM	1.52 %
11PM	12AM	0.92 %
	Sum=	100.0 %

Although these percentages can be manually entered, the user has the option to auto-populate this table by clicking the "Insert Default Hourly Factor" button in the upper left section of the tab and choosing the default distribution profile which best aligns with the site of interest. As shown below in Exhibit 3, five default options for hourly demand distribution are provided.
These distributions, listed below, are based on NCDOT continuous count data:

1) Two Minor Equivalent Peaks - Minor AM, Minor PM
2) Two Major Equivalent Peaks - Major AM, Major PM
3) Two Peaks - Minor AM, Major PM
4) Three Peaks - Minor AM, Noon, Major PM
5) Tourist Area - No Prominent Peaks

Exhibit 3. Demand Distribution Profile Selection



Users can auto-populate the distribution table by clicking the corresponding radial button and clicking the "OK" button. To change the distribution, click the "Insert Default Hourly Factor" button again and either hit "Cancel" or select a different distribution and click "OK" again. Percentages can be entered manually by typing directly into the cells for each hour in the column labeled "% AADT." Regardless of entry type, the final distribution in the table should add up to a total sum of 100%.

Once turning movement count data for the specified analysis period and the hourly demand distribution have been entered, the user has finished Step 2 and can either choose to move forward with the next steps by clicking "Next" or clicking "Previous" to modify previous entries.

AADT - No or Few Turning Movement Counts Available

The final entry option "AADT" is based on planning level data using average annual daily traffic (AADT) data. This method can be useful during the early planning stages of a project, especially if the user does not have access to turning movement counts. Using this method, the user is required to enter the two-directional AADT for each approach of the intersection. Two-directional AADTs are the total traffic recorded in both directions along the roadway that intersects at or near the TWSC intersection of interest.

To begin entering data using the "AADT" option, enter the AADT value for each approach into the "Demand Flow Rate Data" table as shown in Exhibit 4 below.

Exhibit 4. AADT Demand Flow Rate Input Table Example

Approach:	Eastbound (West Leg)	Westbound (East Leg)	Northbound (South Leg)	Southbound (North Leg)
AADT or FLOW RATE:	9000	8500	4000	4000

Current Traffic Turning Distribution

Approach:	Left Turn	Through	Right	Sum
EB % Movement:	10 %	70 %	20 %	100 %
WB % Movement:	10 %	70 %	20 %	100 %
NB % Movement:	10 %	70 %	20 %	100 %
SB % Movement:	10 %	70 %	20 %	100 %

Next, the distribution of turning traffic for each approach must be entered in the "Current Traffic Distribution" table, as shown in Exhibit 5. The user is required to enter the percentages of turns for left, through, and right lanes on each approach leg. For each leg, the sum for the total percentage of traffic should be 100%.

Exhibit 5. Distribution of Turning Traffic Table Example

Approach:	Eastbound (West Leg)	Westbound (East Leg)	Northbound (South Leg)	Southbound (North Leg)
AADT or FLOW RATE:	9000	8500	4000	4000

Current Traffic Turning Distribution

Approach:	Left Turn	Through	Right	Sum
EB % Movement:	10 %	70 %	20 %	100 %
WB % Movement:	10 %	70 %	20 %	100 %
NB % Movement:	10 %	70 %	20 %	100 %
SB % Movement:	10 %	70 %	20 %	100 %

Finally, similar to the "Peak Hour Count" entry method, the hourly demand distribution is required to populate traffic demand over the entire day. The most likely entry method for this will be using one of the defaults provided in the tool by using the "Insert Default Hourly Factor" button. For more details on how to populate the distribution table, see Exhibit 2 and the "Peak Hour Count" section above.

Once AADT, turning movement distribution, and the hourly demand distribution data are entered, the user has finished Step 2 and can either choose to move forward with the next steps by clicking "Next" or clicking "Previous" to modify previous entries.

5. STEP 3: CRASH DATA

Step 3: Crash Data focuses on past crash data for the intersection being analyzed.

➔ ***What you need for Step 3*:**

Crash Data - the most recent 3 to 5 years for the current TWSC intersection broken down by the standard crash types, as described in the Exhibit 6 below.

Exhibit 6. Crash Severity Type Categories

Category	Description
K (fatal)	Death occurred within twelve months of the crash
A (disabling)	Injuries serious enough to prevent normal activity for at least one day such as massive loss of blood, broken bones, etc.
B (evident)	Non-fatal or A injuries are evident at the scene such as bruises, swelling, limping, etc.
C (possible)	No visible injury but there are complaints of pain or momentary unconsciousness
O (property damage only)	Pain or momentary unconsciousness

Source: NCDOT, 2013

Before entering data, the user will select the number of years of data they will be entering. To choose the appropriate number of years, click the number field and then type in the number of years for which data is available. At least 3 years of crash data, preferably more, should be used. Then enter the total number of crashes experienced per year at the intersection of interest, broken down by 1) Fatal, 2) Type A, 3) Type B, 4) Type C, and 5) PDO collisions, as described above in Exhibit 6. Note that the number input into the cells should be a whole number; however, the calculated “average number of crashes per year” values may include decimals.

