GIS TOOLS TO ESTIMATE
AVERAGE ANNUAL DAILY TRAFFIC

Final Report

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16. Abstract

This project presents five tools that were created for a geographical information system to estimate Annual Average Daily Traffic using linear regression. Three of the tools can be used to prepare spatial data for linear regression. One tool can be used to calculate a connectivity importance index for the streets of a city. The main tool can be used to conduct linear regression to estimate Annual Average Daily Traffic. The tools were created for ArcGIS 10 using open-source python scripting.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

Annual Average Daily Traffic (AADT) is the total annual volume of traffic passing a point in both directions divided by 365. It is not feasible to continuously monitor every street to collect annual volumes. Research has shown that AADT can be estimated using linear regression with observed data for a sample of locations. The observed data is usually only collected for a short-duration (typically 48 hours) using pneumatic-tube counters that are moved throughout a city. For example, Figure ES-1 shows where traffic engineers have collected short-duration counts since 2005 in Moscow, Idaho.
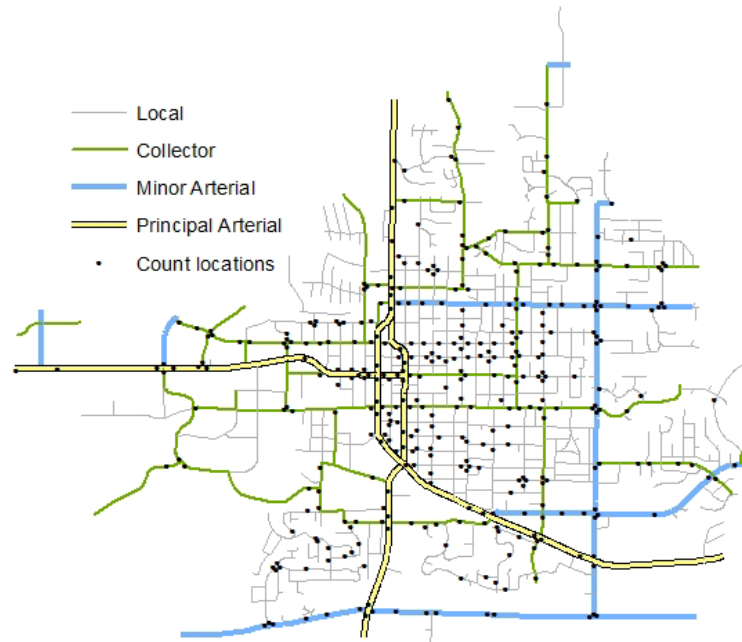
Figure ES-1. Short-duration count locations in Moscow, Idaho

This report introduces five tools that were created for a geographic information system (GIS) to estimate AADT. Three of the tools are preparation tools used to prepare geographic data for linear regression. Two of the tools conduct analysis. One of the analysis tools calculates a connectivity importance index for every street in a network. The resulting index can be used with linear regression to estimate AADT. The other analysis tool executes the linear regression and is the primary tool from this project. Figure ES-2 shows the interface for this tool, called "Estimate AADT." The user provides the input street file with the observed

AADT data and identifies characteristics of the street links as explanatory variable(s) for the regression. For example, the analyst might include as explanatory variables the number of lanes, speed limit, and adjacent land use. Figure ES-3 shows the output from the tool.

Figure ES-2. Tool Interface

Figure ES-3. Regression Results

INTRODUCTION

Annual Average Daily Traffic (AADT) is the total annual volume of traffic passing a point in both directions divided by 365. AADT value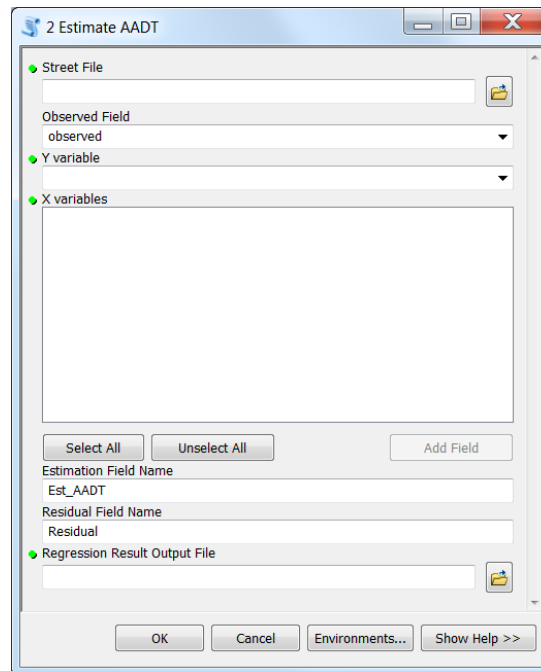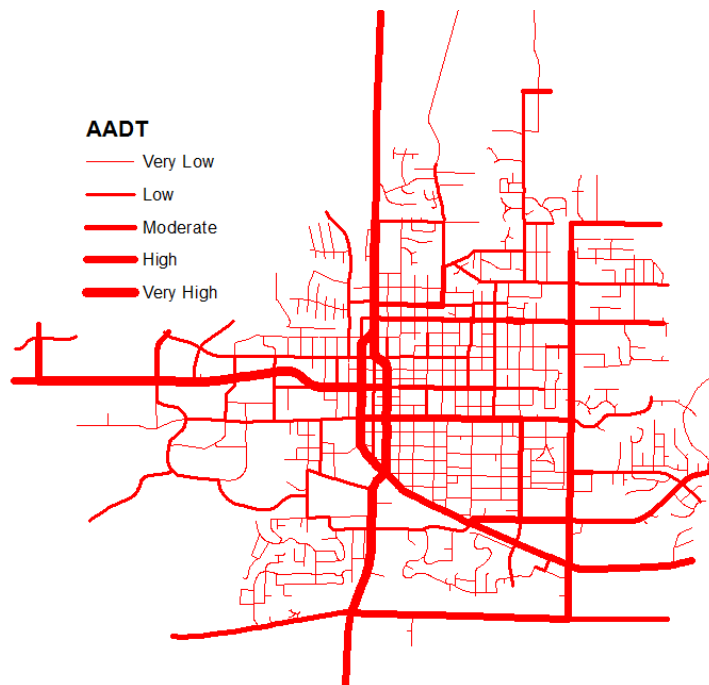s are critical for numerous transportation planning and traffic engineering activities, including assessing level of service, scenario analysis, accident analysis, prioritization of capital investments, before and after evaluation studies, trend analysis, and regional travel demand model validation.

