Capacity Analysis for Planning of Junctions (CAP-X) Tool User Manual

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16. Abstract **The Capacity Analysis for Planning of Junctions (CAP-X) Tool is intended to aid in the determination of a preferred alternative for a given intersection project by providing an objective, quantifiable basis to compare the operational performance of different intersection types. This tool may be of use to transportation planners, transportation engineers, and highway and street designers. This document provides information and guidance on how to use the CAP-X Tool, a macro-based, Microsoft Excel spreadsheet, to assess the operational performance of a variety of intersection geometry and control scenarios in terms of volume to capacity ratio and multimodal accommodations.**		
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

FOREWORD

This document is a user manual for the Capacity Analysis for Planning of Junctions (CAP-X) Tool, a macro-based, Microsoft Excel format spreadsheet. This user manual provides instructions and guidance on how to use this spreadsheet tool to perform operational performance analysis for a variety of intersection geometry and control scenarios. The CAP-X Tool provides an objective, quantifiable basis for comparing the operational performance of different intersection types that will help users determine a preferred alternative for a given intersection project. This tool may be of use to traffic operations researchers and practitioners, transportation planners and engineers, and highway and street designers.

Michael S. Griffith
Director, Office of Safety Technologies
Federal Highway Administration

DISCLAIMER

The Capacity Analysis for Planning of Junctions (CAP-X) Tool is intended to assist planners and engineers with planning level operation analysis of junctions. This analysis forms one component of a comprehensive intersection control evaluation (ICE) or alternatives analysis. As such, the results of the CAP-X Tool – overall v/c ratio and multimodal accommodations analysis – should not be the sole basis of choosing a given intersection or interchange form for implementation. The CAP-X Tool is not intended to be an intersection/interchange form selection tool.

COVER PHOTO CREDITS

Left: Lee Rodergerdts, Kittelson & Associates, Inc

Top Right: Federal Highway Administration

Bottom Right: Pete Jenior, Kittelson & Associates, Inc

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INTRODUCTION

WHAT IS INTERSECTION CONTROL EVALUATION (ICE)?

The primary intent of any transportation project, whether new construction or retrofitting existing infrastructure, should be to promote a sustainable transportation system that safeguards the mobility and safety of all users. One of the greatest opportunities for realizing this goal lies at intersections, where crossing traffic patterns place users of various modes in conflict with each other and create delay. Therefore, transportation practitioners should work to deploy the most prudent intersection control type at each intersection. Though engineering judgement is often required when selecting the most 'appropriate' intersection design, engineers, researchers, and designers are able to evaluate a multitude of quantifiable factors and help facilitate an informed decision-making process.

To aid in this effort, many States have implemented Intersection Control Evaluation (ICE) policies/procedures, which provide practitioners with a consistent framework to evaluate and screen the applicability of proven combinations of geometry and traffic-control strategies at intersections. The goal of ICE is to better inform the decision making of the road agency to identify and select an alternative that meets the project purpose and reflects the overall best value, in terms of specific performance-based criteria within available resources. While the evaluation criteria may vary between specific ICE polices/procedures, they typically encourage practitioners to consider both qualitative (e.g., project purpose, multimodal needs, land use, community goals) and quantitative (e.g., traffic operations, safety performance, right-of-way impacts, etc.) factors and foster a holistic evaluation of a wide set of control strategies.

As with most transportation studies, ICE is scalable, meaning the corresponding level of effort for screening and analysis should be commensurate with the magnitude and nature of the project – less effort for simple, more effort for complex. The premise of an ICE policy or evaluation is the same whether it involves new intersections or modification to existing intersections. **Figure 1** illustrates the decision making process, and the ICE role in it.

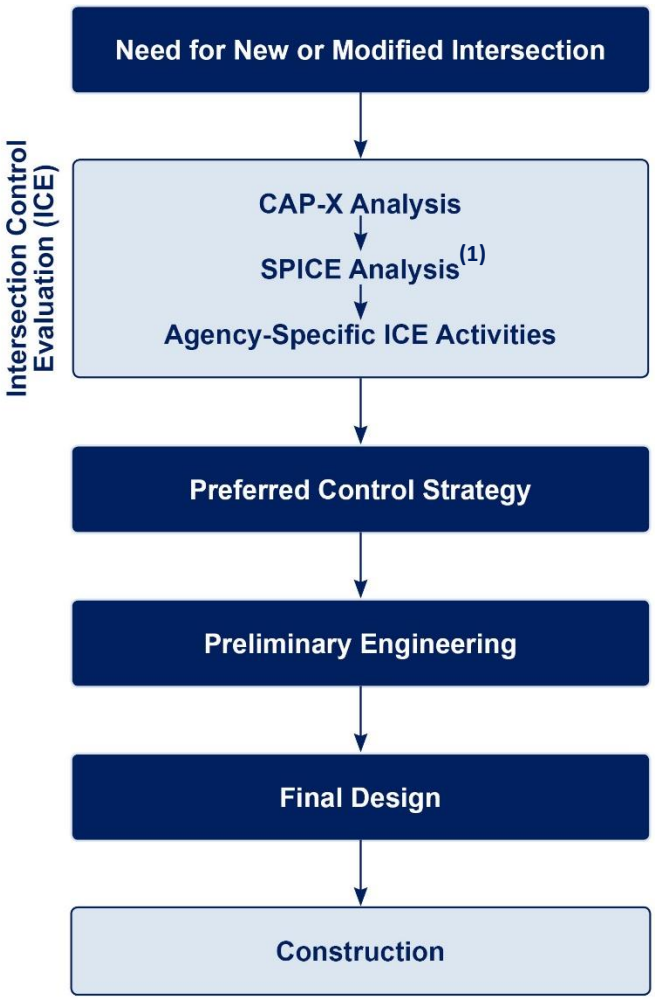


Figure 1. Decision Making Process.

ROLE OF THE CAP-X TOOL

For ICE to promote the equitable and comprehensive assessment of potential intersection control strategies, the evaluation framework and the performance criteria employed must facilitate consistency and objectivity. With respect to operations performance, this requires a quantifiable comparison between control strategies that estimates the volume to capacity ratio, in order to rank the suitability of each intersection type.

The Capacity Analysis for Planning of Junctions (CAP-X) Tool was developed to provide practitioners with a means of evaluating the anticipated operational performance of innovative intersection control strategies within a single tool. The CAP-X Tool uses a critical lane volume analysis to determine the volume to capacity ratio for a variety of intersection control strategies and also provides an assessment of the pedestrian and bicycle accommodations for the selected intersection types.

Based on the input parameters, the tool is able to generate a list of intersection types, ranked by volume to capacity ratio and given a multimodal score based on pedestrian and bicycle accommodations. Practitioners can choose to directly use turning volumes as input into the spreadsheet or grow the volumes based on a user specified volume growth percentage.

CRITICAL LANE VOLUME ANALYSIS

The operational performance of each selected intersection type is evaluated based on a critical lane volume analysis. This analysis uses six steps in order to determine the volume to capacity ratio (v/c ratio) for a given intersection. An overview of the six steps are as follows:

- Identify intersecting configuration and conditions, including the movements served at the intersection, the number of lanes, and the movement volumes
- Determine the desired phasing sequence of the intersection
- Determine the critical volume per lane that can be accommodated
- Find the sum of the critical volumes (the maximum of each movement that is served concurrently for signalized intersections and a function of gap acceptance for two-way stop controlled intersections)
- Determine the maximum critical volume for the intersection
- Determine the v/c ratio.

In the CAP-X Tool these critical lane volume and v/c ratio calculations are carried out in individual worksheet tabs for each intersection type. The majority of these tabs do not require or offer any user input and are displayed only for informational purposes. There are three intersection types for which these tabs are used for the number of lanes user input, they are discussed under the *Alt Num Lanes Input Tab* section of this document. An example of the spreadsheet tab for each intersection type which displays the critical lane volume and v/c ratio calculations is illustrated for the partial displaced left turn in **Figure 2**.

In this example intersection type, there are three individual zones which make-up the entire intersection type (the central junction and two left-turn crossover points). Each zone is analyzed individually, and the overall v/c ratio is taken as the maximum of the individual zone v/c ratios. In Zone 1, the critical lane volume is shown as 574 passenger car equivalents per hour. This value is derived by adding the two conflicting movements, 31 southbound left-turns (modified by the 0.95 left-turn adjustment factor) and 541 northbound through vehicles. The Zone 1 v/c ratio is then calculated by dividing the 574 critical volume by the 1,800 critical lane volume sum limit (the default suggested value for a two-phase signal), resulting in the Zone 1 v/c ratio of 0.32.

