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Developing a GIS-Based Intersection Traffic Control Planning Tool

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Developing a GIS-Based Intersection Traffic Control Planning Tool

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Dedication

I would like to dedicate this thesis to my mom and dad. Without their support and encouragement I would not be where I am today.

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Abstract

Developing a GIS-Based Intersection Traffic Control Planning Tool

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The purpose of this study was to include consideration for intersections into the previously created GIS traffic control planning tool. Available data for making intersection control calculations were collected and integrated into the design of the tool. The limitations created by required assumptions were addressed, as well as more advanced techniques for overcoming these problems. The tool can be use to estimate capacity calculations at any signalized intersection within the NCTCOG modeling region. These calculations can be used to inform users about the effects of a construction plan. Inputs for using dynamic traffic assignment to further understand these effects is then addressed, focusing on the development of a subnetwork to reduce computation time for multiple temporary traffic control plans.

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Chapter 1 – Introduction

1.1   Motivation for the Work

The original motivation behind the development of a traffic control planning tool

was a need for TxDOT's Dallas District construction personnel to be able to quickly

make informed decisions about proposed traffic control plans associated with both small

and large construction projects. For large construction projects where the traffic control

may be needed for several days, weeks or months, a detailed plan fully considering

highway user costs is necessary. However, in the case of a short duration afternoon

project, less detailed analyses may be required but safety of work zone personnel as well

as highway users is a primary consideration. The goal of the tool is for the user to be able

to examine a work zone site and the region around the site, and evaluate, revise, and tune

the traffic control plan to maximize safety and minimize costs. If the project is not large

enough to require detour routes then the tool could be used to understand what affect it

will have on the traffic on the roadway, and inform drivers with the temporary traffic

control devices.

Building a temporary traffic control (TTC) plan requires information and data

about the roadway of interest (MUTCD 2009). This necessary data includes geometry

such as lane width, shoulder width, and length of the construction zone. It is just as

important to have traffic information on the roadway with peak hour volumes, speeds,

and the number of lanes in each direction. The motivation behind developing a TTC is to

provide a temporary controlled construction zone that allows people to efficiently and safely travel through the effected corridor. In addition to highway user safety, the designer must consider the worker's safety. The power of this tool will help with small decisions that need to be made for re-routing traffic. Ideally, this tool with the use of engineering judgment should make it easier to modify a plan that will limit potential delay caused by the construction. One issue with the tool is that it only provides a general understanding of the changes in the of volume to capacity ratio as new capacities are calculated.

A more thorough investigation into the effects could be accomplished through the use of a traffic assignment tool that could offer more details on the influence of a traffic control plan. Dynamic traffic assignment (DTA) provides many new abilities in the realm of traffic network analysis. This is due to the ability of DTA to capture the effects of time-varying traffic flow, which are lost in traditional static traffic assignment. One major issue with DTA is the time it takes to analyze a large network. However, techniques have been developed for use with static assignment to examine part of a large network, or subnetwork, which allow for this computation time to be reduced. These concepts could be adapted to a network for use with DTA, which could drastically reduce the computation time. This could ideally be applied to a full network to create a subnetwork of interest given a certain construction location. Once, the subnetwork has been developed then a variety of scenarios could be relatively quickly tested to predict impacts of proposed traffic control.

1.2   Work Methodology and Objectives

Previous work completed on this project produced a freeway link capacity calculator, which allows the user to examine a particular freeway link and adjust certain parameters. By adjusting these parameters changes are made to the capacity, which can inform the user how much effect a traffic control plan may have on traffic flow or congestion. Various improvements have been made to the tool including providing hour of day traffic volumes, and accounting for HOV lanes, and HOT lanes. This tool was completed in ArcGIS 9, which creates some issues for the transition to the latest version of ArcGIS 10.

The work described here details the addition of an arterial street intersection tool to the basic freeway link tool. Unlike the freeway link capacity tool there are significant limitations on the amount of data available for intersection capacity calculations due to the level of detail required for intersection analysis. At the intersection level it is necessary to have information on the arterials that connect to the highway including their geographic location, volumes, and numbers of lanes. This data is not included in the census' topographically integrated geographic encoding and referencing (TIGER) database or the pavement management information system (PMIS) files. These were the files that were integrated with the North Central Texas Council of Government's (NCTCOG) demand data shapefile for the original highway capacity tool. The NCTCOG shapefile is the output of the Dallas-Fort Worth regional network travel demand model. NCTCOG currently uses the four step model, which ends with a static traffic assignment.

The volume data in the NCTCOG shapefile is the result of this traffic assignment step in their model (NCTCOG 2009). The initial data that was used for the highway capacity tool was created in 2007. Since traffic volumes change continually, the newest available roadway dataset was acquired. This was the 2011 NCTCOG demand layer that is now used in the intersection capacity tool.

Consistency of this data is important for this project and other future GIS projects. Ideally, the shapefile will remain the same and as new data is produced the tool would be able to accept the new data to produce updated results. The major problem is that these datasets are ever-changing with possible new link ID's, entirely new links, and changed geometry. These considerations should be included in this tool, but also need to be accounted for in the way that TxDOT and NCTCOG manage their data resources.

The major limitation of the new dataset is the lack of certain information that can improve capacity calculations. These include the missing geometries, the lack of hourly volumes, and other relevant data that impacts traffic conditions such as on street parking. Signal locations for TxDOT system highways have been geocoded, but only their locations are available for use. Another powerful data set that could drastically improve the functionality of this tool is the traffic signal timing plans. This lack of data will require assumptions to produce green time to cycle length ratios; however, the user will still be able to produce an estimated volume to capacity ratio of surrounding roadways.

The study area of this project is a combination of the TxDOT Dallas district and the available roadway network for the NCTCOG coverage area, which can be seen in

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figure 1.1. While this is the study area for this project, the methodology of this analysis could be applied to any roadway network for a metropolitan area. The desire of this project was to create a GIS based tool that will calculate the capacities of each leg of the intersection. Then, like the highway capacity tool, certain parameters will be changeable to examine different scenarios. An example screen shot of a portion of the network can be seen in figure 1.2.
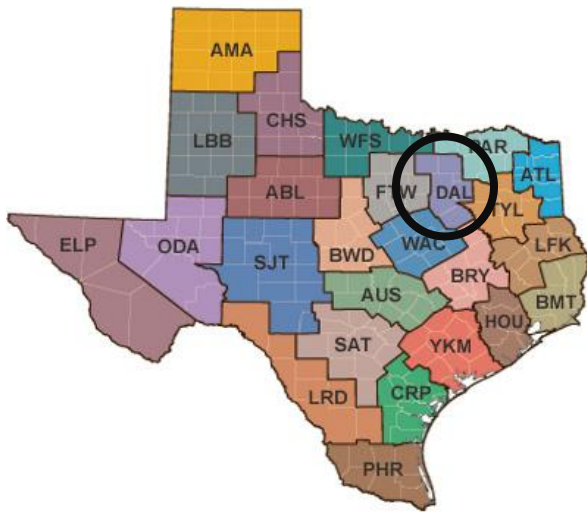
Figure 1.1: Dallas TxDOT District Map
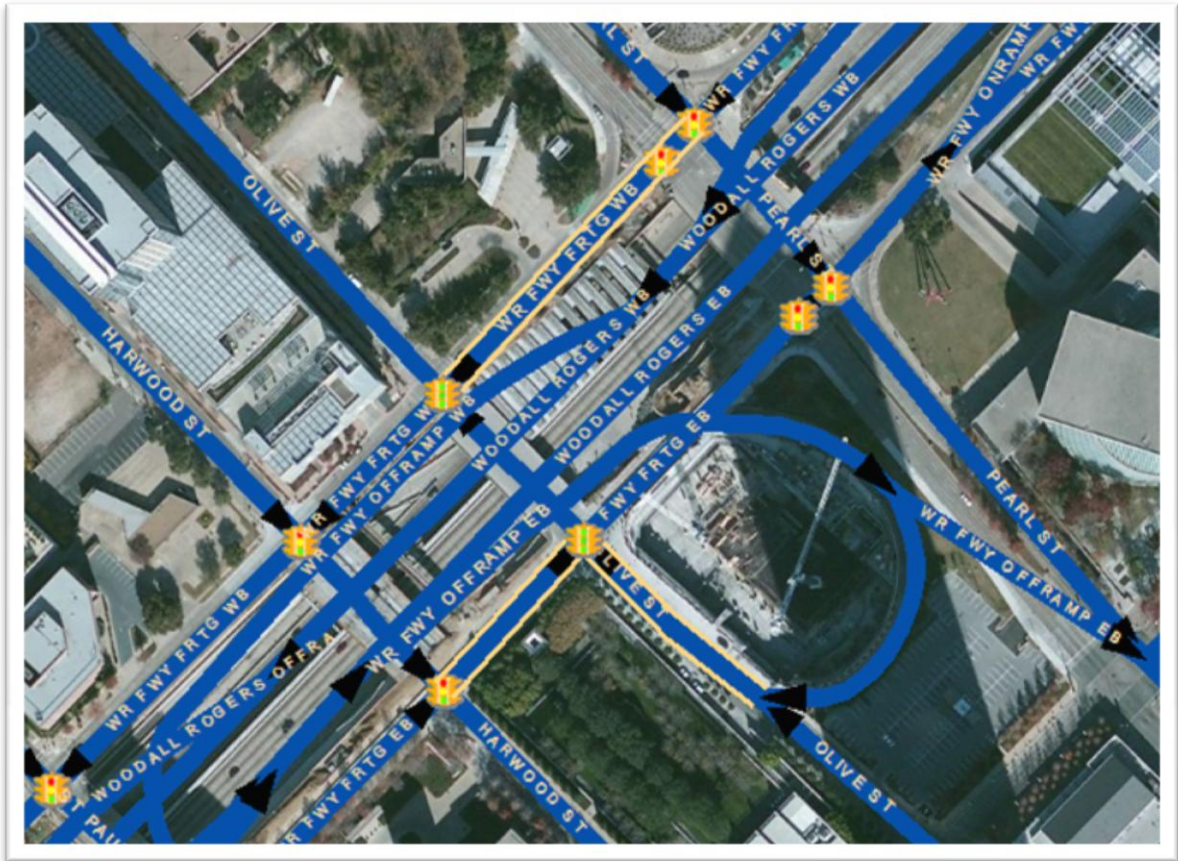
Figure 1.2 Example Intersection with the NCTCOG Demand Data and Signal Locations

1.3 Summary

This thesis will cover the methodology behind the intersection capacity tool, and how it may be used to provide insight into the development of a traffic control plan. The basic premise is that the roadway network developed by the MPO for travel demand modeling will be used to make capacity calculations for intersections. These capacity calculations will be performed through a graphical user interface within ArcGIS. This

intersection capacity calculator can then be used in conjunction with the highway capacity calculator to examine TTC plans.

The rest of this thesis will go into detail about the tool development process. Chapter 2 will include a review of important concepts relevant to the GIS tool. Chapter 3 will discuss updates that were required between the highway capacity tool and the intersection capacity tool. Chapter 4 will look at current procedures employed by NCTCOG for demand and capacity analysis. Chapter 5 will describe the intersection capacity calculation methodology and creation of the tool. Chapter 6 will cover possible improvements that may be made with more readily available data and possible extensions of the tool. Chapter 7 will touch on the future use of DTA subnetwork analysis for traffic control plans. Chapter 8 will be a summary and will provide conclusions based upon the work.

Chapter 2 – Background and Literature Review

2.1 Geographic Information Systems for Transportation

Geographic Information Systems (GIS) have emerged as a powerful tool in the geospatial modeling environment and will continue to pervade the tools that civil engineers use to solve problems. The field of transportation is no exception to this adaptation of geographically referenced data. In fact it is particularly important that the topology of the transportation system is considered when performing any analysis; as it is the connections and location of the networks that dominate traveler behavior. GIS is in essence a database system, with the added benefit of a geographical representation of various attributes of the data. When investigating the applications of GIS in transportation, or GIS-T, it is important to acknowledge the limitations of both the software and algorithms used for analysis.

Common GIS software platforms used in the transportation industry are ESRI's ArcGIS and Caliper's TransCAD. ArcGIS has more generic GIS applications as well as some transportation tools, but is the leading GIS software package. TransCAD is specifically designed for transportation applications, but has a licensing cost that leads some agencies to invest in ArcGIS. TransCAD also has fewer visualization capabilities; however, its capabilities continue to increase. TransCAD's major advantages are its built-in transportation modeling capabilities for roadway networks. However, it is common practice for transportation agencies to develop their own models and networks within

TransCAD. This can be done using GIS software developer's kit to create customized programs for common routines in GIS. TransCAD claims to have the ability to perform four step trip-based travel forecasting as well as more advanced activity based modeling and dynamic traffic assignment (Caliper 2005). There is a substantial dispute that TransCAD's more advanced modeling capabilities do not contain the necessary standards for such analysis. For example, most modern DTA applications include traffic simulators for estimating how travel times change with changing traffic volumes. However TransCAD's dynamic assignment estimates travel times using the empirical BPR travel time function rather than simulation. The DTA analysis in TransCAD seems to be a static assignment approximation for shorter time intervals within the peak hour.

ArcGIS has other spatial analysis capabilities that can be applied to transportation issues such as spatial statistics, but lacks the built in transportation networks for its network analysis. Since most agencies use their own network for traffic assignment, the built-in NAVTEQ networks are often not used. In essence, ArcGIS is better for developing or displaying a roadway network and TransCAD is better for the modeling and analysis of that network. In addition to these two platforms, there are numerous other packages that are less popular but accomplish the same tasks. Compatibility between some of these less commonly used platforms data structures has been integrated into ArcGIS and TransCAD.

2.2 GIS-T Standards and Practices

A major issue in the integration of GIS in the transportation industry is the standardization of the data and platforms that are used. A wide variety of institutions have begun accumulating network data in their own way - without oversight encouraging a standard to allow for greater interoperability. In addition to TransCAD there are a number of other transportation modeling packages that require specific inputs (Boxill 2005). Different agencies have preferences for certain packages based on previous use of the software, but it is important to be concerned with the interchangeability of the networks as the industry encounters new breakthroughs in transportation modeling procedures. The movement of this aspect of the industry should be to accept national GIS standards similar to those that have been adopted for traffic analysis by the Highway Capacity Manual 2010.

The problem with the lack of a standard across GIS systems is an issue of redundancy. For instance, if an engineering consulting firm is designing an interchange it is important for them to survey the area for obstacles, utilities, existing geometric layout, signal timing, and traffic information. This is a time consuming and costly process that must be performed before any design process. However, if these data had been officially recorded in a GIS database that was maintained by the government agency that owns the roadway, then this cost could be eliminated for future projects (Ziliaskopoulos 2000). Standardization is key to the coordination of different agencies that control roadways in the same region. Furthermore, as documentation of the new design is currently required

in paper format – digital records of the design should also be stored in the public agency's GIS as part of the submittals from the consulting firm. This would guarantee that the most current as-builts are accurately geographically referenced for any future project on the same roadway, preventing the need for redundancy of surveying the area. Also, previous calculations such as intersection signal timing could be documented in an easily accessible format, which would allow for new calculations to be made with little adjustment other than updating the input data. As intelligent transportation systems begin to provide more data on a regular basis it will be important to have an automated database that captures these large data streams. Details such as newly paved shoulder lengths and parking utilization can be regularly collected and stored in this standardized GIS. This data will hopefully advance the utilization and accuracy of the new transportation models that are being used for planning applications.

The complexity of models is increasing as quickly as the number of different models being developed. In an industry that is changing so fast, it is important to maintain some consistency of procedures to allow for widespread improvements (Dueker 2000). Investment in cutting edge transportation models has occurred at an uneven rate across agencies. Large regions such as New York or Los Angeles are the first to adopt new models such as activity based travel demand due to their large size and corresponding funding resources. On the other hand, smaller cities have retained the standard four step model due to the costs of transition to higher level models. The state of Illinois has acknowledged this lack of federal standards and has developed its own

(DuPage County 2009). These standards, along with other agencies established standards, could be used as a basis for national system. A standardization of the data inputs for the models could give smaller agencies an advantage by using the larger agencies as a foundation for the more advanced models. It is also important to understand the applicability of different models to different size networks, as well as possible subnetworks, that are analyzed for transportation planning. While consulting firms will continue to provide the majority of the work for network and model development it is important for the analysis to be understood by the public agency officials, which can be accomplished with more standards being centrally developed at the national level. The United States Department of Transportation (USDOT) has begun the process of standardizing GIS-T data through the agency Transportation for the Nation (TFTN 2011). While the planning for this program is just beginning, the standards adapted by this system need to account for higher level transportation models. Not only will standards help improve applications of existing models, but it will provide a basis to begin development of other robust transportation planning tools and techniques.

2.3 Traffic Control Planning GIS-T Tool

The Texas Department of Transportation (TxDOT) has to develop or oversee development of traffic control plans for most roadway projects. In the case of a large, long duration project the traffic control plan must include consideration of worker as well as highway user safety, user costs, and network impacts. However, a large fraction of all projects are smaller and less invasive. These may have shorter durations and/or minimal

traffic impact so traffic control planning can be examined through a simple preliminary analysis. Therefore it was valuable for TxDOT to develop a way to perform a basic analysis of the capacity of highway sections on the state system, and compare estimated volumes to capacity to identify best site specific traffic control planning measures and, if needed, best temporary alternate routes. The tool for uninterrupted flow highway capacity calculations has been developed and was documented in a series of theses (Spurgeon 2008, Gao 2008, Karl 2009, Goldberg 2011).

A major issue was encountered that is inherent within the GIS software development environment. Since the tool was originally designed in ArcGIS 9, there have been a number of changes that occurred with the new version of ArcGIS software package including the loss of support for previous software development. Therefore, the highway capacity tool that was previously developed in Visual Basic is no longer supported by ArcGIS 10. By transferring the code to another language that can be used by the new version of ArcGIS the original tool could be salvaged. The next step to develop this tool was to add interrupted flow capacity calculations, or intersection capacity analysis. This will allow for more insight from the preliminary analysis as arterial intersections can be considered while planning a detour. The problems created by the ever-changing software platforms need to be considered with the development of the new tool.

There are a variety of improvements that need to be addressed with the new tool. First, the current travel demand model that the North Central Texas Council of

Governments (NCTCOG) is using makes some large generalizations about the capacity calculations (NCTCOG 2009). These generalizations are due to a lack of data, which also impact the GIS tool that was developed. However, some assumptions may allow for more accurate capacities than generated by the current NCTCOG model. If these more accurate capacities were used in the original static traffic assignment, it has the potential to improve the predictive power of the model. The major improvement that is to be made to the capacity calculation tool is to add directional flows to the incoming volumes. The previous model made generalizations about the incoming intersection flows. With the inclusion of disaggregate directional data, the new model will improve the calculations made. Important data that could easily be incorporated into a GIS database will be addressed for future improvements. The new tool will also allow for changes of the cycle length and time of day analysis. Lane volumes will replace total link volumes to correct for improperly-apportioned signal green time for intersections with multi-lane intersection approaches. Also, subnetwork analysis will be considered to determine the interrelationship between the GIS network development and traffic assignment algorithms. Subnetwork DTA analysis will be evaluated as an extension of the traffic control planning for larger projects.

Chapter 3 – Major Changes in the Software Development

3.1 The Freeway Link Capacity Tool

Complete information on the freeway link capacity tool can be found in the previously mentioned theses (Spurgeon 2008, Gao 2008, Karl 2009, Goldberg 2011). They will be discussed here to present the issues with their development as the ArcGIS platform has changed. GIS user development provides a number of possible avenues from which to choose, and certain methods have advantages for particular tasks. In versions of ArcGIS prior to version 10, Visual Basic for Applications was a commonly used language throughout many aspects of the software. Similar to the way Visual Basic for Applications (VBA) code could be used in Microsoft Excel, ArcGIS supported the use of VBA Macros to automate certain processes. The VBA code ran in the background, but provided information through a graphical user interface. This interface could be used to make modifications to capacity calculations by changing input values. While this method of ArcGIS tool development was powerful, there are a few drawbacks.

One major issue with the VBA script is that most of the values in it are hard coded. If the freeway time of day volume data needed to be changed, then there would be significant difficultly updating the code to reflect these changes. Instead, a database table could have provided more flexibility in the data updating. Another disadvantage is that it cannot effectively use the tools that are already provided by ArcGIS. Predefined toolsets that are part of ArcGIS are likely to be a part of the software in future releases. By

utilizing these functions the longevity of the user developed tools can be assured. Despite these concerns, the need to migrate the development from VBA stems from the changes that have occurred between ArcGIS 9.3 and 10.0.

> Visual Basic for Applications (VBA) for ArcMap and ArcCatalog has been deprecated at ArcGIS 10. VBA will not be installed with ArcGIS Desktop 10. To continue to use existing VBA macros for ArcMap and ArcCatalog at 10, a VBA license file must be requested from ESRI. However, it is recommended that no further development occur on VBA.
>
> Beyond ArcGIS 10, ESRI will no longer support VBA as a development platform. Users who have custom functionality built using VBA should actively plan strategies to rewrite their applications using a supported development language, such as Python, VB .NET, or C#, so their applications continue to be operational and supported in future releases of ArcGIS. (ESRI 2010)

Therefore, other development methods needed to be considered for the future of this project.

3.2 ArcGIS Changes and Requirements

The two primary methods for development in ArcGIS are now the use of Add-ins and ArcObjects. Add-ins are most similar to the VBA Macros because it is code that has been integrated in the background of ArcGIS and can be used as a standalone tool. Add-ins can be written in JavaScript or .NET languages, such as Visual C#. The primary advantage of add-ins is that they allow the user to incorporate tools from ArcGIS toolsets. Previously, an add-in was created for the intersection capacity calculations for this project. This code was written in visual C sharp; however, despite the .NET capabilities few ArcGIS tools were utilized and alternative lines of code were substituted. Another problem associated with the previously created code was that it was having difficulty

communicating with the appropriate data in ArcGIS. While the code could be updated using the original C sharp language, an alternative was chosen to provide a greater ease of use and maintenance.

Another strategy was to use ArcGIS Engine, which is a newly incorporated development package that ESRI offers. It comes with significant support including predefined GIS components that can be embedded into a user designed program. However, this package requires an annual license and may provide capabilities that are more than is required for the creation of an intersection traffic control planning tool. The other primary method for developing inside ArcGIS is the model builder tool. The model builder allows the user to combine built-in toolsets of ArcGIS in a pseudo code of logic to perform more complicated tasks. This method has less flexibility than the others in terms of programming capabilities, but is powerful enough to accomplish many tasks. The model builder is also intuitive for a beginning GIS user to understand, with all the functions being easily updateable. This allows the tool to be used anywhere ArcGIS is available.

3.3 Consideration for the Intersection Capacity Tool

The model builder uses predefined toolsets in ArcGIS that are unlikely to change like the supported add-in languages have. This will provide some freedom from the changes that will inevitably alter the incorporation of user developments in ArcGIS. ArcObjects refers to the set of functions and tools that are predefined in ArcGIS. Since

they are the foundation of the ArcGIS software they will most likely continue to be a standard for the ArcGIS package. Another advantage of the model builder system is that it is easy to document and recreate if changes to the toolsets alter the function of the developed intersection capacity tool. Consideration will also be made for new datasets, and what it will take to modify them for the intersection capacity tool. In light of the problems associated with the freeway link capacity tool, it is most important that this tool remain functional for future users.

When planning for the new version of the intersection capacity tool it was important to assess what datasets were available describing the roadway information. Previously, the TIGER dataset, or the U.S. Census dataset, was used for the roadway network structure. This was because the metropolitan planning organization's (MPO), North Central Texas Council of Governments (NCTCOG), network dataset had some difficulty with the accuracy of its geographic references. Some other sources for road network data were inspected including the NAVTEQ street networks, figure 3.1, and OpenStreetMap data.
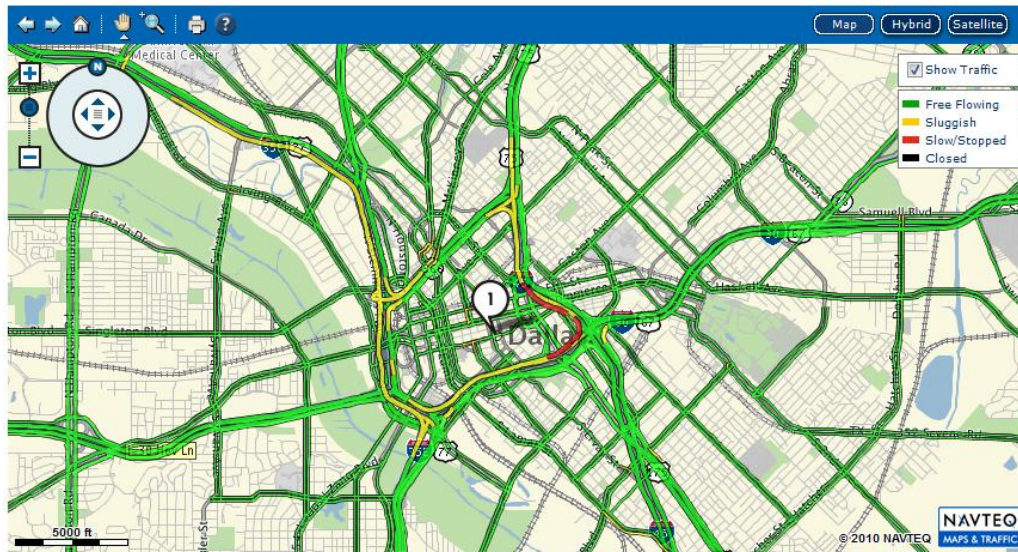
Figure 3.1: NAVTEQ Dallas Network Example

The Center for Transportation Research also holds a network dataset that was being prepared for dynamic traffic assignment analysis. However, the development of that network dataset has not been completed. Also, the CTR dataset was based on an older version of the NCTCOG demand network. Significant efforts have been extended to make the Dallas DTA network functional, but there is currently no funding available for that effort. It was determined that obtaining the newest available NCTCOG dataset would be best for creation of the intersection capacity tool. Despite the availability of several different roadway networks, the original MPO network is the best data for transportation modeling. This is because the MPO has created the dataset with the intention of using it for this purpose. NCTCOG's network has important transportation data, excludes minor network links, and contains the most up to date information. The 2011 dataset was the best available dataset, and also contains predicted volumes for major roadway links, which will be used to assist capacity calculations for the tool.

