AN EVALUATION OF TURNING MOVEMENT COUNTS AND ESTIMATION OF INITIAL TURNING PROPORTIONS

A Thesis

by

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ABSTRACT

An analysis on the impact of traffic is required before transportation designs can be performed. This impact analysis is even further supported with a shift towards creating more environmentally sustainable designs. Turning movement volumes are an important variable in traffic impact analysis. They provide the basic input needed in various transportation processes including traffic studies, forecasting, analysis, and determining the operational performance of an intersection. In an urban planning setting, turning movement counts provide the variable needed to properly utilize the four-step modeling process that generates the flow of vehicles in a network. Manual counting of turning vehicles is the most common practice to obtain turning movement volumes, however, this can be an expensive and exhaustive task.

This research provides an evaluation of existing turning movement counts at various intersections in College Station, Texas. Initial turning movement proportion ranges are estimated using definable roadway characteristics, such as lane group and functional classification. These proportions and the intersection approach volumes/AADT are then used to estimate turning movement volumes for the intersection with Hauer's algorithm and a basic proportion distribution method. The accuracy of each turning movement volume estimation is analyzed for the different turning proportions and compared to observing turning movement volumes. Finally, a recommendation is proposed for the range of turning movement proportions to estimate turning movement volumes.

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Contributors

This work was supervised by a thesis committee consisting of Professor Gene H. Hawkins (advisor) and Professor Dominique Lord of the Department of Civil and Environmental Engineering and Dr. Sue Chrysler of the Traffic Operations Group/SAFE-D UTC at Texas A&M Transportation Institute (TTI).

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All other work conducted for the thesis was completed by the student independently.

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CHAPTER I

INTRODUCTION

Before most transportation engineering design projects can begin, an impact analysis of the traffic that will be generated from the project will need to be performed. Also, with the shift towards more environmentally sustainable designs, the traffic impact analysis is even more important. It assesses the impact of added traffic and proposes solutions that allow for basic transportation needs to be met while limiting emission, waste, and other negative environmental impacts. Turning movement counts are an important variable in performing traffic impact analyses. They provide the basic values needed in traffic studies, analysis, forecasting, and in the study of the operational performance of an intersection. Turning movement counts are also important in an urban planning setting. In order to properly use the four-step modeling process, the path that the vehicles flow is important, and the turning movement shows the motion from origin to destination.

Manually counting turning movements, both in-person and by video, is the most common way for obtaining the turning volumes at an intersection. However, this can be an expensive and exhaustive task. Another solution would be to install a detector in each lane for accurate automatic data collection. This, however, is also very expensive. Past research has proposed algorithms for the estimation of turning movement volumes. In order to generate an accurate estimation of the turning volumes, an emphasis was placed on a ‘good’ initial estimation of turning proportions.

This research provides an evaluation of existing turning movement counts at various intersections in Bryan/College Station, Texas. Initial turning movement volumes are estimated using newly proposed techniques and then compared to traditional methods. The accuracy of each turning movement volume estimation is analyzed for the different turning proportions. Finally, a recommendation is proposed for the most accurate estimate of turning movement volumes. Rather than exact values, a reasonable range for the turning movement proportion is presented that gets close to the actual volumes for the turning movement, because of variability in approach volumes over time.

PROBLEM STATEMENT

Manual counting of turning movement volumes can be an expensive and time consuming task. This is, however, the more common way of obtaining turning movement volumes. Past research has proposed algorithm to automate this process, but there is one basic and important factor that is not expanded on: initial turning proportions. They all rely on establishing “good” initial turning proportions for the algorithms to provide accurate volume estimations but do not explain the process of obtaining these proportions. This thesis attempts to do just that by providing recommendations for initial turning proportions and the algorithm that works best with the proportions to give an accurate estimation of turning movement volumes.

RESEARCH OBJECTIVE

The goal of this thesis is to provide an analysis of turning movement volumes at several intersections and introduce methods for generating turning movement proportions that can be used for transportation planning and management purposes. Existing turning movement volumes from multiple intersections, different days of the week, and varying years are evaluated. Initial turning movement proportions are determined from the evaluation of the turning volumes. Obtained intersection approach/AADT volumes are then used to estimate turning movement volumes. Accuracy of the proportions are then evaluated. The objectives for this thesis and an explanation of each is shown below:

- Analyze Turning Movement Counts
    - Evaluate changes to turning movement volumes by year, day of the week and time of the day. Determine average volume of turning movement for each day of the week and time of the day.
- Determine Relationships Between Turning Movement Volume and Approach Volume.
    - Obtain total AADT volumes for the intersection approaches. TxDOT provides a database that includes AADT volumes for most of the intersections that are used in this analysis. The approach volumes come from data obtained from several sources.
    - Determine the initial turning movement proportion based on newly proposed techniques. Some of the techniques that are used are proportion estimates based on functional classification, number of turning lanes at the intersection, day of the week, intersection control, etc. Variability in the proportion estimates are tested with five-minute interval times for each turning movement.
- Estimate Turning Movement Volumes
    - Estimate turning movement volumes for the intersection using each of the initial turning movement proportions calculated from the previous objective. Hauer's

proposed algorithm and a basic proportion distribution method are used to compute the turning movement volumes.

- Check accuracy of estimates and turning movement proportions with observed turning movement counts. After confirmation of accuracy, determine a range for reasonable turning movement proportions from techniques analyzed that can be used to estimate turning movement volumes.

- Present case study identifying the effects that the determined proportion range has on LOS and delay at an intersection and evidence to support other decisions made to achieve the range.

THESIS ORGANIZATION

A description of the thesis organization is presented in this section. Chapter I introduces the research topic, presents the problem that will be analyzed, and outlines the objectives used to come to a resolution. Chapter II gives an insight on the background needed to understand the thesis topic. Several key terms are defined, and a literature review is presented on the studies that are available on turning movement estimation in this chapter. Chapter III details the study methodology. Data organization and analysis are further expanded on along with assumptions made and their justification. This chapter also discusses the software used (JMP/Excel/HCS7) to estimate the turning movement proportion. Chapter IV provides an analysis of the data and results of the estimated proportions from the analysis using the techniques previously addressed. Chapter V presents a summary of the thesis and recommendation for initial turning proportions to be used in turning vehicle movement estimation.