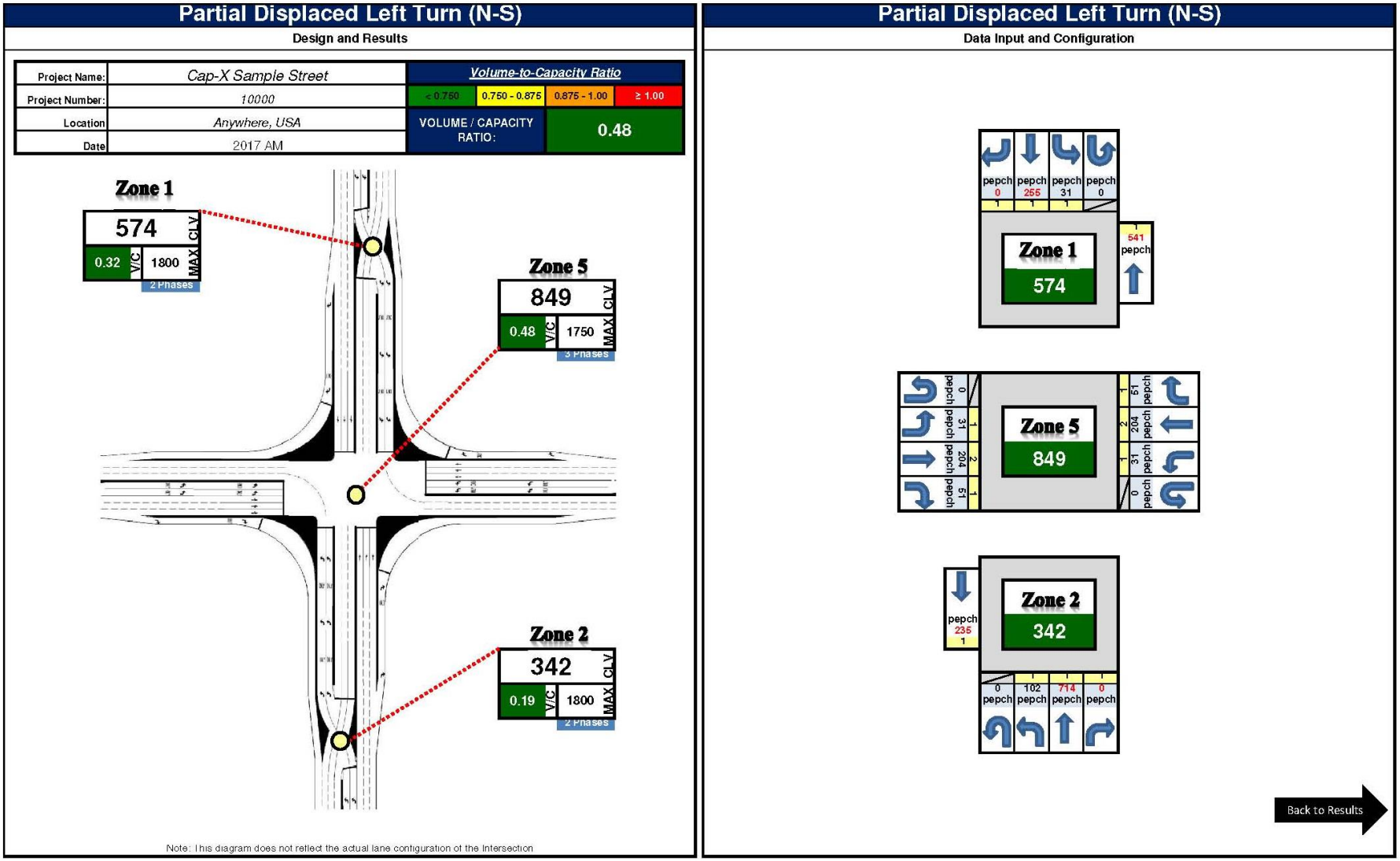


Figure 2. Example of Operational Analysis for Partial DLT.

RANGE OF ANALYSES

The CAP-X Tool is intended for use in conducting a planning-level analysis of alternatives at the early stages of the project. The tool allows the user to quickly compare the volume to capacity ratio of various alternative intersection types with minimal data input (e.g., turning volumes, lane configuration). The results of the planning-level analysis, while not comprehensive, will still provide a relative comparison between control strategies.

RELATIONSHIP TO OTHER TOOLS

While serving as a means of evaluating a wide range of control strategies in a consistent and reproducible manner, the CAP-X Tool is not intended to replace the functionality of more detailed analysis tools. The CAP-X Tool only provides planning-level analysis and relative ranking of included alternative intersection treatments.

USING THE CAP-X TOOL

FUNCTIONALITY AND REQUIREMENTS

The CAP-X Tool is an Excel-based macro workbook. To facilitate the full functionality of the tool, it is important for the user to e*nable* macros (use the prompt dialog at the top of the workbook) upon opening the spreadsheet. These macros serve several purposes within the tool, including:

- Transferring user inputs/selections between Excel tabs to prevent the need for repetitive input/selections.
- Hiding/displaying tabs and drop-down menus where appropriate based on user inputs.

Many of the tabs within the CAP-X tool are connected by macros, which rely on user inputs/selections where prompted. Fields with either optional or required user inputs are shown in yellow. In the case of optional inputs, suggested values are provided in the orange cells.

To prevent erroneous inputs, overriding of cell descriptions, or breaking of macro functionality, cells not requiring/permitting user inputs are locked. These cells can only be overridden by unlocking the Excel spreadsheet and using the password: kai123

INTRODUCTION TAB

The *Introduction* tab provides an overview of the purpose, intent, and functionality of the CAP-X Tool. While no user input is required on this tab, users should review the information on this tab prior to

getting started in the CAP-X tool. This tab also provides maintenance and contact information regarding the specific version of the CAP-X Tool.

ABBREVIATIONS & ASSUMPTIONS TAB

The *Abbreviations & Assumptions* tab provides an overview of all abbreviations used throughout the CAP-X Tool, general assumptions, intersection-specific assumptions, and instructions for how to input the number of lanes for approaches with shared lane configurations. While there are no user inputs required on this tab, users should review the information on this tab prior to using the analysis portion of the CAP-X Tool.

VOLUME INPUT TAB

The *Volume Input* tab is the first step in the CAP-X analysis and includes two sections for user data entry. The top section allows the user to enter general project information about the project to which the CAP-X Tool is being applied. Following the project information inputs, there is a button labelled "Reset Tool to Defaults." Clicking this button allows the user to remove all user inputs/outputs and resets all values to their defaults. **Table 1** illustrates the user inputs for this section of the tab.

Table 1. Project Information on the Volume Input Tab.

Project Name:	CAP-X Sample Street
Project Number:	10000
Location	Anywhere, USA
Date	2017 AM
Number of Intersection Legs	User Entry (3 or 4)
Major Street Direction	User Entry (North-South or East-West)

The Traffic Volume Demand section requires the user to enter vehicle turning volumes (veh/hr), heavy vehicle percentage (for each approach), growth percentage (for each approach), volume adjustment factors, truck to PCE factor, multimodal activity level, and critical lane volume sum limits. The volume growth percentage is an optional input to grow volumes to a future analysis year based on a user supplied growth percentage, this value defaults to zero percent (no growth). The adjustment factor converts turning vehicles to equivalent through vehicles for analysis, default values are provided in the CAP-X Tool. The truck to PCE factor converts trucks to passenger car equivalent values, the factor value defaults to the suggested value of 2.00. The multimodal activity level can be set to low, medium, or

high. There is also a button labeled “Edit Multimodal Intersection Configuration” that will take the user to the *Multimodal Scoring* tab, more information about this tab is provided in its respective section. The critical lane volume sum limits allow the user to modify the saturation value for critical lane volume sum at an intersection, user provided changes to this value are optional and default values are provided in the CAP-X Tool. **Table 2** illustrates the Traffic Volume Demand user inputs on the tab.

Table 2. Traffic Volume Demand Inputs.