Note: If data is missing for a crash type in a given year, leave the corresponding cell empty, as shown for Type A in Year 1 in Exhibit 7. Adding a “0” into a cell will result in miscalculations. Alternatively, if crash data indicated there were no crashes of a particular type in a given year, enter a “0” into the appropriate cell, as shown for Type K in Exhibit 7.

Exhibit 7. Crash Data Inputs Table Example

Number of years for Crash Data

Number of Years of Crash Data Available (3-5) yrs:	3

Update Crash History Table

Crashes at Intersection

Severity:	K	A	B	C	O
Number of Crashes Year 1	1	1	1	0	2
Number of Crashes Year 2	0	2	0	0	2
Number of Crashes Year 3	0	0	1	1	3
Number of Crashes Year 4	N/A	N/A	N/A	N/A	N/A
Number of Crashes Year 5	N/A	N/A	N/A	N/A	N/A
Average Number of Crashes Per Year:	0.33	1.0	0.67	0.33	2.33

After entering all crash data, either choose to move forward with the next steps by clicking “Next” or click “Previous” to modify previous entries.

6. STEPS 4, 5, AND 6: CONVERSION-SPECIFIC CONFIGURATIONS

Steps 4, 5, and 6 are broken down by alternative type. In the tab for each step, the user will enter two key sets of inputs specific to each alternative type: construction costs and geometric configuration. Users are advised to enter all inputs for each step before moving on to the next one.

➔ **<u>What you need for Steps 4, 5, and 6:</u>**

1) **Construction Costs**: Estimates for the cost of constructing each alternative facility at the specific intersection of interest, considering related costs such as:
   - Preliminary design
   - Utility moves/additions
   - Right-of-way purchases
   - Infrastructure changes (island removal, driveway realignment, connection to city signal system, etc.)
2) **Configurations**: Plans for the geometric configurations for each of the alternative facilities that would be installed at the intersection of interest, including:
   - Roundabout - Right-turn bypass configuration (none, yield, or add lane) planned for each approach
   - AWSC - Number of lanes planned for each approach
   - Signal - Number of lanes for each movement (left, through, and right) planned for each approach

Before entering the configurations for each facility option in the tabs of Steps 4, 5, and 6, the user should select the appropriate construction cost for each alternative. Construction costs for the purposes of this tool are the capital funds needed to convert an intersection from a two-way stop to another intersection type, including pre-construction (right-of-way purchases and preliminary engineering) and physical construction (utility moves/additions, infrastructure changes/additions, etc.).

When entering the anticipated initial design and construction costs for each conversion type, the user can either enter one of the default cost estimates provided in the tool or enter their own estimation. Suggested default cost options are show in Exhibit 8. At a minimum, the default cost estimates should be used to check any estimates entered manually, as initial estimates are often lower than the actual costs provided by this tool are based on actual project costs.

Exhibit 8. Default Construction Cost Tiers

Intersection Type	Construction Costs	Cost	Description
Roundabout	Low	$500,000	basic one-way roundabout installation with minimal right-of-way (ROW) purchase
	Medium	$750,000	significant ROW purchase OR significant utility move
	High	$1,000,000	significant ROW purchase AND one or more of these: significant utility move, realignment, raising of intersection, or other additional features costing more than $10,000
AWSC	Low	$10,000	basic installation: marking and signs
	Medium	$25,000	addition or removal of flashers
	High	$75,000	two or more of these: addition or removal of island and/or pavement, addition/removal of flasher, utility work, or other feature
Signal	Low	$60,000	standard installation with few to no additional costs, aside from pedestrian signal heads installation
	Medium	$90,000	connect to city signal system AND at least one of these: installation of pedestrian signal heads, crosswalks, utility move, lane reassignment, or other feature OR at least two of these: installation of pedestrian signal heads, crosswalks, utility move, lane reassignment, or other feature
	High	$300,000	turn lanes installed and/or realignment, likely ROW purchase OR three or more of these: installation of

			pedestrian signal heads, crosswalks, utility move, lane reassignment, or other feature

The dollar amount of each of these design plus construction cost options in the tool varies by conversion type. The user should enter the estimated construction cost that best fits the nature of the conversion at the specific site of interest. For example, a conversion at an intersection that would require a realignment may be significantly more costly than one that does not and as a result a user may chose a funding option higher than the lowest option.