It is not feasible to continuously monitor every street in a community to obtain annual volumes, so typically AADT is approximated from "short-duration counts" (usually for 48 hours). However, it is still very time consuming and expensive to install and reinstall short-duration counters, such as pneumatic tubes, throughout a city. For this reason researchers have explored using linear regression to estimate AADT based on characteristics of the roadway and adjacent area, such as functional classification, number of lanes, speed limit, or population density (Anderson et al. 2006).

Problem Statement

Despite promising results in academic literature, linear regression is not used very often in practice. One reason might be the lack of tools to help manage and analyze the large amounts of spatial data that is needed. Another reason might be that for many communities the potential roadway explanatory variables such as number of lanes, speed limit, or adjacent employment density do not exhibit enough variability to get reliable linear regression results. For example, if most of the street segments have just one lane, then "number of lanes" is a useless explanatory variable for running a linear regression. To be useful, an explanatory variable needs to have variability, and the variability needs to be correlated with AADT.

Two innovations might improve the feasibility of using linear regression to estimate AADT. First, is to create tools for geographic information systems (GIS) to help manage the data and execute the linear regression. Most communities have access to GIS software and many already have shapefiles with roadway attributes that could be used in the linear regression. Second, is to develop new metrics for roadway segments that exhibit greater variability

across roadway segments. For example, researchers have developed metrics for "street connectivity" that provide a score for every link in a roadway network, and the scores have been shown to have high correlation with traffic volumes (Hillier, 1996).

Project Goals

This project focused on two goals:

- create a set of GIS tools to estimate AADT based on linear regression, and
- create a tool for quantifying street connectivity that can be used as an explanatory variable for linear regression to estimate AADT

The next section provides a literature review of AADT estimation and methods to quantify connectivity. This is followed by a section that introduces the five new tools that were created. The final section provides conclusions and suggestions for future research.

LITERATURE REVIEW

AADT Estimation

There are three areas of research concerning AADT estimation: expanding short-duration counts to annual values (e.g., Tang et al. 2003), forecasting future-year counts from historical values (e.g., Jiang et al. 2006), and spatially extrapolating counts from one location to another. This project deals with the third research area, i.e., the spatial extrapolation of counts. It is noted that forecasting future-year counts from historical data is a very common activity, but not addressed as part of this project.

A simple approach to spatial extrapolation is to use characteristics of the roadway and surrounding area to create a model for one location that can be transferred to another location. (A more complex approach is to use a large scale travel demand model, such as the ubiquitous 4-step model.). An example of a simple model is provided by Mohamad et al. (1998) wherein multiple linear regression is used to estimate AADT for the county roads throughout the state of Indiana using four explanatory variables: county population, total arterial mileage of the county, whether the road is urban or rural, and whether the road is

close to a state highway or not. The resulting R-squared was 0.77. Six other explanatory variables were explored, but did not improve the model.

Anderson et al. (2006) developed a model with five explanatory variables for a small community in Alabama, including functional classification, number of lanes, population within a half mile, employment within a half mile, and whether the road is a through street or destination street. The resulting R-squared was 0.82.

A series of studies explored dozens of explanatory variables for the non-state roads of Florida. In the first study, Xia et al. (1999) specified a model with functional classification, number of lanes, area type, auto ownership, whether the road is close to a state highway or not, and nearby employment. The resulting R-squared was 0.60. Zhao and Chung (2001) improved the R-squared to 0.82 by including a few sophisticated GIS-derived accessibility measures. The model was improved even further by Zhao and Park (2004) through geographically weighted regression (GWR). GWR exploits the spatial aspect of observations to produce more locally specific model parameters.

Recently, researchers have demonstrated another technique that exploits the spatial aspect of observations, called kriging, wherein AADT is estimated for unobserved locations through spatial interpolation of observed locations. Eom et. al. (2006) demonstrate kriging for Wake County, North Carolina using five explanatory variables: functional classification, number of lanes, area type, median income, and speed limit. Wang and Kockelman (2009) demonstrate a similar model for the state highways of Texas. Selby and Kockelman (2011) show that kriging can reduce average-absolute-error by 16%–79%, depending on the data and model specification used.

The high R-squared achieved in these studies suggests that for the particular study area, the explanatory variables could provide a satisfactory estimate of AADT. However, for many communities, the explanatory variables found in these studies would exhibit very little variation and therefore poor estimation power. For example, small communities typically have streets with fairly uniform characteristics such as speed limit, number of lanes, and adjacent land use.

Quantifying Connectivity Importance

Dill (2004) reviews various methods to quantify street connectivity. This project focused on an innovative technique called space syntax, which has recently experienced considerable discussion in planning, architecture, and spatial sciences, especially in Europe, but very little attention in the transportation field in the United States (Raford, 2009). Space syntax was developed by architect Bill Hillier and colleagues to quantify the configuration of hallways and rooms in a building and was later extended to analyze the open space of outdoor urban environments (Hillier, 1996).

Space syntax allows the calculation of various measures of configuration and connectivity. One measure called "local integration" is intended to represent how integrated (i.e., important) a street segment is in terms of movement across the entire network (integration is a modified form of "betweenness centrality" in graph theory).

A number of studies have analyzed small scale layouts, like buildings or downtown areas, and found a strong correlation between integration and pedestrian volumes (Hillier et al. 1993; Raford and Ragland, 2004). A handful of studies have attempted large scale analysis of whole communities to calculate the correlation between integration and vehicle volumes. For the most part, the large scale studies have focused on the theoretical implications that space syntax reveals about urban form, spatial cognition, and movement, with little or no emphasis on the implications for estimating AADT. For example, three urban form studies (Peponis et al., 1998; Penn et al., 1998; Jiang, 2009) compared integration with vehicle flow rates observed for short periods (between five and sixty minutes) at locations throughout Atlanta, Georgia and London, England. The studies focused on analyzing different types of urban form for different subareas. The analysis produced R-squared values between 0.06 and 0.77, depending on the street configuration of the subarea.

These results are remarkable considering integration is calculated solely from street configuration and does not take into account any information about roadway characteristics, adjacent land use, or origin-destinations. However, the low R-squared for certain subareas indicates that integration alone cannot explain the variability in observed vehicle volumes.

Abhijit (2009) suggests the correlation might be improved if the calculation for integration were to include information about land use or origin-destinations.