Traffic Volume Demand							
	Volume (Veh/hr)				Percent (%)		
	U-Turn	Left	Thru	Right	Heavy Vehicles	Volume Growth	
Eastbound	0	30	200	50	2.00%	0.00%	
Westbound	0	30	200	50	2.00%	0.00%	
Southbound	0	30	200	50	2.00%	0.00%	
Northbound	0	100	500	200	2.00%	0.00%	
Adjustment Factor	0.80	0.95		0.85			
Suggested	**0.80**	**0.95**		**0.85**			
Truck to PCE Factor				**Suggested = 2.00**		2.00	
Multimodal Activity Level			**Low**	Edit Multimodal Intersection Configuration			
Critical Lane Volume Sum Limit	2-phase signal		**Suggested = 1800 (Urban), 1650 (Rural)**			**1800**	
	3-phase signal		**Suggested = 1750 (Urban), 1600 (Rural)**			**1750**	
	4-phase signal		**Suggested = 1700 (Urban), 1550 (Rural)**			**1700**	

Following the Traffic Volume Demand user input section, there is a table displaying the equivalent passenger car volumes for each turning movement. This table is an output provided for informational

purposes based on the user provided traffic volume demand values and does not contain any cells that can be modified by the user. These equivalent passenger car values are used in the calculations of the critical lane volumes for each intersection type.

BASE AND ALT SEL TAB

The *Base and Alt Sel* tab includes a user input for the existing intersection configuration (Step 2A) and allows the user to select which alternative intersection types are to be included in the analysis and ranking (Step 2B).

This tab includes a drop-down menu to select the intersection control of the existing intersection. The number of lanes for the existing configuration is displayed on this tab; however, to edit the existing number of lanes, the user is referred to the *Alt Num Lanes Input* tab. Based on the user selected existing intersection configuration, the v/c ratio, pedestrian accommodation, and bicycle accommodation results for the existing configuration are displayed on this tab.

In the alternative selection section of this tab, the user can turn on or off individual intersection types (shown in yellow) or entire intersection groups, such as grade separated intersections or roundabouts (shown in orange). **Table 3** shows the user inputs for alternative selection.

Table 3. Alternative Selection User Inputs.

Rankings Inclusion		Yes/No	Comment
At-Grade Non-Roundabout Intersections?		Yes	
Traffic Signal		Yes	
Two-Way Stop Control		Yes	
All-Way Stop Control		Yes	
Continuous Green T		No	
Quadrant Roadway	S-W	Yes	
	N-E	Yes	
	S-E	Yes	
	N-W	Yes	
Partial Displaced Left Turn		Yes	
Displaced Left Turn		Yes	
Signalized Restricted Crossing U-Turn		Yes	
Unsignalized Restricted Crossing U-Turn		Yes	
Median U-Turn		Yes	
Partial Median U-Turn		Yes	
Bowtie		Yes	
Split Intersection		Yes	
Grade Separated Intersections?		Yes	
Echelon		Yes	
Center Turn Overpass		Yes	
Roundabouts?		Yes	
50 ICD Miniroundabout		Yes	
75 ICD Miniroundaobut		Yes	
1x1		Yes	
1x2		Yes	
2x1		Yes	
2x2		Yes	
3x3		Yes	
Grade Separated Interchanges?		Yes	
Diamond		Yes	
Partial Cloverleaf A		Yes	
Partial Cloverleaf B		Yes	
Displaced Left Turn Interchange		Yes	
Contraflow Left Interchange		Yes	
Diverging Diamond Interchange		Yes	
Single Point		Yes	
Single Point with Roundabout		Yes	

MULTIMODAL PED TAB

The *Multimodal Ped* tab contains optional user inputs used in conducting the assessment of pedestrian accommodations. Default values are available and populated for all inputs in the tab, and the pedestrian analysis will still be carried out if the user does not make any modifications to this tab. For each row, the analyst uses drop-down menus to select the number of crossings, as well as the number of lanes and vehicle speed category for each crossing. **Table 4** shows a portion of the Cap-X Pedestrian Input.

Table 4: Multimodal Ped Tab Inputs (partial)

Pedestrian Crossing Configurations for Non-roundabout Intersections														
TYPE OF INTERSECTION	Sheet	# Of X-ings	Crossing #1		Crossing #2		Crossing #3		Crossing #4		Crossing #5		Crossing #6	
			# Lanes	Veh Speed	# Lanes	Veh Speed	# Lanes	Veh Speed	# Lanes	Veh Speed	# Lanes	Veh Speed	# Lanes	Veh Speed
Traffic Signal	FULL	6	2 Lanes	Stop / Signal	3+ Lanes	Stop / Signal	2 Lanes	Stop / Signal	2 Lanes	Stop / Signal	2 Lanes	Stop / Signal	2 Lanes	Stop / Signal
Two-Way Stop Control	N-S	4	3+ Lanes	>30mph	3+ Lanes	>30mph	2 Lanes	Stop / Signal	2 Lanes	Stop / Signal	2 Lanes	<20mph	2 Lanes	<20mph
	E-W	4	3+ Lanes	>30mph	3+ Lanes	>30mph	2 Lanes	Stop / Signal	2 Lanes	Stop / Signal	2 Lanes	<20mph	2 Lanes	<20mph
All-Way Stop Control	FULL	4	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph
Continuous Green T	W	6	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph
	N	6	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph
	E	6	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph
	S	6	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph	2 Lanes	<20mph

It does not matter in which order pedestrian crossings are evaluated, as long as all crossings are included in the analysis. For consistency, it is recommended to begin the evaluation in the north-east quadrant of the intersection, and then numbering crossings sequentially in a clockwise direction. The goal of the multimodal methodology is to provide a framework that can be used to conduct a high-level assessment of multimodal accommodations at various intersection types. These assessments can then be used as an additional reference point when comparing intersection alternatives under differing conditions.

Pedestrian Crossing Methodology

The pedestrian crossing assessment method is intended to assess the safety and level of comfort of each crosswalk for pedestrians. The method also captures bicyclists who chose to traverse the intersection using the sidewalk or multi-use path system and acting as a pedestrian. The pedestrian crossing assessment considers two different dimensions: (1) Vehicle Speed at Crossing, and (2) Number of Lanes. The assessment is best applied separately for each crossing. However, simplifying assumptions can readily group multiple (similar) crossings.

Vehicle Speed at Crossing

The vehicle speed at each crossing is evaluated based on general design assumptions and categorized into one of four conditions:

- **Vehicles stopped** – Traffic at the crossing is stopped at regular intervals either through a pedestrian signal or a stop sign. The stopped condition creates regular crossing opportunities. In order for a crossing to fit this category, vehicular traffic has to be stopped at the pedestrian crossing and has to be stopped for a sufficient duration across all lanes, and at a sufficient frequency to represent a safe crossing opportunity.
- **Vehicle speed less than 20 mi/h –** Traffic at the pedestrian crossing is traveling at design speeds less than 20 mi/h and is slow-enough to minimize risk of conflicts. This speed threshold is consistent with European speed limit practices for neighborhood streets and has been linked in research to high yielding behavior. Design speeds under 20 mi/h are generally achieved through geometric design (curve radii), or other speed-reducing treatments, including raised crosswalks.
- **Vehicle speed between 20 mi/h and 30 mi/h –** Traffic traveling below 30 mi/h is less likely to yield than in the prior category, and there is an increased likelihood of injury in the event of a collision. The 30 mi/h threshold is further consistent with guidance in the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities and the AASHTO Guide for the Development of Bicycle Facilities.
- **Vehicle speed in excess of 30 mi/h –** At speeds above 30 mi/h drivers are unlikely to yield to pedestrians and the risk of injury or death to pedestrians is high in the event of a collision. This condition is categorized as “high speed” and results in a challenging and potentially dangerous crossing environment.

Number of Lanes at Crossing

The number of lanes of each pedestrian crossing is evaluated to account for the level of exposure pedestrians have to vehicular traffic during the crossing. Each crossing is categorized into one of three conditions:

- **1-Lane Crossing** – pedestrians have to cross a single lane at a time.
- **2-Lane Crossing** – pedestrians have to cross two lanes at a time, introducing the risk of a “multiple threat” situation with a vehicle stopped/yielding in the near lane blocking the view (and audible information) between the pedestrians and vehicles in the far lane.
- **3-Lane Crossing or greater** – pedestrians have to cross three or more lanes at a time, increasing the level of exposure of pedestrians significantly.

Completing Pedestrian Crossing Assessment

The assessment of vehicular speed and number of lanes is based on general design assumptions. For example, it can be assumed that single-lane roundabouts and channelized turn lanes can be designed at a "low" design speed, and that intersections either have signalized (stopped condition) or unsignalized crosswalks. For complex intersection designs, each crosswalk should be considered individually. An intersection may have anywhere from four crossings (two major and two minor street crossings at standard intersection) to sixteen crossings (four right turns, four left turns, and two-stage mainline and side-street crossings at all four approaches of a DLT). For intersections with channelization islands (e.g. roundabouts) or medians (e.g. RCUTs and MUTs), each crossing component should be evaluated separately.