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Chapter 4 – Current Capacity and Demand Analysis Practice

4.1 Capacity and Demand Basics

Capacity and demand are two fundamental concepts of traffic operations. Demand is the desired utilization rate of a link, and volume is the flow rate at which vehicles actually use the link. Capacity is defined in the highway capacity manual, as "the maximum rate at which vehicles can traverse a point or short segment during a specified time period" (HCM 2010). In other words, capacity provides an understanding of the fraction of demand that can be accommodated at the location of interest. Capacity can be calculated using a variety of different algorithms, dependent on the type of roadway, as described in the HCM 2010. The highway capacity manual divides capacity calculation methods into two major groups: interrupted flow and uninterrupted flow. The uninterrupted flow concepts were used for the freeway link capacity calculator. For the intersection capacity tool the interrupted flow capacity concepts will be used.

Demand is an estimated quantity that is derived through various traffic demand forecasting assignment models. Demand includes the number of vehicles that wish to use a particular link and for most traditional "static" traffic assignment models is not limited by link capacities. Volume is the actual measured quantity that represents the fraction of the demand that actually traversed the location of interest. Volume and demand may be essentially equal if demand is less than capacity. Volume can be measured in the field using a number of vehicle counting techniques. Since volume counts can be resource

expensive, current traffic volume data of all Texas intersections is not readily available. Due to the lack of volume data, the demand data will be used instead as a proxy for the volume data.

The HCM signalized intersection capacity procedure estimates capacity as the product of "maximum flow per hour of green time" and "the fraction of time the signal is green". Ideally the signal cycle time and green time would be available to determine green time to cycle length ratio. Due to the size of the dataset and limitations in acquiring data, signal timing is not available for the NCTCOG network dataset. Instead, the ratio of the critical lane volume for each signal phase to the sum of the critical lane volumes can be used to approximate the green times since these ratios are typically used in most signal timing algorithms to estimate the green fractions. The volumes that are going to be used for this approximation are the demands that are the output of NCTCOG's transportation planning model. However, in this tool an approximation of the sum of critical lane volumes will be used as an input for the interrupted flow capacity calculations.

4.2 NCTCOG's Four Step Model

NCTCOG is in charge of maintaining the Dallas-Fort Worth Regional Travel Demand Model (DFWRTM). This is the metropolitan transportation planning model for predicting travel demand in the region. The Dallas model is a traditional trip-based four-step static model, based on assumptions of steady-state conditions. The inputs for the trip generation, trip distribution, mode choice, and traffic assignment steps come from data

collections mostly from the late 1990s. This data includes important information primarily consisting of travel demand surveys and traffic counts. The network data and the model itself are contained within customized TransCAD software development kits. The network and the outputs from the model are the inputs for the intersection capacity tool. Therefore, it is important to understand the origin of the data being used by the tool to understand the limitations of the data.

The trip generation and trip distribution step are carried out using demographic employment and travel time data from census and travel surveys. Next the mode choice step combines information about the transit and highway networks and mode preferences to determine the proportion of trips that will occur by private vehicle or transit. With this information on the number trips, origins and destinations in each traffic analysis zone, and the mode split of these trips, a static traffic assignment is performed to estimate the vehicle demand on each network link (NCTCOG 2009). An image of the traffic analysis zones, or traffic survey zones as the DFWRTD refers to them, can be seen in figure 4.1. It is important to understand how the network was set up by the MPO to understand the area of study.
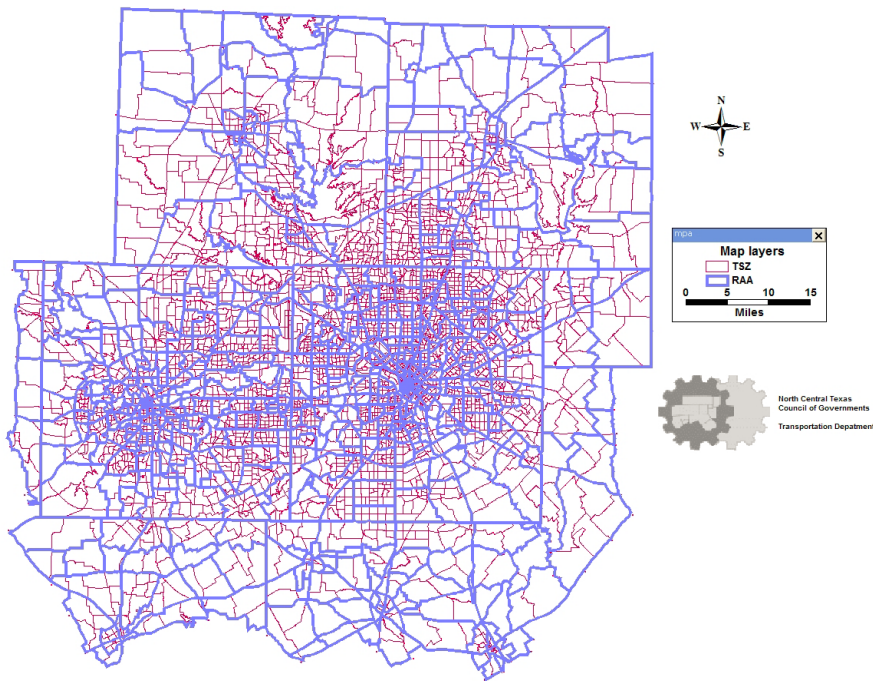
Figure 4.1 Traffic Survey Zones for the DFWRTM

The roadway network represents links of the entire roadway system that were important for the inclusions in the travel demand model. Dallas-Fort Worth employs some programs within TransCAD for taking this skeleton network and turning it into a TransCAD network. The first of which is called "Create Roadway," which takes a geographic line file, or E00 file, and turns it into a TransCAD road network. Attribute data fields for each roadway link are checked to find input data errors. The next program used in the Dallas-Fort Worth model is called "Copy Link Approaches". Essentially, it creates centroid connectors for the origins and destinations of the network. The final program is called "Roadway Preparation," which finalizes the network dataset by creating more data fields that will be necessary to run the model.

One of the important calculated fields is capacity. There are quite a few assumptions that are made in estimating capacity. These assumptions prevent the procedure from including many of the factors that the HCM method prominently uses. The following pseudo-code describes the procedure.

$$[Hourly\ Capacity\ Dir]_{l,t} = \begin{cases} null & ,\ f = 9 \\ 1000000 & ,\ f = 0 \\ [cap]_{l,t} * [Num\ Lanes\ Dir]_{l,t}, & Otherwise \end{cases}$$

$$[cap]_{l,t} = \begin{cases} CAPACITY & ,\ CAPACITY > 0 \\ dividedCap[AreaType][f] & ,\ DIVID = 1 \\ undividedCap[AreaType][f] & ,\ DIVID = 2 \end{cases}$$

where

l = a link.

t = a time period value of AM, PM, OP.

f = the functional class of the link. For DIVID=1, the functional class must be between 1 and 8. For DIVID=2, the functional class must be between 1 and 7.

$CAPACITY$ = Saturation capacity of the link.

$DIVID$ = Traffic Directional Division Code of the link.

$AreaType$ = The area type of the link.

$[Num\ Lanes\ Dir]_{l,t}$ = Number of Lanes for Time Period t and Direction Dir field for link l.

Figure 4.2 Capacity Calculation Procedure for DFWRTM

As shown in figure 4.2 the calculation makes an assumption of the base capacity based on the area type of the link's location and the functional class of the link, seen in table 4.1 and 4.2 (NCTCOG). The capacity calculation does not take into consideration

whether a traffic control device (signal or stop sign) operates on a particular link. This base capacity is then multiplied by the number of lanes to determine the link's capacity.

Table 4.1: DFWRTM Divided Link Base Capacity Assumptions

Area Type	Functional Class						
	Freeway	Principal Arterial	Minor Arterial	Collector	Freeway Ramp	Frontage Road	HOV
CBD	2050	725	725	475	1250	725	2050
Outer Business District	2125	775	775	500	1375	775	2125
Urban Residential	2150	850	825	525	1425	850	2150
Suburban Residential	2225	925	900	575	1600	900	2225
Rural	2300	1025	975	600	1725	975	2300

Table 4.2: DFWRTM Undivided Link Base Capacity Assumptions

Area Type	Functional Class						
	Freeway	Principal Arterial	Minor Arterial	Collector	Freeway Ramp	Frontage Road	HOV
CBD	N/A	650	650	425	1250	650	N/A
Outer Business District	N/A	725	725	450	1375	725	N/A
Urban Residential	N/A	775	750	475	1425	750	N/A
Suburban Residential	N/A	875	825	525	1600	825	N/A
Rural	N/A	925	875	550	1725	875	N/A

The traffic assignment step is the final part of the four-step modeling process. The DFWRTM uses three different time periods to evaluate the assignment: AM peak, PM peak, and off-peak. Signalized intersection delay is only accounted for in the free flow time by adding assumed delays from table 4.3. In table 4.4, the link performance function

calculation and associated parameters can be seen. Assumptions are made based on the area type and functional class in the same manner as the base capacities.

Table 4.3: Traffic Control Delay in Seconds by Functional Class and Area Type

Area Type (AT)	Functional Class (FC)							
	1	2	3	4	5	6	7	8
1	0	9	9	12	12	9	12	0
2	0	8	9	11	11	8	11	0
3	0	6	7	9	9	6	9	0
4	0	5	6	8	8	5	8	0
5	0	4	5	6	6	4	6	0

Table 4.4: DFWRTM Link Performance Function Calculation

$$TravelTime = FreeFlowTime + Min\{A.e^{B.(vol/cap)}, C\} * Length$$

Parameter	Freeway	Arterial
A	0.015	0.05
B	6.0	3.90
C	4.0	5.0

The travel time function includes capacity in the calculation, and since the capacity does not account for traffic control the travel time may be less accurate. The model also uses a generalized cost to combine out-of-pocket user costs and travel time costs. Running the traffic assignment step in TransCAD utilizes the concept of user equilibrium for generalized cost. TransCAD's built in traffic assignment model is then used to produce the output of link volumes and travel times for the three study periods.

4.3 Improvements on the Capacity Calculations

The major improvements that can be made to the demand and capacity calculations is considering interrupted flow characteristics. This could provide improvements to the current method, which makes broad assumptions about the difference between functional classes. By using concepts behind the GIS database the standard method for capacity calculation can be applied from the HCM 2010. In addition to the HCM capacity, green time split calculations will be used to allocate time to the different legs of the intersections. The basic function of the intersection capacity tool is to 1) calculate saturation flow per leg of the intersection, 2) calculate green time to cycle length ratio based on the NCTCOG demand, and 3) calculate the capacity based on the G/C ratio and saturation flows. These three major calculations are explained in detail below.

Equation 4-1 contains the calculation used to determine the saturation flow rate of each incoming leg of the intersection under prevailing conditions. This is done by assuming a value for the base saturation flow rate per lane, multiplying by the number of lanes and multiplying by correction factors accounting for the surrounding environment and traffic conditions. The most important factors are the right turn and left turn adjustments, however, other factors include lane width, heavy vehicles, grade, area type, parking, bus stops, pedestrian, and bicycle impacts. Due to the level of detail required for application of all the factors, several assumptions were made to account for the lack of data.

Saturation Flow Rate

$$s = s_o N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{RT} f_{LT} f_{Lpb} f_{Rpb} \qquad \text{Equation 4-1}$$

s = prevailing saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (veh/h)

s_o = base saturation flow rate per lane (pc/h/ln)

N = number of lanes in lane group

f_w = adjustment factor for lane width

f_{HV} = adjustment factor for heavy vehicles in traffic stream

f_g = adjustment factor for approach grade

f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group

f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area

f_a = adjustment factor for area type

f_{LU} = adjustment factor for lane utilization

f_{RT} = adjustment factor for right turns in lane group

f_{LT} = adjustment factor for left turns in lane group

f_{Lpb} = pedestrian/bicycle adjustment factor for left-turn movements

f_{Rpb} = pedestrian/bicycle adjustment factor for right-turn movements

Assumptions:

$s_o = 1900$

N = determined by the NCTCOG 2011 demand dataset

$f_{LT} = 0.95$

$f_{RT} = 0.95$

$f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{Lpb} f_{Rpb} = 0.95$

      Beyond the saturation flow process the most important calculation for determining interrupted flow capacity is the proportion of green time to the cycle length

that the incoming leg of the intersection sees. While the DFWRTM assumes that all roadways with the same classification have the same base capacity, it does not account for the large variable affect that signalized intersections have on the capacity of the roadway. The most accurate way to calculate the G over C ratio would be to use actual timing plans if they could be obtained. However, another option is to determine a cycle length that seems appropriate for an intersection of interest and divide the green time based on the ratio of incoming volumes.

G over C Ratio

$$\frac{g_i}{C} = \frac{(C - \sum Y_i)}{C} * \frac{V_i}{\sum V_i} \qquad \text{Equation 4-2}$$

g_i = green time for leg i (sec)
C = cycle length (sec)
Y_i = clearance interval for phase i (sec)
V_i = volume on leg i (veh/h)
Assumptions:

V_i = unknown, the expected NCTCOG direction AM or PM demand is used instead
V_i and Y_i are summed over all legs approaching the intersection
Y_i = 4 seconds
C = 150 seconds for diamond, otherwise 100 seconds, but can be changed manually

As stated before, since actual volumes are not available for the calculation in equation 4-2 an approximation of the volumes was used. This approximation was from the NCTCOG 2011 demand data set, which is the output of their static traffic assignment model. Now that the saturation flow rate under prevailing conditions and the green time

to cycle length ratio have been determined, the capacity calculation is simply the multiplication of these values.

Capacity

$$c_i = s_i * \frac{g_i}{C} \qquad \text{Equation 4-3}$$

c_i = capacity of leg i (veh/h)

s_i = saturation flow of leg i (veh/h)

g_i /C = effective green ratio for leg i

Equation 4-3 is the final step in the capacity calculation, and from here the volume to capacity ratio can be calculated. The intersection capacity calculation method assumes that each approach to the intersection receives its own exclusive green signal phase. Since most TxDOT controlled intersections are diamond interchanges, this approximation is satisfactory for the green time splits. Caution should be used for the application of this method to other more complex signal timing plans. This algorithm will be explained in further detail in the next chapter as it describes how these calculations can be performed in ArcGIS with the geographic datasets.

Chapter 5 – Intersection Capacity Analysis Tool

5.1 Inputs for the Tool

The primary inputs for the tool are two datasets: the NCTCOG demand output from their in-house four step model and the TxDOT traffic signal locations that were geo-coded by interns at the University of Texas at Austin. The NCTCOG demand shapefile is made up of polylines representing the roadway network for the Dallas-Fort Worth region. The traffic signals are represented as points and multipoints in a geodatabase file, for diamond intersections that have more than one signal head. Due to the large size of the signal and roadway database it is important that the network shapefile be converted to a geodatabase file. This will allow for faster rendering, selecting, and geoprocessing. Two basemaps are also included in the tool's map file. These are the Bing Aerial Map and Bing Hybrid Map, the first of which is just aerial photography and the second includes street names and some directional information. The aerial map is set as the default display so that the data frame is less cluttered. However, the hybrid map can be used to help verify road direction or names if needed.

The final adjustments to the dataset before implementing in the tool are allocating a coordinate system and modifying the data fields. Regardless of what coordinate system the initial data files are in, they need to be projected to the same coordinate system so that they display properly and measurements are accurately made. For this tool the network and signal files were projected to State Plane Texas North Central US Feet. Also, the data

frame that contains these two data layers must also be set to the same projected coordinate system.

The signal dataset is utilized to extract the location of the signal relative to the incoming links. The symbology of the signals layer was changed to represent a traffic signal with red, yellow, and green lights displayed. When the signal is selected this can be verified by the colors of the signal all turning to green. Even though there are a number of fields that were included in the original signals geodatabase file, there are only a few that are of interest for this tool. In the layer properties manager, under fields, only Signal ID, City, County, Street A, Street B, Point x, and Point y should be set to visible. The Signal ID is the reference number for the traffic signal as coded by the interns. The city and county are the respective jurisdictions of the signal. Street a and street b are the primary streets of the intersection. Geographic information is stored in the point x and point y fields which were generated by creating fields and calculating the x and y coordinates of the points or multipoints. All of the data in the signal layer is only for verification by the user if desired. Additional signals may be added to the layer using the create feature tool within the editor. The only fields that will be accessed by the tool are the point x and point y locations.

The network dataset contains much more data because the output of the traffic assignment model for NCTCOG is used for several different planning purposes. Topology of the network has been recorded by geo-coding the roadways, the direction of the links in the network is contained in a from-to system that correlates to the AB and BA

direction for the number of lanes and volumes. In order to get a visual understanding of this referencing, the symbology for the network layer can be set to an arrow that displays the A to B direction. For clarity labels were also added to this layer to display the road name. When the links are selected a border will be added to the line for confirmation. The following fields are of particular interest: Street, PKLNA, PKLNB, AMHRVOL_AB, AMHRVOL_BA, AMHRVOL_AB, AMHRVOL_AB. This will provide the link's street name, the number of lanes in the ab and ba direction, and the am and pm peak hourly volume in both directions. Likewise with the signal attribute table the location fields will need to be added to the network. However, rather than just using the x and y coordinates of the signal, the location fields for the network data set need to include and x, y coordinate for both the start and end of the link. This can be done in the same way as creating the geometry field for the signals.

Unlike the signal layer the network layer will also need other fields that will be used for the calculations. These fields include a number of lanes, volume, lane volume, saturation flow rate, green time to cycle length ratio, capacity, and volume to capacity ratio.. An example screen shot of the NCTCOG demand attribute table can be seen in Table 5.1. The attribute table should be displayed as a reference to examine the calculations performed by the tool.

Table 5.1: Sample NCTCOG Demand Attribute Table

STREET	PKLNA	PKLNB	AMHRVOL_A	AMHRVOL	PMHRVOL_A	PMHRVOL_B	NUM_LANE	VOLUME	LANE_VOL	SAT_FLOW	G_OVER_C	CAPACITY	V_OVER_C
ST PAUL ST	3	0	639.07	0	834.88	0	3	834.88	278.293333	4887.0375	0.257154	1256.72363	0.664331
WR FWY FRTG EB	3	0	942.62	0	886.08	0	2	886.08	443.04	3258.025	0.409387	1333.79368	0.664331
WR FWY FRTG WB	3	0	296.38	0	822.88	0	3	822.88	274.293333	4887.0375	0.253458	1238.66033	0.664331

Rather than changing any of the original data fields, these new fields can be modified without losing any of the data from the original demand shapefile. When a selection is made the locations can be used to populate the correct number of lanes and volumes. Then, the tool will calculate the remaining fields allowing for adjustments of the number of lanes or volumes that were found in the dataset.

5.2 Assumptions

There are three major assumptions that are included in the functioning tool. The first assumption is a simplification of several of the prevailing condition factors used to estimate the saturation flow rate. The next major assumption is that the demand that is predicted by the static traffic assignment model can be used as an approximation for the link volume. Lastly, rather than determining the green time to cycle length ratio from signal timing, the g over c ratio is assumed to be proportional to the volume of that leg over the sum of all leg volumes. Since the demand data set does not contain information about lane groups to determine a critical lane volume, the link volume divided by the number of lanes will be used. These assumptions will have a significant impact on the

calculations perfomed by this tool; however, due to the availability of data this accuracy is the greatest that can be achieved.

5.3 Algorithm for Calculations

The basic algorithm for intersection capacity calculations can be seen in Figure 5.1. This traffic control planning tool allows the user to pan to an intersection of interest, and select the appropriate features required for the input. Then the tool can be selected which will offer a dialogue box of different parameters that can be adjusted by the user. These parameters include cycle length, time of day, number of lanes, and volumes. The number of lanes or volumes can be adjusted for each intersection leg. If the number of lanes or volumes is not manually modified, then the location of the features will be used to populate the number of lanes and volumes with the correct values from the demand dataset. Now the lane volume will be calculated by dividing the number of lanes by the volume. These lane volumes will be used for the sum of critical lane volumes in order to calculate the green time to cycle length ratios. Using the approximations for the prevailing condition factors and the number of lanes the saturation flow rate is calculated. Finally, the capacity is calculated for each leg of the intersection, and the corresponding volume to capacity ratio is determined.
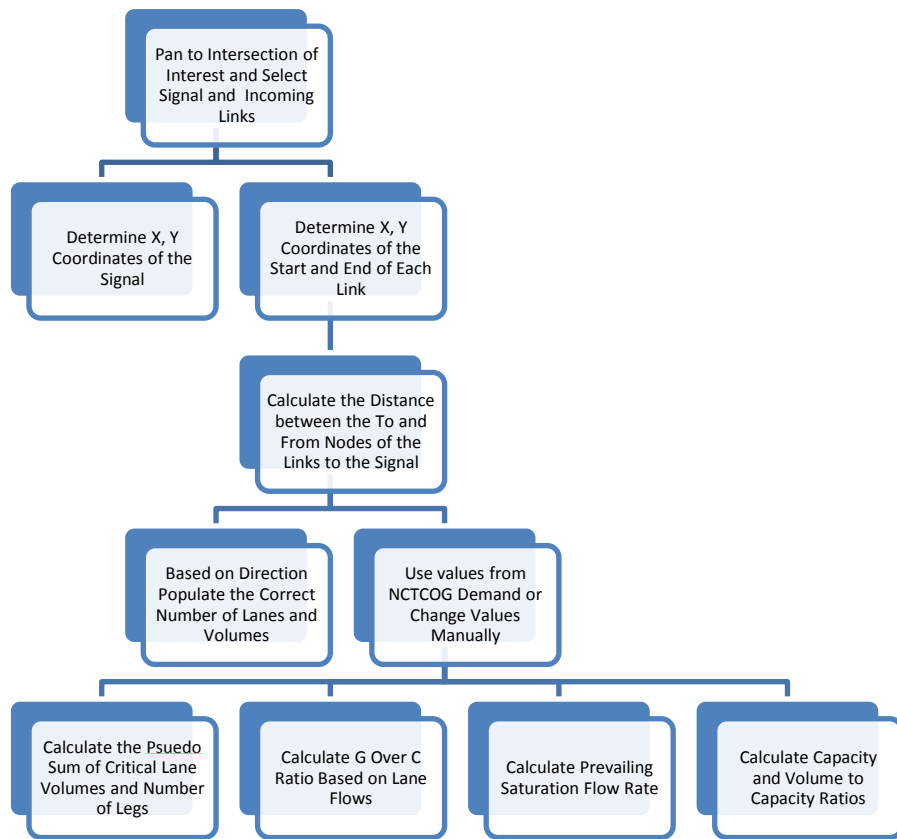
Figure 5.1: Flow Chart of the Methodology for Calculating Intersection Capacity

A powerful tool that can help the user find the intersection of interest for a given study is the built-in geo-coding tool in ArcGIS. Geo-coding simply means to assign geographic information to a feature. In this case we want to use the geo-coding tool to find the intersection much like could be done with an online mapping service. This tool is available through the geo-coding toolbar, which can be viewed by right clicking on the menu bar and selecting the geocoding tools. This should bring up a tool bar that looks like the one in figure 5.2.
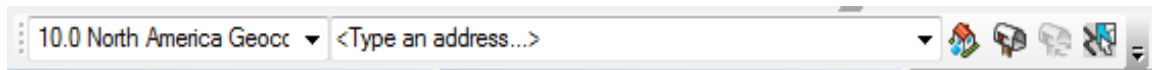
Figure 5.2: Geo-coding Toolbar

The input for the tool should be in the form "Street A and Street B City, State." Once the intersection name is entered if the tool worked correctly it should display that the intersection was found. Then, by right clicking where the address was typed, the user can pan to the selected location. This will save the user from potentially wasting time searching for the intersection.

Once the correct intersection has been displayed in the map viewing area, the next step is to select the traffic signal and the corresponding legs entering the intersection. This should be done by starting with the traffic signal because selecting it often selects multiple roadways coming into it. Now the shift key should be held to continue adding and removing appropriate links from the selection. Deselect roadways that are not incoming legs of the intersection, this includes one way streets not entering the intersection and streets between signals for diamond intersections. This can be determined from knowledge of the area, the Bing Hybrid Aerial Map, and/or the attribute table. Now that the signal is selected and all links with incoming volumes are selected the tool is ready to be run.

The intersection capacity calculator tool has been designed in ArcGIS model builder. Models are called from ArcToolbox and all of the associated models can be added to the map by adding the Capacity Calculator toolbox to ArcToolbox by right

clicking and selecting add toolbox. There are six models that need to be in the map in order for the calculations to be performed correctly. These models are labeled Direction, Change Number of Lanes, Change Volumes, Sum of Volumes, G Over C Ratio, and Intersection Capacity Calculator. The intersection capacity calculator is the main model that calls each of the other models to perform the entire calculation. When this model is opened the dialogue box in Figure 5.3 appears.
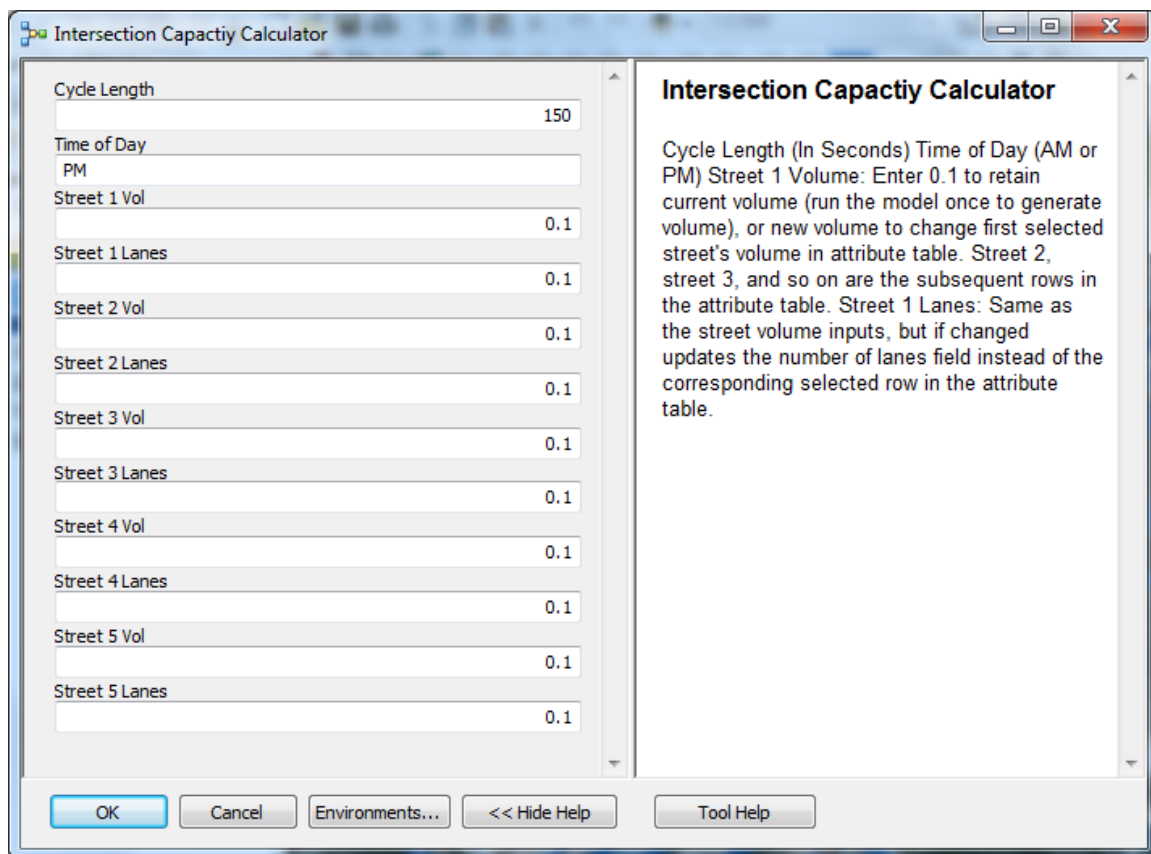
Figure 5.3 Intersection Capacity Calculation Dialogue Box

This dialogue box allows the user to change parameters as desired. The use of these parameters will be explained in further detail as the structure of the model is

explained. If the model is run with the default parameters it will perform the capacity calculations with the data from the demand data set. The results of the calculation can be viewed in the NCTCOG 2011 Demand attribute table. These results can be examined by the user to determine if input value changes are desired for the calculation. Then, the calculation can be performed again by opening the model and running it again with adjusted values.