CHAPTER II

LITERATURE REVIEW

Vehicle turning movement volumes are essential in traffic and transportation planning processes, including planning studies, capacity analysis, traffic signal coordination, level of service analysis and signal timing calculation. A common practice of obtaining turning movement counts is through manual collection of data. Figure 1 shows an example of a count sheet that can be used when collecting turning movement data. However, manual collection of turning movement counts is intensive and expensive. The individuals would need to account for as many vehicles moving through the intersection as possible, leading to human error. There has been previous research performed on estimating turning movement counts without the need for extensive manual data collection.

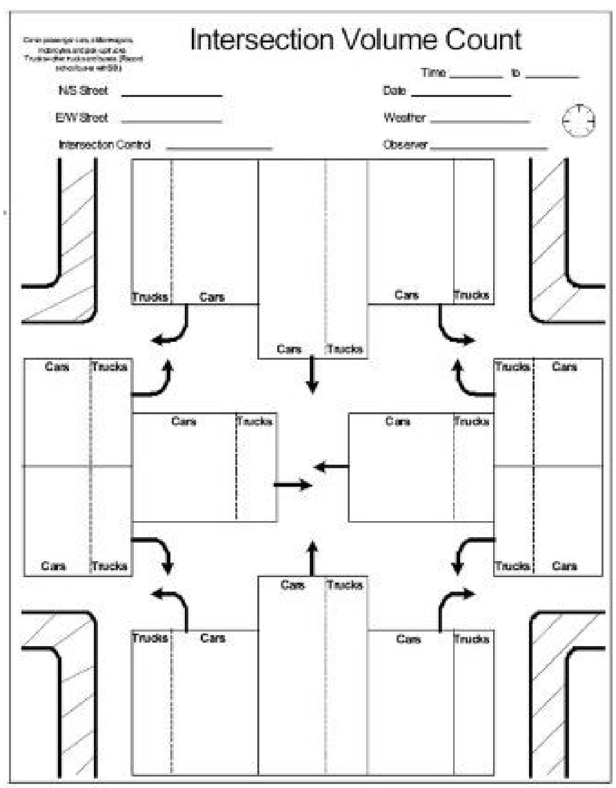


Figure 1 Count sheet for manual turning movement counts.

Several techniques have been suggested for turning movement volume estimation. The first technique studied was performed by Hauer, estimating turning movement volume from automatic traffic counters. The method used for estimation closely followed the algorithm proposed by van Zuylen, and is based on Kruithof's algorithm, first described in the late 1930s (*2*). In the study, Hauer used volumes from automatic counting machines to create a method for estimation of turning volumes (*1*). Automatic counting devices can accurately provide intersection approach volumes but are unable to provide actual turning movements because it would require following individual vehicles as they move through the intersection. Hauer's technique involved identifying most likely traffic flow matrix that match the given automatic counts by using turning proportions. The approach counts are categorized by intersection classification, such as collector and arterial, and turning proportions are estimated from the counts. Estimates of vehicle flows are then determined and compared with observed flow, and the accuracy of the estimation is determined.

Schaefer summarized more of the previous studies conducted on turning movement estimation (*2*). In his paper, he mentioned four techniques that are used to estimate initial turning movement proportions. The techniques mentioned were proportion estimation by type of intersection, historical turning movements, short period counts and average turning proportions. The four "good" methods of initial turning movement proportion estimation were then used to calculate turning movement volumes via the algorithm employed by Hauer (*1*). Schaefer concluded that estimation of turning proportion by type of intersection was best used for the development of turning movement volumes from link volumes when cost and time are prohibitive, the link data is manually smoothed, and peak hour estimation of turning movements are made from average daily traffic model forecasts (*2*). From the historical turning movement technique, the conclusion drawn was that this method of estimation is valid if traffic flow patterns remained constant and historical turning movement data is obtainable for the intersection. The short period counts method is the most accurate technique for estimation, but it requires some manual data collection, which can add to expenses. Finally, from the average turning proportions, a coarse approximation of turning movements can be established but accuracy is limited for low volume intersections.

Davis and Lan proposed two studies on turning movement estimation when less-than-complete counts are available. The first study concluded that estimates generated from less-than-complete counts provide more variable estimation of turning movement than from complete counts (*3*). A Monte Carlo experiment was used to determine that estimation from less-than-complete counts is possible with a recommended required minimum amount of information. The second study proposed two algorithms for turning movement estimation that do not rely on a full set of automatic counters at intersections. Davis and Lan proposed nonlinear least-square (NLS) and quasi maximum likelihood (QML) algorithms to estimate turning proportions and discovered that although both algorithms were able to provide accurate estimations, the QML estimator was a more effective estimator than NLS (*4*).

Chen et al. applied a path flow estimator (using the four-step modeling process) to derive turning movement volumes for a network. The study generated complete link flows and turning movement flows from origin-destination trip tables and traffic counts at certain intersections using nonlinear path flow estimator (PFE) (*5*). The results from the study showed that the PFE method provided favorable estimation of turning movement volumes. The final research studied was by Ghanim and Shaaban. In their research, the relationship between approach volumes and turning movements was used to make predictions for turning volumes with an artificial intelligence approach (*6*). The main goal of the research was to estimate turning movement volumes without the need for any information beyond the approach volumes. An Artificial Neural Network Model (ANN) was trained to estimate turning movement volumes from approach volumes at signalized intersections. The results showed that the ANN model was able to estimate turning movement volumes.

Previous research has provided accurate techniques for estimation of turning movement volumes. This thesis aims to apply the algorithm proposed by Hauer to estimate initial turning movement proportions for the Bryan/College Station area to test the accuracy of turning movement volume estimation from approach/AADT volumes. From the results, a range will be proposed for reasonable turning movement proportions from which turning volumes can be estimated.

BACKGROUND

Before expanding on the analysis of turning movement proportion and providing a recommendation, a review of the background knowledge is presented to better understand this topic. Definitions are provided for the different features of an intersection as well as an introduction to some basic traffic concepts.

INTERSECTION

An intersection can be defined as an area where two or more public roadways join or cross (*7*). Each road coming from the intersection is called the intersection leg. There are several types of intersection of roadways, including at-grade, grade separated, and interchanges. The intersection types focused on in this thesis are at-grade intersections. For these intersections, Level of Service analysis can be used to determine the number of lanes required for each movement of each leg. The purpose of having an intersection is to control the flow of vehicles and prevent traffic deadlock. In order to have an efficient intersection system, consideration must be provided for all modes of transportation.