The pedestrian crossing assessment relies on the combination of the two analysis dimensions. Each dimension is assigned a numerical score based on its vehicle speed and exposure condition. The two scores are multiplied to arrive at a combined crossing score on a 100-point scale. A higher score generally corresponds to a safer pedestrian crossing. **Table 5** and **Table 6** summarize the scores for vehicle speed and exposure, respectively. **Table 7** provides combined scoring when multiplying the two dimensions.

Table 5: Vehicle Speed Scoring for Pedestrian Crossings

Vehicle Speed	Score
Stopped	10
< 20 mi/h	8
20 – 30 mi/h	6
> 30 mi/h	4

Table 6: Pedestrian Exposure Scoring for Pedestrian Crossings

# of Lanes	Score
1	10
2	8
3+	6

Table 7: Combined Pedestrian Crossing Scoring

Vehicle Speed	1-Lane	2-Lanes	3 Lanes
Stopped	100	90	80
< 20 mi/h	90	64	48
20 – 30 mi/h	80	48	36
> 30 mi/h	70	32	24

The color coding in **Table 8** symbolizes potential categories of “excellent”, “good”, “fair”, and “poor” that may be applied to each pedestrian crossing.

Table 8: Pedestrian Crossing Assessment Scoring Bins

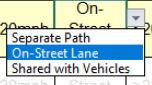
Combined Pedestrian Scoring	Lower Limit	Upper Limit
Excellent	80	100
Good	60	79
Fair	40	59
Poor	0	39

MULTIMODAL BIKE TAB

The *Multimodal Bike* tab contains optional user inputs used in conducting the assessment of bicycle accommodations. Default values are available and populated for all inputs in the tab, and the bicycle analysis will still be carried out if the user does not make any modifications to this tab. For each row, the analyst uses drop-down menus to select the number of crossings, as well as the number of lanes and vehicle speed category for each crossing. **Table 9** shows a portion of the CAP-X Bicycle Input. Each intersection or interchange type is provided in a separate row. For each row, the analyst uses drop-down menus to select the number of segments, as well as the separation type and vehicle speed category for each crossing.

Table 9: CAP-X Bicycle Segment Implementation

Bicycle Segment Configurations for Non-roundabout Intersections															
TYPE OF INTERSECTION	Sheet	# Of Seg.	Segment #1		Segment #2		Segment #3		Segment #4		Segment #5		Segment #6	
			Bike Lane	Veh Speed	Bike Lane	Veh Speed	Bike Lane	Veh Speed	Bike Lane	Veh Speed	Bike Lane	Veh Speed	Bike Lane	Veh Speed
Traffic Signal	FULL	6	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph
Two-Way Stop Control	N-S	4	On-Street Lane	>30mph	On-Street Lane	>30mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	>30mph
	E-W	4	On-Street Lane	>30mph	On-Street Lane	>30mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	>30mph
All-Way Stop Control	FULL	4	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph
Continuous Green T	W	6	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph
	N	6	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph
	E	6	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph
	S	6	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph	On-Street Lane	<20mph



It does not matter in which order bicycle segments are evaluated, as long as all crossings are included in the analysis. For consistency, it is recommended to begin the evaluation in the north-east quadrant of the intersection, and then numbering crossings sequentially in a clockwise direction.

Bicycle Segment Methodology

The bicycle segment method is intended to assess the safety and level of comfort of each bicycle travel segment through an intersection. The method assumes that bicycles use the travel lane or dedicated bicycle facility. For bicyclists who chose to traverse the intersection using the sidewalk or multi-use path system, the pedestrian crossing assessment method above is used. The bicycle segment assessment considers two different dimensions: (1) Vehicle Speed in Segment, and (2) Separation Type between bikes and motorized traffic. The assessment is best applied separately for each segment through the intersection. However, simplifying assumptions can readily group multiple (similar) segments.

Vehicle Speed in Segment

The vehicle speed in each segment is evaluated based on general design assumptions and categorized into one of three conditions. Descriptions of these conditions are consistent with what was given for pedestrian crossings above.

- **Vehicle speed less than 20 mi/h**
- **Vehicle speed between 20 mi/h and 30 mi/h**
- **Vehicle speed in excess of 30 mi/h**

Separation Type

The separation type between bicycles and vehicular traffic is evaluated for each segment through the intersection and is categorized into one of three conditions:

- **Separate Path –** Bicycles are physically separated from vehicles on a separate path. Separation is provided through either a physical barrier or curb. A bike facility separated by paint only falls into the next category.
- **On-Street Bike Lane** – Bicycles travel in a dedicated on-street bike lane with a width of at least 5 feet, but no physical separation to motorized traffic is provided.
- **Shared Lane with Vehicles** – Bicycles travel in a lane shared with vehicular traffic.

Completing Bicycle Segment Assessment

The assessment of vehicular speed and separation type is based on general design assumptions. For example, it can be assumed that single-lane roundabouts and channelized turn lanes can be designed at a "low" design speed, but that major roadways are likely to be at "high" speeds. For complex intersection designs, each approach to the intersection should be considered as an individual segment, as well as each unique maneuver that cyclists have to complete. An intersection may have anywhere from four segments (two major and two minor street crossings at standard intersection) to twelve segments (four right turns, four left turns, and all four mainline approaches of a DLT). In general, channelized lanes and u-turn movements should be considered as separate segments.

The bicycle segment assessment relies on the combination of the two analysis dimensions. Each dimension is assigned a numerical score based on its vehicle speed and exposure condition. The two scores are multiplied to arrive at a combined crossing score on a 100-point scale. A higher score generally corresponds to a more comfortable and likely safer bicycle segment. **Table 10** and **Table 11** summarize the scores for vehicle speed and exposure, respectively. **Table 12** provides combined scoring when multiplying the two dimensions.

Table 10: Vehicle Speed Scoring for Bicycle Segments

Vehicle Speed	Score
< 20 mi/h	10
20 – 30 mi/h	8
> 30 mi/h	6

Table 11: Separation Type Scoring for Bicycle Segment

Separation Type	Score
Separate Path	10
On-Street Bike Lane	8
Shared Lane with Vehicles	6

Table 12: Combined Bicycle Segment Scoring

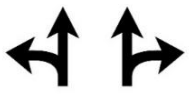
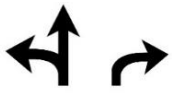
Vehicle Speed	Separate Path	On-Street Bike Lane	Shared Lane with Vehicles
< 20 mi/h	100	80	60
20 – 30 mi/h	80	64	48
> 30 mi/h	60	48	36

The color coding in **Table 9** symbolizes potential categories of "excellent", "good", "fair", and "poor" that may be applied to each bicycle segment, using thresholds previously shown in Table 4.

ALT NUM LANES INPUT TAB

The *Alt Num Lanes Input* tab allows users customize the number of lanes for each turning movement for both the existing configuration and the selected alternatives. The number of lanes is used in conjunction with the user supplied turning volumes in order to determine the critical lane volume for each junction. For non-roundabout intersection alternatives and grade separated intersection alternatives, lanes with shared movements are input by entering "0" in either the left or right column for the given movement. Example lane configurations and their associated user input are shown in **Table 13**.

Table 13. Example User Inputs for Shared Lanes.

Example Lane Configuration				
User Input (L,C,R)	0,1,0	0,2,0	0,1,1	1,1,0

A drop-down selection allows the user to choose to display analysis for intersections only or intersections and interchanges. This option toggles whether or not the table for modifying the number of lanes at interchanges is shown. The three tables with user inputs to select the number of lanes are

illustrated in **Table 14** (non-roundabout intersections), **Table 15** (grade separated intersections), and **Table 16** (interchanges).

Each intersection type includes a link in the *Sheet* column that, when clicked, takes the user to the analysis tab for the selected intersection type. There are three intersection types which utilize their respective intersection specific tab for the number of lanes inputs rather than the *Alt Num Lanes Input* tab. These three intersection types are the quadrant roadway, split intersection, and single point interchange with roundabout.

Table 14. Number of Lanes for Non-roundabout Intersections.