These parameters represent variables that have been declared and are integrated into the model. The main model provides organization for how the other models are combined using these input variables and selected features to determine all data that is required for the calculations. An overview of the entire model can be seen in figure 5.4.
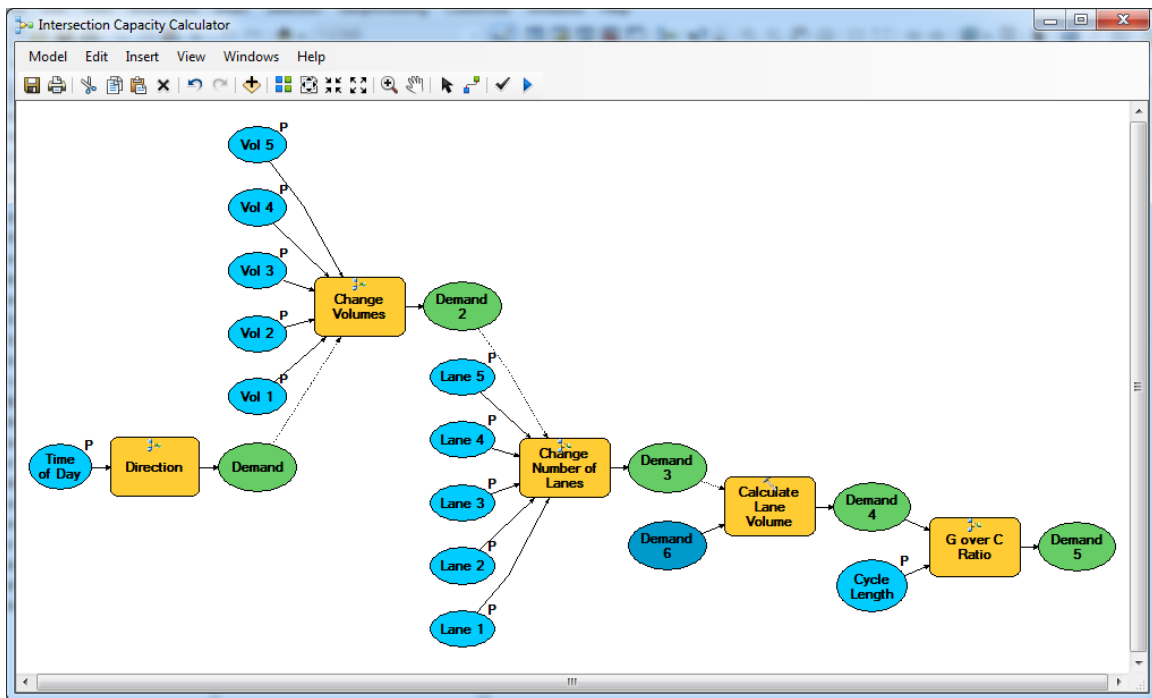
Figure 5.4: Intersection Capacity Calculator Main Model

In figure 5.4 the light blue ovals represent the model variables, or parameters. They are marked with a "P" in the upper right corner, and can be changed by using the dialogue box in figure 5.3. Dark blue ovals are input datasets, and the green ovals are the outputs of processes on those datasets. These changes could be an added field, new selections of features, or changes in field values. Processes are the yellow boxes and can be an individual tool such as calculate field, or it could be a submodel comprised of several processes.

The first submodel that is called in the main model is the direction analysis of the selected features. The directional information associated with the network is important because all of the links are coded as bidirectional. This means that each link has two directional volumes and numbers of lanes. In this dataset the directions have been coded as AB and BA. An AB direction means that the direction follows the from-to or start-end node of the links, and BA is the reverse. The start and end node of each link is determined by the way that they were geo-coded, which determines the topological direction of the link. In ArcGIS, the topology can be visualized by setting the symbology of the links to an arrow. The arrow will point in the topological direction, or the AB direction. In addition to visualizing the direction, geographic information can also be determined from the links. Four fields were created and were populated using the calculate geometry option within the ArcGIS attribute table. Calculating the geometry of a polyline feature class gives the option to determine the x and y coordinates of the starting, middle, and end point of the line. For each link in the feature class the start and

end coordinates have been calculated. This will allow the model to determine the proximity of the start node and end node to the signal. If the end node is closer to the signal, then the AB direction will be used and vice versa.

To perform this calculation the first submodel, Direction, must be called in the main model. The only modifiable parameter of this submodel is the time of day. The time of day input can be either AM or PM, and this will determine the proper volume to use. As well as the adjustable time parameter, the signal database and the network are both included in the model as fixed parameters. The key to this submodel are two model only functions that cannot be used as normal tools in the ArcGIS interface. Instead they are used like in-line variables to gather data within the structure of the model. The first of these functions is a model iterator. Model iterators work like iterators in any coding language such as a for loop or while loop. However, ArcGIS has iterators that are built for the geodatabases including iterating through selected features, all feature classes, or rows in a table. The iterator in this submodel will perform all processes in the submodel for each of the selected feature classes. Since the iterator works through successive selected features, the calculations will be carried out in the attribute table row by row.
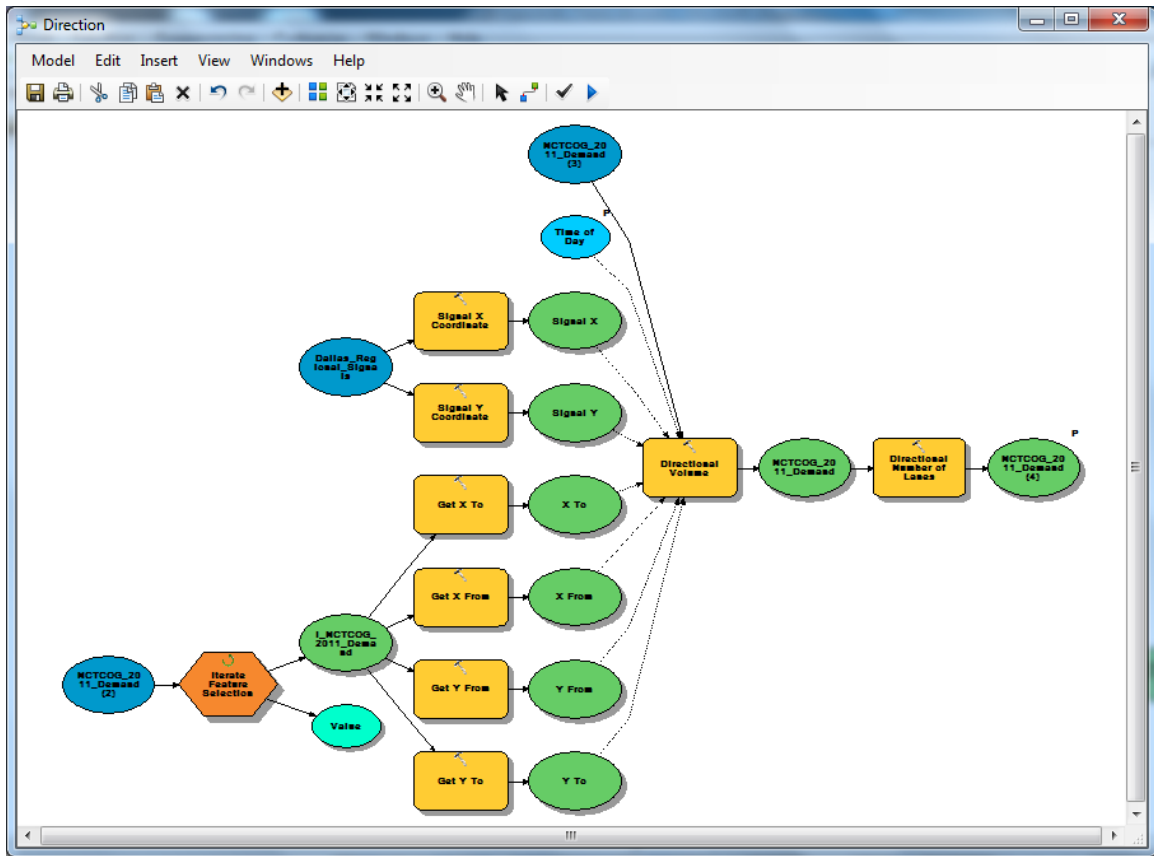
Figure 5.5: Direction Submodel Calculates the Volume and Number of Lanes

For the first iteration step it will use the first selected feature in the link feature class. The next model tool that is used is called the Get Field Value, and will be used to retrieve the location data from the selected signal and the first selected link. The get field value tool works by inputting the dataset and a field and it will bring the corresponding value into the model to use as a variable. The x, y coordinates for the signal, start of the link, and end of the link are submodel variables called Signal X, Signal Y, X From, Y From, Y To, and Y To. Next the distance is calculated and the proper values for volume

and the number of lanes are determined. This can be accomplished through the use of the Calculate Field tool and python scripts.

Figure 5.6 is the dialogue box for the Calculate Field tool that calculates the volume for the correct direction. The tool has been renamed directional volume. The input table and field name are the NCTCOG 2011 Demand and the created field VOLUME. ArcGIS has the capability of making calculations via an expression using the fields of the dataset. In addition, the expression can call a function that can be entered into code block. The code block is made for both python and visual basic; however, due to discontinuation of visual basic in ArcGIS, python is preferred. The volume function calls the code block and sends it the corresponding variable information including the x, y data and time of day as in-line variables.
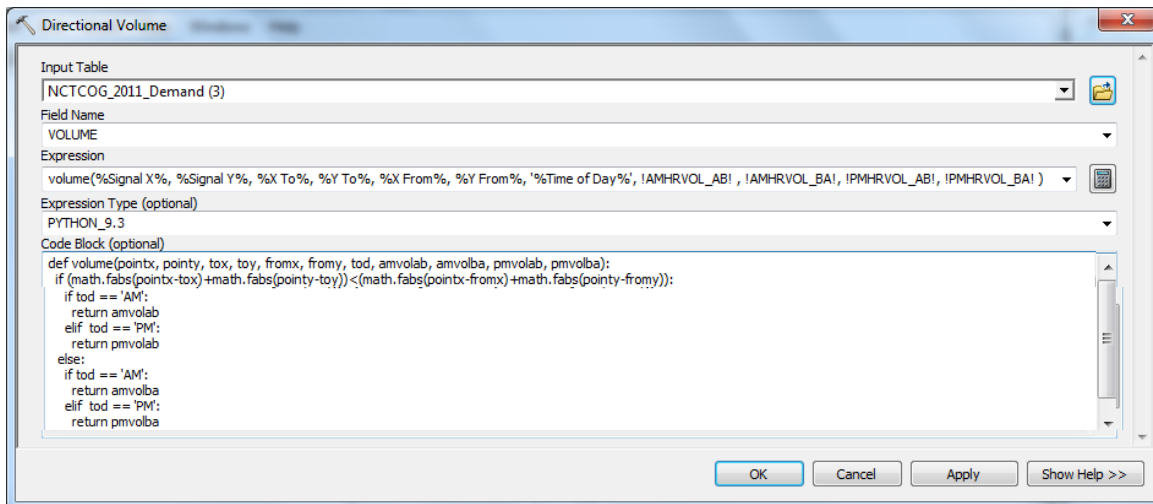
Figure 5.6: Calculate Field Based on Directional Volume

In-line variables are model variables that are used in expressions for processes. They are called by surrounding the name of the variable used in the model with

percentages (for example %Time of Day%). When the in-line variable is a text string, single quotation marks must be used to indicate that it is text that should be passed to the function. In addition to the in-line variables being passed to the function, the AB and BA volumes for both AM and PM are retrieved.

Now that all data required to make the calculation is available to the code block, the if-then statements are used to populate the fields with the correct data. Nested if-then statements are used so the AM and PM times as well as the AB and BA directions can be differentiated. The first if statement asks if a pseudo distance between the from node and the signal is greater than the distance between the to node and the signal. If this is true then the AB volume will be returned. The nested if loop then determines if the AB volume should be for the AM or PM based on the user input. Else statements are used if the opposite is true. In order to determine the number of lanes the same logic is used except it does not include the time of day because link lane numbers are only differentiated by peak and off-peak. Now that the whole process is complete for the first selected feature, the iterator runs the entire model again for each selected link. Each link gets its own volume and lane number based on its individual analysis.

The next major step in the main model allows the user to change volumes or number of lanes to perform multiple calculations on the same intersection. This should come after the directional placement of volume and number of lanes so that they can be overwritten by the new user input values. The parameters for the submodel to change volumes are the numbers of Street Volumes 1, 2, 3, 4, and 5. These replace the

corresponding volume fields of the street in the corresponding number row in the attribute table. The user should open the attribute table as changes are being made to the volumes. The submodel shown in figure 5.7 uses the same processes to change the volumes or number of lanes. Therefore, the logic will only be described for the volume adjustment.
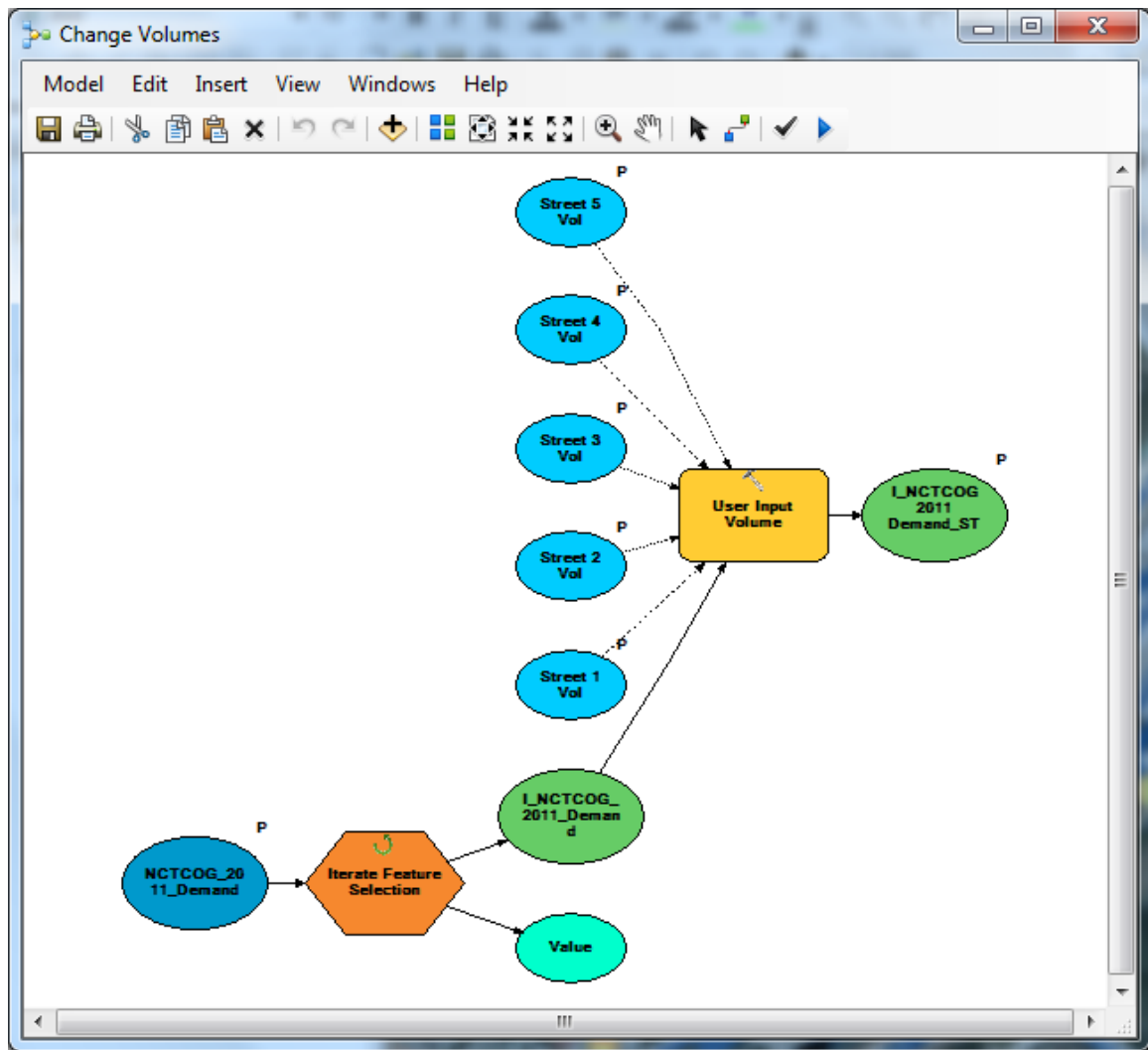
Figure 5.7: User Input Volume Submodel

Similar to the Direction submodel, the Change Volume submodel utilizes the Iterate Feature Selection tool. The input is the demand dataset, which means that the model will perform a feature by feature calculation. Based on the user input another python code block determines the correct values to modify the volume field. In figure 5.8, the Calculate Field Tool has been renamed User Input Volume. Another expression was used this time requiring the inputs of the 5 street volumes, the iteration number, and the current volume. The current volume should be the directional volume since the model should be run once before adjustments are made. The first iteration has a default n value of zero, so in order to match the corresponding rows in the data table one must be added to the iteration value. For many streets the user may want to retain the directional volume, and in order to do so needs to enter 0.1 as the street volume parameter. If statements are used in the codeblock to determine the iteration number, and if the input volume was 0.1 returns the original volume. If the volume is anything other than 0.1, then it returns the user input value to the volume field.
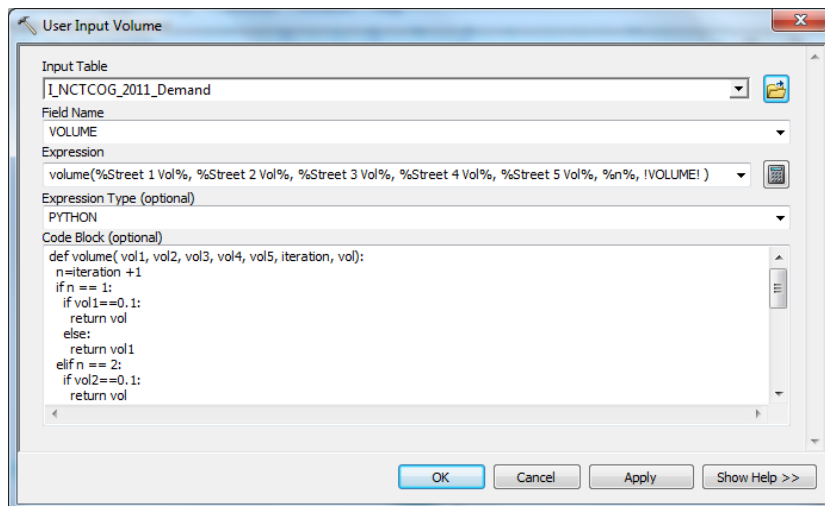
Figure 5.8: User Input Volume Calculate Field Code Block

These if statements can be seen in the code block in figure 5.8 for the first iteration, and the subsequent if statements are exactly the same with the correct iteration number and street volume. Directly after the volume adjustment in the main model, the number of lanes adjustment is performed in the same way. By changing the number of lanes and volumes through the submodel routine, the user is not forced to enter the attribute table in the editor to change the fields of interest. By changing the fields before the capacity calculations, several scenarios can be evaluated and effects of the change in number of lanes or the volume can be examined. The next step in the main model is to calculate the lane volumes for each of the incoming links.

After the previous steps in the main model, the desired volumes and number of lanes have been associated with the selected links. The next step in the process will be to evaluate the sum of critical lane volumes. However, due to the nature of the NCTCOG demand dataset, knowledge of the turning movements is not available. This means that right turn lanes and left turn lanes cannot be differentiated from the through lanes. In addition, the static model output does not explain any route information, it only calculates link volumes. Therefore, determining the critical lanes in each lane group is not possible. In order to complete the calculations for the green time to cycle length ratio an approximation must be used for the critical lane volumes. The best approximation that can be made from the dataset is that the critical lane volumes are equal to the link volume divided by the number of lanes. This step in the main model is just a calculation of the Lane Volume field for all records using the ratio of volume to the number of lanes. While

this is the best approximation available, it should be noted that this will have an impact on the accuracy of the capacity calculations. Perhaps if a more advanced dynamic traffic assignment model were used by Dallas, turning movements could be predicted, and critical lane volumes could be more accurately estimated.

The final stage of the model is the actual capacity calculations. These are held within the sub model G Over C, and within this submodel the cycle length value is input. In the previous version of the tool the cycle length was fixed at 100 seconds for normal intersections, and 150 seconds for diamond intersections. In the new model builder version the user can input any value as the cycle length if one is known for a particular intersection. Now all of the parameters of the tool have been used. However, before the cycle length is used the Sum of Volumes sub model must be called from the G Over C sub model.

The Sum of Volumes model is important because it calculates the approximation that will be used for the sum of critical lane volumes and the number of legs of the intersection. The models organization can be seen in figure 5.9. In order to calculate the sum of critical lane volumes the iterate field values model tool is used. This iterator works by iterating through all the selected features values of the chosen field.
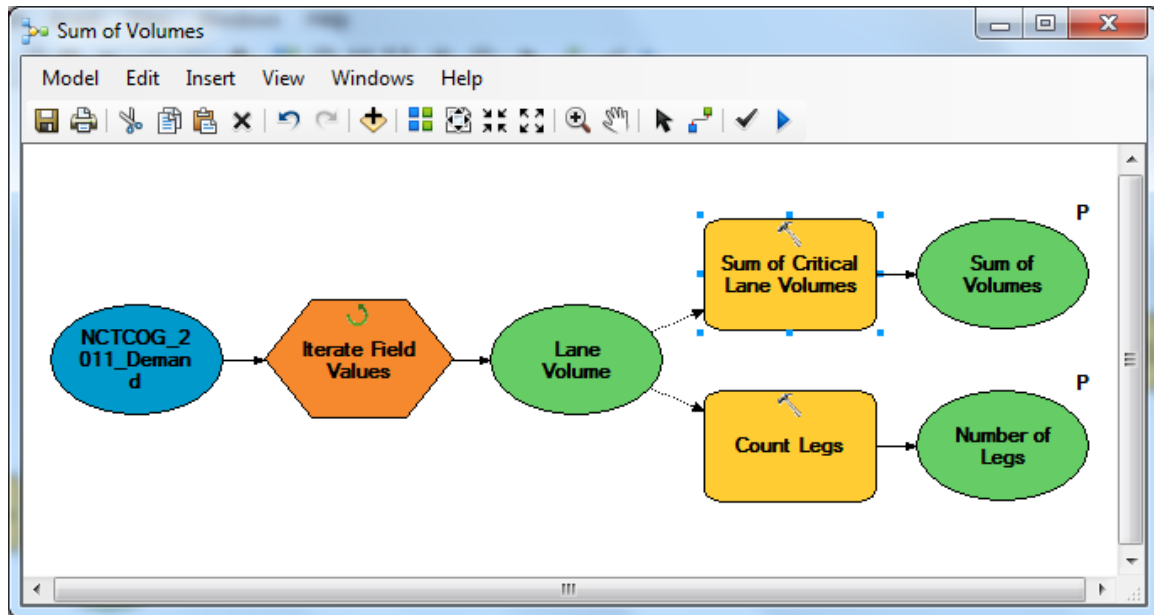
Figure 5.9: Sum of Volumes Sub Model

The input dataset is the demand and the field of interest is the newly calculated lane volume field. The simpler calculation is for the number of legs of the intersection, and it uses the calculate value model only tool. Like the get field value in the Direction sub model, the calculate value only works within the model builder. Since the iteration number %n% used in the models starts at zero, at the end of this sub model run the iteration number will be one less than the number of legs. The true number of legs can be calculated using the expression %n% plus one.