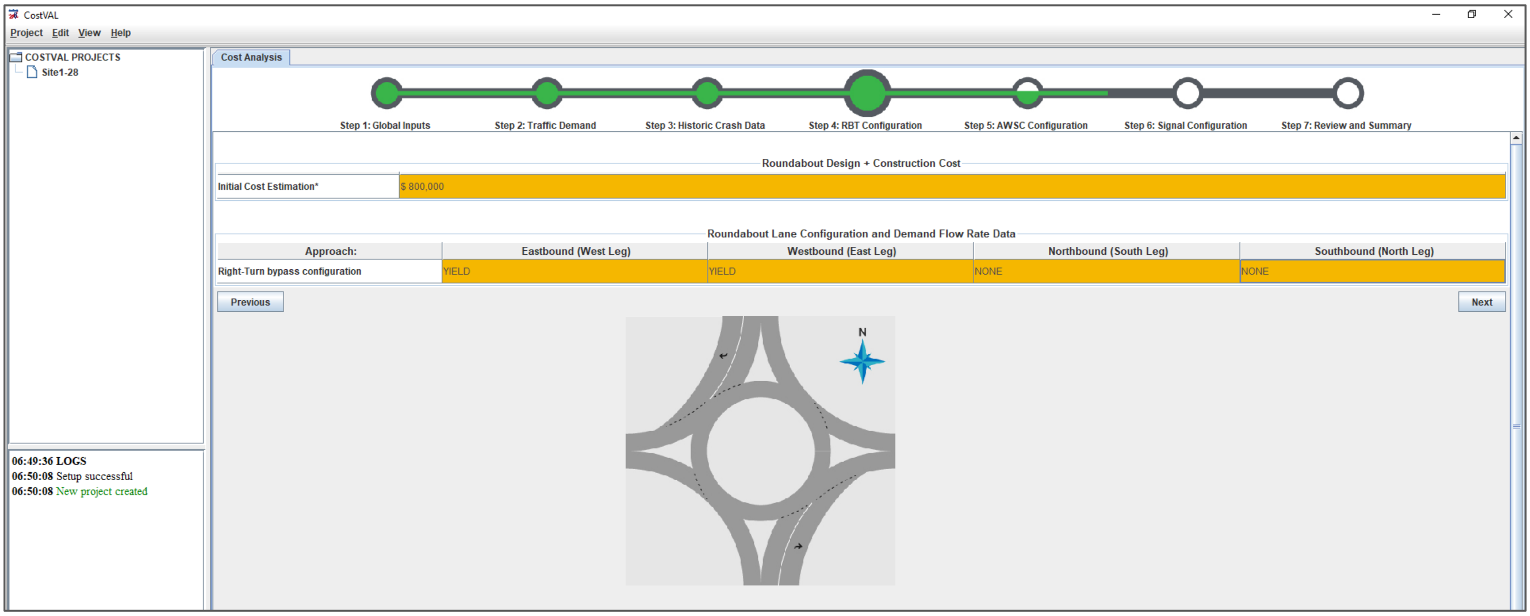
NOTE: There is not a pull down menu for the "Design + Construction Cost" table; the user must manually enter the construction cost into the table.

For each configuration step, the user is required to input configuration data for all three facility options once estimated construction costs have been selected, as described below. The configuration data entered by the user in each of these alternative-specific steps should be based on what the tool user and/or decision makers have determined to be the most appropriate facility configuration for the site. These geometric configuration inputs will be used with 2010 HCM methodologies to project future delays for each facility alternative.

Step 4: Roundabout Configuration

Once roundabout construction costs have been entered, the user can enter the desired geometric characteristics for the associated roundabout. In the "Roundabout Lane Configuration and Demand Flow Rate Data," the user must provide lane and right turn bypass configurations for each approach. As shown in Exhibit , the user can either manually select configurations in the table for each approach and selecting the best option from the pull down menu that appears, or can auto-populated the configuration table using the tool's Geometry Designer.

Exhibit 9. Roundabout Geometric Configuration Example



To adjust the configuration using the Designer, select the appropriate chosen configuration using the pull down menu for each of the four approaches. A new image should appear with each new configuration selection; examine these pictures to ensure they align with your planned configuration. Because this tool is only designed for one lane roundabouts, the user has the option of selecting one of the three following approaches for each leg of the intersection:

1) None - standard single lane with yield control
2) Yield - a dedicated right turn lane that has to yield
3) Add Lane - a dedicated right turn lane that does not have to yield