NEW GIS TOOLS

Overview

This project developed five new GIS tools. The tools are written in open-source python script and compatible with the Basic License of ArcGIS® 10. The tools are organized in an electronic folder for easy sharing and distribution. The tools can be run directly from a CD or USB flash drive, but it is preferable to copy the tools to the hard drive to achieve faster execution.

Figure 1 shows the folder structure for the new tools. The subfolder for the GIS tools called "ExampleData" contains example shapefiles. The subfolder called "ToolData" is critical for operation and should not be modified. It contains subfolders for special python libraries, a scratch folder, the python scripts, supporting shapefiles, and output symbology. Advanced users wishing to modify the GIS tools can open the python scripts with text-editing software, such as notepad.
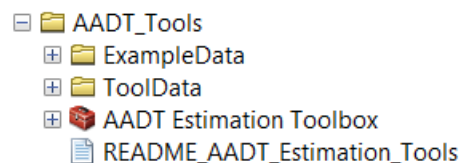

Figure 1. Folder Structure for GIS Tools

The five GIS tools are organized in two "toolsets" within the AADT Estimation Toolbox. Figure 2 shows the toolbox organization and the following subsections describe each tool. The Help Files are presented in Appendix B.
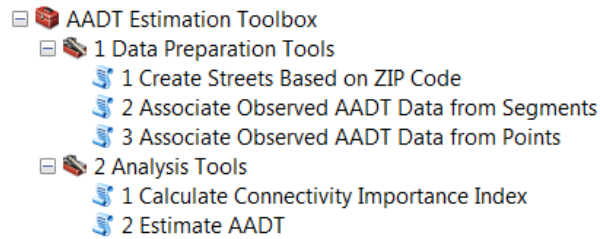
Figure 2. AADT Estimation Toolbox

Data Preparation Tools

Create Streets Based on ZIP Code

The first tool in the data preparation toolset is called "Create Streets Based on ZIP Code." The tool creates a polyline shapefile for a specified zip code or set of zip codes in Idaho. Figure 3 shows the interface. The user provides a set of contiguous zip codes and a name for the resulting shapefile. This tool is intended for communities that do not have a polyline shapefile for the streets of their community. This tool is especially useful because the resulting street network has correct topology which is required to use the tool "Calculate Connectivity Importance Index." More information about topology is provided in Appendix A.
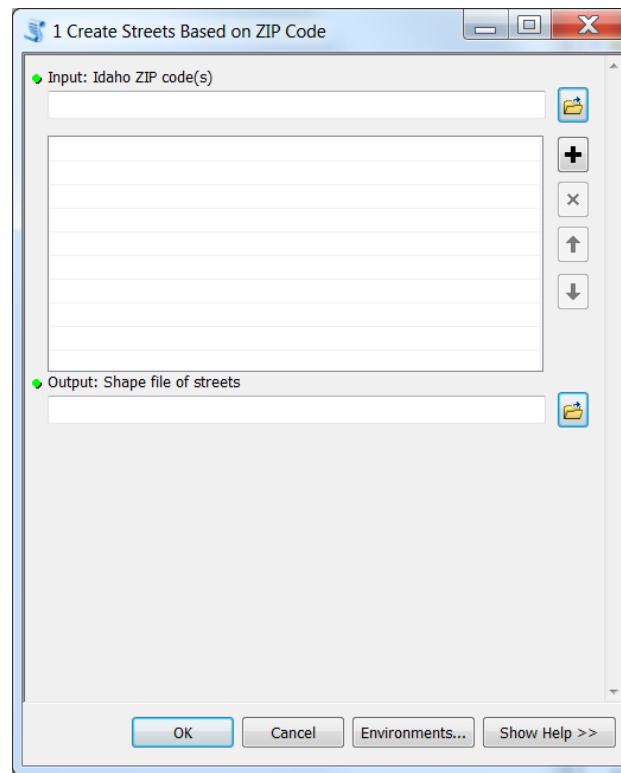
Figure 3. Interface for "Create Streets Based on ZIP Code"

Associate Observed Segment AADT Data

The next tool is called "Associate Observed Segment AADT Data." This tool is intended to be used with the segment AADT available through the Idaho Transportation Department (ITD). Every year ITD provides a polyline shapefile of selected roadways. Each roadway segment has attributes for AADT and the percentage of commercial traffic. Figure 4 shows the interface for the tool and Figure 5 shows the output. There are many streets in Figure 5 where AADT was not observed.
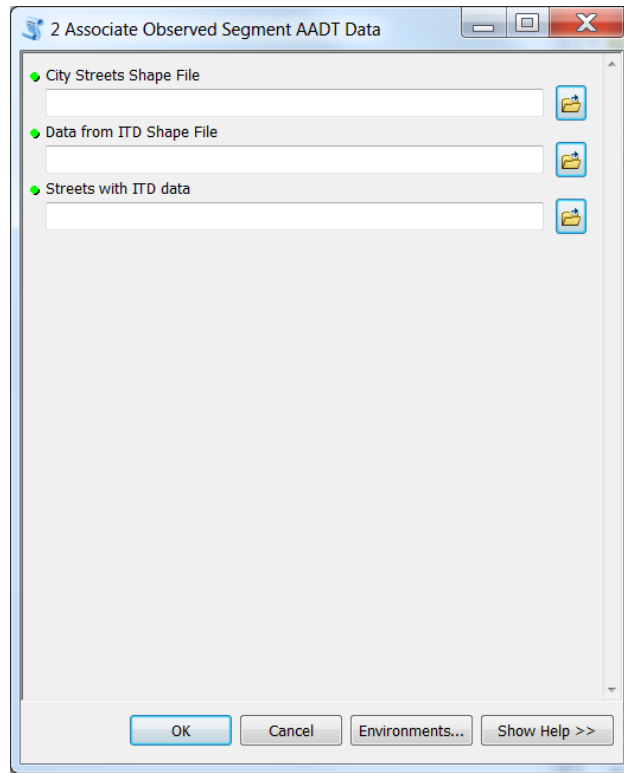
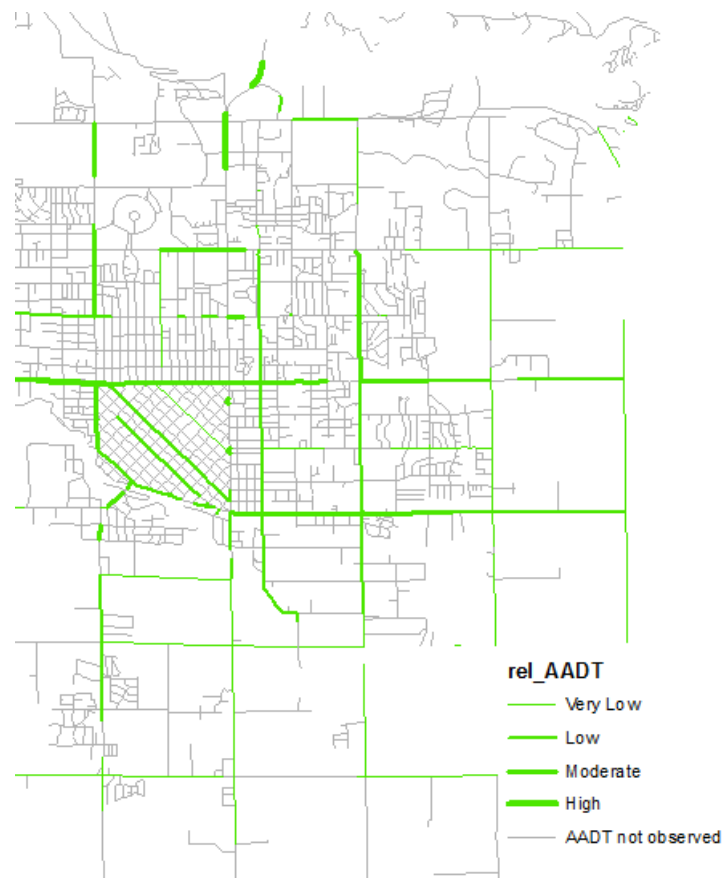**Figure 4. Interface for "Associate Observed Segment AADT Data"**