In order to calculate the sum of critical lane volumes, the values of the lane volume field need to be summed. Again the calculate value tool will be used, but this time with a bit more logic behind it. In figure 5.10, the code for calculating the sum of lane volumes can be seen. The function initializes the variable sum of volumes, and requires the lane

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volume field data and the iteration number to be evaluated. For the first iteration, the sum

of volumes will equal the first lane volume. Then, as the iterations continue the lane

volumes will continue to be added to the sum of volumes total. Finally, the sum of lane

volumes and the number of legs of the intersection are made model parameters so that

they can be sent to the G Over C model.
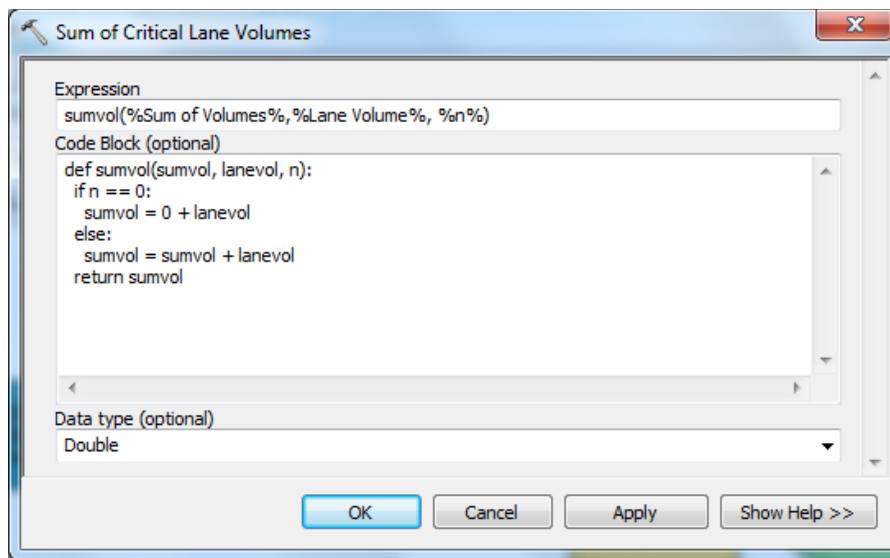
Figure 5.10: Sum of Lane Volumes Calculate Value Dialogue Box

With the input of the cycle length, sum of lane volumes, and number of legs the G

Over C Model has all of its required inputs.
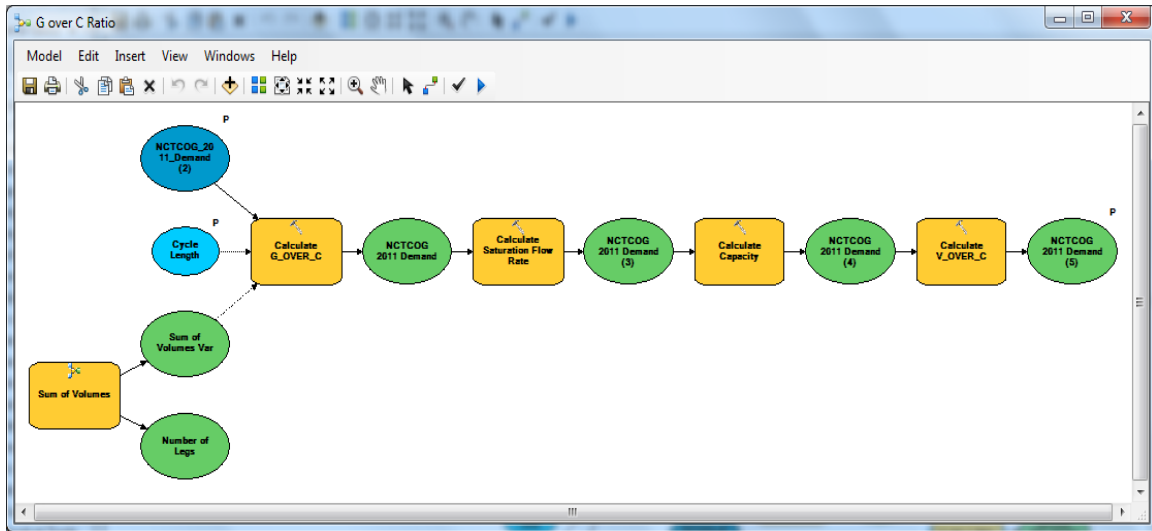
Figure 5.11 G Over C Ratio Sub Model

Each of the calculations in this model are relatively straightforward and are performed sequentially using the calculate field tool. As shown in figure 5.11, the first field that will be calculated is the g over c ratio. The g over c ratio is a quantity representing the effective green time allocated to each leg of the intersection as a proportion of the cycle length. As usual the dataset used for the g over c calculation is the network demand. The dialogue box for this calculation mimics equation 4-2, and can be seen in figure 5.12.
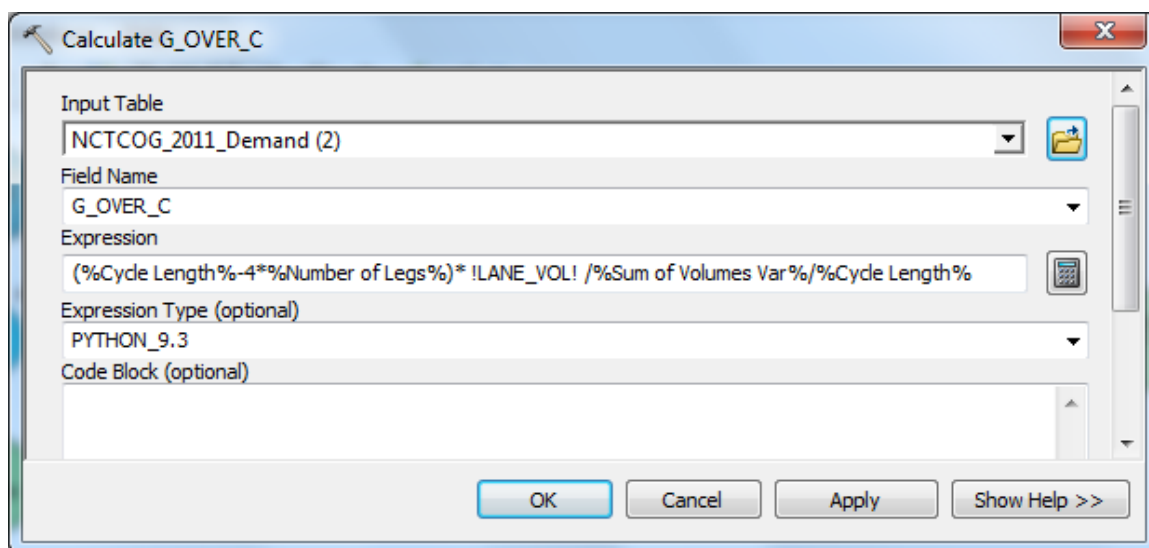
Figure 5.12: Calculate Field G Over C Dialogue Box

The next field that is required for the capacity calculation is the saturation flow rate. Since many assumptions have been made about the factors that affect the saturation flow rate the calculation is only based on the number of lanes for the given link. And like the dialogue box in 5.12 mimics equation 4-2, the saturation flow rate expression in figure 5.13 represents equation 4-1. The calculate field for the capacity multiplies the saturation flow rate by the g over c ratio. Finally, the calculate field for the volume to capacity ratio divides the total link volume by the calculated capacity.
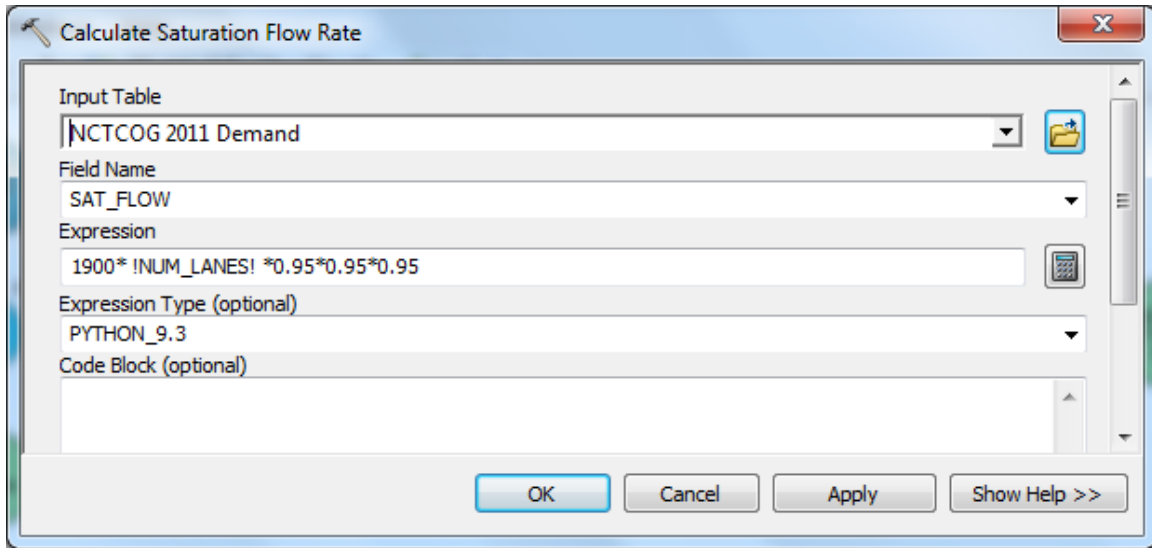
Figure 5.13: Calculate Field Saturation Flow Rate Dialogue Box

5.4 Output for the Tool

The output for the tool is the calculated values populated in the attribute field for the demand data set. Since this tool is meant to be iterative, in that a user could modify the inputs for a number of scenarios, then the desired information can be exported to the layout view by means of a report file. In order to use the report file that has been created for this purpose the user should go to View > Reports > Run Report, and then select the capacity report file. Once this has been run the user can select the button Add report to ArcMap Layout. An example of this report can be seen in the Appendix.

Chapter 6 – Improvements to the Traffic Control Planning Tool

6.1 Data to Improve the Accuracy of the Calculations

The availability of data has a major impact in the accuracy of the calculations of this tool. First, there is the list of adjustment factors contained within the saturation flow rate equation.

f_w = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles in traffic stream
f_g = adjustment factor for approach grade
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area
f_a = adjustment factor for area type
f_{LU} = adjustment factor for lane utilization
f_{RT} = adjustment factor for right turns in lane group
f_{LT} = adjustment factor for left turns in lane group
f_{Lpb} = pedestrian/bicycle adjustment factor for left-turn movements
f_{Rpb} = pedestrian/bicycle adjustment factor for right-turn movements

Each of these factors represents a data item that is not readily available for use in the calculations. Since the data that is being used to calculate the capacities contain no information about turning movements, an assumption was made for a reasonable value of turning adjustment factors. In addition, the typical improvements that would be made to the calculation by deriving the exact product of the remaining adjustment factors are outweighed by the cost of obtaining the data.

Currently, the tool framework allows the use of a static assignment model's output of link flows to determine the capacity of movements approaching the signal. The impact of a change in the number of lanes or change in volume can be captured through

the effects on the capacity. The tool does this by providing new green times based on the altered geometry and traffic volumes. By investigating the impact on green times the user can determine how much impact the traffic control plan will have on the different legs of the intersection. Also, since the model divides green time in order to provide equal volume to capacity ratios, the volume to capacity ratio can give a measure of the total impact to the signal.

Besides the lack of descriptive data the other major tool limitation is that it uses static traffic assignment data as a surrogate for traffic volumes within an interface that cannot rerun the traffic assignment to predict the changes in traffic demand due to a work zone capacity reduction. Therefore, any calculations provided by the tool cannot be used to improve the input data. The tool requires another environment in order to improve the original calculations. In the static traffic assignment problem it is not uncommon for demand values greater than capacity to be generated. Algorithms have been examined that correct for these volume to capacity errors (Nie 2004). However, little has been done to provide accuracy to calculations for the intersection capacities within most regional traffic assignment models. As discussed earlier, a common procedure is to assume base capacity values dependent on the locations and type of roadway. In the traffic assignment framework this treats signalized and unsignalized intersection capacities in the same manner, only correcting for signalization with a few delay assumptions. This creates a false input of equal capacities in the network assignment problem. In the static assignment realm this has the potential to lead to a misplacement of the corresponding

congestion due to low capacity caused by signalization. Even more importantly, the sensitivity of dynamic traffic assignment to link capacity estimates could negatively affect the ability to capture congestion around important intersections.

6.2   Multiple Intersection Calculations

One important application of this tool is using it to provide capacity data for an entire network where signal timings are available. In CAMPO's regional traffic assignment model, similar to the NCTCOG model, capacities are assumed based on functional class and location. However, signal timing information is available for some of the signalized intersections in the network. Since the tool for the application in the Dallas network uses static assignment flows to apportion green time, the use of these signal timings is not justified in replacing capacities for the regional network. In addition, many of the assumptions used for the tool are based on the operations of most diamond interchange signals on TxDOT owned frontage roads. However, if access to actual signal timing plans is available, then portions of the tool may be used to enhance the accuracy of the capacity calculations.

With the knowledge of the link identifiers and the signal locations, green time to cycle length ratios could be calculated for all links with known signal timings. In reference to issues discussed earlier with data redundancy and database storage of information relevant to transportation modeling, the importance of standardized traffic signal timing plan data and documentation of calculations can be demonstrated through

these capabilities. Not only should timing plans be stored in the database, but documentation of previous data used is important for understanding the current signalization conditions and how the signal may be improved. Once a subselection of all the links entering signalized intersections with known data has been created, the tool's final model, figure 5.11, may be implemented to derive accurate capacity calculations. These capacities may replace the previously assumed capacities in the assignment process. As data storage improves for important saturation flow rate adjustment factors, even more accurate capacity estimates may be calculated.

6.3   Level of Modeling Detail for TTC

Issues with the static assignment problem also lead to more information to be desired from the output data. As with the approach for more accurately calculating capacities for regional networks, it is important to take into consideration the level of detail the model will retain. It is often claimed that traffic simulation models can be categorized into microscopic, mesoscopic, and macroscopic. The traffic assignment performed in the static user equilibrium model provides the least amount of detail in traffic operations because it does not employ simulation. Microscopic simulation focuses on the movement of individual vehicles within a small portion of the network, which requires very detailed information. Mesoscopic is a term that has been applied to the use of simulation within dynamic traffic assignment because of its ability to capture some of the established traffic flow theory, but also deal with full extent of a regional network. It is important to note that as the level of detail increases the relevance of accurate capacity

calculations should be greater. However, accurate traffic characteristics should be implemented at all levels as the prevalence of necessary data increases.

The limitations of static traffic assignment are that the output is limited to link flows. Also, the static traffic assignment has limited capabilities for determining effects of changes in capacity due to incidents or construction. On the other hand, micro-simulators often require a small, detailed portion of the network in order to run the traffic simulation. The size of the microscopic network is often a limitation in the ability for the vehicles to be rerouted accurately due to changes in the roadways. Data for the microsimulation may be provided by real traffic counts, but this does not allow for the prediction of how the traffic flows change due to network alterations. This is where the results from a dynamic traffic assignment may provide detailed data to a microsimulation model to make improvements to intersection calculations. Research has been done to examine the importance of adaptive signal control, dynamic traffic assignment, and intelligent transportation systems for traffic impacts (Hu 2009). However, practice has not yet caught up with the capabilities of the determining rerouting through DTA.

Chapter 7 – Dynamic Traffic Assignment for Traffic Control Planning

7.1   DTA and TTC

A typical issue with the development of temporary traffic control for construction sites is the exclusion of alterations to timing plans for signalized intersections. Anecdotal evidence of traffic signals operating with normal timing plans, despite a leg of the intersection being completely blocked due to a construction event, emphasize the importance of retiming such signals to reduce delay. Also, within a large construction site several different capacity restrictions, road alterations, and detours can be implemented over the long term time period of the project. Certain construction phases may require major retiming efforts, an option that is often not investigated and commonly addressed by manually overriding the traffic control signal, or the use of traffic control enforcement personnel. Several different timing plans could be developed for traffic control scenarios with the proper use of dynamic traffic assignment. Issues preventing this analysis in the past include lack of data, lack of design review, and multi-jurisdictional coordination issues (NCHRP 2010).

The use of DTA to determine localized rerouting has the potential to provide the data that has previously been unavailable. Using different methods of incident management in current DTA software can help to predict changes created by TTC implementations of detours, temporary capacity changes, and advanced warning systems. Alterations in route flows and turning movements can quickly provide estimates for

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changes to the signal, or can be used as inputs for a microsimulation to accurately retime the signal plan. The greatest limitation to this analysis is the impact of network size on the time it takes to solve for dynamic user equilibrium. Methods of subnetwork analysis for dynamic traffic assignment could provide the capability of running scenarios for local impacts relatively quickly. Methods of identifying the impact region of proposed traffic control may help the user determine the local area, or subnetwork, that would be required for analysis (Pesti 2010). Thus, allowing for multiple scenarios for different stages of construction to be examined. Also, the impact of time of day on traffic flows can be accounted for in the dynamic traffic assignment. Different signal timings could potentially be produced as a function of the time of day.

For the preliminary experimentation into the use of dynamic traffic assignment for localized TTC impacts, the software VISTA has been used. A verified Austin downtown subnetwork model was examined for impacts discernible through the DTA output. Impacts to the system can be modeled in a variety of ways. Exploration of these methods was used for a real traffic control plan that would close a portion of second street in the downtown area. First, the link capacity value may be adjusted, which will directly impact the vehicles that use that link. Two other methods have been created to represent other purposes of network alterations. These are the creation of an incident event and the declaration of a prohibited link. An incident event allows for partial capacity reduction and attempts to simulate a lack of prior knowledge for the user. Therefore, users may reroute once they have approached the incident rather than at the

beginning of their departure. The prohibited link method assumes advanced warning to the user and rerouting starts at departure. A combination of the incident and prohibited link can provide approximation of a proportion of users aware and unaware of network alterations (VISTA 2010).

7.2   DTA and Subnetwork Analysis

DTA subnetwork analysis is a multifaceted problem: the size of the subnetwork, intensity of network alterations, desired detail of impacts to be captured, subnetwork border node treatment, and issues associated with changes outside the subnetwork are being investigated in other studies. To aid with the development of methods and procedures for addressing these issues visualization and data extraction methods have been created. Similar to the traffic control intersection tool, these tools have been implemented in the model builder within ArcGIS. The two major tools that have been created are the path visualization tool and the automated subnetwork selection. The intent of these tools is to provide a foundation for the methodology of using dynamic traffic subnetwork assignment to analyze temporary traffic control conditions.

In order to visualize the paths that use a particular link, an Excel spreadsheet must be created. There should be two separate sheets that will be used by this procedure. One sheet must contain the links in each path "Path_*linknumber*," and the other should contain volumes and travel times on each path "Path_*linknumber*_Data". These input files can be created through the use of queries on the output results from VISTA. The procedure for

extracting the paths involves several functions that have been organized into four models. Only one model, Create Path, must be run to create the final path shapefile. A description of the inputs, tools, and outputs that are used in each model can be seen in the following figures. Before the models can be run all features must be deselected. The last thing that needs to be done is converting "Path_*linknumber*" to a database file so that the ArcGIS tools can use its data as an attribute table. The "Table to Table" conversion tool, sets the input rows to the "Path_*linknumber*" sheet, the output location as the project workspace, and the output table as "Path_*linknumber*.dbf." Designating it as a .dbf file makes it a dBASE table, which can be read by ArcGIS as an attribute table.
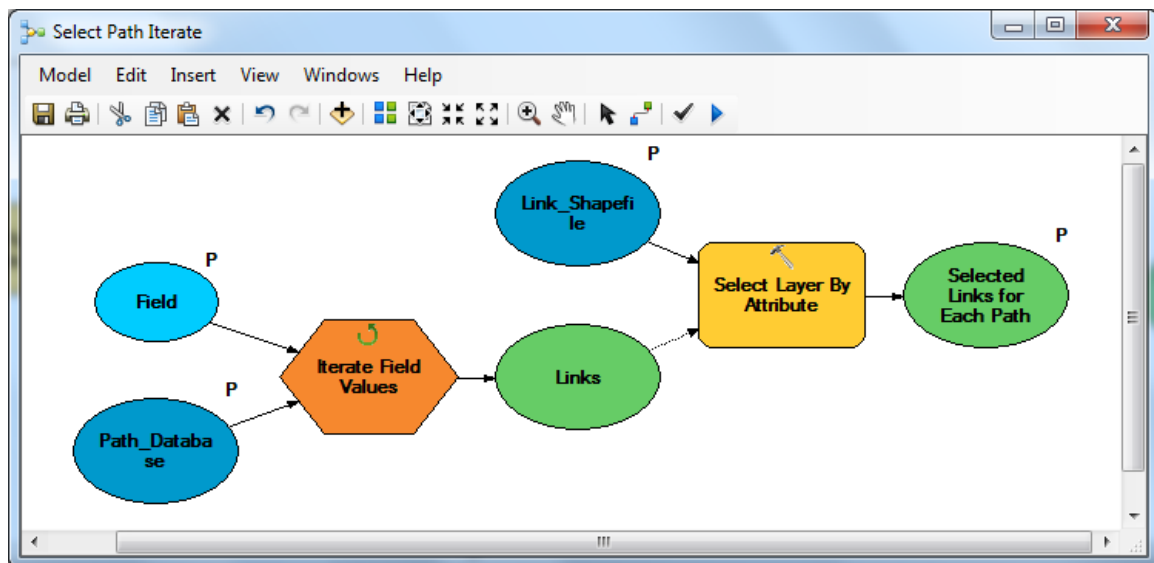
Figure 7.1: Select Path Iterate Selects All Links on a Path

The Select Path Iterate model, in figure 7.1, is used to select all links for a given path in "Path_*linknumber*." In order to do this a field iterator tool is included in the model, which has two inputs: a database table and a field to iterate through. The database

table is set to be the newly created "Path_*linknumber*.dbf." Initially, the field variable is set to "Path_1," the first field designated in the table; however, this variable will be a model parameter, which means it may be changed when the model is run. This will allow for another model to cycle through all paths of interest, by incrementing the field name by one. The iterator output is set as a precondition for the next tool, which guarantees that the iterator will run prior to the next tool. This tool is called "Select Layer By Attribute," which selects features in a layer based on its attribute value. The layer that it will select from is the full network shapefile. The selection type will be add to selection because it should retain the previously selected links until the entire path has been created. The output of the path iterator is now being called in the expression for the Select Layer By Attribute tool. For each of the link values that are being iterated through in the path field, the appropriate links are being selected by matching the link IDs in the link shapefile. This is the first use of an in-line variable in these groups of models. The use of this inline variable can be seen in figure 7.2. After the Select Path Iterate model has been called all links on one path will now be selected.
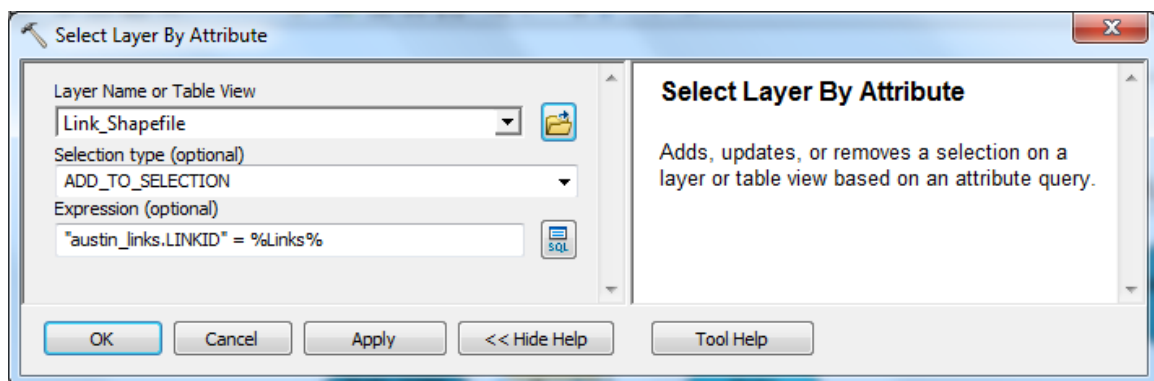
Figure 7.2: Select Layer By Attribute Dialogue Box
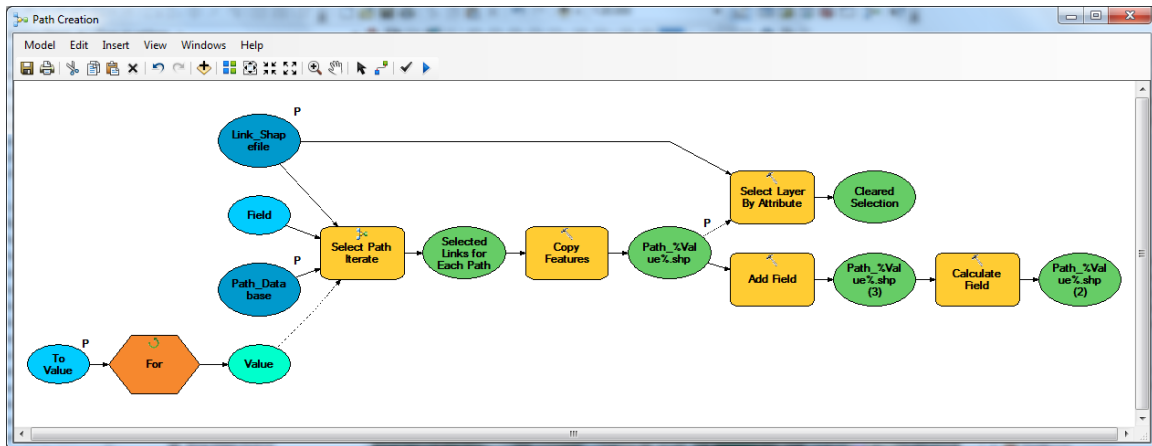
Figure 7.3: Path Creation Copies the Select Path Iterate Output to a Shapefile

The Path Creation model, in figure 7.3, will call the Select Path Iterate model within its procedure automatically. The main function behind the Path Creation tool is a for-iterator that allows the Select Path Iterate model to run for a set number of paths. This "To Value" variable is the first input for this model and allows the user to specify the number of paths that should be created. If the path database file has been organized by decreasing volume, then the most used paths will be selected first. The Select Path Iterate model is then brought into the Path Creation model as a submodel. Again the path database file has been set as the input to the Select Path Iterate submodel. The major difference this time is that the field value uses an expression calling the for iterator output, which can be seen in figure 7.4.