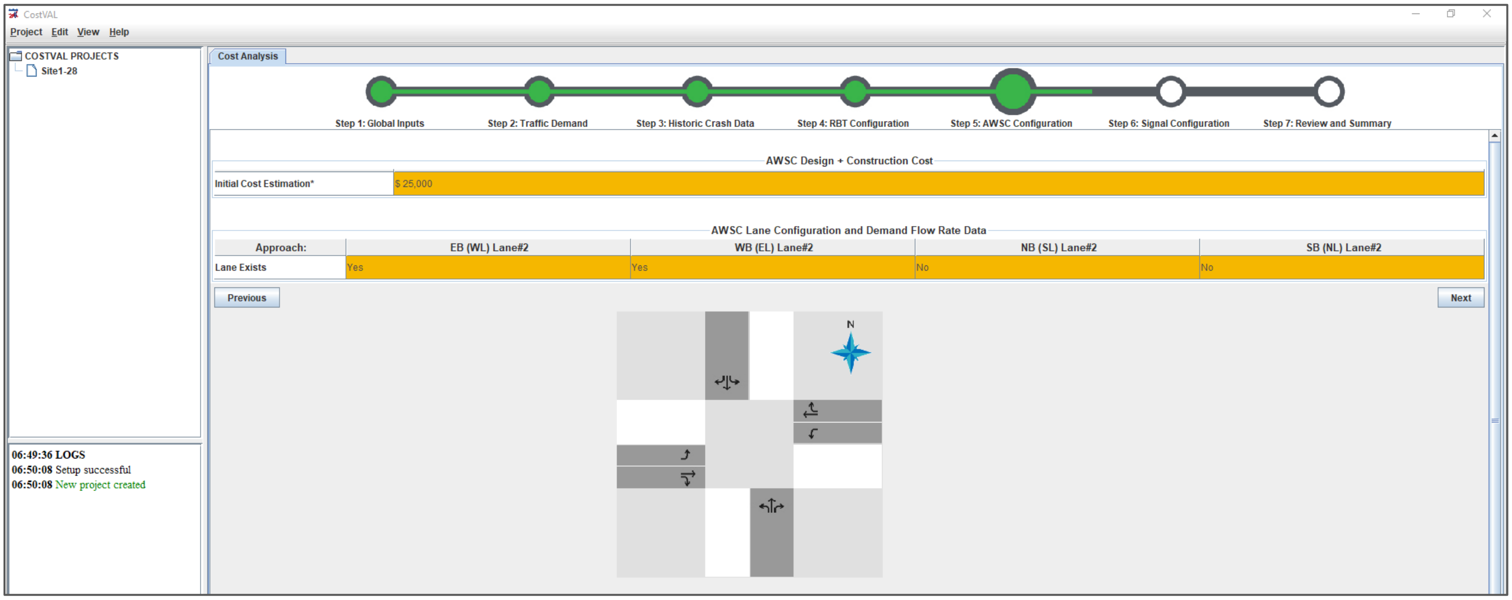
At any point in the process, the user can develop a new configuration, or to manually enter data into the table. Both the “Design + Construction Cost” and the “Roundabout Lane Configuration and Demand Flow Rate Data” tables should be inspected to ensure the correct inputs have been selected before clicking the “Next” button to move to the next step, or click “Previous” to modify previous entries.

Step 5: AWSC Configuration

After entering AWSC construction costs, the user can enter the desired geometric characteristics for the planned AWSC. Users will provide data for the number of lanes for each approach in the “AWSC Lane Configuration and Demand Flow Rate Data” table.

As shown in Exhibit 10.The user can either manually select configurations by clicking in the yellow cells for each approach and selecting either “Yes” or “No” from the dropdown box that appears, or can auto-populated the configuration table using the tool’s Geometry Designer. To adjust the configuration using the Designer, select the appropriate chosen configuration using the drop down boxes for each of the four approaches. A new image should appear with each new configuration selection; examine these pictures to ensure they align with your planned configuration. Any entry of “Yes” in Lane 1 and “No” in Lane 2 means the approach has a shared left-through-right lane configuration. If Lane 2 entry is also “Yes” then there is a left turn bay present for the left turn and the through-right are shared. “Yes” is the default entry for all Lane 1 cells for each approach; this default cannot be altered by the user.

Exhibit 10. AWSC Geometric Configuration Example



At any point in the process, the user can develop a new configuration, or to manually enter data into the table. Both the “Design + Construction Cost” and the “AWSC Lane Configuration and Demand Flow Rate Data” tables should be inspected to ensure the correct inputs have been selected before clicking the “Next” button to move to the next step, or click “Previous” to modify previous entries.

Step 6: Signal Configuration

Once construction costs for the proposed signalized intersection have been entered, the user can input the signal geometric characteristics. Then, enter the expected minimum and maximum cycle lengths for signal timing, shown in the “Signal Timing Configuration” table in Exhibit 11.

NOTE: Because isolated intersections typically run using a fully actuated mode, signal inputs for this step are used to calculate delay with the assumption full actuation.