Number of Lanes for Non-roundabout Intersections																	
TYPE OF INTERSECTION	Sheet	Northbound				Southbound				Eastbound				Westbound			
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Traffic Signal	FULL		0	1	0		0	1	0		0	1	0		0	1	0
Two-Way Stop Control	N-S		1	1	0		1	1	0		0	1	0		0	1	0
All-Way Stop Control	FULL		0	1	0		0	1	0		0	1	0		0	1	0
Quadrant Roadway	S-W	Use the respective intersection tab(s) to specify the # of lanes inputs.															
	N-E																
	S-E																
	N-W																
Partial Displaced Left Turn	N-S		1	1	0		1	1	0		1	2	1		1	2	1
Displaced Left Turn	FULL		1	2	1		1	2	1		1	2	1		1	2	1
Signalized Restricted Crossing U-Turn	N-S	1	1	2	0	1	1	2	0				1				1
Unsignalized Restricted Crossing U-Turn	N-S	1	1	2	0	1	1	2	0				1				1
Median U-Turn	N-S	1		2	0	1		2	0			2	0			2	0
Partial Median U-Turn	N-S	1		2	0	1		2	0		0	2	0		0	2	0
Bowtie	N-S			1	1			1	1			1	1			1	1
Split Intersection	N-S	Use the respective intersection tab(s) to specify the # of lanes inputs.															

Table 15. Number of Lanes for Grade Separated Intersections.

Number of Lanes for Grade Separated Intersections																	
TYPE OF INTERSECTION	Sheet	Northbound				Southbound				Eastbound				Westbound			
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Echelon	N-S		1	2	1		1	2	1		1	2	1		1	2	1
Center Turn Overpass	Full		1	2	1		1	2	1		1	2	1		1	2	1

Table 16. Number of Lanes for Interchanges.

Number of Lanes for Interchanges																	
TYPE OF INTERCHANGE	Sheet	Northbound				Southbound				Eastbound				Westbound			
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Diamond	E-W		1	2	1		1	2	1		1	2	1		1	2	1
Partial Cloverleaf A	E-W		1		1		1		1			2				2	
Partial Cloverleaf B	E-W		1		1		1		1		1	2	1		1	2	1
Displaced Left Turn	E-W		1	2	1		1	2	1		1	2	1		1	2	1
Contraflow Left Interchange	E-W		1		1		1		1		1	2	1		1	2	1
Diverging Diamond Interchange	E-W		1		1		1		1		1	2	1		1	2	1
Single Point	E-W		1	2	1		1	2	1		1	2	1		1	2	1
Single Point with Roundabout	E-W	Use the respective intersection tab(s) to specify the # of lanes inputs.															

SUMMARY RESULTS

The *Summary Results* tab provides an overview of the results for the top ten selected intersection types, ranked by overall v/c ratio. In addition to the v/c ratio, the multimodal score, pedestrian accommodation, and bicycle accommodation results are provided in this summary tab. An example of the results summary table for non-interchanges is illustrated in **Table 17**. In this example, the displaced left turn, echelon, and center turn overpass all share the number one v/c ranking with an overall v/c ratio of 0.20. The intersection types with the highest multimodal score within the top ten types listed are the median U-turn and partial median U-turn. These intersections both offer “excellent” pedestrian and bicycle accommodations and are ranked near the bottom of the list with v/c ratios of 0.30 and 0.31 respectively.

Table 17. Example of Results Summary for Non-Interchanges.

TYPE OF INTERSECTION	Overall V/C Ratio	V/C Ranking	Multimodal Score	Pedestrian Accommodations	Bicycle Accommodations
Displaced Left Turn	0.20	1	7.2	Good	Good
Echelon N-S	0.20	1	7.2	Good	Good
Center Turn Overpass	0.20	1	7.2	Good	Good
Quadrant Roadway S-W	0.22	4	6.7	Good	Good
Quadrant Roadway S-E	0.23	5	6.7	Good	Good
Quadrant Roadway N-W	0.24	6	6.7	Good	Good
Quadrant Roadway N-E	0.26	7	6.7	Good	Good
Median U-Turn N-S	0.30	8	9.4	Excellent	Excellent
Partial Median U-Turn N-S	0.31	9	9.4	Excellent	Excellent
2 X 1 Roundabout	0.38	10	8.3	Good	Excellent

DETAILED RESULTS

The *Detailed Results* tab provides complete v/c ratios and critical lane volumes for each relevant zone of each selected type of intersection, as well as the overall v/c ratio. Results are color coded based on the overall v/c ratio, with green depicting v/c ratios less than 0.750, yellow from 0.750 to 0.875, orange from 0.875 to 1.00, and red greater than 1.00. A summary of the results that fall within these ranges is provided in the table in the top section of this tab. Results are separated into a different table for each of the intersection type categories: non-roundabout intersections, grade separated intersections, roundabouts, and interchanges. Pedestrian accommodation results and bicycle accommodation results are also given for each of the selected intersection alternatives. An example of the detailed results table for non-roundabout intersections is provided in **Table 18**. In this example, the base condition, a traffic signal, shows an overall v/c ratio of 0.65 with "good" pedestrian and bicycle accommodations. Example results for grade separated intersections, roundabouts, and interchanges, are illustrated in **Table 19**, **Table 20**, and **Table 21**, respectively.

Table 18. Example Detailed Results for Non-Roundabout Intersections.

Results for Non-roundabout Intersections														
TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Traffic Signal	FULL	-	-	-	-	-	-	-	-	1102	0.65	0.65	Good	Good
Two-Way Stop Control	N-S	-	-	-	-	-	-	-	-	--	1.26	1.26	Fair	Good
All-Way Stop Control	FULL	-	-	-	-	-	-	-	-	1572	1.31	1.31	Excellent	Excellent
Quadrant Roadway	S-W	-	-	390	0.22	-	-	242	0.14	373	0.21	0.22	Good	Good
	N-E	352	0.20	-	-	291	0.17	-	-	459	0.26	0.26	Good	Good
	S-E	-	-	392	0.22	379	0.22	-	-	408	0.23	0.23	Good	Good
	N-W	313	0.18	-	-	-	-	282	0.16	424	0.24	0.24	Good	Good
Partial Displaced Left Turn	N-S	574	0.32	342	0.19	-	-	-	-	849	0.48	0.48	Good	Good
Displaced Left Turn	FULL	303	0.17	225	0.12	150	0.08	186	0.10	357	0.20	0.20	Good	Good
Signalized Restricted Crossing U-Turn	N-S	437	0.24	702	0.39	709	0.39	576	0.32	-	-	0.39	Excellent	Excellent
Unsignalized Restricted Crossing U-Turn	N-S	286	0.22	816	0.35	745	0.80	363	0.45	-	-	0.80	Good	Good
Median U-Turn	N-S	309	0.17	486	0.27	-	-	-	-	536	0.30	0.30	Excellent	Excellent
Partial Median U-Turn	N-S	271	0.15	447	0.25	-	-	-	-	551	0.31	0.31	Excellent	Excellent
Bowtie	N-S	-	-	-	-	286	0.24	286	0.22	847	0.48	0.48	Excellent	Excellent
Split Intersection	N-S	-	-	-	-	778	0.44	510	0.29	-	-	0.44	Good	Good

Table 19. Example Detailed Results for Grade Separated Intersections.

Results for Grade Separated Intersections																
TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Zone 6 (Raised)		Overall v/c Ratio	Ped	Bike
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Echelon	N-S	-	-	-	-	-	-	-	-	204	0.11	357	0.20	0.20	Good	Good
Center Turn Overpass	FULL	-	-	-	-	-	-	-	-	357	0.20	140	0.08	0.20	Good	Good

Table 20. Example Detailed Results for Roundabouts.

Results for Roundabouts															
TYPE OF ROUNDABOUT	Zone 1 (North)			Zone 3 (East)			Zone 2 (South)			Zone 4 (West)			Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3			
50 ICD	0.42	-	-	0.39	-	-	1.06	-	-	0.80	-	-	1.06	Excellent	Excellent
75 ICD	0.40	-	-	0.38	-	-	1.03	-	-	0.67	-	-	1.03	Excellent	Excellent
1 X 1	0.29	-	-	0.27	-	-	0.78	-	-	0.40	-	-	0.78	Excellent	Excellent
2 X 1	0.14	0.14	-	0.25	-	-	0.36	0.38	-	0.35	-	-	0.38	Good	Excellent
2 X 2	0.14	0.14	-	0.18	0.18	-	0.36	0.38	-	0.13	0.13	-	0.38	Good	Excellent

Table 21. Example Detailed Results for Interchanges.