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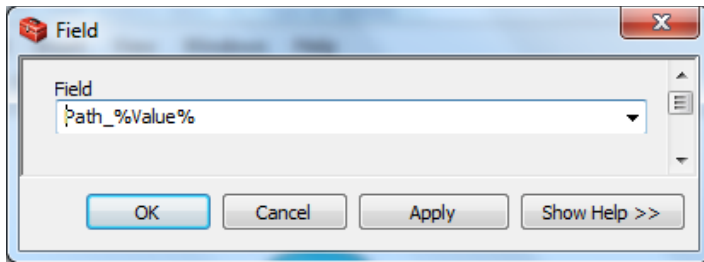
Figure 7.4: Field Variable Calling the Iterator Output

This will add a 1 to whatever input number was specified thereby iterating through all relevant paths. After one path has been completely selected, the selected features are copied to their own shapefile called "Path_%Value%.shp". Once the path has been copied, all features must be deselected so they are not included in the next path. In order to do so, the Select Layer By Attribute tool is used again this time with the selection type set to clear selection. Finally, we want to add a field to the newly created shapefile "Path_#.shp" and populate it with a Path_ID to keep track of the links used in each path. The output of this model will be an individual shapefile for each path that has been created, and these will be merged into one shapefile using the next two models.
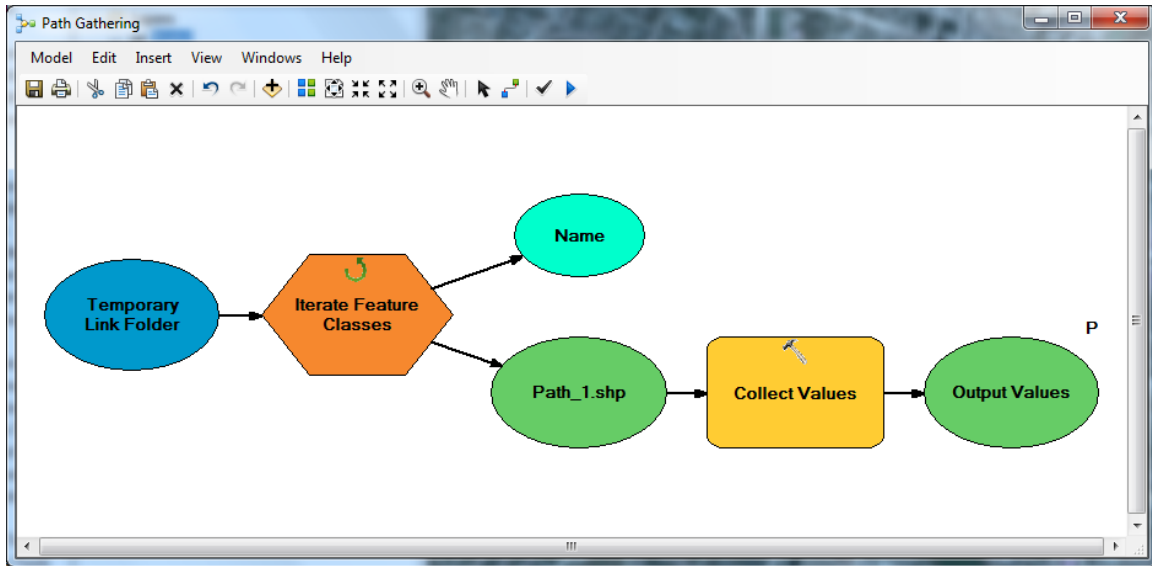
Figure 7.5: Path Gathering Collects All Shapefiles Created by the Path Creation Model

The previous model should output all path shapefiles to an empty folder called New Link. This will allow the user to manually delete all the individual shapefiles after they have been merged. The Path Gathering model, figure 7.5, simply extracts from the folder "Temporary Link Folder," and iterates over all feature classes in that folder. The Collect Values tool stores all the names of the shapefiles in that folder. The multivalue output parameter "Output Values" will be used by the Create Path model to merge all shapefiles in the Temporary Link Folder. By using the Output Values as the input for the merge tool a single shapefile called Paths.shp will be created that contains the paths that were previously created.

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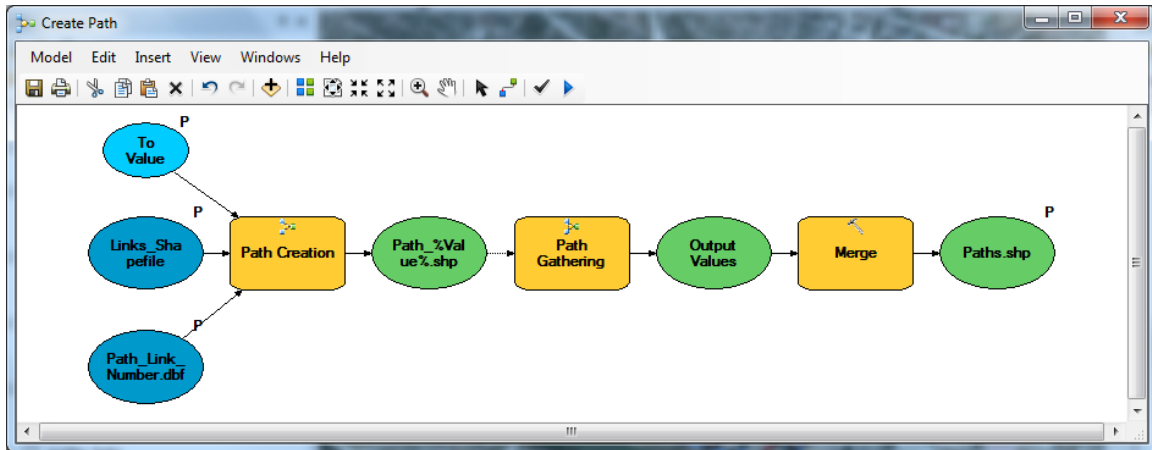
Figure 7.6: Path Merge Combines All Paths Into One Shapefile

The Create Path model will combine each of the other three models to produce one resulting Path.shp. The Temporary Links Folder is full of individual path shapefiles that should be cleared before the model is used. Figure 7.7 represents the interface for the model. The inputs are: the name or the path shapefile, the Austin links shapefile, the path database file, and the number of paths to display.
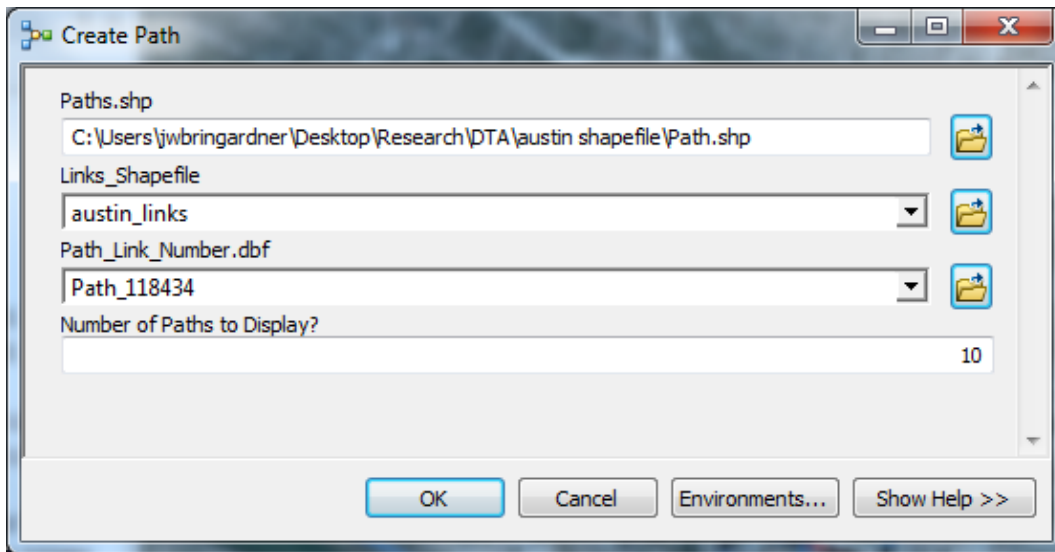
Figure 7.7: Create Path Main Model Input Parameters

Joining the attribute table of the resulting paths shapefile with the "Path_*linknumber*_data," by the path field should bring in path volume and travel time data. In order to visualize the paths an arrow can be used to represent each link and a graduated color or graduated symbol may be applied using the volume field. Figure 7.8 is a demonstration of a possible output of the path selection model, using the base case DTA network and the modified TTC plan on second street full network. The blue paths are the ones that vehicles were using prior to the change in the network, and the red paths are where diversions occurred due to the change.
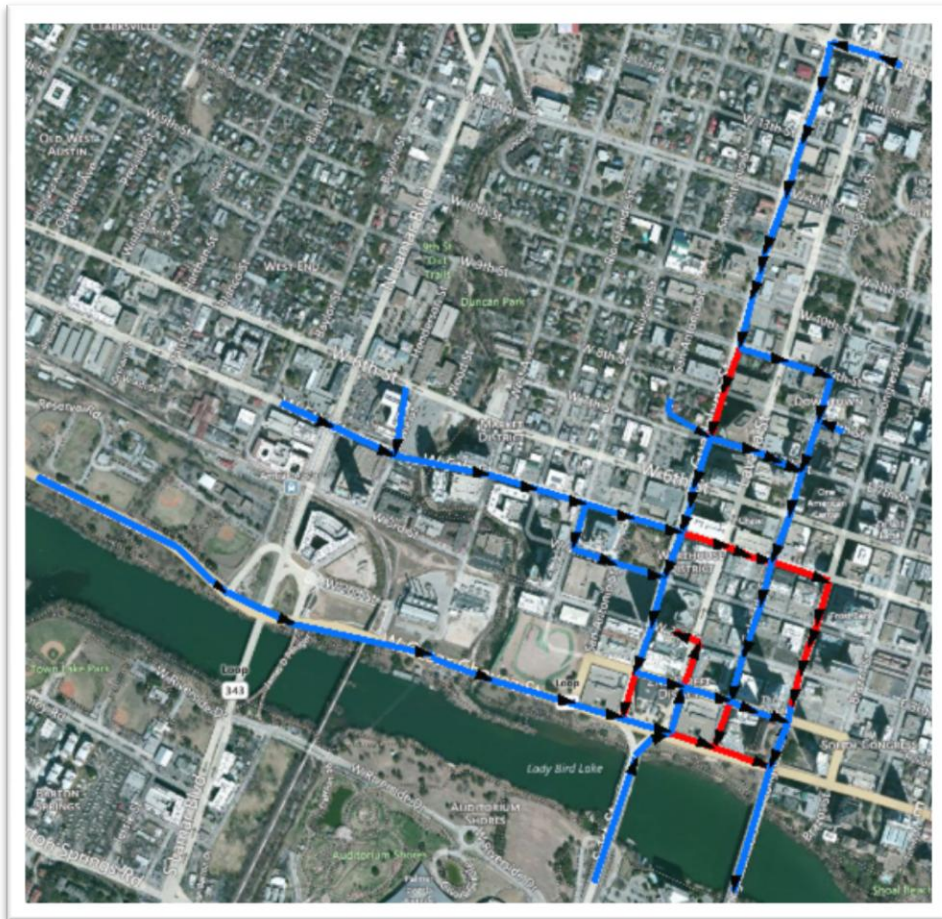
Figure 7.8: Map of Paths Used in the Base Case (Blue) and Alternative (Red) Scenario

The DTA routing information provides a much greater understanding of the impacts than static traffic assignment. Figure 7.9 reveals the static assignment response to the same scenario ran in the DTA network from figure 7.8 (Boyles 2012). The static assignment is unable to capture many of the changes that would be experienced in the network.
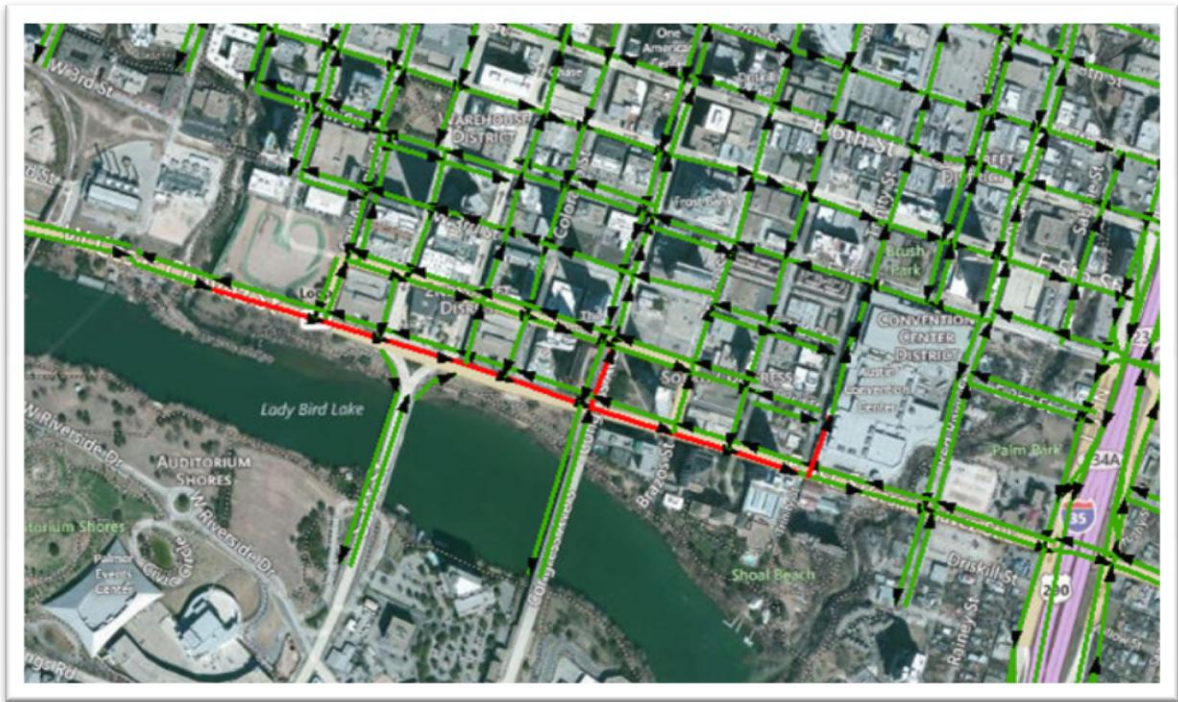
Figure 7.9: Static Assignment Volume Increases for Same Second Street TCP

The extent of the original paths in the base case have the potential to be used as a measure of the radius of a circular area that might comprise a subnetwork selection. Or if the alternative scenario network can be run then the nearest deviation from the paths may be used a radius selection. In order to create a subnetwork, within the context of VISTA, the corresponding links, nodes, centroids, and connector IDs must be exported as text

files. To obtain the necessary IDs this would normally mean manually selecting these features. Two new methods have been adopted to create a more automated version of this process. These are a subnetwork radius selection and a subnetwork ordered connection selection. The premise behind each of the main functions of the models is to automatically select a set of links, and then select the corresponding nodes, centroids, and connectors. The subnetwork radius selection is based on a specified distance, and subnetwork order is based on the number of connected links.

Since the method for selecting the links is the only difference between the two models, the selection of the rest of the network data will be covered first. Assuming the proper links have been selected, the nodes are the next selection required in this process. Due to errors in the locational data, the select layer by location tool needs to be set to select nodes within 25 feet of the links. Once the nodes have been selected, then the connectors can be selected by the touches boundaries with nodes in the select layer tool. Finally, the centroids, like the nodes, must be selected within 25 feet of selected connectors. Each of these separately selected layers are exported to a shapefile, from which the IDs may be copied into a text file.

Figure 7.10 is a sample portion of the subnetwork radius selection model. The selected data from each previous step is used to select data from the subsequent data sets. The inputs for this and the subnetwork order selection tool should be the link shapefile with the link of interest selected. It is this first selected link that is used to initiate the

radius and ordered selections. The radius selection simply uses the input distance to select

all links within that distance of the original link selected.
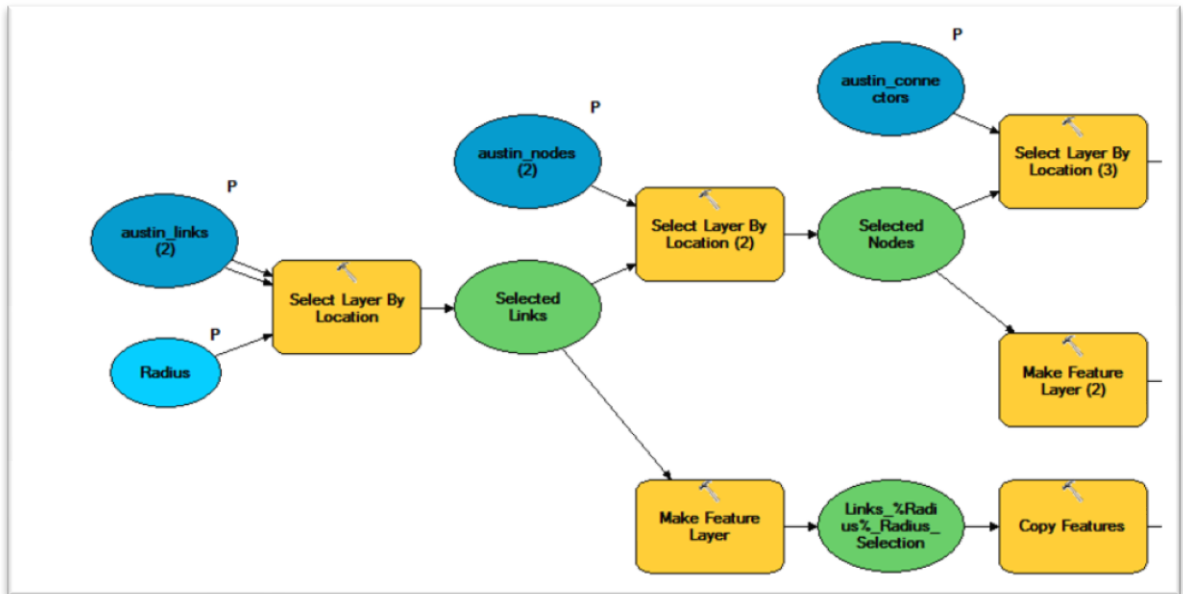
Figure 7.10: Portion of the Subnetwork Radius Selection Model

The alternate selection method for the subnetwork was inspired by a concept

based on vulnerability analysis of a road network (Chen 2012). Figure 7.11 represents the

algorithm that was used in the corresponding paper. For use, within the model builder

environment this algorithm replaces the select layer feature within the specified radius.

This means that if the parameter for the number of connected links, η, is 2 then all links

connected to the originating link and all links connected to these links will be selected. In

other words, if the degree of separation between any given link and the original link is

less than η, it will be included in the new selection.

Input: Impact area size parameter η, link a (connecting tail node j and head node h)
Output: the impact area of the link a
Step 1: Initialization:
    Set the distance from the node l to the link a as $w_l := \infty$, $\forall l \in N$.
    Set $w_j := 0$ and $w_h := 0$.
    Set scan eligible node set as $SE := \{j, h\}$.
    Set node set of impact area as $N_a := \{\phi\}$.
Step 2: Node selection:
    Select the node l with minimum w_l from SE.
    Set $SE := SE \backslash \{l\}$ and $N_a := N_a \cup \{l\}$.
Step 3: Path extension:
    For each link b merging into node l (Denote m as the tail node of link b)
      If $w_l + 1 \leqslant \eta$ and $w_m < w_l + 1$
        Set $w_m := w_l + 1$ and $SE := SE \cup \{m\}$.
      End if
    End for
    If $SE = \phi$, then goto Step 4; Otherwise, goto Step 2.
Step 4: Generate link set for the sub-network:
    Set link set of impact area as $A_a := \{\phi\}$.
    For each node $l \in N_a$
    For each link b emanating from node l (Denote k as the head node of link b)
      If $k \in N_a$, then $A_a := A_a \cup \{b\}$.
    End for
    End for

Figure 7.11: Chen's Algorithm for Ordered Connection Subnetwork Creation

The model builder requires a submodel to perform this operation. Figure 7.12 shows the submodel that is called to create the ordered connection selection. The input to the submodel, Eta, is the parameter previously discussed. In Chen's paper, a magnitude of about 6 was able to capture many of the effects in the network. The submodel will run Eta times, and each time it selects all links that touch boundaries with the previous selection. Thus, creating the ordered connection subnetwork selection, which will be used in the main model as the input for selected links. The main model is a duplicate of the radius model with the link selection step replaced by the subnet order iteration submodel.
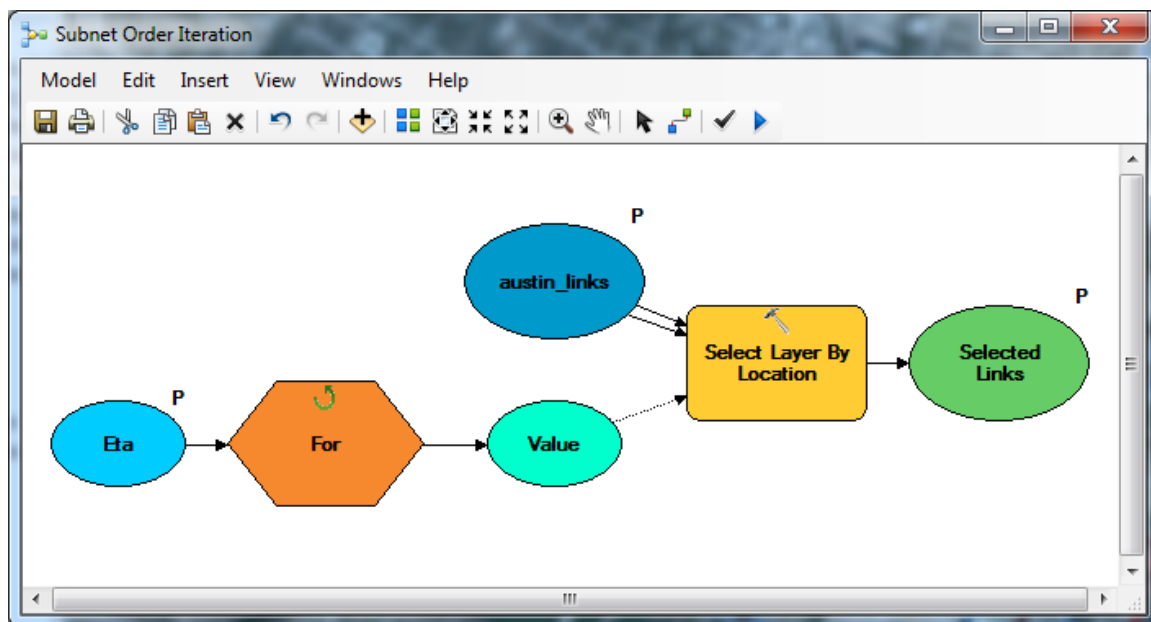
Figure 7.12: Subnet Order Iteration Submodel Used to Select Links

Chapter 8 – Summary

There is a gap between the emerging GIS technologies, data storage, advanced transportation models and their uses for roadway construction and improvement projects. The tools presented are intended to be an indication of the power available in these transportation technologies when there are standards for databases and the models that use them. The development of the intersection traffic control tool dramatizes the importance of data interchangeability, as well as account for variation in the future releases of the ArcGIS software platform.

Several assumptions were made in the creation of the intersection tool due to the quality of the data available. The tool is intended to provide basic capacity estimations for approaches to signalized intersections for the TxDOT controlled highway system. Since these signals are primarily diamond interchanges, traditional four phase signal timing plans were assumed, thereby, providing a separate signal phase to each leg of the intersection. Adjustment factors for prevailing traffic conditions were summarized with preset values due to a lack of information required to calculate them. The flow rates used to apportion green time to the phases were derived from the NCTCOG static regional network traffic assignment model. The availability of this data at all TxDOT signalized intersections made it a viable option, compared to actual traffic counts. Traffic counts at many intersections are missing, from different years, and account for different times of day.

These limitations of the data limit the accuracy of the model, but also lead to the need for better analysis methods to aid the investigation of traffic control. The next level of detail that is provided by DTA analysis can enhance the accuracy of the predictions created by the tool. Since the ArcGIS tool is in a static environment, no iterative process may be used to modify the original traffic assignment. These modifications could include a more accurate capacity calculation for all links in a regional network with a signalized intersection. Even if static traffic assignments were run with alternative scenarios the impacts identified would be limited.

The use of a subnetwork for DTA analysis has the potential to predict changes in traffic demand or volume due to potential traffic control plans. More work is being done to define the method for selecting a subnetwork in the DTA environment. Although there are methods for subnetwork selection for static traffic assignment, the nature of DTA models is too different to apply the same concepts. Therefore, GIS aids have been created to help encourage the development of these methods. These models include a tool to visualize the paths that a particular link of interest uses. After a modification to the network has been made, rerouting of the traffic demand using the altered link can be shown. These paths may be used as inputs to a subnetwork selection. To create subnetworks for a DTA assignment the corresponding links and nodes must be identified. The final tools offer two different methods for selecting these features and extracting the subnetwork in VISTA.