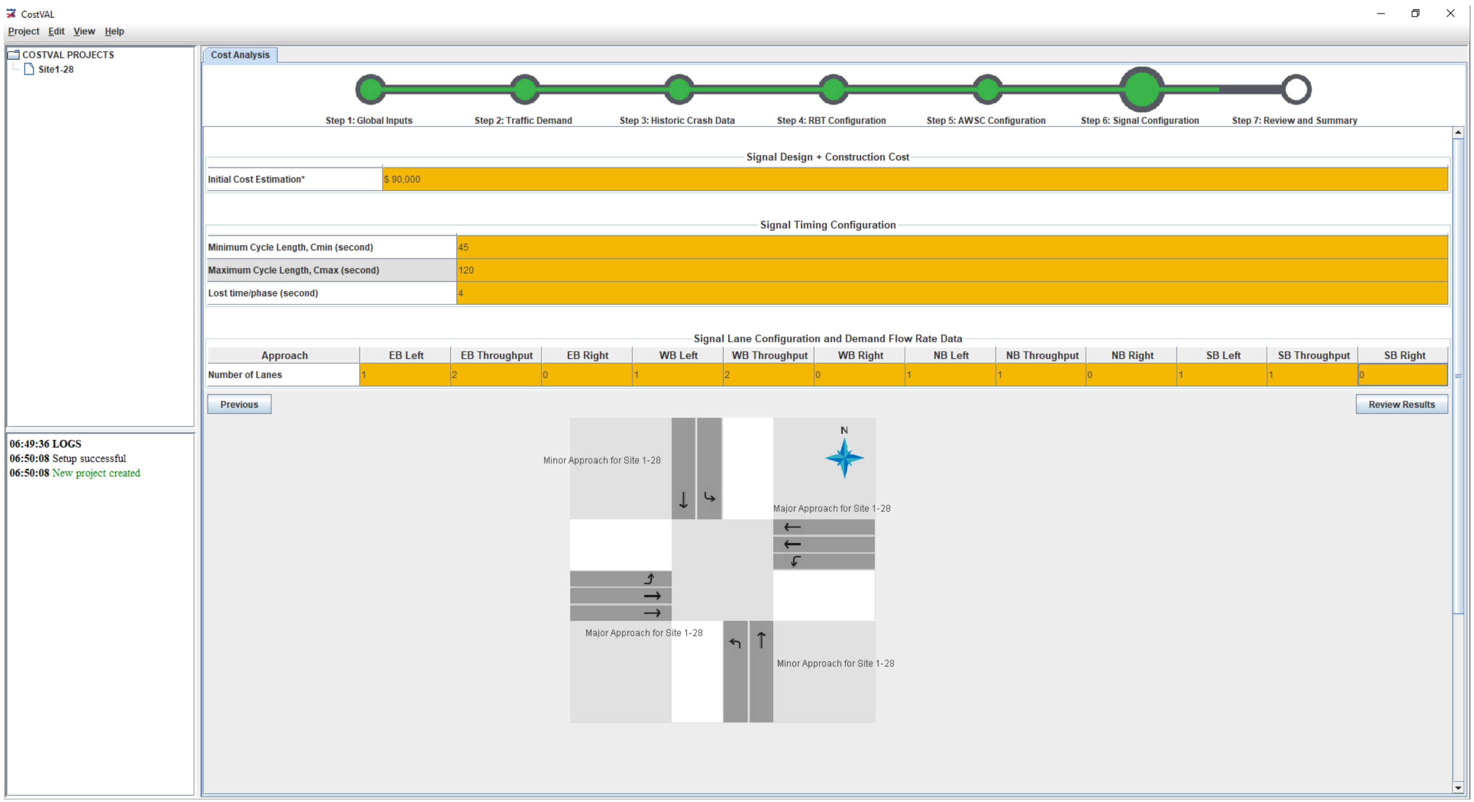
Exhibit 11. Signal Min and Max Cycle Length Table Example

Signal Timing Configuration

Minimum Cycle Length, Cmin (second)	45
Maximum Cycle Length, Cmax (second)	120
Lost time/phase (second)	4

Next, the user can select the proposed configurations either manually using the “Signal Lane Configuration and Demand Flow Rate” table, or they can auto-populated the configuration table using the tool’s Geometry Designer below the table, as shown in Exhibit 12.

Exhibit 12. Signal Geometric Configuration Example



To adjust the configuration of lanes using the Designer, select the appropriate chosen configuration using the drop down boxes for each of the four approaches. A new image should appear with each new configuration selection; examine these pictures to ensure they align with your planned configuration. The user should enter the lane configuration as it appears at the stop bar by selecting either a 0, 1, or 2 for each turning movement for each approach, with these numerical options indicating:

1) “0” for Left or Right - no dedicated lane for the turn movement
2) “1” for Left or Right - a dedicated turning lane for the turn movement
3) “1” or “2” for through - either one or two dedicated through lanes, respectively

For example, an entry of 0-1-0 for left-through-right, such as that shown for the north and southbound directions above, would mean the approach has a shared left-through-right lane. An entry of 1-1-1 for left-through-right, such as that for the east and westbound directions above, would mean the approach has a through lane with left and right turn lanes (or turn pockets). Volumes per movement and lost time per phase are calculated internally in the model.