Figure 5. ITD's Segment AADT Data Associated with a Street File

Associate Observed Point AADT Data

The third data preparation tool is called "Associate Observed Point AADT Data." This tool is intended to be used with a community's count data. For example, the City of Moscow periodically installs pneumatic-tube counters throughout the city to collect short-duration coverage counts, which are adjusted to approximate AADT. Figure 6 shows 341 count locations scattered throughout the city since 2005. The city engineers choose locations to collect coverage counts based on specific needs for various studies or simply in an effort to maintain periodic monitoring. Figure 7 shows the interface for the tool.
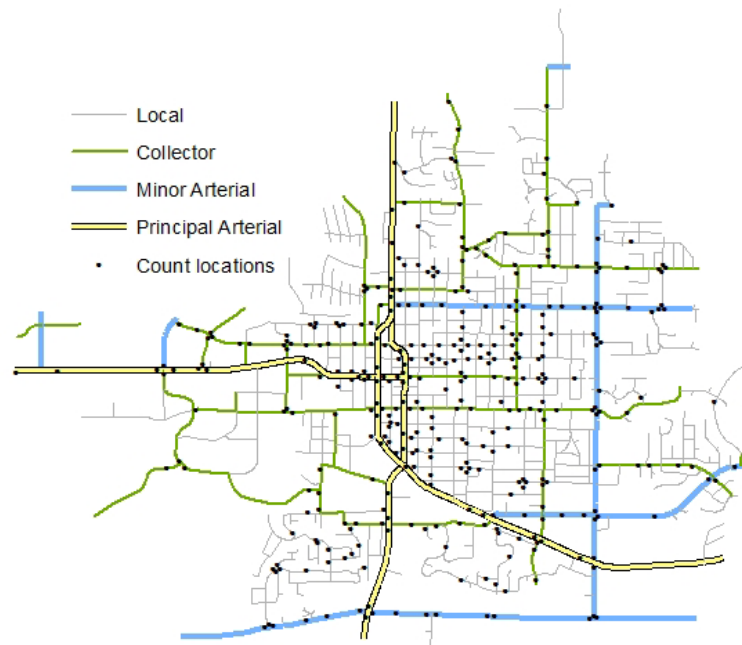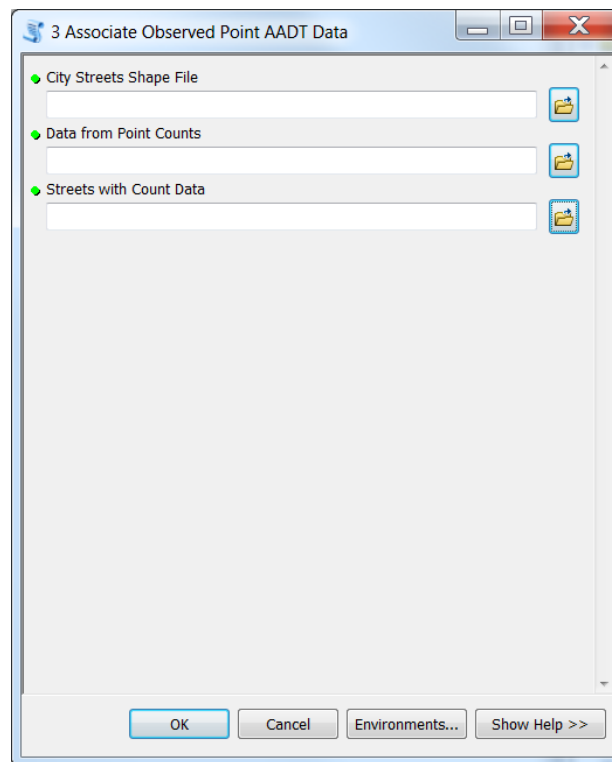
Figure 6. Street Network and 341 Count Locations

Figure 7. Interface for "Associate Observed Point AADT Data"

The observed AADT for the city of Moscow demonstrates the need for using new metrics, such as street connectivity, to conduct linear regression analysis. Table 1 summarizes the observed AADT by functional class and reveals significant variation in AADT within each functional class, especially for local streets and collectors. The variation cannot be explained through typical AADT estimation variables, such as number of lanes, speed limit, and adjacent land use because these variables are fairly uniform within functional class for the case study community. Indeed this is the motivation for the "Calculate Connectivity Importance Index" that is explained in the next section.

Table 1. AADT by Functional Class for the Case Study Community

functional class	road miles* (%)	number of count locations	observed AADT			
			min	max	mean	std. dev
local	63	150	62	4,878	773	758
collector	19	107	197	11,441	3,756	2,563
minor arterial	9	47	379	8,234	3,640	2,112
principal arterial	8	37	6,338	21,738	12,087	3,964

* 89 miles total

Analysis Tools

Calculate Connectivity Importance Index

The first analysis tool is called "Calculate Connectivity Importance Index." The interface is shown in Figure 8. The user provides a street shapefile and identifies the speed limit field. (Note this tool requires a street network with correct topology. See Appendix A for more information about topology.) Next, the user of "Calculate Connectivity Importance Index" must choose a calculation method (see Figure 8). There are three calculation methods to choose from: (1) Betweenness Centrality, (2) Space Syntax, (3) Origin-Destinations.