Results for Interchanges																
TYPE OF INTERCHANGE	Sheet	Zone 1 (Rt Mrg)		Zone 2 (Lt Mrg)		Zone 3 (Ctr. 1)		Zone 4 (Ctr. 2)		Zone 5 (Lt Mrg)		Zone 6 (Rt Mrg)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Diamond	E-W					493	0.28	293	0.17					0.28	Good	Good
Partial Cloverleaf A	E-W					150	0.08	225	0.12					0.12	Fair	Fair
Partial Cloverleaf B	E-W					166	0.09	150	0.08					0.09	Fair	Fair
Displaced Left Turn	E-W	207	0.11			186	0.10	735	0.41			332	0.18	0.41	Good	Good
Contraflow Left Interchange	E-W					213	0.12	375	0.21					0.21	Good	Good
Diverging Diamond Interchange	E-W	213	0.12	271	0.15	150	0.08	225	0.12	235	0.13	358	0.20	0.20	Excellent	Excellent
Single Point	E-W	213	0.12			242	0.14					358	0.20	0.20	Good	Good
Single Point with Roundabout	E-W		0.08		0.29						0.24		0.22	0.29	Good	Excellent

REPORT TABS

The *Summary Report* tab and the *Detailed Report* tab replicate and combine information shown on previous tabs into a single location for documentation purposes. There are no user inputs on either of these tabs. The *Summary Report* tab includes the project information table, the traffic volume demand table, and the results summary. The *Detailed Report* tab includes the project information table, the traffic volume demand table, and the detailed results tables for each group of intersection types.

CASE STUDIES

CASE STUDY #1. NEW PRIVATE ACCESS DRIVEWAY

Private Development Company A proposes a new residential development on a currently vacant plot of land adjacent to Route 500 in Concordville. The development plan, which includes 75 single-family homes, proposes access to Route 500 by a single, new intersection. The proposed development would open in 2018 and is being evaluated at a design year of 2024. **Figure 3** illustrates the location of the proposed site.

Original Photo: © 2014 Google® (modified by Kittelson & Associates, Inc.)

Figure 3. Case Study #1, Site Location.

Best described as a suburban area, the surrounding land uses include private residential developments, vacant plots, and an 18-hole golf course a half-mile to the east. This section of Route 500 is a two-lane, undivided arterial featuring curb-and-gutter, a shared-use path running along its north side, and a 35 mile-per-hour posted speed limit. It primarily serves as a means of accessing the adjacent private residential developments and experiences little through traffic. As the land directly opposite the proposed development on Route 500 is currently undeveloped, no intersections or site access points lie along the frontage of the proposed development. Consequently, a new access point to Route 500 is proposed, and analysts undertook an Intersection Control Evaluation (ICE) was undertaken.

While a proposed new intersection could conceivably consider any or all intersection types and control options, in this case the list of viable alternatives were vetted prior to a CAP-X analysis. Through prior coordination, the State and the developer agreed to the following list of intersection-control strategies to asses further:

- Two-way Stop-Control

- Traffic Signal
- Roundabout
- Continuous Green Tee

The CAP-X Tool was applied to help evaluate the three identified control strategies based on anticipated operational performance. The following steps were applied:

1. Review information provided on the *Introduction* tab.
2. Enter basic project information and traffic volumes on the *Volume Input* tab.
3. Select alternatives on *Base and Alt Sel* tab.
4. Enter number of lanes data on the *Alt Num Lanes Input* tab.
5. Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Each of these steps is then outlined.

Step #1: Review the information provided on the *Introduction* tab.

Prior to applying the CAP-X Tool, the information on the *Introduction* tab was reviewed.

Step #2: Enter project information on the *Volume Input* tab.

As **Table 22** and **Table 23** show, the basic project information and traffic volumes were entered on the *Volume Input* tab.

Table 22. Case Study #1, Project Information in Volume Input Tab.

Project Name:	*Concordville Residential Development*
Project Number:	*XX-####-XX*
Location	*Concordville*
Date	2017 AM
Number of Intersection Legs	3
Which leg is the minor street?	S

Table 23. Case Study #1, Traffic Volume Input.

Traffic Volume Demand							
	Volume (Veh/hr)				Percent (%)		
	U-Turn	Left	Thru	Right	Heavy Vehicles	Volume Growth	
Eastbound	0	0	800	25	2.00%	0.00%	
Westbound	0	10	700	0	2.00%	0.00%	
Southbound	0	0	0	0	2.00%	0.00%	
Northbound	0	40	0	20	2.00%	0.00%	
Adjustment Factor	0.80	0.95		0.85			
Suggested	**0.80**	**0.95**		**0.85**			
Truck to PCE Factor				**Suggested = 2.00**	2.00		
Multimodal Activity Level			**Low**	Edit Multimodal Intersection Configuration			
Critical Lane Volume Sum Limit	2-phase signal		**Suggested = 1800 (Urban), 1650 (Rural)**		**1800**		
	3-phase signal		**Suggested = 1750 (Urban), 1600 (Rural)**		**1750**		
	4-phase signal		**Suggested = 1700 (Urban), 1550 (Rural)**		**1700**		

Step #3: Select alternatives and enter information on *Base and Alt Sel* tab.

After entering the basic project information, the alternatives were selected for analysis on the *Base and Alt Sel* tab. **Table 24** illustrates the alternative selection entered into the tool. As determined in the preliminary stages, only four control strategies are proposed for evaluation. All other control strategies were excluded from the evaluation by selecting *No* under the *Yes/No* column at the bottom of the tab.

Table 24. Case Study #1, Alternative Selection.

Rankings Inclusion		Yes/No	Comment
At-Grade Non-Roundabout Intersections?		Yes	
Traffic Signal		Yes	
Two-Way Stop Control		Yes	
All-Way Stop Control		No	
Continuous Green T		Yes	
Quadrant Roadway	S-W	No	
	N-E	No	
	S-E	No	
	N-W	No	
Partial Displaced Left Turn		No	
Displaced Left Turn		No	
Signalized Restricted Crossing U-Turn		No	
Unsignalized Restricted Crossing U-Turn		No	
Median U-Turn		No	
Partial Median U-Turn		No	
Bowtie		No	
Split Intersection		No	
Grade Separated Intersections?		No	
Echelon			
Center Turn Overpass			
Roundabouts?		Yes	
50 ICD Miniroundabout		No	
75 ICD Miniroundaobut		No	
1x1		Yes	
1x2		No	
2x1		No	
2x2		No	
3x3		No	
Grade Separated Interchanges?		No	
Diamond			
Partial Cloverleaf A			
Partial Cloverleaf B			
Displaced Left Turn Interchange			
Contraflow Left Interchange			
Diverging Diamond Interchange			
Single Point			
Single Point with Roundabout			

Step #4: Enter number of lanes on the *Alt Num Lanes Input* tab.

As **Table 25** shows, the number of anticipated lanes for each strategy evaluated was entered on the *Alt Num Lanes Input* tab.

Table 25. Case Study #1, Number of Lanes Input.

Number of Lanes for Non-roundabout Intersections																			
TYPE OF INTERSECTION	Sheet	Northbound				Southbound				Eastbound				Westbound					
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R		
Traffic Signal	FULL		1	1	1		1	1	1		1	1	1		1	1	1		
Two-Way Stop Control	E-W		1	1	1		0	0	0		1	1	1		1	1	1		
Continuous Green T	S		1		1							1	1		1	1			

Step #5: Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Table 26 and **Table 27** show the results from the *Detailed Results* tab.

Table 26. Case Study #1, Non-Roundabout Detailed Results.

Results for Non-roundabout Intersections														
TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Traffic Signal	FULL	-	-	-	-	-	-	-	-	872	0.50	0.50	Good	Good
Two-Way Stop Control	E-W	-	-	-	-	-	-	-	-	--	0.45	0.45	Fair	Good
Continuous Green T	S	-	-	-	-	-	-	-	-	870	0.50	0.50	Fair	Fair

Table 27. Case Study #1, Roundabout Detailed Results.

Results for Roundabouts															
TYPE OF ROUNDABOUT	Zone 1 (North)			Zone 3 (East)			Zone 2 (South)			Zone 4 (West)			Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3			
1 X 1	0.00	-	-	0.62	-	-	0.10	-	-	0.59	-	-	0.62	Excellent	Excellent

The application of the CAP-X Tool for these four intersection types show that the two-way stop controlled intersection is anticipated to have the lowest v/c ratio. However, all four intersection types have v/c ratios well under 1.0 and appear to be able to accommodate the operational demands of this junction. The roundabout alternative is noted as offering excellent pedestrian and bicycle accommodations. Alternative selection for this location should include the other portions of the ICE procedure, including detailed operations analysis and safety analysis.

CASE STUDY #2. INTERSECTION IMPROVEMENT

The intersection of Route 19 (Sulaski Highway) and Route 380 (N Bridge Street) near Charleston has been identified as a location in need of intersection improvements due to poor operational performance. A recently conducted operational analysis determined the intersection currently operates at capacity with a level-of-service (LOS) *E* during the weekday p.m. peak period. Each through movement has volume that exceeds capacity. **Figure 4** illustrates the study intersection.