At any point in the process, the user can develop a new configuration, or to manually enter data into the table. All three of the input tables for this step should be inspected to ensure the correct inputs have been selected before proceeding.

Step 6 is different from previous steps because the user cannot immediately proceed to the next step once the configurations are finalized. Instead, after finalizing all signal construction cost and configuration inputs, the user must click the “Review Results” button in the middle of the page instead of proceeding to another step. This action is necessary to process the final outputs of the tool, including the projected value of the costs and benefits of each alternative. The user should click the “Next” button if they changes need to be made to inputs before the final analysis is run. The analysis process may take several seconds.

While the analysis is running, a pop-up box may appear notifying the user that a Level of Service of F (LOS F) is projected to occur for one or more of the conversion alternatives at some point during the timeframe of analysis. The user must click “OK” in the popup to acknowledge this message and to continue with the analysis. If an LOS F is projected, the user can return to the previous steps make adjustments to the period of analysis, geometric configuration(s), or other inputs to address the LOS F as appropriate. For some intersections, high levels of demand my lead to an LOS F regardless of the geometric configurations of facilities. In such cases, users can use the comment sections of the tool’s printable report to explain related recommendations.

At that time, the user must click the “Review Results” to proceed to the Review and Summary step, which will show the final outputs of the tool.

IMPORTANT NOTE: Anytime changes are made to inputs on any page, the user must return to Step 6 and click the “Review Results” button again. A failure to do this can result in inaccurate outputs, which defeats the purpose of using this tool.

7. STEP 7: REVIEW AND SUMMARY

Once the six previous steps have been completed, user inputs are used to monetize the costs and benefits of each intersection option.

➔ ***What to pay attention to in Step 7:***

1) **Net Present Value:** The total long-term benefits minus the costs projected for each intersection alternative; the option with the highest Net Present Value is the one recommended by the tool.
2) **Errors:** Look for table values that are unexpectedly large or small; if something looks erroneous check user inputs to ensure they are accurate and appropriate.

One table in this step shows the first full year of each facility alternative after construction compared to projections for the same year of the current TWSC intersection, as shown in Exhibit 13.

Exhibit 13. Snapshot of Intersection Options in First Year Example

Snapshot of Intersection Options in 1st Year of Analysis

Benefit/Cost	TWSC	Roundabout	AWSC	Signal
% Reduction in Fatal & Type A Crashes	0 %	71 %	71 %	44 %
% Reduction in B & C Crashes	0 %	71 %	71 %	44 %
% Reduction in PDO Crashes	0 %	71 %	61 %	44 %
Annual Number of Fatal & A Injury Crashes	1.3	0.4	0.4	0.7
Annual Number of B & C Injury Crashes	1	0.3	0.3	0.6
Annual Number of PDO Crashes	2.3	0.7	0.9	1.3
Annual Crash Cost	$ 5,883,500	$ 1,706,200	$ 1,707,700	$ 3,294,700
Daily User Delay (hours per day)	11.4	11.3	20	47.6
Annual User Delay Cost	$ 111,600	$ 111,100	$ 196,300	$ 466,700
Annual User Fuel Cost	$ 4,200	$ 4,200	$ 7,300	$ 17,500
Construction Cost	$ 0	$ 800,000	$ 25,000	$ 90,000
Annual Maintenance Cost	$ 0	$ 2,500	$ 0	$ 2,500

NOTE: The monetized values in this table are not discounted. This table provides a simple snapshot of how applying a given alternative may change outcomes at the existing intersection. However, the data in this table are not the final outputs of the analysis and should not be used to compare the long-term costs of alternatives.

The final outputs of the analysis are presented in another table labeled the "Long-Term Difference between TWSC and Conversion Alternatives," shown in Exhibit 14. This table breaks down the long-term, discounted costs and benefits of each alternative based on variable type, and most importantly, provides the ultimate deliverable of the analysis: the Net Present Values for each option.