Intersection Type

At-grade intersections can be broken down into more categories. The basic categories of at-grade intersections are three-leg, four-leg, multi-leg, and roundabout. The traffic counts collected for the Bryan/College Station area exclusively included counts at three-leg and four-leg intersections. Figures 2 and 3 show typical three- and four-leg unchannelized intersections with only one lane in each direction.

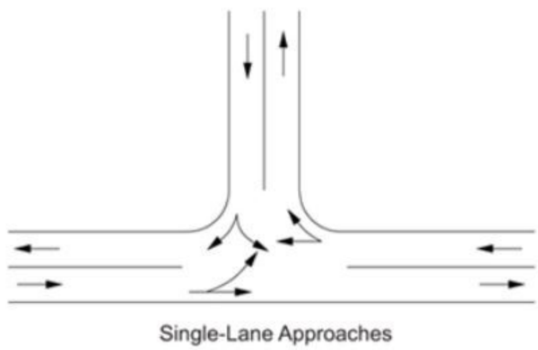


Figure 2 3-leg intersection. Reprinted from (7).

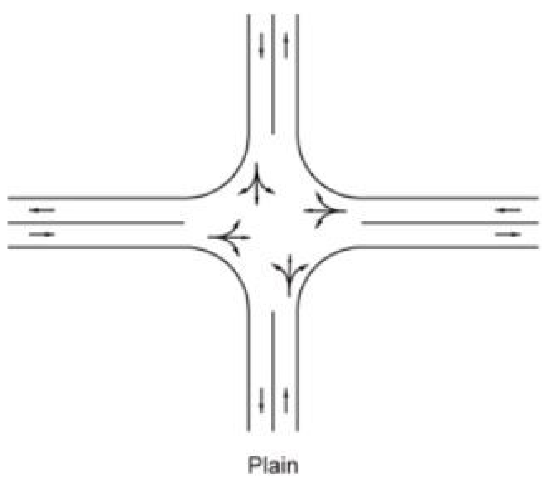


Figure 3 4-leg intersection. Reprinted from (7).

Intersection Control

Intersections can also be further classified by the control that is present at the intersection. Controls determine the manner through which traffic moves through the intersection and the order of service for all modes of transportation. The control types are installed based on the volume of vehicles and speed of the roadway. Common types of intersection controls are: Uncontrolled, Yield Controlled, Stop Controlled, and Traffic Signal Controlled (*8*). Traffic signal controlled, uncontrolled, and stop controlled are the prevailing intersection controls for the roads used in this analysis.

- Uncontrolled - For this type of control there are no signage present. These are typically found on local roads and streets with low volume and speeds.
- Yield Controlled - This control type includes a yield sign at the intersection to guide vehicle movement. It is mostly used in rural low-volume areas and not recommended in locations where pedestrians are expected.
- Stop Controlled - A stop sign controls the intersection for this type. Vehicles are required to stop before entering the intersection. This control is used on lower speed facilities with relatively low and equal peak hour volumes.
- Traffic Signal Controlled - This control is required for roads with large volumes of traffic. A traffic signal is placed to mitigate traffic. Use of this control type results in increased capacity. Signals interrupt heavy traffic to provide service for other traffic movements. However, constant maintenance is required, and increased crashes could be observed at the intersections.

Functional Classification

Intersections are a part of an even larger system that deals with movement of vehicles and access to facilities along the roadway. The legs that make up the intersection of the roadway are classified based on their function. This function can range from access to mobility of the road. Figure 4 shows the relationship between access and mobility as well as the general class of roads that fit within the functionality (arterial, collector, and local).

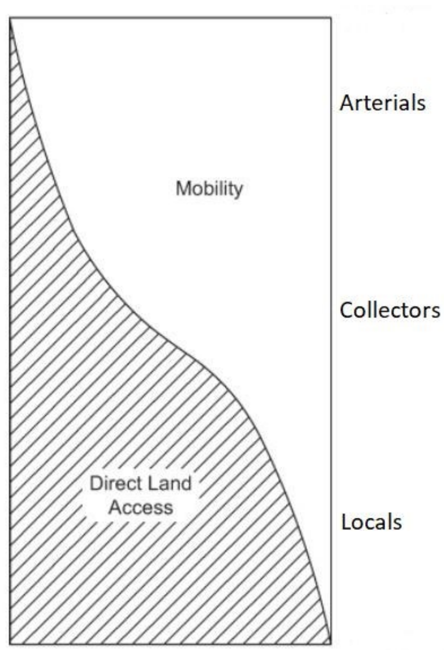


Figure 4 Relationship between access and mobility. Reprinted from (7).

These general classes can be subdivided into groups that reflect the changes in access and mobility. Listed below are the main classifications in order of increasing access and decreasing mobility for an urban area (*7*).

- Principal Arterial - The main objective of principal arterials is to provide a connection between all freeways crossing the city and lower-level roads. Principal arterials can serve as a major center of activities for urbanized areas. They generally have the highest traffic volume corridors, speeds and longest trip desires. Trips entering and leaving urban areas as well as most through movement bypassing the central city are carried on this class of road.

- Minor Arterial - Minor arterial roads also provide connection between freeways and lower-level roads. The main difference from principal arterial is that minor arterials add more emphasis on land access and less on mobility. However, because speed and volume are still high on these roads direct access to local neighborhoods and highly dense areas are not permitted.

- Major Collector - Major collectors make the connection between arterials and local roads. They are proponents of traffic circulation and are able to provide land access to residential, commercial and industrial facilities. This results in medium speeds and high use of traffic signs and signals.

- Minor Collector - Minor collectors provide similar functions with major collectors. They, however, pay more attention to access and have lower speeds. Intersections are more closely spaced on minor collectors and the roads tend to be shorter.

- Local - Local roads have the lowest level of mobility and connect traffic to their final destination. Direct access is provided to adjacent lands and connection to other road classes. Speeds are usually the lowest on local roads and service to through traffic is discouraged.

Figure 5 presents an example of a network that includes the different functional classifications for an urban area. Although useful for analysis, this form of classification does not consider other modes of transportation that are not vehicles. This could result in designs that neglect bicyclists, pedestrians, and other non-motorized vehicles.