Betweenness centrality, method 1, is a graph theory technique to quantify the "importance" of a link in a network. The calculation is made by identifying the shortest path from every node in the network to every other node in the network. Betweenness centrality is the number of times a link is used amongst all the shortest paths.
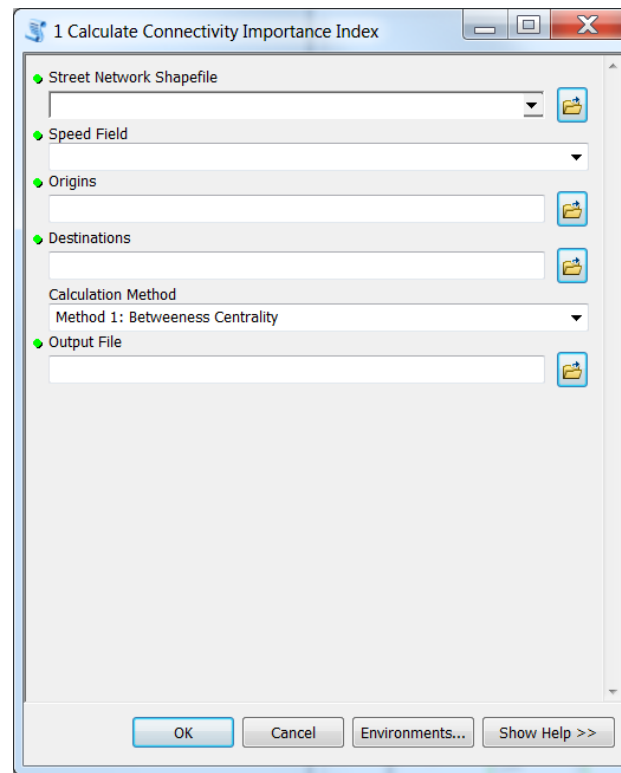
Figure 8. Interface for "Calculate Connectivity Index"

Space syntax, method 2, is a modification of betweenness centrality. The first step of space syntax is to identify "axial lines" that represent unobstructed lines of sight or movement through open space. Various methods for delineating axial lines have been proposed. Thomson (2003) proposed using continuity of angular direction (i.e., through-movement) and other linear attributes to distinguish axial lines. For "Calculate Connectivity Importance Index," axial lines are defined based on street name (i.e., links with the same name constitute an axial line). With the axial lines defined, the tool calculates the betweenness centrality for the axial network. In space syntax terminology this is called global integration. Previous research has demonstrated a correlation between vehicle volumes and integration (see "Literature Review").

The first two methods do not use any land use data for the calculation. Instead the connectivity importance index is based entirely on spatial configuration of the network. The third method is a novel calculation that incorporates land use information. The method requires the user to provide a shapefile for origins and a shapefile for destinations (see Figure

8). The shapefiles can be polygons or points. For example, the origins might be the residential parcels for a city and the destinations might be the commercial parcels. Figure 9 shows the residential parcels (origins) and commercial parcels (destinations) for Moscow, Idaho.
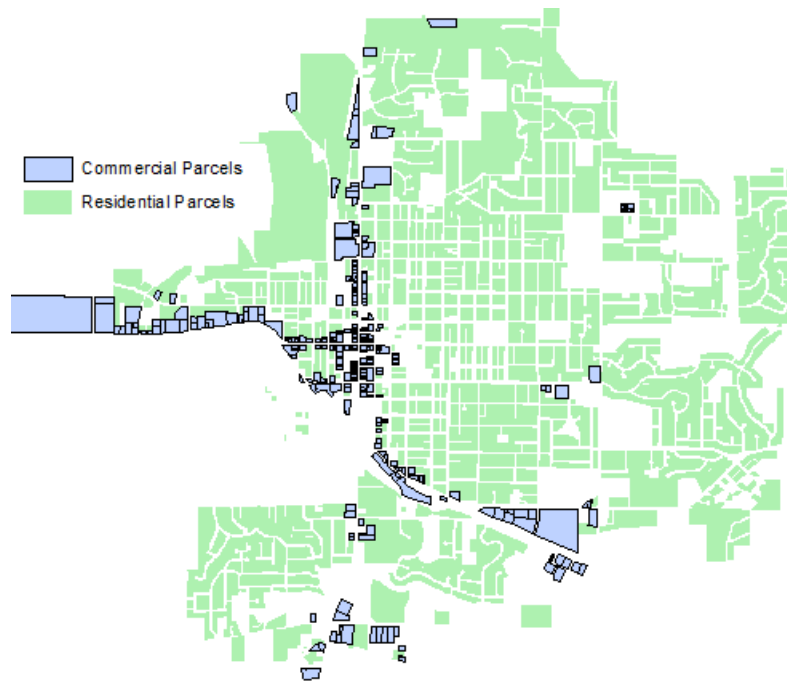
Figure 9. Origins and Destinations for Moscow, Idaho

In method 3, the connectivity importance index that is calculated is similar to betweenness centrality except that the shortest paths that are included in the calculation are for every origin to every destination. Figure 10 shows the results of "Calculate Connectivity Importance Index" for Moscow, Idaho using method 3. As is expected, the streets with a high index (49–100) are the arterials.
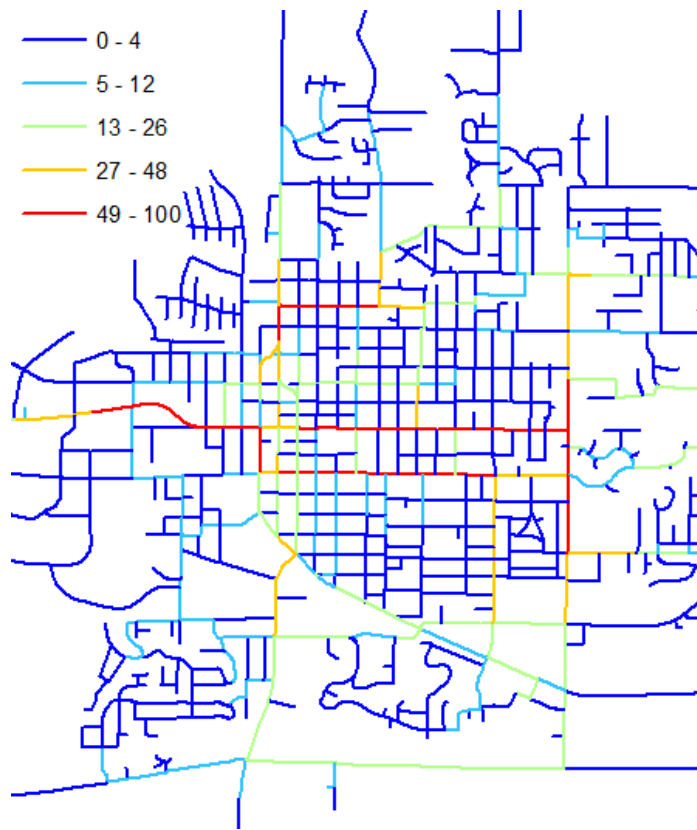
Figure 10. Connectivity Importance Index for Moscow, Idaho