Appendix 1: User Guide

This section will describe how to use the traffic control planning tool for intersections in detail with screenshots to provide an understanding of the user interface. The tool is run through the standard ArcMap interface. In the map titled CTR Traffic Control Planning tool the required toolboxes should already be added to ArcToolbox. If they are not, right click on ArcToolbox and add the correct toolboxes from the same directory in which the map is located.
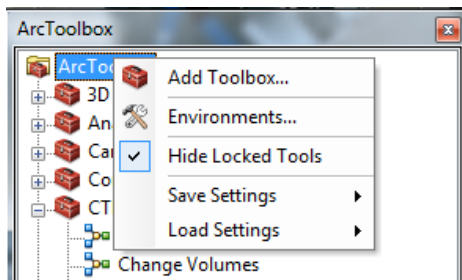
Once all six tools have been loaded ArcToolbox should look like this.
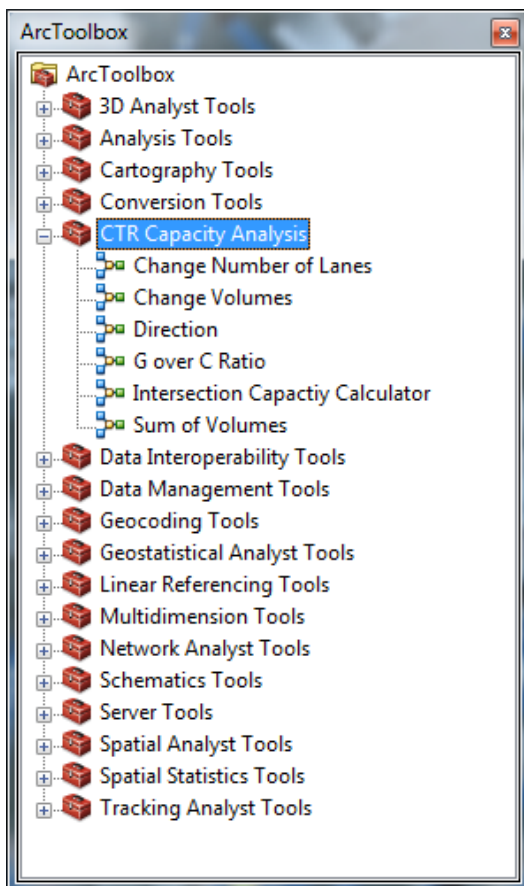
Now that the map is properly set up the following procedure can be used to evaluate capacities at signalized intersections:

1.   The first thing that needs to be done is locating the intersection of interest. This can be done using the geocoding toolbar, if this does not appear in the map then it needs to be added by right clicking in the toolbar space or using the customize drop down menu. The intersection name should be entered into the query bar in the format Street 1 and Street 2 City, State or Zip Code.
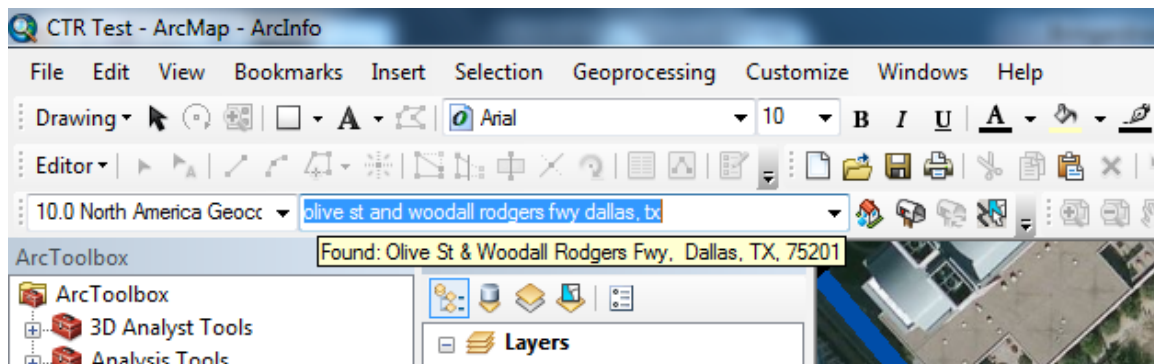
2.   Once the desired intersection has been found, the map display will pan to it if you right click on the name you typed in and select "Pan To".
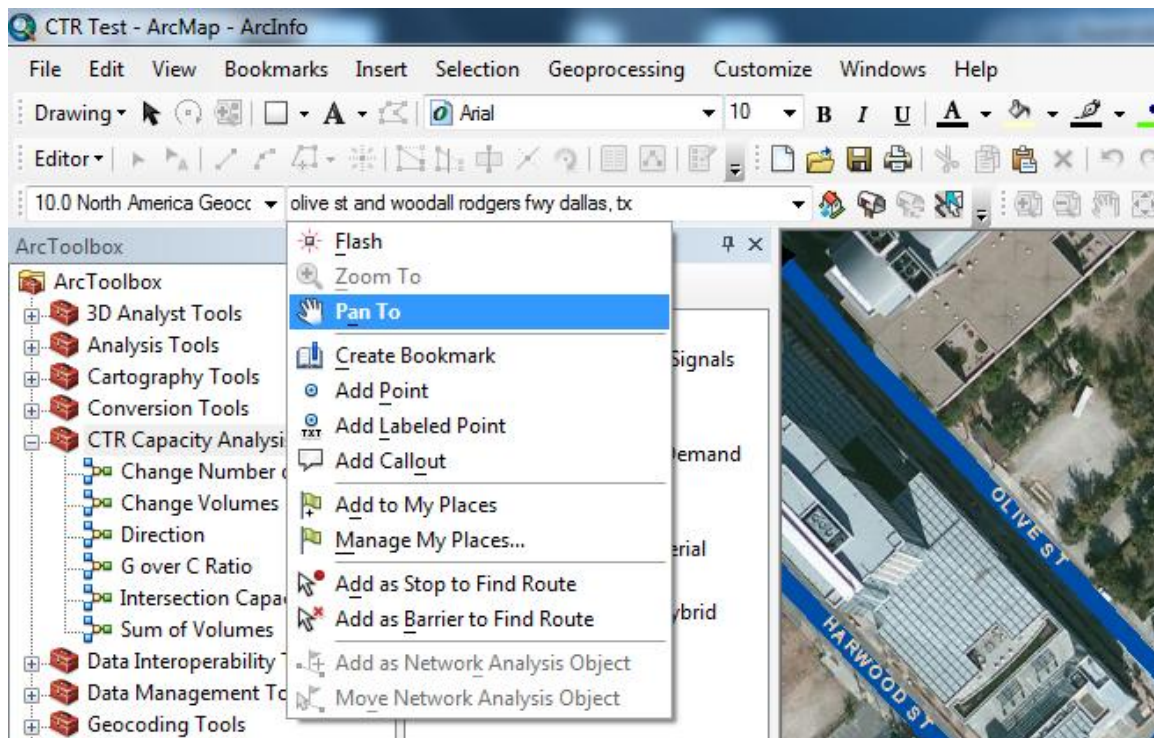
3.　　　At the location of the intersection three different files should be visible: the intersection signals, roadway network, and the basemap. Using previous knowledge of the intersection, the hybrid aerial map, and the network attribute table should help determine which links are entering the intersection. In order for the program to function the signal must be selected along with only the links with volumes entering the intersection. Links between signals in diamond interchanges should not be included. Below is an image of what the map display should look like before starting the program.
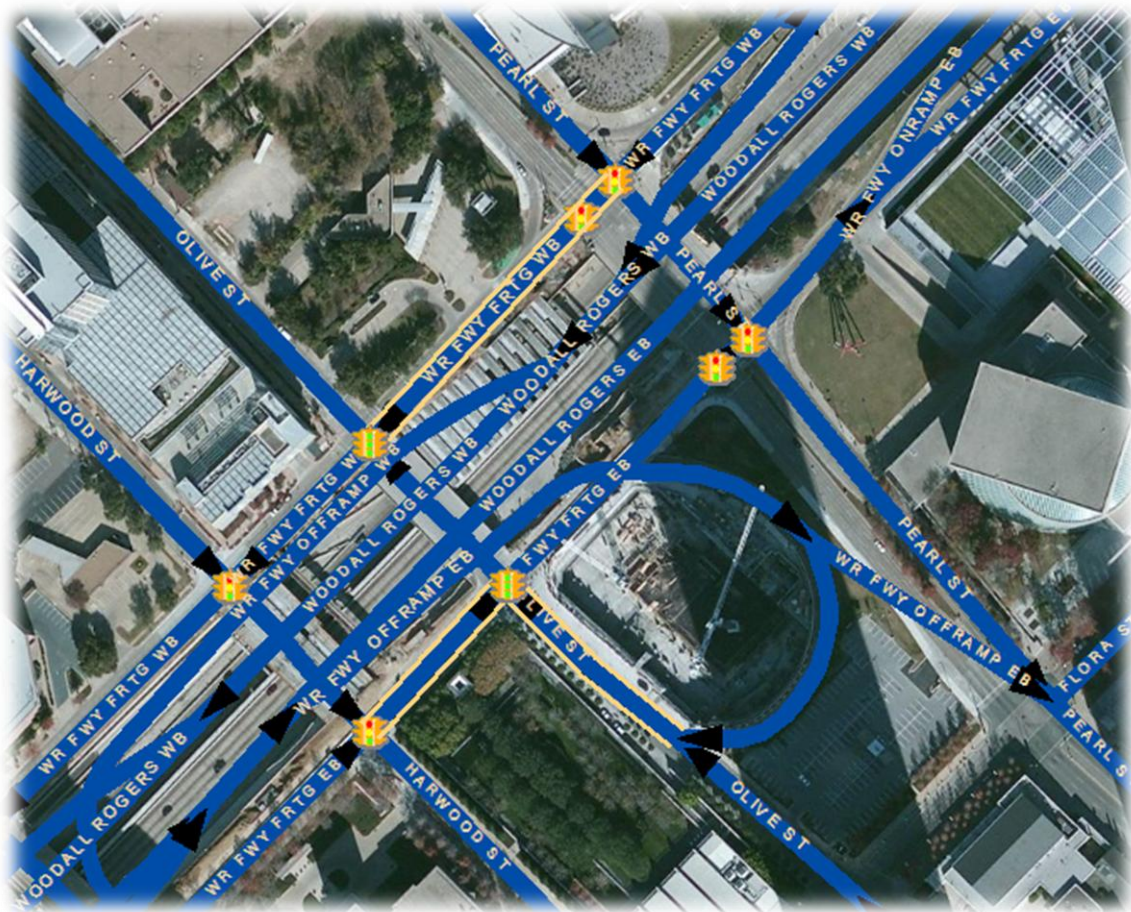
4.   At this point all of the data has been prepared so that it can be sent to the program. To run the program, double click on Intersection Capacity Calculator in Arc Toolbox. Below is an image of the dialogue box. Click OK to run the program once and make calculations on values provided by the demand data set.
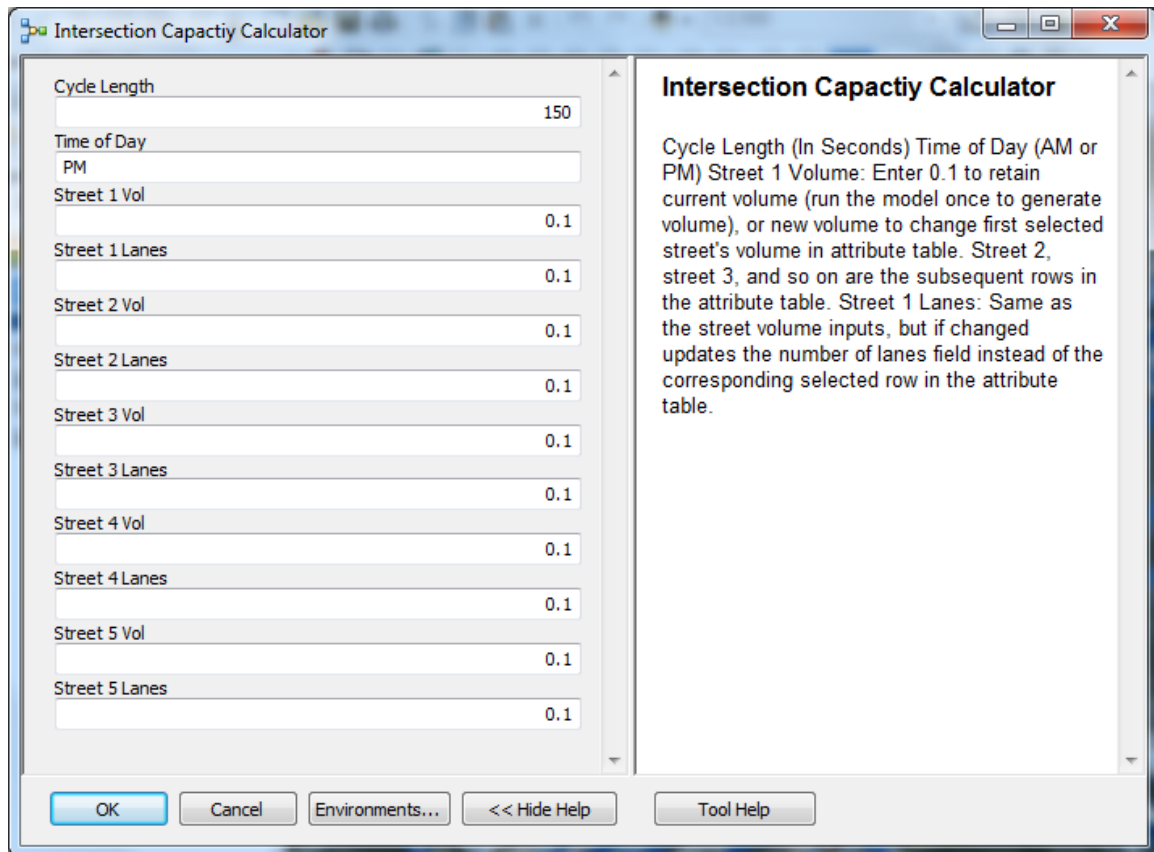
5.   Now that one base run has been complete open the attribute table for the network file. If it was already open click the upper left drop down menu button and select reload cache, and this will refresh the table with the newly calculated values. Now calculations can be performed with any input values desired. Cycle Length is input in seconds and Time of Day is entered as either AM or PM. Then the volumes or the number of lanes of the roadways can be changed. The street number refers to the order the roads are listed in the attribute table, and if a 0.1 is entered then the previous value is retained. In the screen shot below, the change in volume and number of lanes for street 2 will take effect on WR FWY FRTG WB.
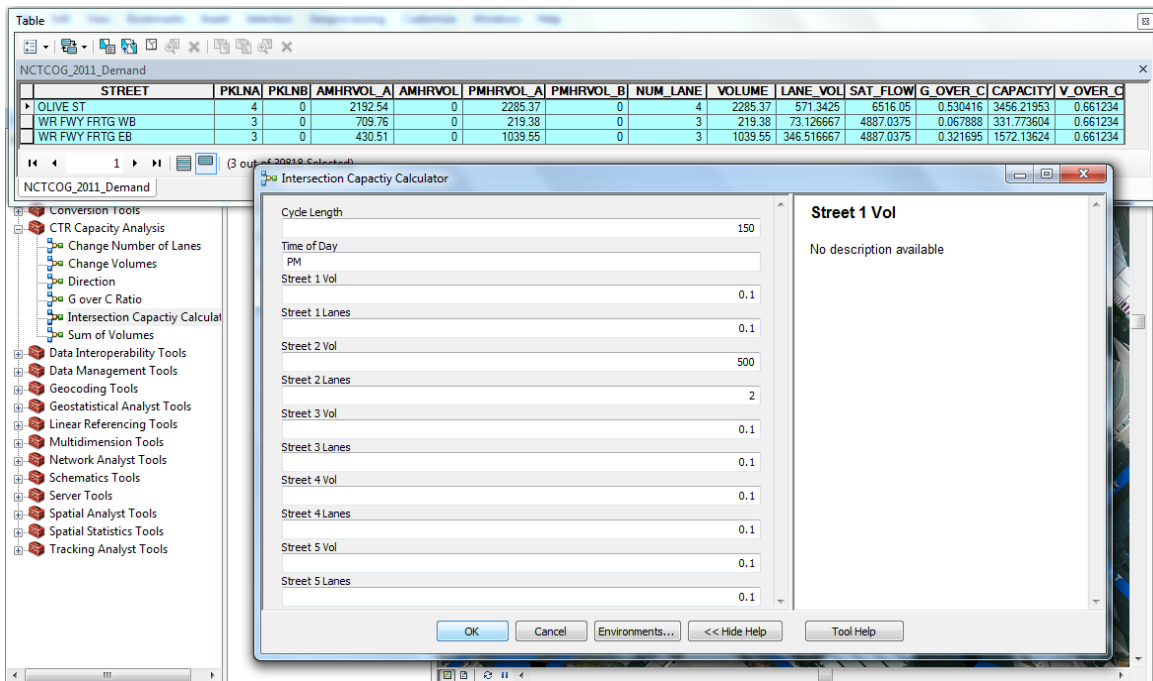
6.   Now that the user has the appropriate scenarios calculated, the results can be displayed in a table and map format. This was saved in a report format that can be run and added to the layout display. Run the report by using the view drop down menu, reports, and run report. Select the button in the report that Add report to ArcMap Layout. Then the user can select export map under the file menu and save in the desired format. The next two screen shots show this process and the last page is a sample .pdf export.
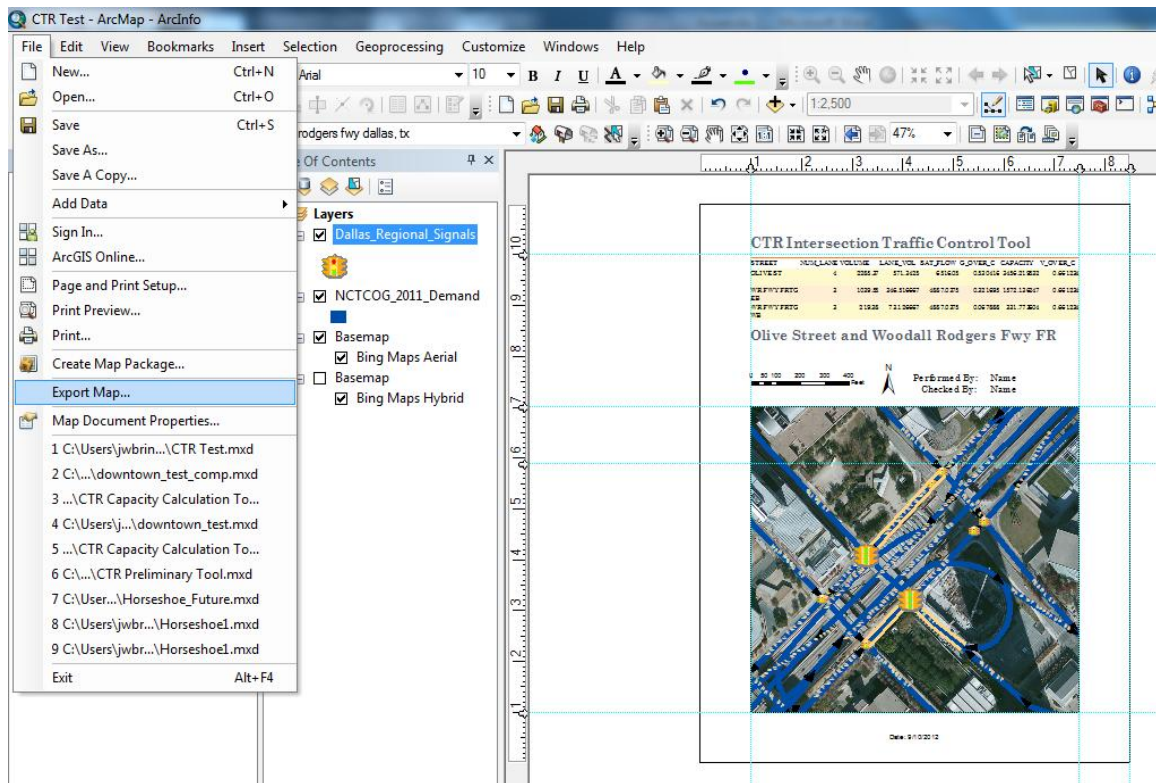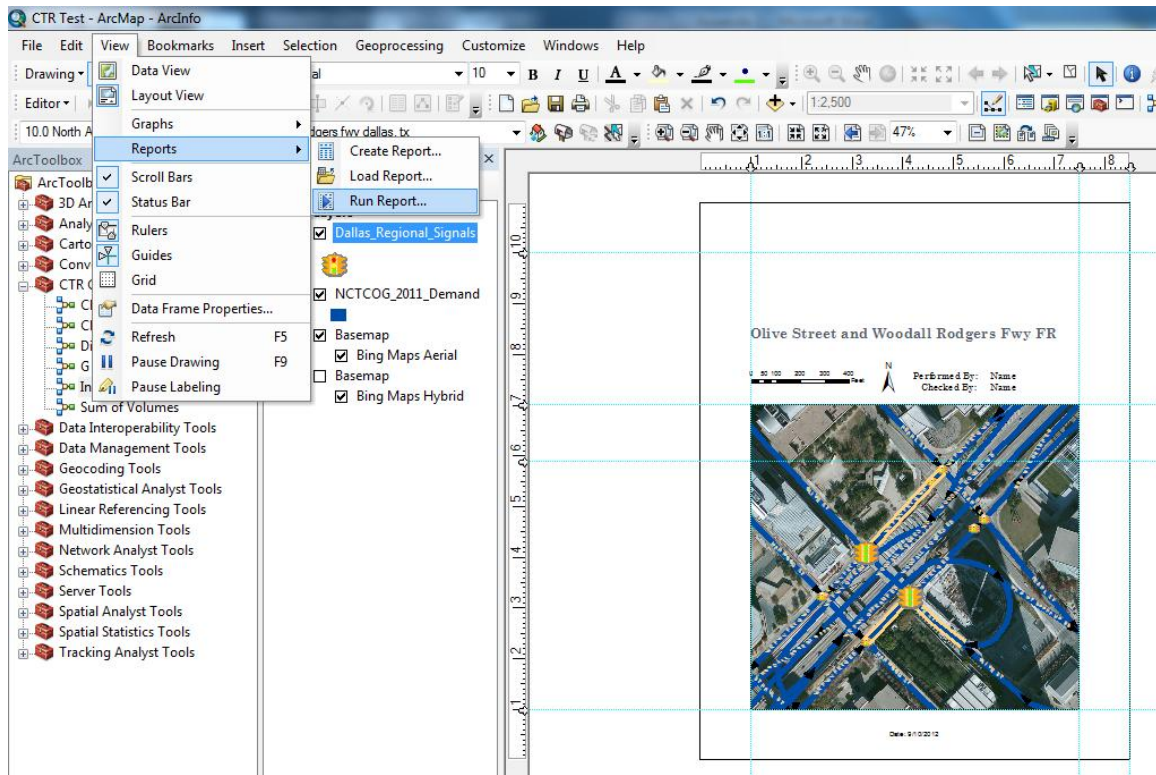
CTR Intersection Traffic Control Tool

STREET	NUM_LANE	VOLUME	LANE_VOL	SAT_FLOW	G_OVER_C	CAPACITY	V_OVER_C
OLIVE ST	4	2285.37	571.3425	6516.05	0.530416	3456.219532	0.661234
WR FWY FRTG EB	3	1039.55	346.516667	4887.0375	0.321695	1572.136247	0.661234
WR FWY FRTG WB	3	219.38	73.126667	4887.0375	0.067888	331.773604	0.661234

Olive Street and Woodall Rodgers Fwy FR
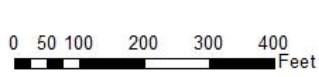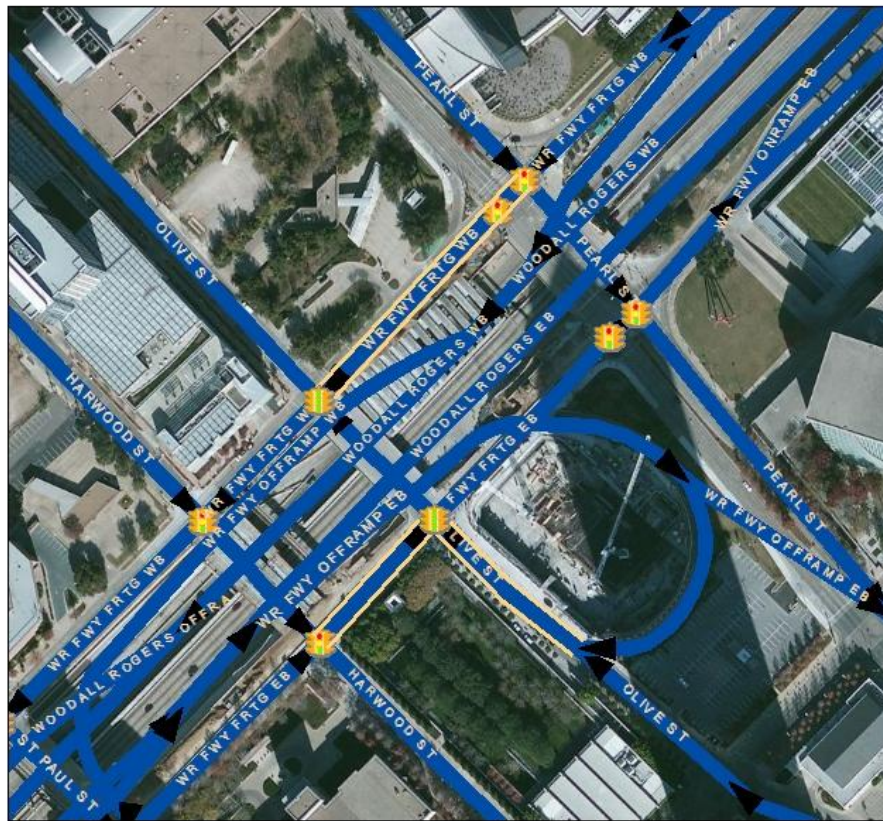
Date: 9/10/2012

Appendix 2: Maintenance Guide

This section will describe in detail how to maintain the tool for use in case of changes in the data or the ArcGIS package. Primarily, this guide will document the code of each tool used in model builder so that it can be replicated.

Data

The first thing that needs to be addressed is the changes that need to be made to new data used by this tool. There are four modifications that need to be made to the data:

1. Fields need to be added: X and Y location fields should be added to both the signal and network data layers, and for the network should include the start and end of the line. The network layer also needs NUM_LANES, VOLUME, LANE_VOL, SAT_FLOW, G_OVER_C, CAPACITY, and V_OVER_C.
2. The shapefiles should be projected to NAD_1983_StatePlane_Texas_North_Central_FIPS_4202_Feet.
3. Shapefiles should be converted to a geodatabase file by right clicking and exporting the data to a new geodatabase.
4. Update the symbology by going to the layer properties and selecting import from the symbology tab. Import symbols from the corresponding older layers.

Map Tool
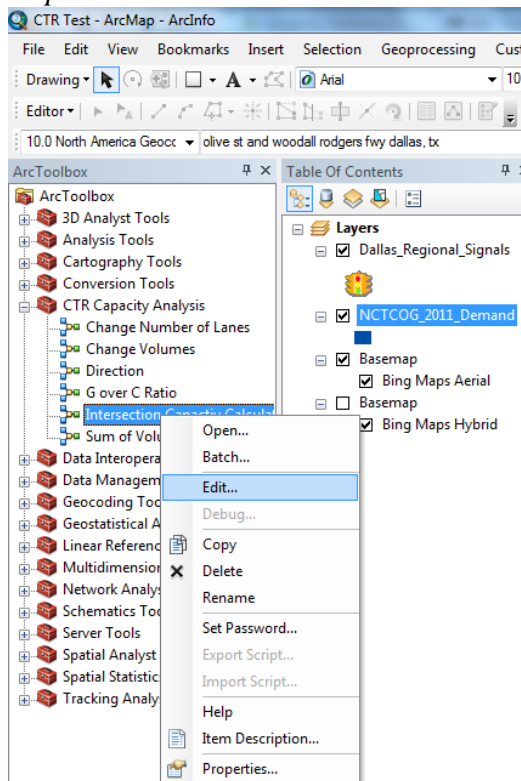
The map tool has been built in ArcGIS model builder and can be edited by right clicking on the tool and selecting edit. The logic and the performance of the tool has been explained in chapter 5 of the thesis. The user's guide contains information on how it can be used. This will focus on screen shots of the model and its individual tools. All of the inputs will be covered including codeblocks for the more advanced functions. Brief descriptions will help clarify each tool. If the data inputs need to be changed due to the update in data above, then every instance of the input data set must be changed in model builder.