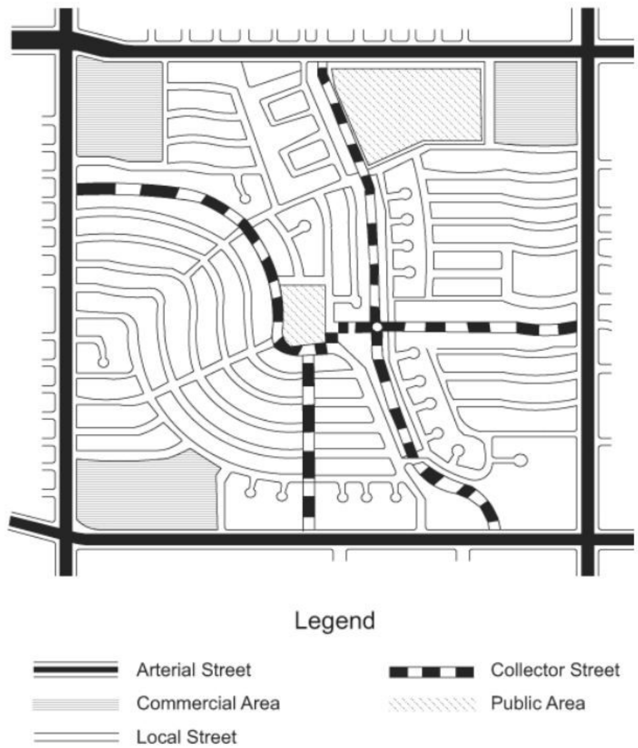


Figure 5 Functional classification in an urban network. Reprinted from (7).

Lane Groups

Lane groups are movements at an intersection that share a stop bar (*9*). Exclusive turn lanes (such as left-turn-only lanes) or shared turning lanes (such as a through lane that also allows right turns) can be used to establish lane groups. HCM 2010 procedure states that intersection capacity should be measured for the critical lane groups (lanes that require most green time). Figure 6 displays all the lane groups that could be present at an intersection.

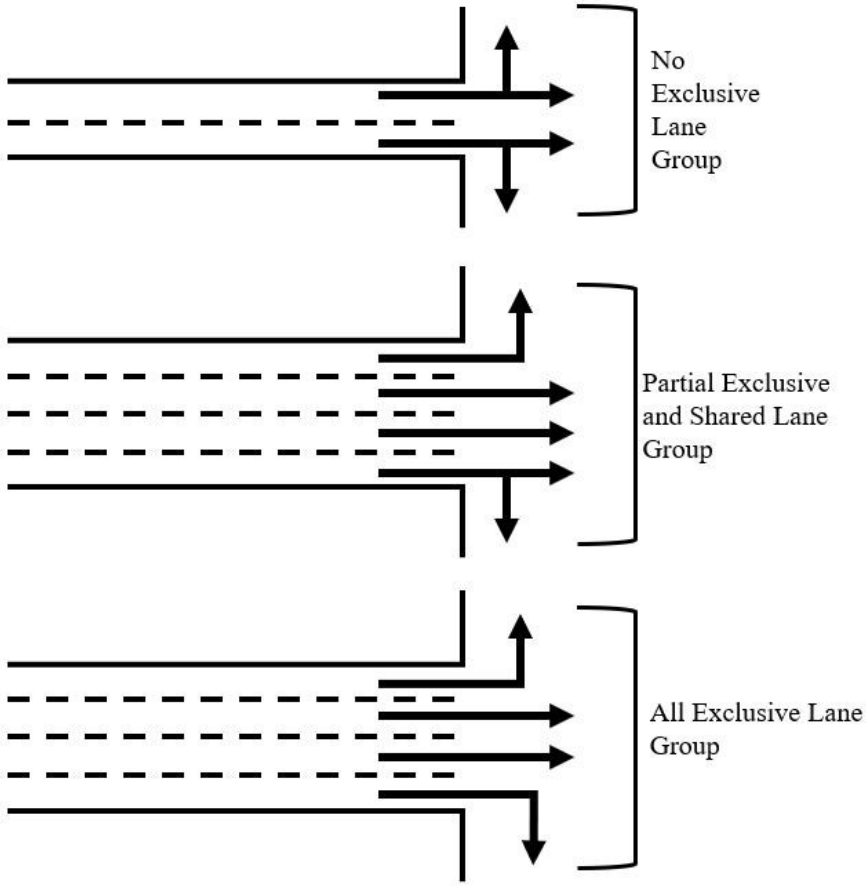


Figure 6 Lane groupings. Adapted from (10).

TRAFFIC CONCEPTS

Some basic traffic concepts that need to be defined for better understanding of the research is presented. These concepts are incorporated into several parts of the project, so it is necessary to provide more information.

Peak/Design Hour

The design hour is an hour within traffic volume that represents a location's peak hour and is used to design signal timing and other elements of a facility (*10*). Peak hour refers to the time period during which the highest volumes of traffic for an intersection is observed. For this research, the peak hour volumes are selected from the traffic counts to perform the analysis for the proportions. The peak morning (AM) and evening (PM) hour volumes are used for the analysis.

Annual Average Daily Traffic

Annual Average Daily Traffic (AADT) estimates the average volume of traffic for all day in a year for a defined segment on a roadway. Several methods are used to find the estimates including a simple average method and the American Association of State Highway and Transportation Officials (AASHTO) method (average of averages). The simple average and AASHTO methods are shown below (*10*). AADT can be converted to design volume in the design hour using the K and D factors.

Simple Average Method:

$$AADT = \frac{1}{n}\sum_{k=1}^{n} VOL_k$$

AASHTO Method:

$$AADT = \frac{1}{12}\sum_{m=1}^{12}[\frac{1}{7}\sum_{j=1}^{7}\left(\frac{1}{n_{jm}}\sum_{i=1}^{n_{jm}} VOL_{ijm}\right)]$$

Where:

VOL_k = daily traffic on kth day of the year

n = number of days in a year (365 or 366)

VOL_{ijm} = daily volume for i^{th} occurrence of the j^{th} day of week within the m^{th} month

i = occurrences of day j in month m for which traffic data are available

j = day of week (1 to 7)

m = month of year (1 to 12)

n_{jm} = number of occurrences of day j in month m for which traffic data are available.