Exhibit 14. Difference between TWSC and Alternatives Example

Long-Term Difference between TWSC and Conversion Alternatives

Benefits/Cost Relative to TWSC	Roundabout	AWSC	Signal
Crash Reduction Benefit	$ 66,701,000	$ 71,893,400	$ 43,813,200
User Delay Decrease Benefit	$ 8,000	$ -1,458,300	$ -6,009,800
User Fuel Cost Saving	$ 0	$ -53,400	$ -225,100
Conversion Construction Cost	$ 800,000	$ 25,000	$ 90,000
Regular Maintenance Cost	$ 39,900	$ 0	$ 42,300
Service Life Replacement Cost	$ 0	$ 26,000	$ 76,700
Total Long Term Benefit (Net Present Value)	$ 66,709,000	$ 70,381,700	$ 37,578,300

Pay special attention to the Total Long-Term Benefits (Net Present Value) row of the outputs table because it outlines the total benefits minus the costs expected for each alternative over the course of the analysis period. These outputs are the Net Present Values (NPVs) of each intersection option being considered. These are the values that should be compared in order to identify the best intersection option based on life cycle costs. The NPVs represent the benefits a transportation agency can expect to gain from an intersection option. Therefore, the intersection type with the highest NPV is considered the best option because it will provide the greatest value in the long-run.

It should be noted that, for some conversions, user delay and the costs associated with them may actually increase due to a projected level of service failure or other factors. This can vary on a case-by-case basis. In cases where user delay is increased due to a conversion, the "benefit" of decreased delay will be a negative value, which is indicated as red text encased by parentheses.

These values will in turn be treated as costs instead of benefits. In such cases, these costs will be subtracted from the value of total net benefits as opposed to being added to it.

Additionally, users and decision-makers should be aware that the highest costs and benefits of a conversion are usually associated with User Delay and Safety. This is because the crash cost estimates can be in the millions and significant delay can result in very high costs to roadway users. For example, tool tests showed that high volume inputs typically result in high delay costs due to excessive facility congestion and high crash data numbers typically result in significant safety benefits, and vice versa.

Once the final outputs have been calculated, users can proceed with editing and printing the tool's report on the analysis, as explained in the "Print Report" section below, or can return to a previous step to edit previous inputs and re-run the analysis.

The user should review these tables carefully before proceeding to printing the summary report. Also, the user should examine the tables for data that does not seem to match inputs for the intersection. These could be signs of input errors. In addition, the Net Present Values for alternatives could be in the billions. If this occurs, the user should double-check all inputs to ensure that the projects are as accurate as possible. If a problem is identified, return to the related step, fix the problem, and click the "Review Analysis" button in the Step 6 again.

8. STEP 8: PRINT REPORT

After the analysis has run and the outputs have been reviewed, the user can develop and print a formal report of the results. First, re-save the project. Then, click "Generate PDF" in the bottom right corner to create a pre-formatted report that can be shared with decision makers, including government leaders. This step requires minimal time because vital inputs and outputs, such as site location and the NPV table, will be automatically fed to the report. To create the report, the user will click the checkboxes next to the content they want to include in the report, as shown in Exhibit 15. An example of the report entry page is shown in Exhibit 16.

Exhibit 15. Example of Printable Report Entry and Results

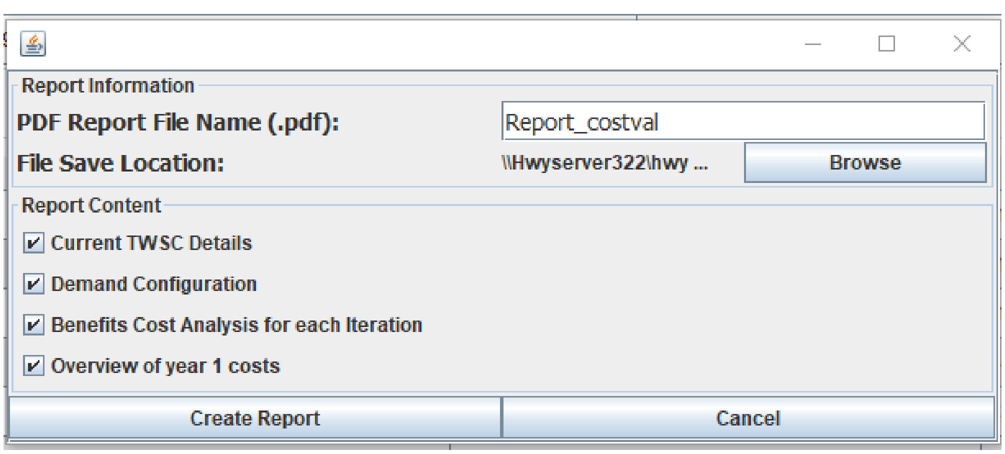


Exhibit 16. Example of Printable Report Entry and Results

Mar 26, 2018 ITRE_AgencyName CostVal Report

Intersection Life Cycle Cost Analysis of Major Approach for Site 1-28 and Minor Approach for Site 1-28

CostVal v1.0

This report provides the results of a life cycle cost analysis for the reconfiguration of the two-way stop controlled intersection at Major Approach for Site 1-28 and Minor Approach for Site 1-28 using the CostVal life cycl tool.