This is the layout of the full model. Dotted arrows means that a variable is set as a precondition to the receiving function.
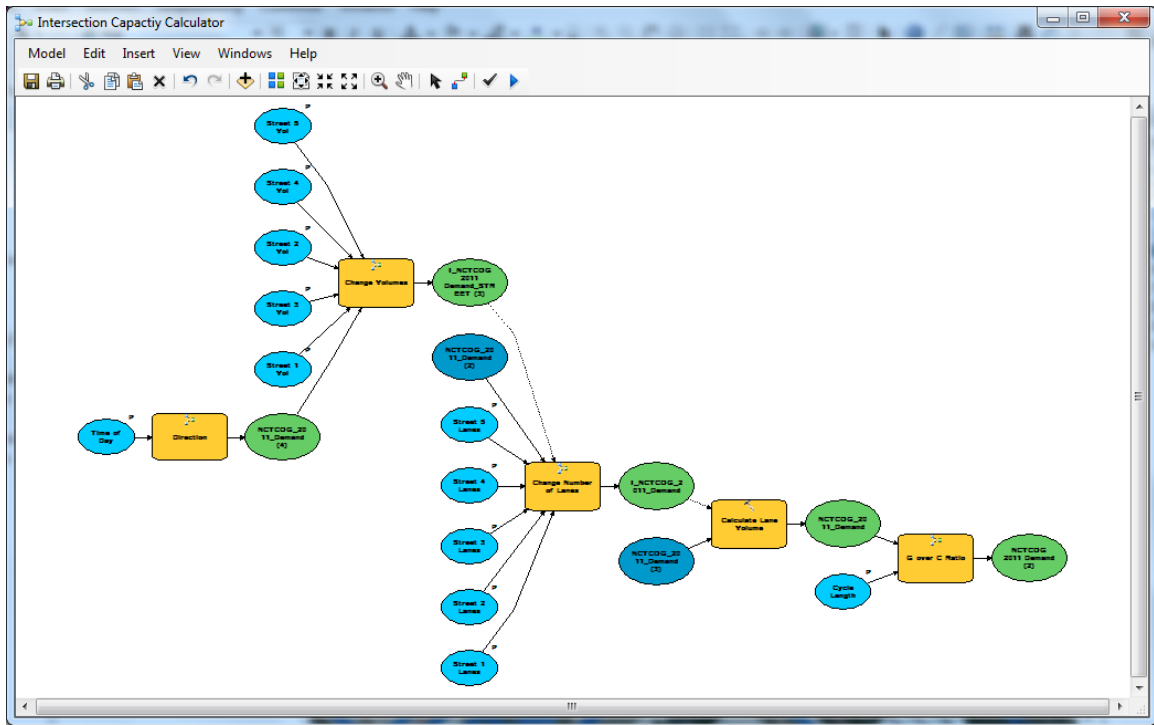
By right clicking on a variable it can be set as a model parameter.
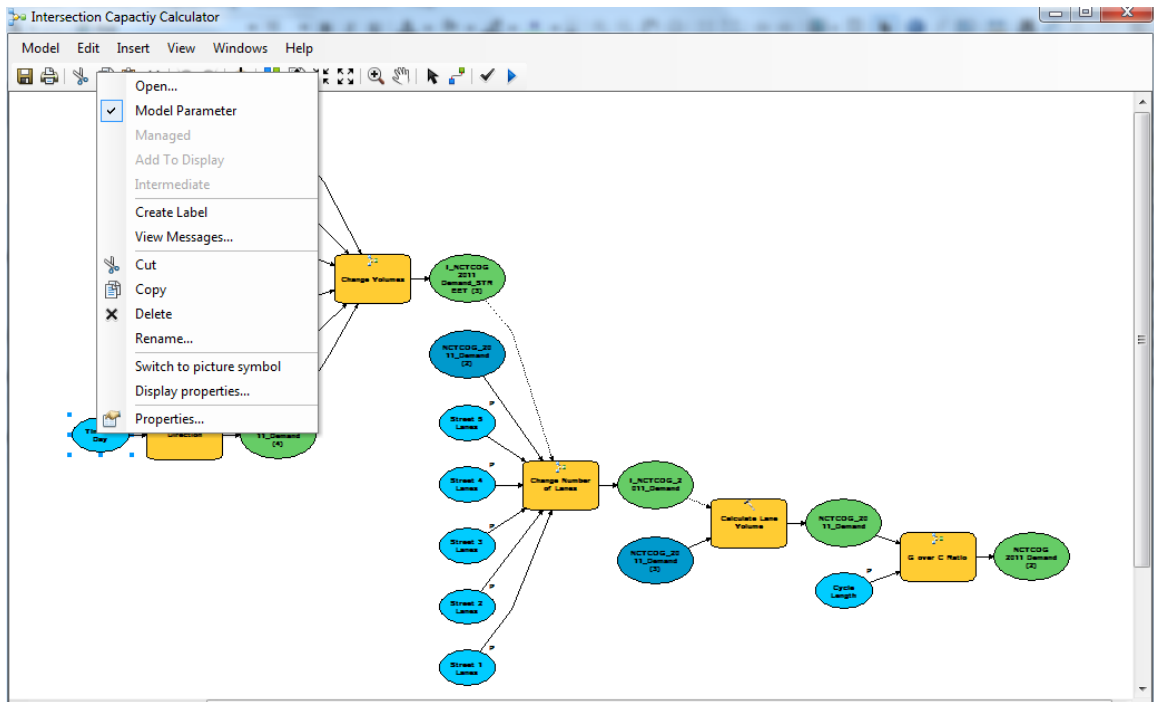
The first parameter is time of day, which is a string variable.
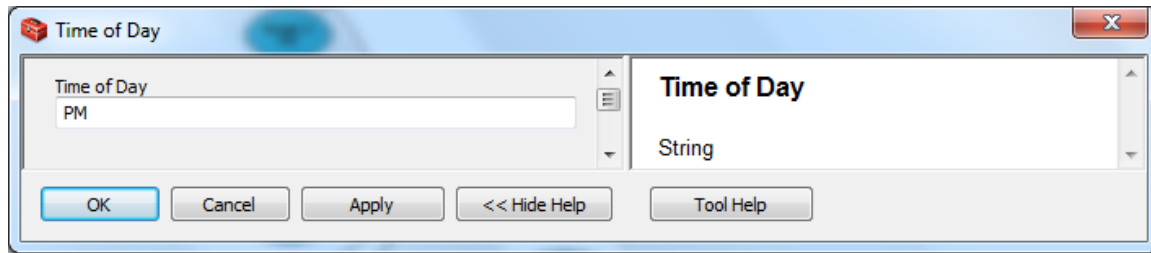
The first submodel is Direction and it uses the Iterate Selected Features to calculate values one feature at a time.
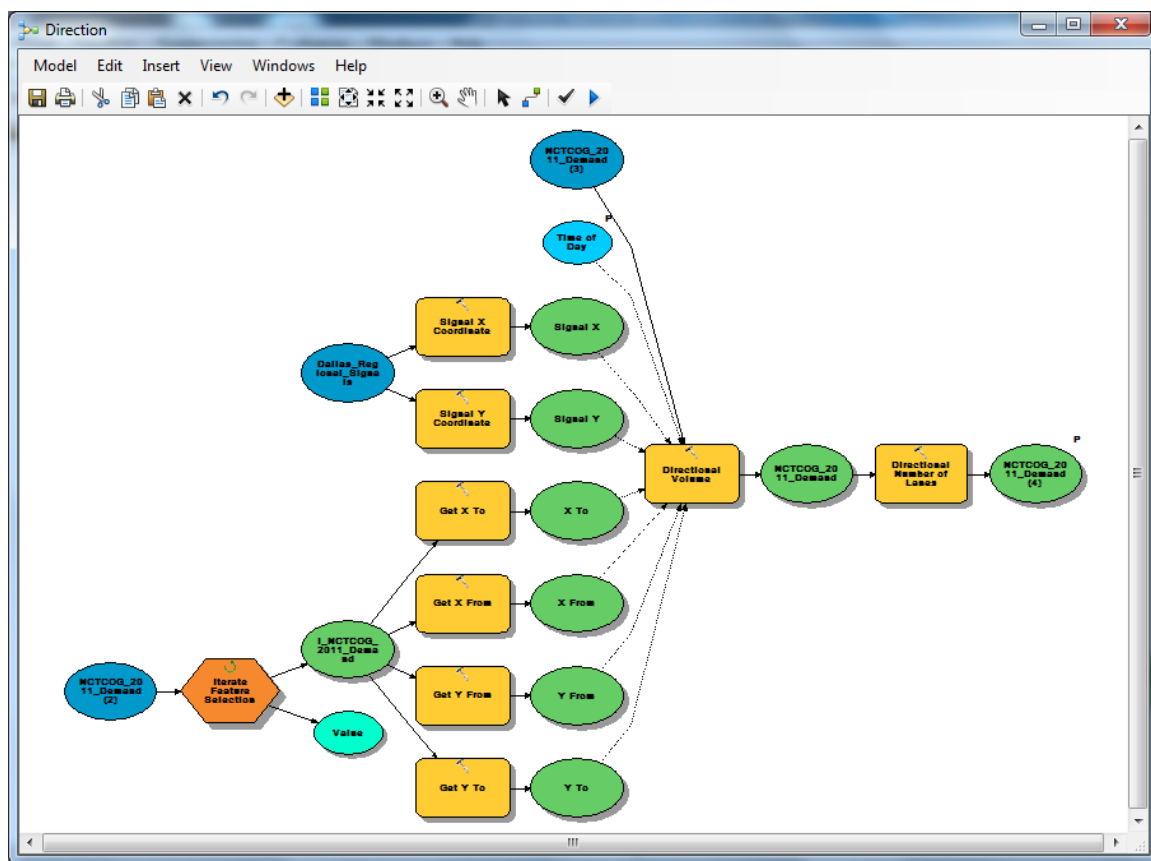
This iterator only requires a feature dataset as input.
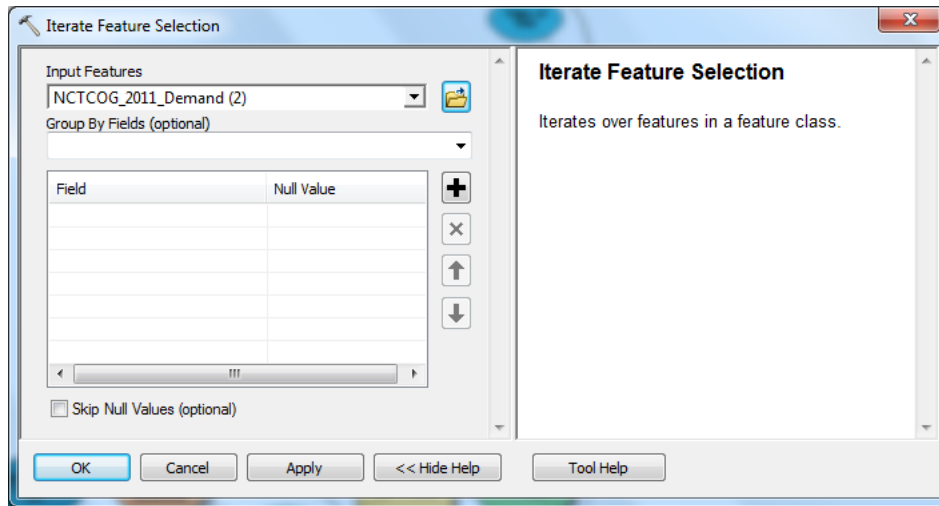
The model only tool Get Field Value is used for all of the coordinate data.
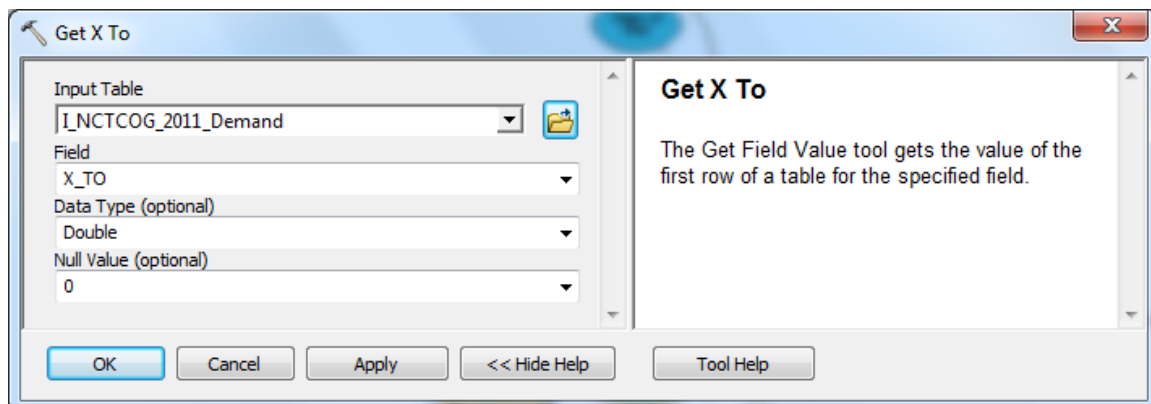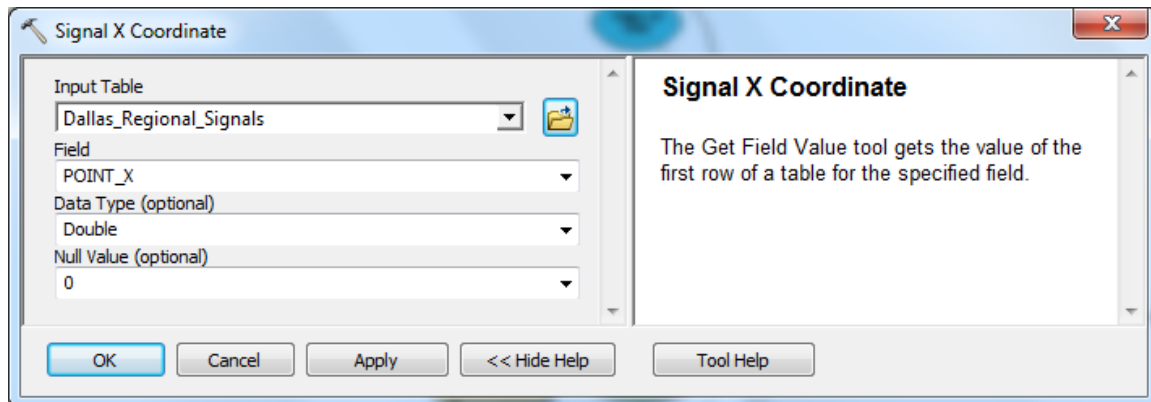
Directional Volume and Direction Number of Lanes are both a Calculate Field Tool.
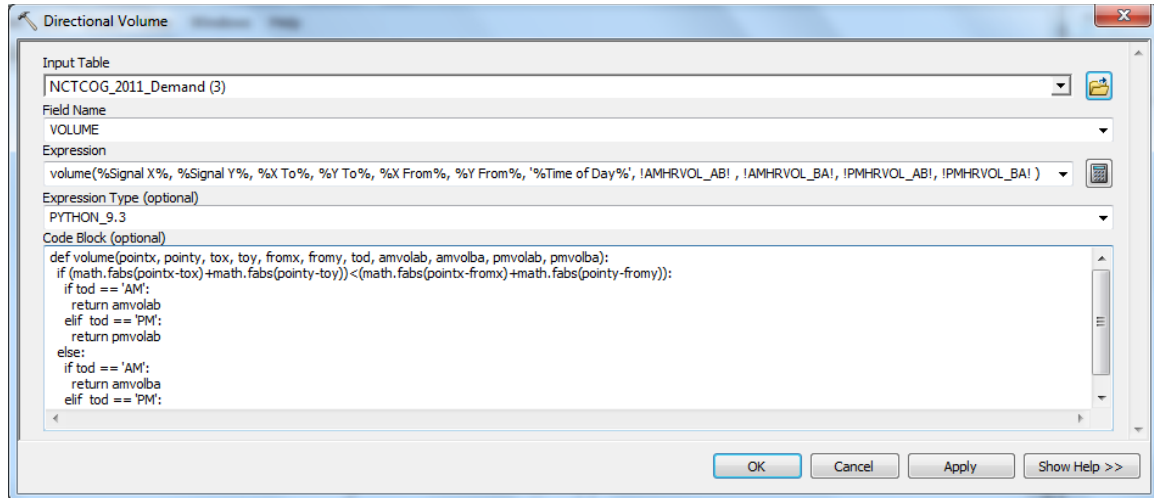
Expression:

volume(%Signal X%, %Signal Y%, %X To%, %Y To%, %X From%, %Y From%, '%Time of Day%', !AMHRVOL_AB! , !AMHRVOL_BA!, !PMHRVOL_AB!, !PMHRVOL_BA!)

Code Block:

```
def volume(pointx, pointy, tox, toy, fromx, fromy, tod, amvolab, amvolba, pmvolab, pmvolba):
  if (math.fabs(pointx-tox)+math.fabs(pointy-toy))<(math.fabs(pointx-fromx)+math.fabs(pointy-fromy)):
    if tod == 'AM':
      return amvolab
    elif  tod == 'PM':
      return pmvolab
  else:
    if tod == 'AM':
      return amvolba
    elif  tod == 'PM':
      return pmvolba
```
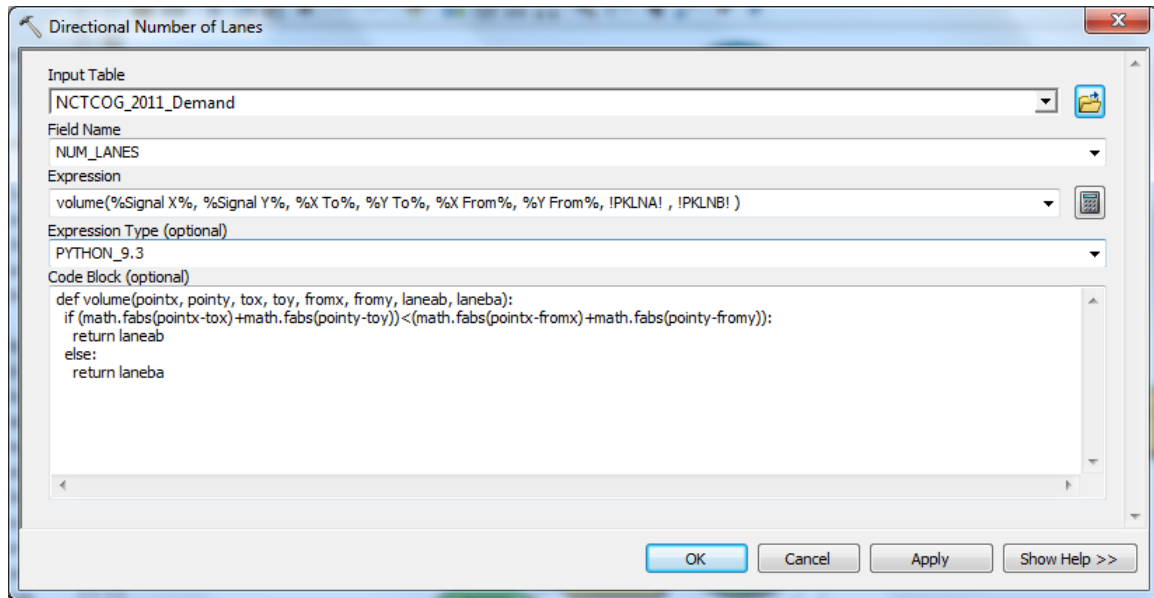
Expression:

volume(%Signal X%, %Signal Y%, %X To%, %Y To%, %X From%, %Y From%, !PKLNA! , !PKLNB!)

Code Block:

```
def volume(pointx, pointy, tox, toy, fromx, fromy, laneab, laneba):
  if (math.fabs(pointx-tox)+math.fabs(pointy-toy))<(math.fabs(pointx-fromx)+math.fabs(pointy-fromy)):
    return laneab
  else:
    return laneba
```

Change Volumes and Change Number of Lanes are the same.
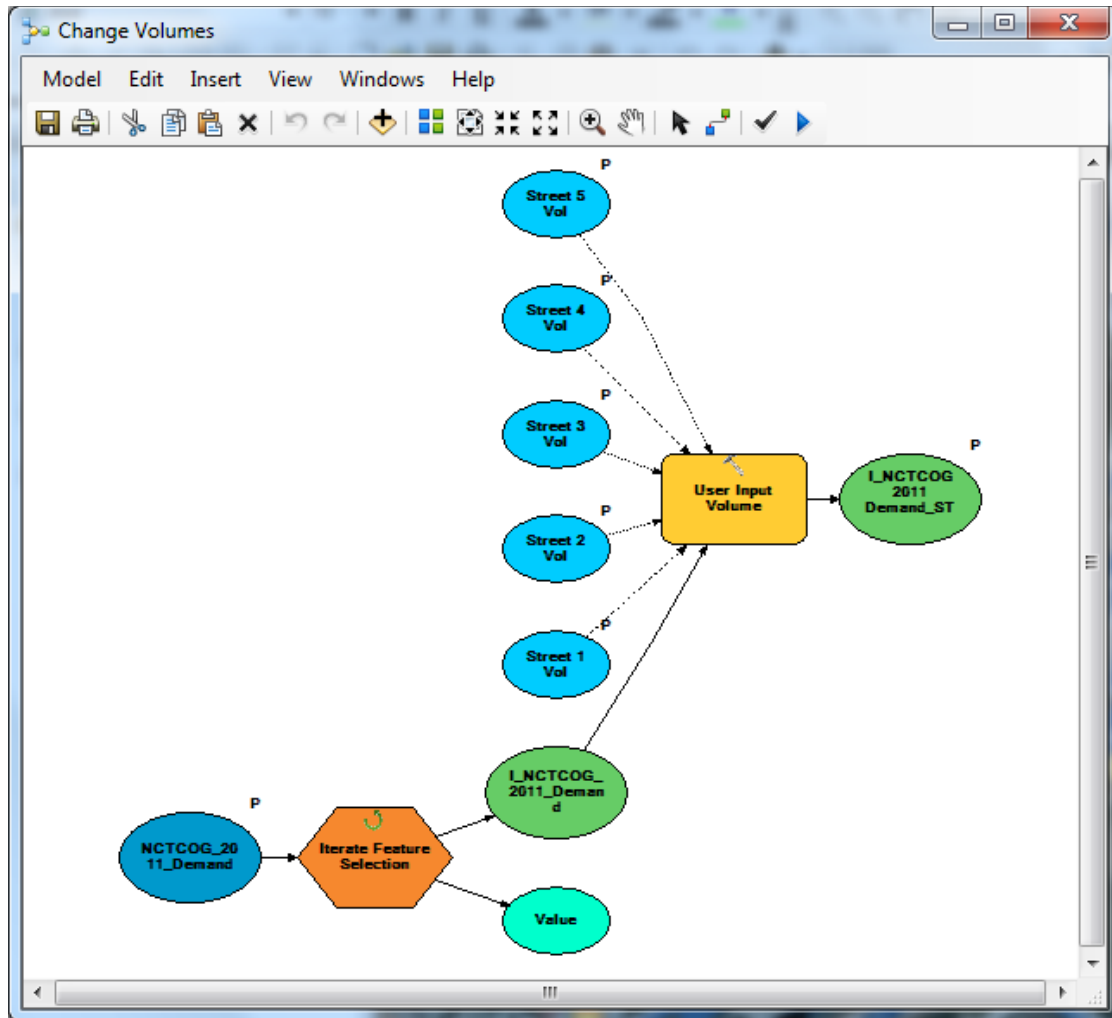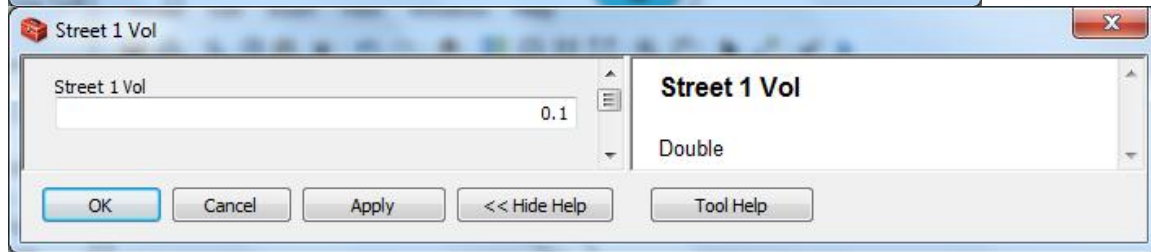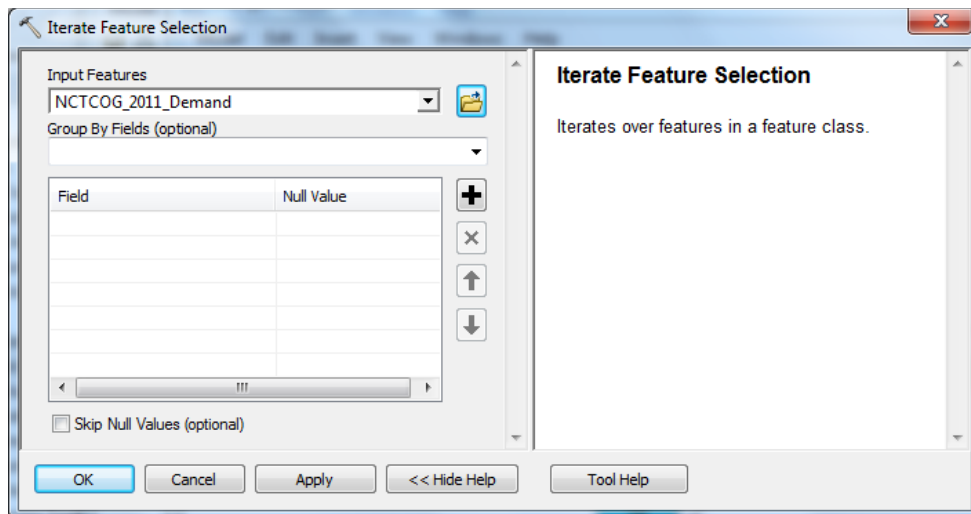
User Input Volume and User Input Lanes are both Calculate Field Tools.
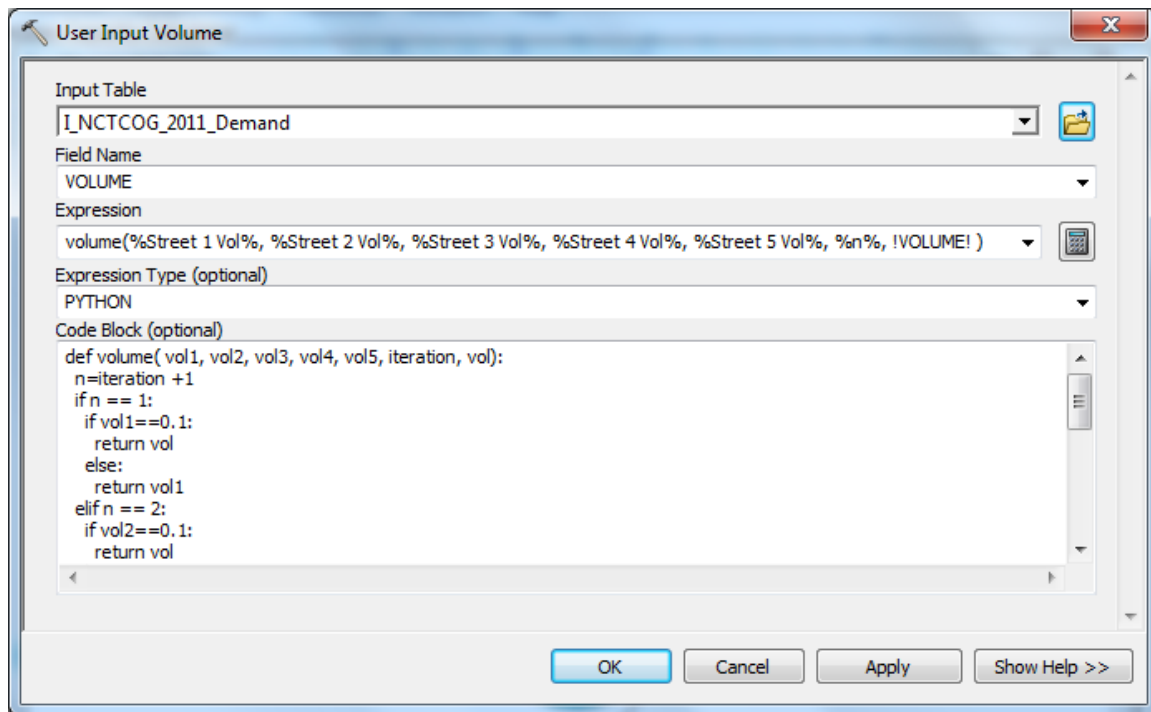
Expression:

volume(%Street 1 Vol%, %Street 2 Vol%, %Street 3 Vol%, %Street 4 Vol%, %Street 5 Vol%, %n%, !VOLUME!)