Directional Factor

When AADT is expressed as a design volume for the peak hour, it can be broken down to represent the volume in each direction of the roadway. Directional factor (D-factor) is the volume (expressed as a proportion) of traffic moving in the higher volume direction during the peak hour (*10*). It considers the fact that traffic volume may be split directionally. D-factor is affected by temporal changes. It can be determined from the following equation below.

$$D - factor = \frac{K^{th}\ highest\ volume\ in\ direction}{volume\ in\ both\ directions} x100$$

K-Factor

K-factor represents the proportion of AADT that occurs during the peak hour. There are several ways that the K-factor can be stated. K-30, K-50, and K-100 are some of these ways and they can be defined as the 30^{th}, 50^{th}, and 100^{th} highest hourly volumes of the year respectively (as a percentage of AADT) (*10*). K-factor is calculated as shown below. It is an important factor that is used to reduce the AADT to the design volume.

$$K - factor = \frac{K^{th}\ highest\ volume}{AADT} x100\%$$

Directional Design-Hour Volume

Directional Design-Hour Volume (DDHV) is the volume of traffic that is a proportion of AADT in the direction of the peak hour (*10*). It is determined using AADT, K-factor, and D-factor. DDHV is important in planning and design and is the volume from which the turning volumes will be determined using the initial turning proportions.

$$DDHV = AADT * K * D$$

SUMMARY

This chapter reviewed some background knowledge needed to better understand this research and previous literature that included discussions about tuning movement proportions. The literature review pointed out the algorithms that have been previously proposed and chose Hauer's algorithm to be used by this research because it allowed for more expansion on defining good initial turning proportions. For the review of the background, intersection definition was broken down by roadway characteristics such as intersection type, intersection control, functional classification and lane group. Finally, the basic traffic concepts that were needed for calculations in this research were defined, including peak hour, AADT, K-factor, D-factor, and DDHV.

CHAPTER III

STUDY METHODOLOGY

The primary objective of this research is to determine initial turning movement proportions for intersections based on different roadway characteristics. The main software used for the analysis was Microsoft Excel. A statistical analysis tool, JMP, is also used to perform any statistical analyses. Because of the nature of the software it could be subject to bias in its calculations. An HCM software, HCS7 was the final tool used to calculate the LOS and delay for each of the intersections. This chapter expands on the design for this research study and assumptions that were made for the data.

RESEARCH DESIGN

This research uses Excel sheets of turning movement counts for intersections in the Bryan/College Station, Texas area. A total of 304 sheets were obtained with turning volume information for 100 different intersections throughout the city from 2010 to 2019. A master list was then created, and the data separated into categories that will be used to determine the initial proportions. The peak hour volumes were determined for each intersection and the turning movement proportions were calculated from the peak volumes. Provided below is more detail about the steps that were taken to prepare the data and perform the analysis.

Methodology

A template was developed for how the raw data would be presented to create some organization. Some of the basic parts of the template include date and time of data collection, street name and direction associated with street name, functional classification of roadway, and intersection control. Figure 7 provides the template that was used to organize the raw data.

Team:																
Date Data Collected:	DD/MM/YYYY															
Day of Week:																
Time (AM, Noon, PM):	AM															
Intersection:	Street 1 @ Street 2															
N-S Road[+]:	Street 1															
E-W Road:	Street 2															
Start Time (military)*:	6:45															
	TURNING MOVEMENT COUNT															
	Northbound				Southbound				Eastbound				Westbound			
12:05 AM	Functional Class		Intersection Control		Functional Class		Intersection Control		Functional Class		Intersection Control		Functional Class		Intersection Control	
	Street 1				Street 1				Street 2				Street 2			
Time*	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right	U-Turn	Left	Thru	Right
6:45 AM																
6:50 AM																
6:55 AM																
7:00 AM																

Figure 7 Raw data organization template.

Table 1 provides a summary of the data that was available for the analysis and characteristics of each intersection that was determined. Several resources were used to determine the information that was not presented on the raw data sheets, such as, the functional classification, number of lanes, intersection control, and AADT values.

Table 1 Data Available for Analysis

From Raw Data	From Other Resources
- 100 intersection in Bryan/College Station - Years: 2010 – 2019 - Data Collection Date/Time - Turning Movement Counts	- Functional Classification (*11, 12*) - Number of Lanes/Signal Control - AADT (*11, 13*)

Although data is available for morning, midday, and evening peak periods, only morning and evening peaks are used for the analysis. These are the periods that are usually used for traffic analysis. The midday data is used to test the initial turning proportions that will be determined to test its accuracy. Data that contained more than 12 hours of counts were reduced to 3 hour periods in the morning, midday, and evening.

Criteria were set for datasets used in the analysis.

- Sheets with unusual data were not used for the analysis. Unusual refers to sheets with empty cells, unusually large/small volumes for that roadway when compared to other sheets, or counts taken at unusual times, like game days. These were removed as an attempt to reduce occurrence of outliers in the analysis

Table 2 below displays the categories that are analyzed for the initial turning proportions. The functional classification major category is broken up into subcategories that consider turning proportions based on time and day of the week with the classification. The lane group major category includes the addition of time and functional classification to the determination. Intersection control major category adds time and functional classification of the roadway to consideration for turning proportion determination. Functional classification is included in each category because it is considered to be an important identifier for a roadway. Some categories were not considered because of lack of available data for analysis. For each category, AM peak, PM peak, and a combination peak periods are considered to find the optimal proportions. Separate calculations are also done for 3-leg intersections and 4-leg intersections to determine which would provide a more accurate proportion estimate. For this research, 26 test intersections counts were set aside from the original 100 intersection counts collected and used later on to determine the accuracy of the estimation and perform LOS and delay analysis.

Table 2 Category for Initial Proportion Estimation

	Major Category	Subcategory
1	Functional Classification	
2		+ Time
3		+ Day of Week + Time
4	Lane Group	
5		+ Time
6		+ Functional Class
7	Intersection Control	
8		+ Time
9		+ Functional Class + Time

For each category, the average proportion for the left, thru, and right movements are calculated. Using the JMP software, 95 percent confidence intervals were determined for each of the turning movements to create a proportion ranges for the variables. Finally, HCS7 was used to generate results for the LOS and delay of the intersection case study. Several assumptions were made when creating the categories and calculating the proportions.