Estimate AADT

The second analysis tool is called "Estimate AADT." The tool uses linear regression to estimate the AADT. The interface is shown in Figure 11. The user provides a street shapefile with observed AADT data for some of the links. Next, the user identifies any number of explanatory variables. Two new fields are created for the estimated AADT and the residual for the street links with observed data. The user can choose the name of the new fields. The user also specifies the location of an output text file that contains the regression statistics, such as R-squared value, the coefficients, and the p-values for the coefficients. Figure 12 shows the results for Moscow, Idaho using the following explanatory variables: functional classification, number of lanes, and connectivity importance index. The R-squared value is 0.72. In this example, all three explanatory variables were statistically significant.
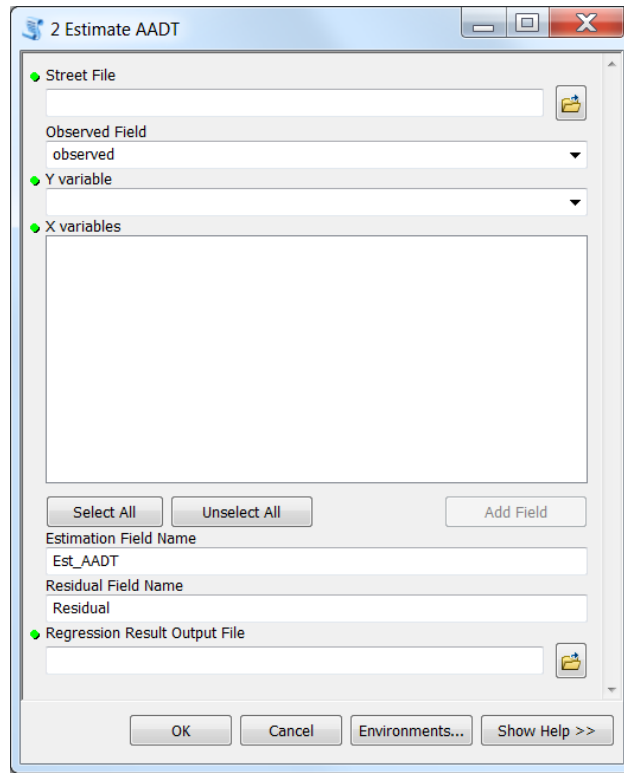
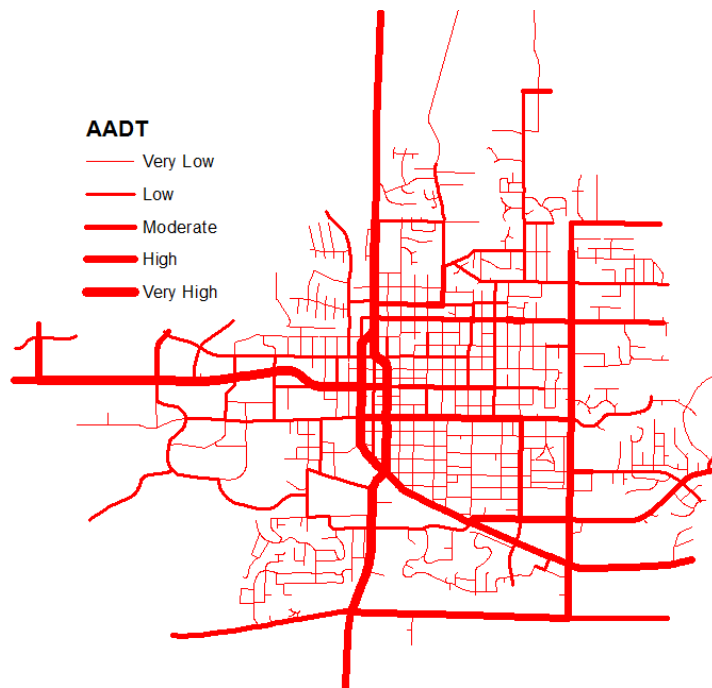**Figure 11. Interface for "Estimate AADT"**

Figure 12. "Estimate AADT" Results for Moscow, Idaho

CONCLUSIONS

This project successfully created a set of GIS tools for estimating AADT based on linear regression. All five tools are easy to use and include help files for explanation of the required input and resulting output. One of the tools calculates a connectivity importance index for every street link in a network. Creating this tool was a key goal for this project because the index varies across links and is correlated with AADT and therefore improves the results from the linear regression.

Future work could focus on improving the connectivity importance index. One possible improvement might be to address external-to-internal and internal-to-external travel, since the current tool considers only internal-to-internal travel. Furthermore, the method for identifying the shortest path could be improved to be more realistic, since the current tool does not consider turning penalties or intersection control.

The regression tool could be improved by automating the process to find the best model. For example, the user could provide a large set of explanatory variables and the tool could execute the "best subsets procedure" to find the best model fit. Other improvements to the tool might be discovered through a systematic testing of data from a variety of cities with different characteristics.