Code Block:

```python
def volume( vol1, vol2, vol3, vol4, vol5, iteration, vol):
 n=iteration +1
 if n == 1:
  if vol1==0.1:
    return vol
  else:
    return vol1
 elif n == 2:
  if vol2==0.1:
    return vol
  else:
    return vol2
 elif n == 3:
  if vol3==0.1:
    return vol
  else:
    return vol3
 elif n == 4:
  if vol4==0.1:
    return vol
  else:
    return vol4
 else:
  if vol5==0.1:
    return vol
  else:
    return vol5
```
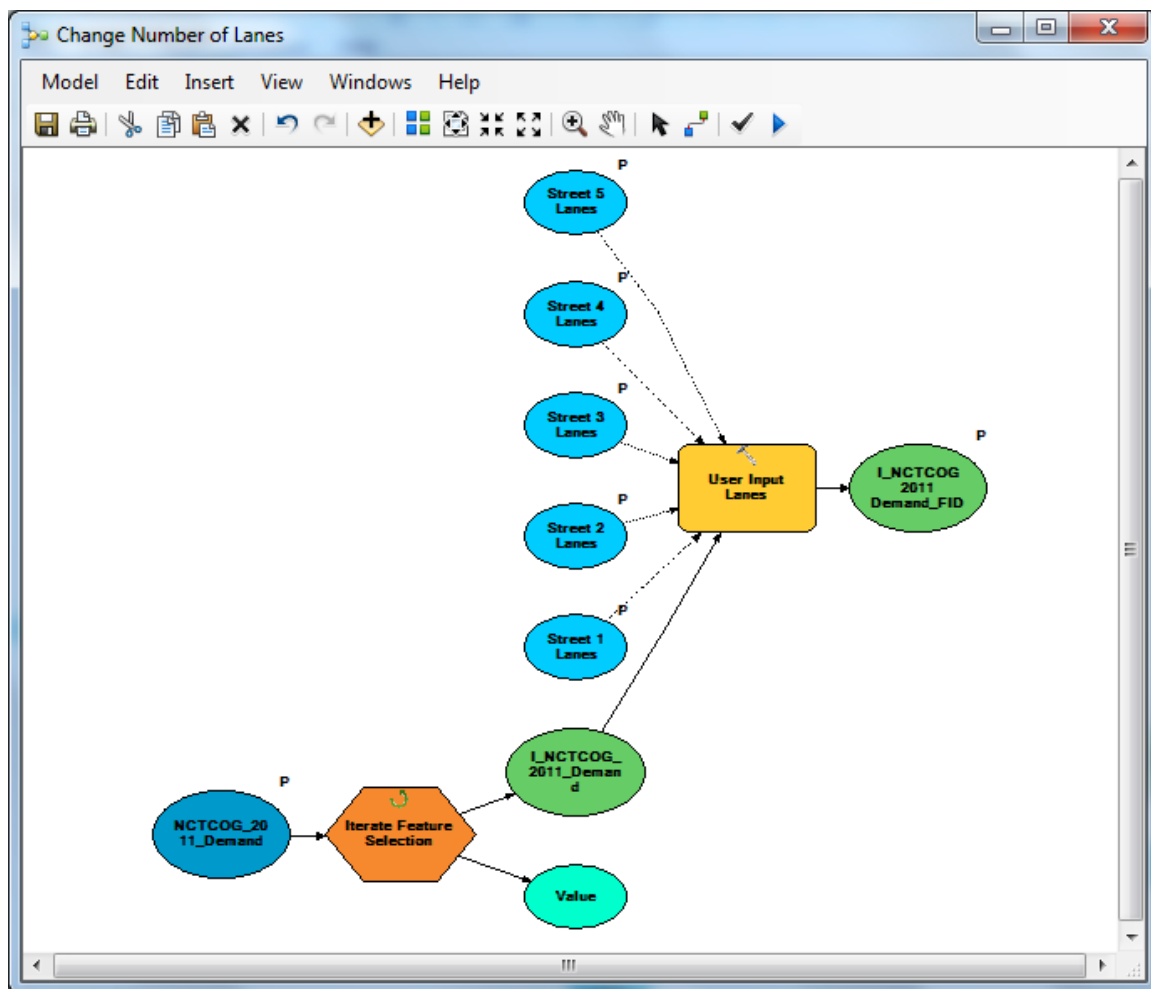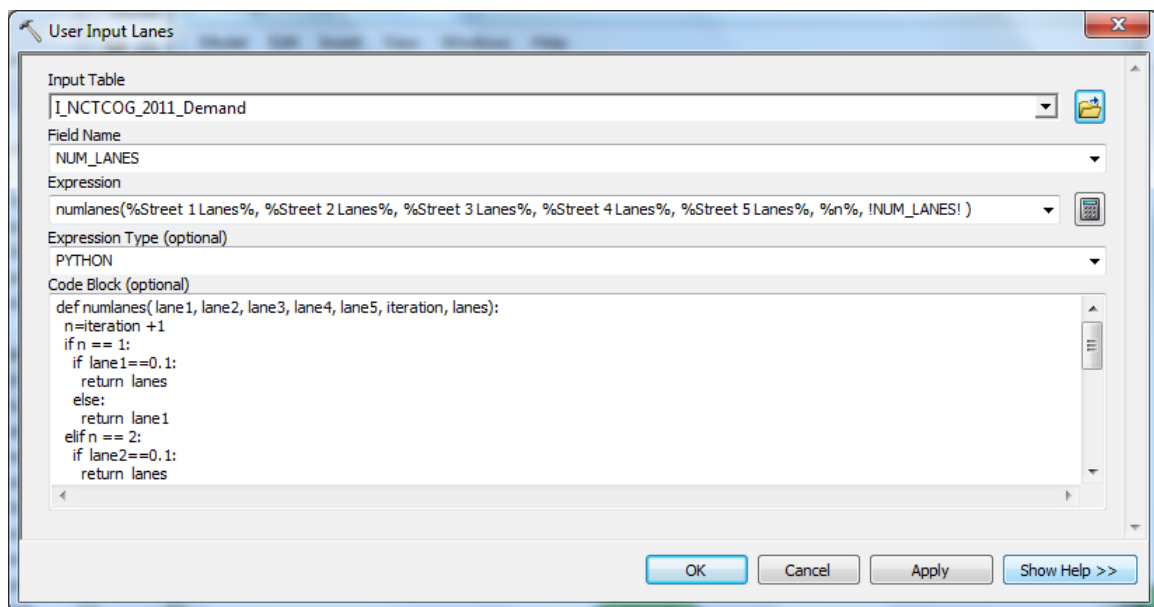
Expression:

numlanes(%Street 1 Lanes%, %Street 2 Lanes%, %Street 3 Lanes%, %Street 4 Lanes%, %Street 5 Lanes%, %n%, !NUM_LANES!)

Code Block:

```
def numlanes( lane1, lane2, lane3, lane4, lane5, iteration, lanes):
  n=iteration +1
  if n == 1:
    if  lane1==0.1:
      return  lanes
    else:
      return  lane1
  elif n == 2:
    if  lane2==0.1:
      return  lanes
    else:
      return  lane2
  elif n == 3:
    if lane3==0.1:
      return  lanes
    else:
      return  lane3
  elif n == 4:
    if  lane4==0.1:
      return  lanes
```
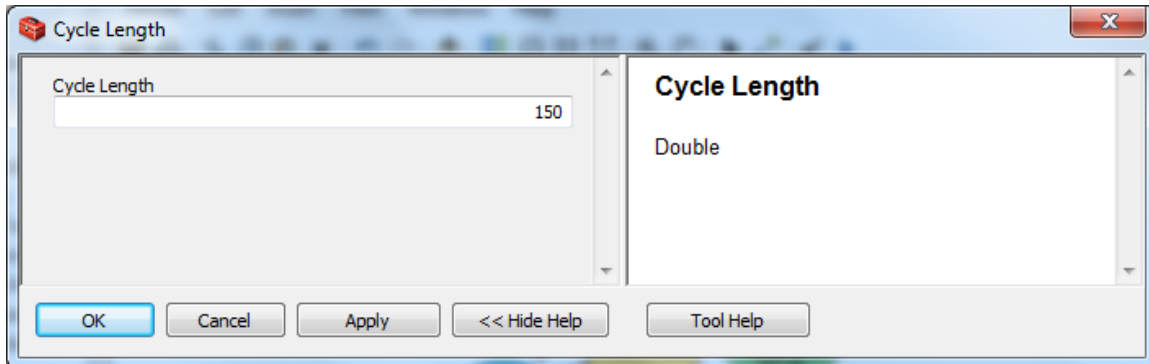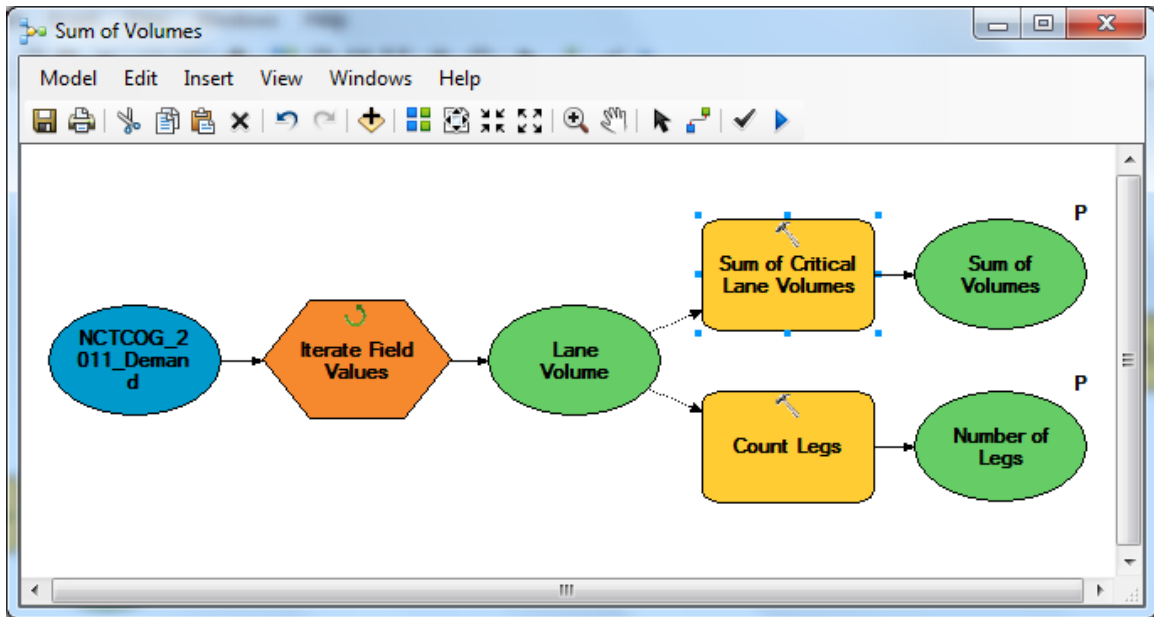
```
    else:
      return  lane4
  else:
   if  lane5==0.1:
      return  lanes
   else:
      return  lane5
```

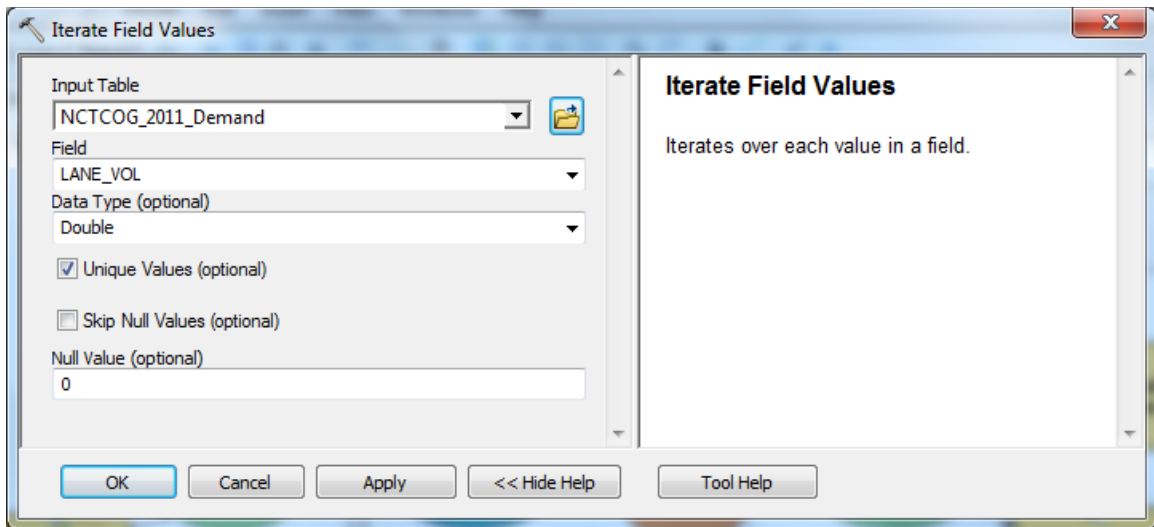Calculate Lane Volume is another Calculate Field Tool.
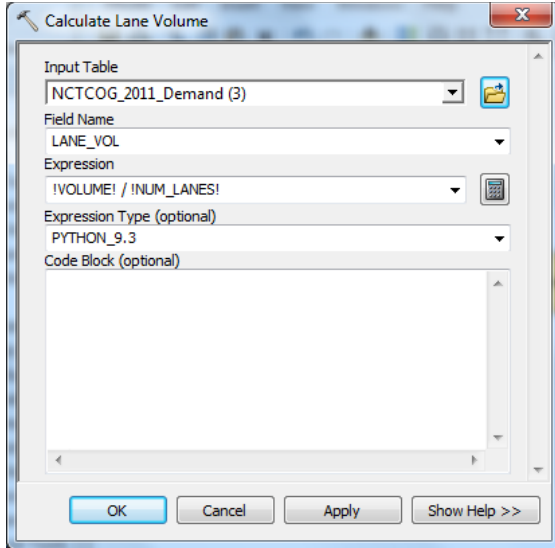
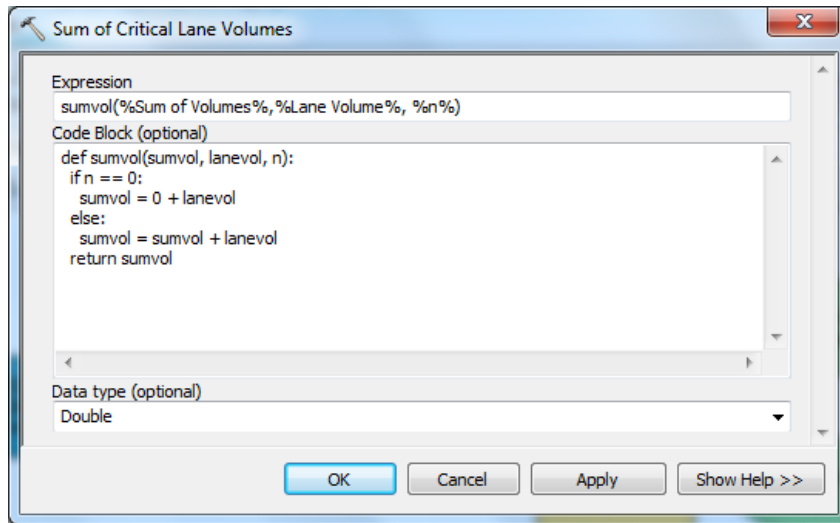

Cycle Length should be a double.

Sum of Volumes uses Iterate Field Values to sum Lane Volumes.

Sum of Critical Lane Volumes and Number of Legs are model only Calculate Value Tools.
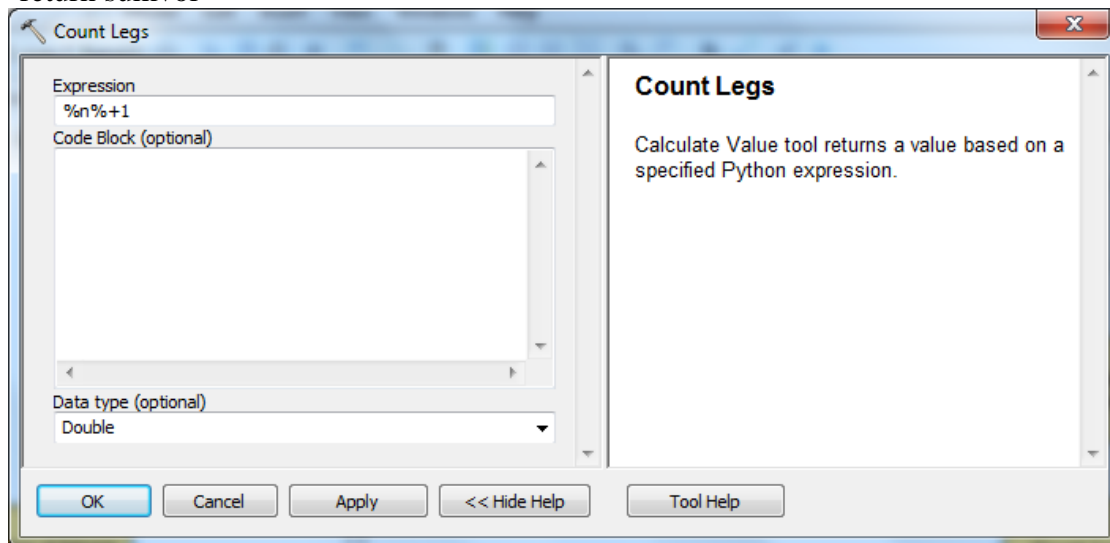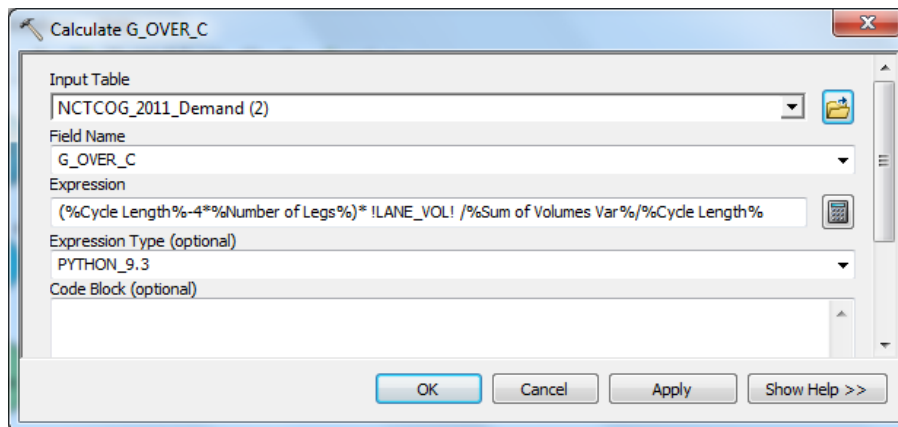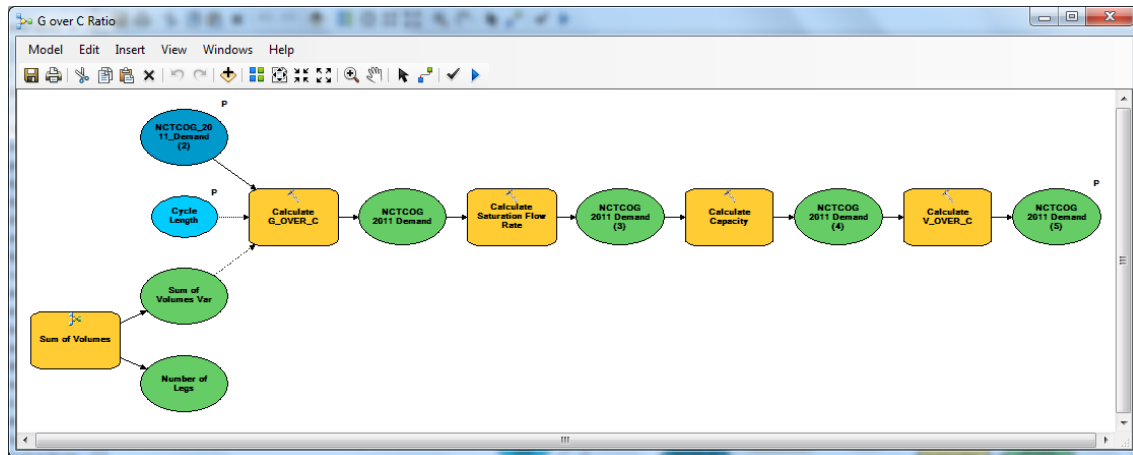

Expression:

sumvol(%Sum of Volumes%,%Lane Volume%, %n%)

Code Block:

```
def sumvol(sumvol, lanevol, n):
  if n == 0:
    sumvol = 0 + lanevol
  else:
    sumvol = sumvol + lanevol
  return sumvol
```
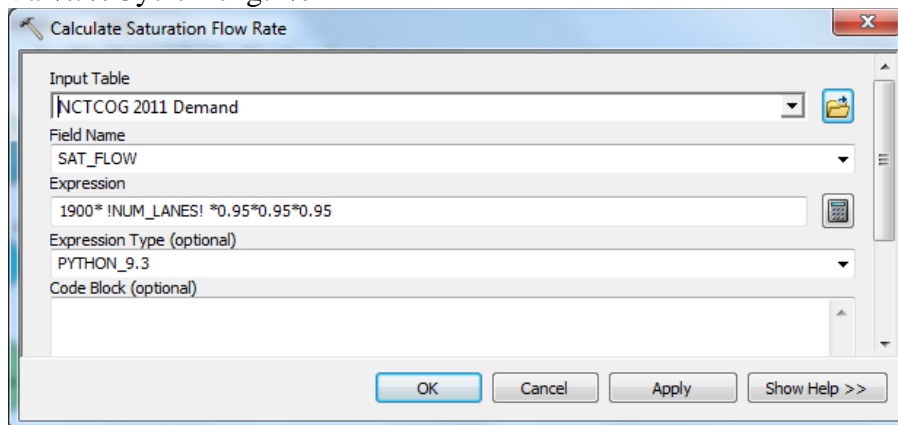
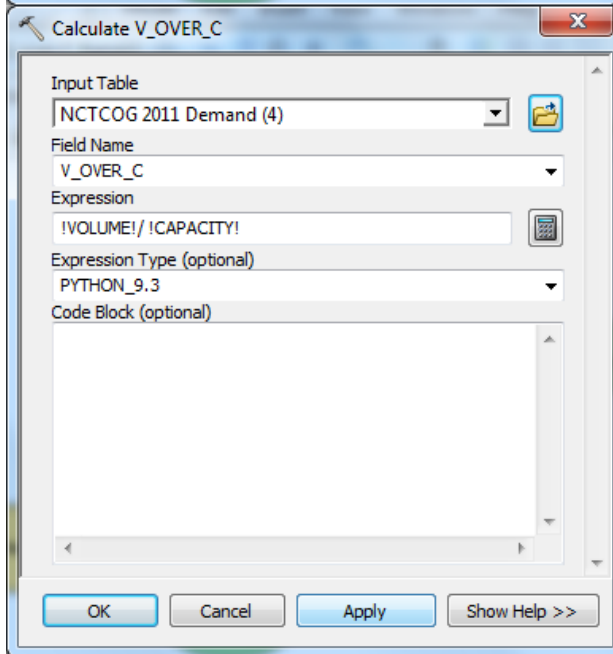The rest of the model is a series of Calculate Field Tools.

Expression:
 (%Cycle Length%-4*%Number of Legs%)* !LANE_VOL! /%Sum of Volumes
Var%/%Cycle Length%

Expression:
1900* !NUM_LANES! *0.95*0.95*0.95

Calculate Capacity

Input Table
NCTCOG 2011 Demand (3)

Field Name
CAPACITY

Expression
!SAT_FLOW!* !G_OVER_C!

Expression Type (optional)
PYTHON_9.3

Code Block (optional)

OK   Cancel   Apply   Show Help >>

Calculate V_OVER_C

Input Table
NCTCOG 2011 Demand (4)

Field Name
V_OVER_C

Expression
!VOLUME!/ !CAPACITY!

Expression Type (optional)
PYTHON_9.3

Code Block (optional)

OK   Cancel   Apply   Show Help >>

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Vita

Jack Bringardner was born in Westerville, Ohio on March 11, 1989 to Betsy and Michael Bringardner. His brother is Mark Bringardner. After graduating from Westerville South High School he attended the Ohio State University. There he received his Bachelor of Science in Civil Engineering with a focus on transportation in the Summer of 2011. He started graduate school at the University of Texas at Austin in Fall of 2011. After receiving a Master's of Science in Engineering he plans to enter the PhD program at UT Austin.

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