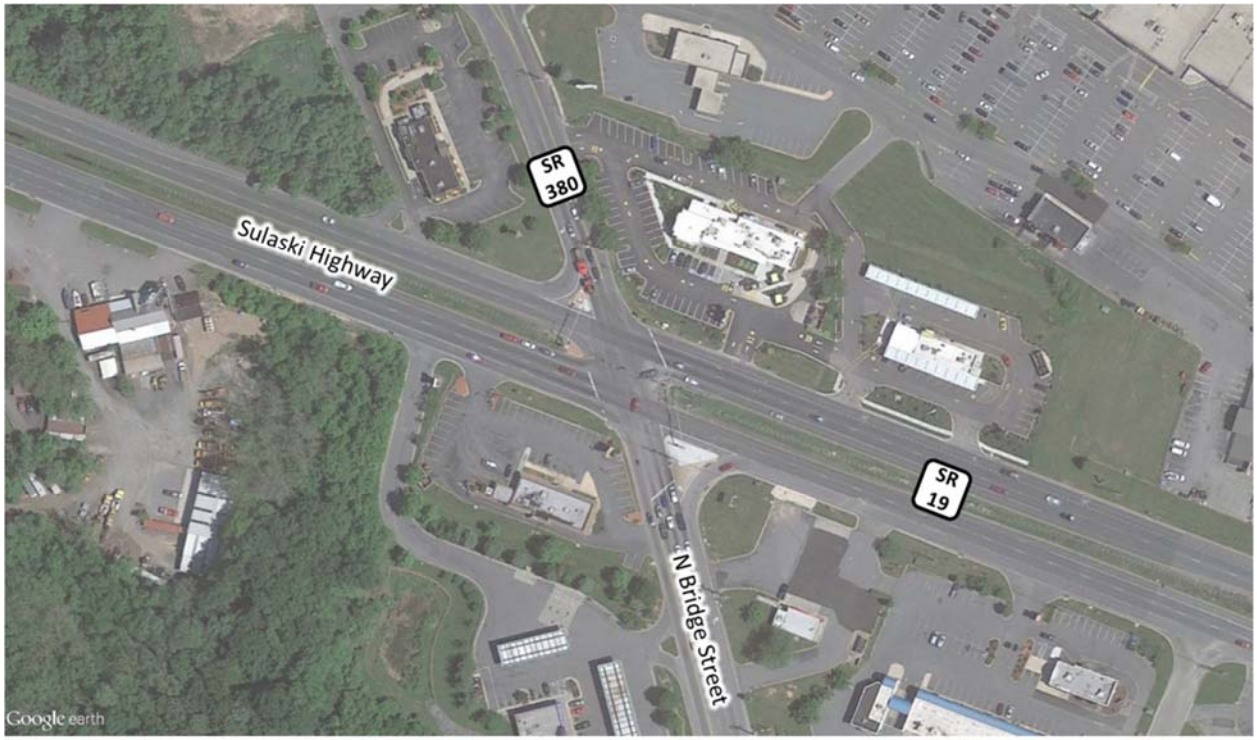


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Figure 4. Case Study #2, Site Location.

Adjacent development makes many of the control strategies unfeasible. Considering right-of-way constraints and crash history at the intersection, the viable control strategies include:

- Traffic Signal (*existing*)
- Median U-Turn
- Signalized Restricted Crossing U-Turn (RCUT)
- Displaced Left-Turn (DLT)
- Bowtie

Currently, channelized right-turn lanes are provided on northbound and southbound approaches; both of the turning lanes have a sufficiently large radius to allow relatively high-speed, yield-controlled turning movements.

To help evaluate the four identified control strategies based on anticipated operational performance the CAP-X tool was applied. The following steps were applied:

1. Review information provided on the *Introduction* tab.
2. Enter basic project information and traffic volumes on the *Volume Input* tab.
3. Select alternatives on *Base and Alt Sel* tab.
4. Enter number of lanes data on the *Alt Num Lanes Input* tab.
5. Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Each of these steps is outlined subsequently.

Step #1: Review the information provided on the *Introduction* tab.

Prior to applying the CAP-X Tool, the information on the *Introduction* tab was reviewed.

Step #2: Enter project information on the *Volume Input* tab.

As **Table 28** and **Table 29** show, the basic project information and traffic volumes were entered on the *Volume Input* tab.

Table 28. Case Study #2, Project Information in Volume Input Tab.

Project Name:	*SR 19/SR 380 Improvements*
Project Number:	*XX-####-XX*
Location	*Charleston*
Date	2017 PM
Number of Intersection Legs	4
Major Street Direction	East-West

Table 29. Case Study #2, Traffic Volume Input.

Traffic Volume Demand							
	Volume (Veh/hr)				Percent (%)	
	U-Turn	Left	Thru	Right	Heavy Vehicles	Volume Growth
Eastbound	0	150	1500	100	2.00%	0.00%
Westbound	0	200	1800	75	2.00%	0.00%
Southbound	0	125	700	85	2.00%	0.00%
Northbound	0	145	800	100	2.00%	0.00%
Adjustment Factor	0.80	0.95		0.85		
Suggested	**0.80**	**0.95**		**0.85**		
Truck to PCE Factor				**Suggested = 2.00**	2.00	
Multimodal Activity Level			**Low**	Edit Multimodal Intersection Configuration		
Critical Lane Volume Sum Limit	2-phase signal		**Suggested = 1800 (Urban), 1650 (Rural)**		**1800**	
	3-phase signal		**Suggested = 1750 (Urban), 1600 (Rural)**		**1750**	
	4-phase signal		**Suggested = 1700 (Urban), 1550 (Rural)**		**1700**	

Step #3: Select alternatives and enter information on *Base and Alt Sel* tab.

After entering the basic project information, the alternatives were selected for analysis on the *Base and Alt Sel* tab. **Table 30** illustrates the alternative selection entered into the tool. As determined in the preliminary stages, five control strategies are proposed for evaluation. All other control strategies were excluded from the evaluation by selecting *No* under the *Yes/No* column at the bottom of the tab.

Table 30. Case Study #2, Alternative Selection.

Rankings Inclusion		Yes/No	Comment
At-Grade Non-Roundabout Intersections?		Yes	
Traffic Signal		Yes	
Two-Way Stop Control		No	
All-Way Stop Control		No	
Continuous Green T		No	
Quadrant Roadway	S-W	No	
	N-E	No	
	S-E	No	
	N-W	No	
Partial Displaced Left Turn		No	
Displaced Left Turn		Yes	
Signalized Restricted Crossing U-Turn		Yes	
Unsignalized Restricted Crossing U-Turn		No	
Median U-Turn		Yes	
Partial Median U-Turn		No	
Bowtie		Yes	
Split Intersection		No	
Grade Separated Intersections?		No	
Echelon			
Center Turn Overpass			
Roundabouts?		No	
50 ICD Miniroundabout			
75 ICD Miniroundaobut			
1x1			
1x2			
2x1			
2x2			
3x3			
Grade Separated Interchanges?		No	
Diamond			
Partial Cloverleaf A			
Partial Cloverleaf B			
Displaced Left Turn Interchange			
Contraflow Left Interchange			
Diverging Diamond Interchange			
Single Point			
Single Point with Roundabout			

Step #4: Enter number of lanes on the *Alt Num Lanes Input* tab.

As **Table 31** shows, the number of anticipated lanes for each strategy evaluated was entered on the *Alt Num Lanes Input* tab.

Table 31. Case Study #2, Number of Lanes Input.

Number of Lanes for Non-roundabout Intersections																	
TYPE OF INTERSECTION	Sheet	Northbound				Southbound				Eastbound				Westbound			
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Traffic Signal	FULL		1	1	1		1	1	1		1	2	1		1	2	1
Displaced Left Turn	FULL		1	1	1		1	1	1		1	2	1		1	2	1
Signalized Restricted Crossing U-Turn	E-W				1				1	1	1	2	1	1	1	2	1
Median U-Turn	E-W			1	1			1	1	1		2	1	1		2	1
Bowtie	E-W			1	1			1	1			2	1			2	1

Step #5: Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Table 32 shows the results from the *Detailed Results* tab.

Table 32. Case Study #2, Detailed Results.