ASSUMPTIONS

Assumptions that were made towards the data are listed below.

- Pedestrians and bicyclists were not counted as part of the volume for the analysis.
- The volume of vehicles making a U-Turn were combined with the Left Turns because the U-Turn would be made from the same lanes as the Left Turns.
- For the sheets that had more than 12 hours of vehicles counts, the data was broken up into 3 hour groups for the peak periods. Morning peak period is assumed to be between 6am –

9am, midday peak period between 11am – 2pm, and evening peaks between 4pm – 7pm. From these periods, the peak hours were determined.

- The train running parallel to Wellborn Rd is not considered to impact the traffic volumes.
- The same functional classification is kept for a roadway throughout the years.
- Multiple of the roads changed over the years, so Google Map's previous years feature is used to determine the number of lanes from specific years as closely as possible.

SUMMARY

Included in this chapter were the design for the research and the steps taken to reach the recommendation. The first step was to organize the Excel sheets and PDFs of turning movement counts and determine their peak hour details. Next, categories for estimating turning movement proportions were defined and the category that gave the better estimates are selected. Initial turning proportion range tables were created, and hourly turning movement volumes were estimated. Lastly, the accuracy of the estimates were tested with variability test and LOS/Delay analysis. Also mentioned in this chapter are some assumptions that were made about the turning movement counts data received and criteria for datasets that were used for the analysis.

CHAPTER IV

DATA ANALYSIS AND RESULTS

This chapter presents the analysis of data, and results that were determined from those analyses. The turning proportion ranges determined in this research are proposed to be used to make preliminary decisions for turning movements at an intersection and may need to be adjusted further along the process when more information becomes available. Major and subcategories were proposed in this thesis to determine the initial turning proportions at an intersection, as discussed in the previous chapter. Using the peak hour for each intersection and the calculated turning proportion from the peak volumes, the average proportion is calculated based on the categories.

Included are: the determined turning proportion ranges, analysis on the accuracy of the volume estimation, case studies that explore the effects on LOS for range of turning proportions, effects of variability on the results, and an example that shows the conversion of AADT to turning volumes using the estimated turning proportions and two possible estimation methods.

TURNING PROPORTION RANGES

Nine total categories were considered that affected vehicle turning proportions at an intersection and analyzed to determine the category that provided optimal proportion ranges. The first step was to select one subcategory from the three major categories (functional classification, lane group, and intersection control) mentioned in the previous chapter. Next, proportion ranges were determined for the selected three. Finally, the three categories were compared, and one category was determined to provide optimal results for turning movement volumes from its proportion ranges. The process for the selection is show on Figure 8.

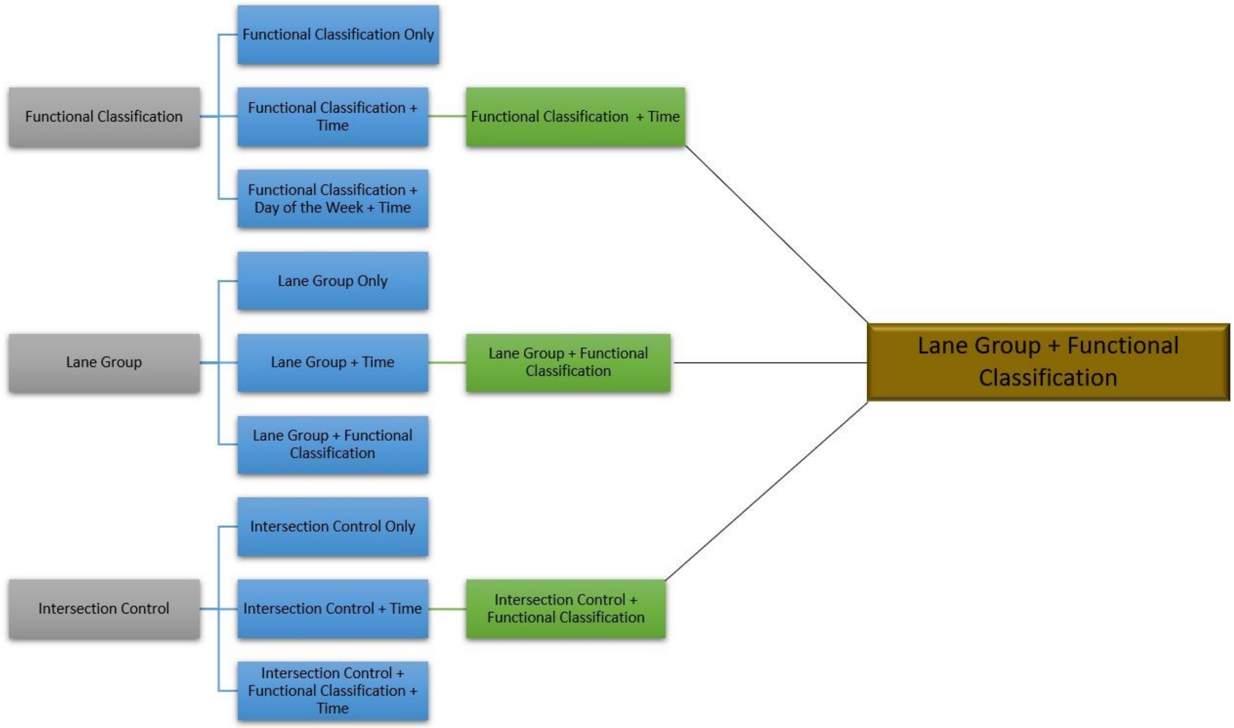


Figure 8 Selection process for the optimal category for turning proportion range.

The first three categories fell under the functional classification major category (functional classification only, functional classification + time, functional classification + day of the week + time). For the functional classification only category the average was determined for intersection approaches that had the same functional classification according to the definition provided. Functional classification + time category took the average of intersection approaches with the same functional classification in the peak direction for the AM and PM peak periods. Functional classification + day of the week + time category took it one step further and separated the averages by intersection approach classification in the peak direction during peak periods, and for available days of the week. The results of the averages from the three categories are provided in Appendix B (Tables B.1 – B.3). Functional classification + time was chosen as the optimal average from these categories because more data was available to increase the accuracy of the prediction, unlike functional classification + day of the week + time, and it uses volumes only in the peak direction, and important consideration when dealing with traffic analysis using directional design hour volumes.