ANALYST

Agency Name:

Analyst Name: Caleb Gellert

Division/Unit:

INTERSECTION

County: Wake

Area Type: Rural

Period of Time Analyzed (years): 25

Annual Volume Growth: 3 %

Peak Hour Factor: 1

SUMMARY

Treatment Proposed by Tool:

Treatment Proposed by Analyst:

Analyst Comments:

Level of Service F Reached for Proposed Configuration(s)?

Analyst Comments:

Page 1 of 5

Current Two-Way Stop Controlled Intersection Details for Major Approach for Site 1-28 and Minor Approach for Site 1-28

The below table details the average number of crashes that have occurred at the intersection under two-way stop control.

Historical Crash Data (Last 3-5 Years)

Number of Crashes by Severity	K	A	B	C	O
Average Number of Crashes Per Year	0.33	1.0	0.67	0.33	2.33

K (fatal): Death occurred within twelve months of the crash

A (disabling): Injuries serious enough to prevent normal activity for at least 1 day

B (evident): Non-fatal or A injuries are evident at the scene like bruises, swelling, limping, etc.

C (possible): No visible injury but there are complaints of pain or momentary unconsciousness

O (property damage only): No physical injury

User Demand for Major Approach for Site 1-28 and Minor Approach for Site 1-28

The below table details the demand rates during the peak period for each of the legs at the intersection under two-way stop control. Values are in vehicles per hour (vhp).

Peak Period Demand Flow Rate

Approach (Leg of Intersection)	Eastbound (West Leg)	Westbound (East Leg)	Northbound (South Leg)	Southbound (North Leg)
Peak Period Demand Flow Rate (vph)	286	286	184	184

Costs and Benefits of Each Alternative for Major Approach for Site 1-28 and Minor Approach

The below tables outline the costs and benefits of each intersection type being considered for this location, compared to the current two-way stop controlled intersection [Period of Time] into the future. These values have been adjusted for the changing value of money over time at a standard rate of 3% per year, similar to inflation.

Benefits Minus Costs Relative to TWSC

This table summarizes the final outputs of the analysis and should be used when comparing the long-term on investment of each alternative. The alternative considered the most cost-effective option is the one with return the greatest long-term benefits, or highest Net Present Value.

Configuration Type	Roundabout	AWSC	Signal
Total Long-Term Benefits (Net Present/Value)	$ 66,709,000	$ 70,381,700	$ 37,578,300

Assumed Benefits Relative to Two-Way Stopped Control

This table shows only the anticipated long-term benefits of each alternative. Note that occasionally an alternative is projected to not perform as well as the two-way stop controlled intersection. In this case, the assumed benefit will instead be a cost, and will be subtracted from the benefits total instead of added, indicated by () around the given dollar amount.

Configuration Type	Roundabout	All Way Stop Controlled	Signal
Crash Reduction Benefit	$ 66,701,000	$ 71,893,400	$ 43,813,200
User Delay Decrease Benefit	$ 8,000	$ -1,458,300	$ -6,009,800
User Fuel Cost Savings	$ 0	$ -53,400	$ -225,100
Total Long-Term Benefits	$ 66,709,000	$ 70,381,700	$ 37,578,300

Year 1 Overview of Costs

This section provides both a snapshot of all four intersection options in the first year of analysis and projections for what the benefits and costs of each alternative will look like into the future. Note that this table is for reference only. NOTE: It is not the final output of CostVal and should not be used to compare the long-term costs of TWSC vs. conversion alternatives.

Benefit/Cost	Two-Way Stop Controlled	Roundabout	All Way Stop Controlled	Signal
% Reduction in Fatal & Type A Crashes	0 %	71 %	71 %	44 %
% Reduction in B & C Crashes	0 %	71 %	71 %	44 %
% Reduction in PDO Crashes	0 %	71 %	61 %	44 %
Annual Number of Fatal & A Injury Crashes	1.3	0.4	0.4	0.7
Annual Number of B & C Injury Crashes	1	0.3	0.3	0.6
Annual Number of PDO Crashes	2.3	0.7	0.9	1.3
Annual Crash Cost	$ 5,883,500	$ 1,706,200	$ 1,707,700	$ 3,294,700
Daily User Delay (hours per day)	11.4	11.3	20	47.6
Annual User Delay Cost	$ 111,600	$ 111,100	$ 196,300	$ 466,700
Annual User Fuel Cost	$ 4,200	$ 4,200	$ 7,300	$ 17,500
Construction Cost	$ 0	$ 800,000	$ 25,000	$ 90,000
Annual Maintenance Cost	$ 0	$ 2,500	$ 0	$ 2,500

Once the analysis has been completed and the resulting report has been printed, the tool project file should be immediately saved a final time. As previously mentioned, users are advised to include the analysis data and site name in the file name.

For further information on this tool, contact Behzad Aghdashi, Institute for Transportation Research and Education at North Carolina State University, at behzad_aghdashi@ncsu.edu.