Finally, this tool could be extended to other aspects of AADT estimation, namely the projection of AADT for a future-year based on historical observations. It is widely known that the most significant factor in predicting AADT is the AADT from previous year(s). Typically future-year predictions are determined through a growth factor applied to a previous year observation. The tool described in this report is focused on estimating AADT at locations where observations were never made. However, future work could investigate how to the connectivity index might help improve future-year predictions. Most likely the regression analysis would need to consider auto-correlation because of the time series nature of including AADT from previous year(s).
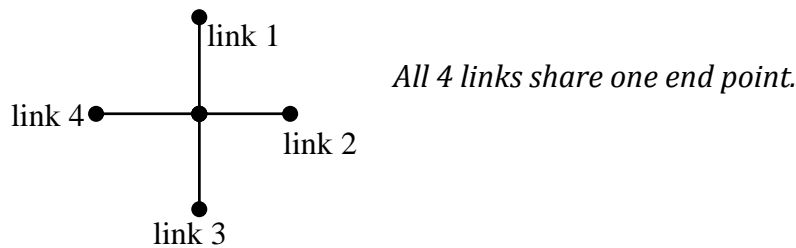
ACKNOWLEDGMENTS

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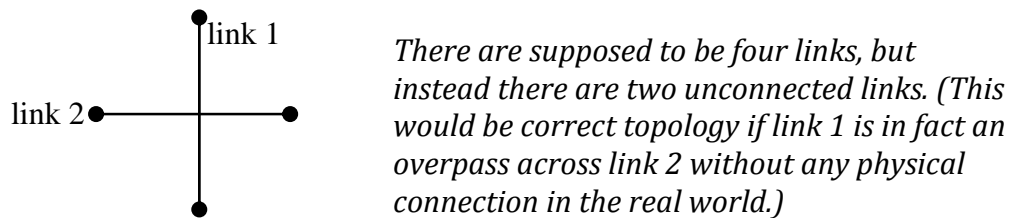
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Zhao, F., and Chung, S. (2001). "Contributing Factors of Annual Average Daily Traffic in a Florida County: Exploration with Geographic Information System and Regression Models." *Transportation Research Record: Journal of the Transportation Research Board*, 1769(-1), 113-122.
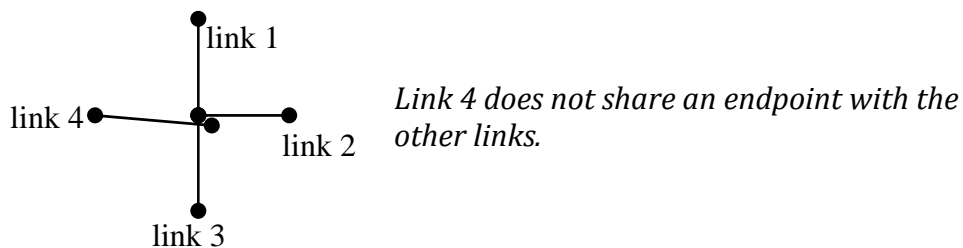
APPENDIX A: TOPOLOGY REQUIREMENT

The new GIS tool "Calculate Connectivity Importance Index" requires correct topology for the street network. This is not a trivial requirement and anyone familiar with GIS knows that obtaining correct topology can be very time intensive. Correct topology means that connections (i.e., shared endpoints) between links are correctly represented with the GIS shapefile. Figure A-1 shows examples of correct and incorrect topology.

All 4 links share one end point.

a. Correct topology

There are supposed to be four links, but instead there are two unconnected links. (This would be correct topology if link 1 is in fact an overpass across link 2 without any physical connection in the real world.)

b. Example of incorrect topology (missing connection)

Link 4 does not share an endpoint with the other links.

c. Example of incorrect topology (misaligned connection)

Figure A-1. Examples of Incorrect and Correct Topology

Many communities have street-centerline files with incorrect topology. Although there are existing ArcGIS tools to fix incorrect topology, we developed the new tool called "Create Streets Based on ZIP Code" to quickly provide a street file with correct topology. The user of the tool provides contiguous zip codes. The output is a street network with "near" correct topology. The user finalizes the output by deleting "isolated links" that are not connected to the main network (and perhaps other links that are not desired for the analysis area). Although it may be time consuming to delete links, in most cases this clean-up process will be much quicker than correcting the topology of an incorrect centerline file.

Figure A-2 shows the output of a "Create Streets Based on ZIP Code." Note that a few streets need to be deleted because they are not connected to the main body of the network and others need to be deleted because they are outside of the desired study area.
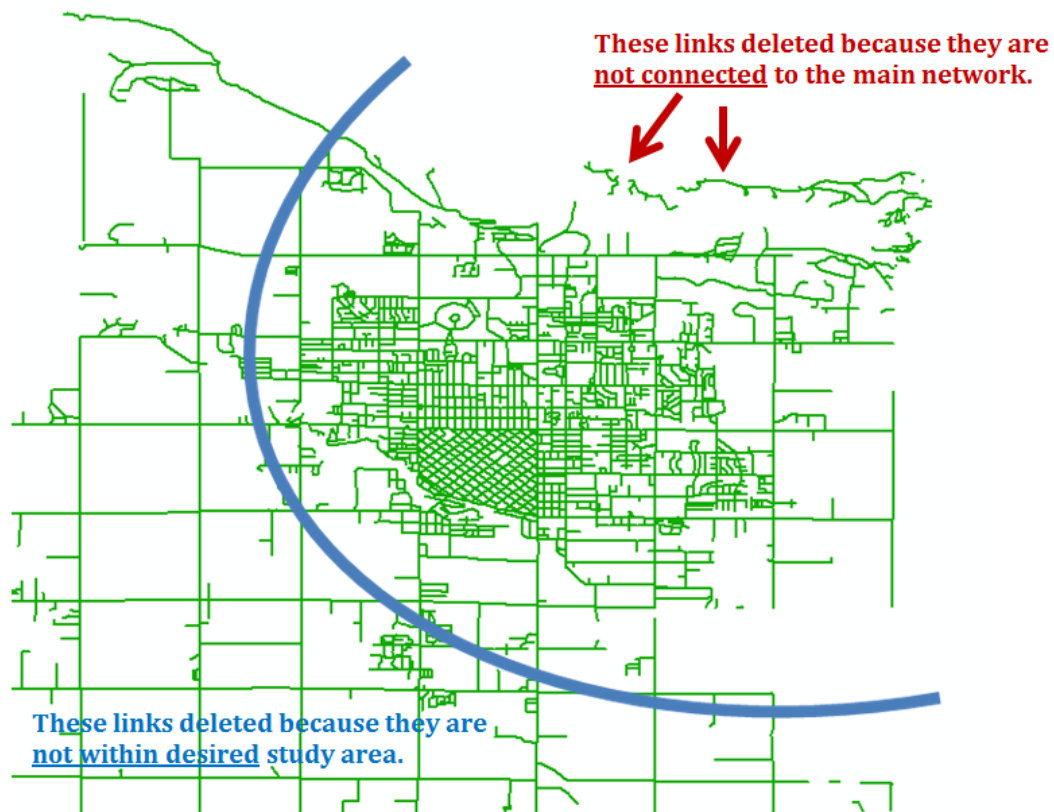