The next three categories were under the major category of lane group (lane group only, lane group + time, lane group + functional classification). Lane group only category calculated the averages for the different variations of lane groupings present in the Bryan/College Station area. The general types of lane groups were broken down by the number of lanes in each direction. Lane group + time category followed the same system of averaging with the addition of the peak time and peak direction conditions. For the lane group + functional classification category, the averages were determined with a combination of number of lanes in each lane group and the classification of the roadway for that intersection approach. An example of the resulting averages from these three categories is presented in Appendix B (Tables B.4 – B.6). Lane group + functional classification category was chosen as the representative because, while the average results are similar, it provided more definitive and specific averages than the other categories.

Intersection control was the final major category considered with subcategories (intersection control only, intersection control + time, intersection control + functional classification + time). The intersection control only category calculated the average of intersection approaches with the same type of intersection control, as previously defined. Intersection control + time category used intersection control at an intersection during the peak hours in the peak directions to determine the averages. Intersection control + functional classification + time combined the intersection control type with the roadway classification during the peak hours and in the peak direction for the determined averages. Appendix B (Tables B.7 – B.9) shows some of the averages that were calculated for these categories. The intersection control + functional classification + time category was selected as the optimal category because it provided more specific average results that more accurately depicted the turning proportions than the other categories.

The three categories selected from the major categories and compared were functional classification + time, lane group + functional classification, and intersection control + functional classification + time. Proportion ranges for the three categories were determined using the JMP software. The category selected as the optimal proportion range is based on the combination of lane group + functional classification. Appendix C (Tables C.1 and C.2) provides the results of the proportion ranges for the functional classification + time and intersection control + functional classification + time categories. Lane group + functional classification was chosen based on several reasons including: the breakdown of the category allowed for more accurate proportion estimation, some of the ranges from the other categories fell within that of the selected category, and functional classification and lane group/number of lanes are roadways characteristics information that are often available when performing an analysis.

To give a more reliable representation of the data, a minimum sample size for the average was calculated using the following equation (*15*):

$$n \geq \left(\frac{t_{\alpha/2,df}}{\Delta}\tilde{\sigma}\right)^2$$

Where:

n = sample size

$t_{\alpha/2,df}$ = t-table distribution value

Δ = desired maximum error bound

$\tilde{\sigma}$ = rough guess of population standard deviation

Significance level was taken to be $\alpha = 0.05$ to achieve a 95% confidence interval for the proportion range, the desired maximum error bound was 0.25, and the rough guess for population standard deviation was 0.25 (based on ¼ of the anticipated range). The resulting minimum sample size was 10. Any proportion range that is included with sample size less than 10 may not provide reliable representation of the data. Sections labeled as "*INSUFFICIENT DATA*" represents proportions for which turning movement counts were not available. Acquiring turning movement counts for locations represented by *INSUFFICIENT DATA* would be a worthwhile endeavor for future activity in this area. With a 95% confidence level, Tables 3 - 5 provides the results for the turning proportion ranges for the selected category. These ranges were determined using the average proportions from the obtained turning movement counts and set to provide estimates within 25 percent of the actual turning volumes.

Table 3 Turning Proportion Range for Lanes with No Exclusive Turning Movements

					4 leg				3 leg			
Lane Group + Functional Class		**Number of Lanes/Movement**	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
	No Exclusive Lanes	1-left/thru/right	Major Collector	Major Collector	0.23 - 0.37	0.29 - 0.41	0.27 - 0.44	18	0.00 - 0.02	0.02 - 0.66	0.34 - 0.97	8
			Local	Principal Arterial	0.35 - 0.58	0.02 - 0.09	0.35 - 0.62	15	*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	0.24 - 0.45	0.05 - 0.22	0.38 - 0.65	16	*INSUFFICIENT DATA*			
		1-left/thru, 1-thru/right	Minor Arterial	Principal Arterial	0.24 - 0.32	0.45 - 0.51	0.21 - 0.28	12	*INSUFFICIENT DATA*			
			Major Collector	Minor Arterial	0.25 - 0.37	0.36 - 0.50	0.19 - 0.33	10	*INSUFFICIENT DATA*			
		1-thru/right	Major Collector	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
		1-left/thru	Major Collector	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			

*Proportions are a percentage of the approach volume

Table 4 Turning Proportion Range for Lanes with Partial Exclusive and Partial Shared Turning Movements

					4 leg				**3 leg**			
Lane Group + Functional Class		**Number of Lanes/Movement**	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
	Partial Exclusive and Partial Shared Lanes	2-thru (1 shared rt)	Principal Arterial	Major Collector	0.05 - 0.15	0.74 - 0.81	0.06 - 0.18	21	0.07 - 0.13	0.88 - 0.90	0.00 - 0.03	10
			Minor Arterial	Major Collector	0.00 - 0.65	0.35 - 1.00	0.00 - 0.22	5	*INSUFFICIENT DATA*			
			Minor Arterial	Minor Arterial	0.00 - 0.00	0.69 - 0.90	0.10 - 0.31	5	*INSUFFICIENT DATA*			
			Principal Arterial	Minor Arterial	0.00 - 0.00	0.74 - 0.93	0.07 - 0.26	5	*INSUFFICIENT DATA*			
		1-left, 1-thru/right	Major Collector	Major Collector	0.04 - 0.13	0.76 - 0.88	0.04 - 0.15	18	*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	0.33 - 0.48	0.13 - 0.24	0.32 - 0.50	32	*INSUFFICIENT DATA*			
			Minor Arterial	Minor Arterial	0.15 - 0.24	0.53 - 0.73	0.11 - 0.24	19	0.00 - 0.27	0.68 - 0.89	0.00 - 0.35	4
		1-left/thru, 1-right	Minor Arterial	Principal Arterial	0.12 - 0.19	0.48 - 0.61	0.24 - 0.37	11	*INSUFFICIENT DATA*			
			Local	Principal Arterial	0.22 - 0.62	0.04 - 0.16	0.30 - 0.67	10	*INSUFFICIENT DATA*			
			Local	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
		3-thru (1 shared rt)	Principal Arterial	Local	0.00 - 0.00	0.96 - 0.99	0.01 - 0.04	4	*INSUFFICIENT DATA*			
			Principal Arterial	Major Collector	0.00 - 0.03	0.93 - 0.98	0.00 - 0.07	4	*INSUFFICIENT DATA*			
*Proportions are a percentage of the approach volume												