Results for Non-roundabout Intersections															
TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Traffic Signal	FULL	-	-	-	-	-	-	-	-	2037	1.20	1.20	Good	Good
Displaced Left Turn	FULL	1104	0.61	1074	0.60	1044	0.58	1153	0.64	1734	0.96	0.96	Good	Good
Signalized Restricted Crossing U-Turn	E-W	2085	1.16	2214	1.23	2264	1.26	1945	1.08	-	-	1.26	Excellent	Excellent
Median U-Turn	E-W	-	-	-	-	1435	0.80	1308	0.73	1836	1.02	1.02	Excellent	Excellent
Bowtie	E-W	929	0.96	1066	1.03	-	-	-	-	2035	1.16	1.16	Excellent	Excellent

From the five intersection types analyzed, only the displaced left turn gives a v/c ratio less than 1.0. The second best performing is the median U-turn intersection, with its v/c ratio of 1.02 only slightly greater than 1.0. The median U-turn intersection also offers excellent pedestrian and bicycle accommodations, as compared to the good rating for the displaced left turn pedestrian and bicycle accommodations. Both the displaced left turn and the median U-turn appear to similarly performing alternatives and warrant further study in the ICE procedure (as well as the existing condition – traffic signal).

CASE STUDY #3. NEW INTERCHANGE

Burgeoning traffic demands along the outskirts of Pueblo have lead to oversaturation of several of interchanges along I-7. To help alleviate congestion, a new interchange between I-7 and Route 535 (Zermatt Road) is being proposed to reroute local trips within the network. **Figure 5** illustrates the site location, which currently features agriculutral land uses in all four quadrants. Engineers used regional traffic models for the opening year (2020) to develop traffic forecasts for the ramp terminals.

Original Photo: © 2016 Google® (modified by Kittelson & Associates, Inc.)

Figure 5. Case Study #3, Site Location.

Currently, the two-lane overpass (Zermatt Road) over the eight-lane highway (I-7) is scheduled for a complete replacement. Each of the interchange control strategies contained with the CAP-X Tool were evaluated to determine their expected performnace:

- Diamond
- Partial Cloverleaf A
- Partial Cloverleaf B
- Displaced Left Turn Interchange
- Contraflow Left Interchange
- Diverging Diamond Interchange
- Single Point

- Single Point with Roundabout

The following steps were applied within the CAP-X Tool:

1. Review information provided on the *Introduction* tab.
2. Enter basic project information and traffic volumes on the *Volume Input* tab.
3. Select alternatives on *Base and Alt Sel* tab.
4. Enter number of lanes data on the *Alt Num Lanes Input* tab.
5. Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Each of these steps is outlined subsequently.

Step #1: Review the information provided on the *Introduction* tab.

Prior to applying the CAP-X Tool, the information on the *Introduction* tab was reviewed.

Step #2: Enter project information on the *Volume Input* tab.

As **Table 33** and **Table 34** show, the basic project information and traffic volumes were entered on the *Volume Input* tab.

Table 33. Case Study #3, Project Information in Volume Input Tab.

Project Name:	*Zermatt Road Interchange*
Project Number:	*XX-####-XX*
Location	*Pueblo*
Date	2017 PM
Number of Intersection Legs	4
Major Street Direction	East-West

Table 34. Case Study #3, Traffic Volume Input.

Traffic Volume Demand							
	Volume (Veh/hr)				Percent (%)		
	U-Turn	Left	Thru	Right	Heavy Vehicles	Volume Growth	
Eastbound	0	140	1325	12030	2.00%	0.00%	
Westbound	0	70	1150	75	2.00%	0.00%	
Southbound	0	250	0	175	2.00%	0.00%	
Northbound	0	50	0	100	2.00%	0.00%	
Adjustment Factor	0.80	0.95		0.85			
Suggested	**0.80**	**0.95**		**0.85**			
Truck to PCE Factor				**Suggested = 2.00**	2.00		
Multimodal Activity Level			**Low**	Edit Multimodal Intersection Configuration			
Critical Lane Volume Sum Limit	2-phase signal		**Suggested = 1800 (Urban), 1650 (Rural)**		**1800**		
	3-phase signal		**Suggested = 1750 (Urban), 1600 (Rural)**		**1750**		
	4-phase signal		**Suggested = 1700 (Urban), 1550 (Rural)**		**1700**		

Step #3: Select alternatives and enter information on *Base and Alt Sel* tab.

After entering the basic project information, the alternatives were selected for analysis on the *Base and Alt Sel* tab. **Table 35** illustrates the alternative selection entered into the tool. As determined in the preliminary stages, all interchange control strategies are proposed for evaluation. All other control strategies were excluded from the evaluation by selecting *No* under the *Yes/No* column at the bottom of the tab.

Table 35. Case Study #3, Alternative Selection.

Rankings Inclusion		Yes/No	Comment
At-Grade Non-Roundabout Intersections?		No	
Traffic Signal			
Two-Way Stop Control			
All-Way Stop Control			
Continuous Green T			
Quadrant Roadway	S-W		
	N-E		
	S-E		
	N-W		
Partial Displaced Left Turn			
Displaced Left Turn			
Signalized Restricted Crossing U-Turn			
Unsignalized Restricted Crossing U-Turn			
Median U-Turn			
Partial Median U-Turn			
Bowtie			
Split Intersection			
Grade Separated Intersections?		No	
Echelon			
Center Turn Overpass			
Roundabouts?		No	
50 ICD Miniroundabout			
75 ICD Miniroundaobut			
1x1			
1x2			
2x1			
2x2			
3x3			
Grade Separated Interchanges?		Yes	
Diamond		Yes	
Partial Cloverleaf A		Yes	
Partial Cloverleaf B		Yes	
Displaced Left Turn Interchange		Yes	
Contraflow Left Interchange		Yes	
Diverging Diamond Interchange		Yes	
Single Point		Yes	
Single Point with Roundabout		Yes	

Step #4: Enter number of lanes on the *Alt Num Lanes Input* tab.

As **Table 36** shows, the number of anticipated lanes for each strategy evaluated was entered on the *Alt Num Lanes Input* tab.

Table 36. Case Study #3, Number of Lanes Input.

Number of Lanes for Non-roundabout Intersections																	
TYPE OF INTERSECTION	Sheet	Northbound				Southbound				Eastbound				Westbound			
		U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Diamond	E-W		1	1	1		1	1	1		1	1	1		1	1	1
Partial Cloverleaf A	E-W		1		1		1		1			1				1	
Partial Cloverleaf B	E-W		1		1		1		1		1	1	1		1	1	1
Displaced Left Turn	E-W		1	1	1		1	1	1		1	1	1		1	1	1
Contraflow Left Interchange	E-W		1		1		1		1		1	1	1		1	1	1
Diverging Diamond Interchange	E-W		1		1		1		1		1	1	1		1	1	1
Single Point	E-W		1	1	1		0	0	0		1	1	1		1	1	1
Single Point with Roundabout	E-W	Use the respective intersection tab(s) to specify the # of lanes inputs.															

Step #5: Review the v/c ratios and multimodal accommodations on the *Detailed Results* tab.

Table 37 shows the results from the *Detailed Results* tab.

Table 37. Case Study #3, Detailed Results.

Results for Interchanges																
TYPE OF INTERCHANGE	Sheet	Zone 1 (Rt Mrg)		Zone 2 (Lt Mrg)		Zone 3 (Ctr. 1)		Zone 4 (Ctr. 2)		Zone 5 (Lt Mrg)		Zone 6 (Rt Mrg)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Diamond	E-W					1849	1.06	1838	1.05					1.06	Good	Good
Partial Cloverleaf A	E-W					1763	0.98	1298	0.72					0.98	Fair	Fair
Partial Cloverleaf B	E-W					1570	0.87	1395	0.77					0.87	Fair	Fair
Displaced Left Turn	E-W	1375	0.76			1620	0.90	1661	0.92			1795	1.00	1.00	Good	Good
Contraflow Left Interchange	E-W					1695	0.97	1818	1.04					1.04	Good	Good
Diverging Diamond Interchange	E-W	1315	0.73	2719	1.51	1763	0.98	1298	0.72	2851	1.58	1818	1.01	1.58	Excellent	Excellent
Single Point	E-W	1315	0.73			1771	1.01					1818	1.01	1.01	Good	Good
Single Point with Roundabout	E-W		0.90		0.99						1.13		1.63	1.63	Good	Excellent

The CAP-X results show that six of the interchange types operate with an approximate v/c ratio less than 1.0 or slightly greater than 1.0, with the partial cloverleaf B having the lowest v/c ratio. More detailed operational and safety analysis is needed before selecting an interchange type for implementation.

For More Information:

Visit [https://safety.fhwa.dot.gov/intersection/ice/]

FHWA, Office of Safety

Jeffrey Shaw
jeffrey.shaw@dot.gov
708-283-3524

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