Figure A-2. Deleting Links to Assure Correct Topology

APPENDIX B: HELP DOCUMENTATION FOR TOOLS

Help documentation for each tool can be accessed by clicking "Tool Help" on the interface as shown in Figure B-1 or by right-clicking the tool and choosing "Item Description" shown in Figure B-2. The difference is that "Item Description" includes images. This appendix reproduces the item description in this order:

- Create Streets Based on ZIP Code

- Associate Observed Segment AADT Data

- Associate Observed Point AADT Data

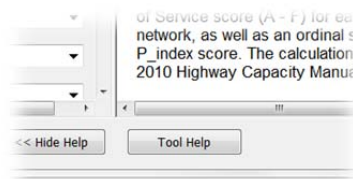- Calculate Connectivity Importance Index
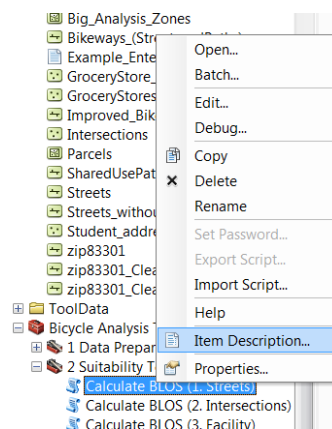
- Estimate AADT

Figure B-1. Tool Help Button

Figure B-2. Item Description Button

Title   **Create Streets Based on ZIP Code**

Summary

Creates a feature class containing street links for specified zip codes.

⚠ **Caution:** The output is a street network with correct topology, but requires deleting "isolated links" that are not connected to the main network and links that are not part of the analysis area. Although it may be time consuming to delete links, in most cases this clean-up process will still be much quicker than fixing the topology of a poorly designed street centerline file. The ExampleData shows a streetfile before and after links are deleted.

📒 **Note**: This tool works only for zip codes in the state of Idaho. The zipcodes need to be contiguous.

Usage

This tool creates street links with correct topology. The output can be used with the tool "Calculate Connectivity Importance Index."

Syntax

CreateStreets (Zipcodes, Output__Clipped_Steets)

Parameter	Explanation	Data Type
Zipcodes	**Dialog Reference** Provide zip code(s) from which to create a streets file.	Multiple Value
Output__Clipped_Steets	**Dialog Reference** Name and folder directory for the output feature containing the newly created street links. The output is a street network with correct topology, but requires deleting "isolated links" that are not connected to the main network and links that are not part of the analysis area. Although it may be time consuming to delete links, in most cases this clean-up process will still be much quicker than fixing the topology of a poorly designed street centerline file. The ExampleData shows a streetfile before and after links are deleted.	Feature Class

Credits

Title   **Associate Observed Segment AADT Data**

Summary

Associates AADT data from a polyline shapefile to a community's street file. The Idaho Transportation Department has AADT data polyline shapefiles for selected locations across the state.

⚠️ **Caution:** ITD's roadway segments may not match up perfectly with your city streets shapefile. It is advised that you inspect the results for any irregularities.

Usage

This tool is intended to be used with ITD's polyline shapefile. Any year of data could be used.

Syntax

AssociateSegmentData (CityStreets, SegementData, Output_Shapefile)

Parameter	Explanation	Data Type
CityStreets	**Dialog Reference** Polyline street file that needs observed AADT Data.	Feature Class
SegementData	**Dialog Reference** Polyline segment AADT data from ITD.	Feature Class
Output_Shapefile	**Dialog Reference** The output polyline street file with AADT.	Feature Class

Credits

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Title   **Associate Observed Point AADT Data**

Summary

Associates AADT data from a point shapefile to a community's street file.

⚠ **Caution:** The tool associates the closest point to a street link, in other words, additional point data beyond the closest is not be included.

Usage

This tool is intended to be used with a city's count data from collections points.

Syntax

AssociatePointData (CityStreets, PointData, Output_Shapefile)

Parameter	Explanation	Data Type
CityStreets	**Dialog Reference** Polyline street file that needs observed AADT Data.	Feature Class
PointData	**Dialog Reference** Point AADT data. The tool associates the closest point to a street link, in other words, additional point data beyond the closest is not be included.	Feature Class
Output_Shapefile	**Dialog Reference** The output polyline street file with AADT.	Feature Class

Credits

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Title   Calculate Connectivity Importance Index

Summary

Calculates a connectivity importance index according to the chosen method:

Method 1: Betweenness Centrality

Method 2: Space Syntax

Method 3: Origins and Destinations.

⚠ **Caution:** The input street network must have correct topology.

Usage

The connectivity score is intended to be used with linear regression to estimate AADT.

Syntax

CalculateConnectivityIndex (StreetNetwork, Speed, Origins, Destinations, Method, Outputfile)

Parameter	Explanation	Data Type
StreetNetwork	**Dialog Reference** Polyline street file (must have correct topology).	Feature Class
Speed	**Dialog Reference** The field with the speed on each link.	Field
Origins	**Dialog Reference** Polygon or point shapefile representing origins.	Feature Class
Destinations	**Dialog Reference** Polygon or point shapefile representing destinations.	Feature Class
Method	**Dialog Reference** Method 1: Betweenness Centrality, Method 2: Space Syntax, Method 3: Origins and Destinations	
Outputfile	**Dialog Reference** The output file with a new field for connectivity index.	Feature Class

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Title   **Estimate AADT**

Summary

Estimates AADT using linear regression.

Usage

The tool is used to estimate AADT for locations that do not have observed AADT.

Syntax

EstimateAADT (StreetNetwork, Observed, Y_variable, X_variables, EstimatedName, ResidualName, OutputText)

Parameter	Explanation	Data Type
StreetNetwork	**Dialog Reference** Polyline street file (must have correct topology).	Feature Class
Observed	**Dialog Reference** The field that indicates if there is observed AADT.	Field
Y_variable	**Dialog Reference** The field with observed AADT.	Field
X_variables	**Dialog Reference** The field(s) for the explanatory variables.	Field
EstimatedName	**Dialog Reference** The name of the new field with estimated AADT.	Text
ResidualName	**Dialog Reference** The name of the new field for the residuals if there is observed AADT.	Text
OutputText	**Dialog Reference** The output textfile with the regression results.	Text

Credits

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