Table 4 Continued

					4 leg				3 leg			
Lane Group + Functional Class		**Number of Lanes/Movement**	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
	Partial Exclusive and Partial Shared Lanes	1-left, 2-thru (1 shared rt)	Principal Arterial	Minor Arterial	0.14 - 0.20	0.70 - 0.77	0.08 - 0.12	52	0.22 - 0.34	0.66 - 0.78	0.00 - 0.00	6
			Minor Arterial	Principal Arterial	0.18 - 0.24	0.57 - 0.66	0.15 - 0.20	21	*INSUFFICIENT DATA*			
			Principal Arterial	Local	0.00 - 0.20	0.69 - 0.96	0.01 - 0.17	4	0.00 - 0.07	0.80 - 0.98	0.00 - 0.19	6
			Principal Arterial	Major Collector	0.04 - 0.13	0.82 - 0.90	0.04 - 0.07	21	0.00 - 0.05	0.94 - 0.98	0.00 - 0.03	9
			Major Collector	Principal Arterial	0.32 - 0.45	0.41 - 0.59	0.09 - 0.15	11	*INSUFFICIENT DATA*			
			Minor Arterial	Major Collector	0.15 - 0.23	0.65 - 0.76	0.06 - 0.15	26	*INSUFFICIENT DATA*			
			Minor Arterial	Minor Arterial	0.13 - 0.26	0.56 - 0.67	0.11 - 0.26	10	0.10 - 0.16	0.84 - 0.90	0.00 - 0.00	5
		1-left, 1-left/thru, 1-right	Local	Principal Arterial	0.30 - 0.67	0.07 - 0.25	0.22 - 0.49	6	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
		1-left, 1-left/thru, 1-thru, 1-right	Minor Arterial	Principal Arterial	0.30 - 0.46	0.19 - 0.42	0.23 - 0.40	10	*INSUFFICIENT DATA*			
*Proportions are a percentage of the approach volume												

Table 4 Continued

Lane Group + Functional Class		Number of Lanes/Movement	From	To	4 leg Left	4 leg Thru	4 leg Right	4 leg Sample Size	3 leg Left	3 leg Thru	3 leg Right	3 leg Sample Size
	Partial Exclusive and Partial Shared Lanes	1-left, 3-thru (1 shared rt)	Principal Arterial	Local	0.03 - 0.07	0.90 - 0.95	0.02 - 0.04	30	0.04 - 0.13	0.82 - 0.93	0.02 - 0.07	12
			Principal Arterial	Major Collector	0.05 - 0.08	0.84 - 0.91	0.04 - 0.09	30	0.00 - 0.05	0.94 - 0.96	0.00 - 0.05	7
			Principal Arterial	Minor Arterial	0.12 - 0.16	0.76 - 0.81	0.06 - 0.09	25	*INSUFFICIENT DATA*			
		2-left, 3-thru (1 shared rt)	Principal Arterial	Principal Arterial	0.16 - 0.30	0.50 - 0.63	0.13 - 0.27	11	*INSUFFICIENT DATA*			
			Principal Arterial	Minor Arterial	0.21 - 0.41	0.54 - 0.78	0.00 - 0.07	12	*INSUFFICIENT DATA*			
		1-left, 4-thru (1 shared rt)	Principal Arterial	Local	0.01 - 0.05	0.94 - 0.98	0.00 - 0.03	4	*INSUFFICIENT DATA*			

*Proportions are a percentage of the approach volume

Table 5 Turning Proportion Range for Lanes with All Exclusive Turning Movements

					4 leg				3 leg			
		Number of Lanes/Movement	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
Lane Group + Functional Class	All Exclusive Lanes	1-left, 1-right	Major Collector	Principal Arterial	0.53 - 0.75	0.00 - 0.00	0.25 - 0.47	12	*INSUFFICIENT DATA*			
			Minor Arterial	Minor Arterial	0.49 - 0.81	0.00 - 0.00	0.19 - 0.51	5	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.24 - 0.40	0.00 - 0.00	0.60 - 0.76	6	*INSUFFICIENT DATA*			
		1-left, 1-thru, 1-right	Local	Principal Arterial	0.00 - 0.32	0.01 - 0.96	0.00 - 0.75	4	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.29 - 0.38	0.33 - 0.42	0.24 - 0.35	18	*INSUFFICIENT DATA*			
			Major Collector	Minor Arterial	0.21 - 0.25	0.37 - 0.49	0.28 - 0.40	8	*INSUFFICIENT DATA*			
			Local	Minor Arterial	0.67 - 0.81	0.01 - 0.03	0.18 - 0.30	4	*INSUFFICIENT DATA*			
		3-thru, 1-right	Principal Arterial	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
		1-left, 1-thru, 2-right	Principal Arterial	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
		1-left, 2-thru, 1-right	Principal Arterial	Principal Arterial	0.10 - 0.20	0.33 - 0.69	0.14 - 0.54	13	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.09 - 0.19	0.46 - 0.61	0.26 - 0.38	13	*INSUFFICIENT DATA*			
			Minor Arterial	Major Collector	0.01 - 0.03	0.80 - 0.88	0.10 - 0.18	10	*INSUFFICIENT DATA*			
*Proportions are a percentage of the approach volume												

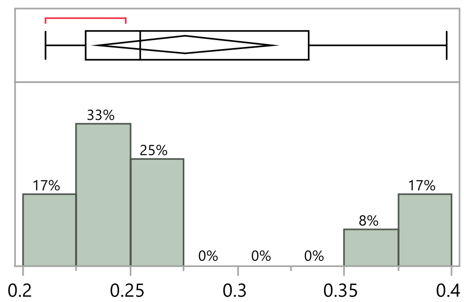
Table 5 Continued

					4 leg				3 leg			
		Number of Lanes/Movement	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
Lane Group + Functional Class	All Exclusive Lanes	1-left, 2-thru, 1-right	Major Collector	Principal Arterial	0.10 - 0.21	0.51 - 0.65	0.22 - 0.31	10	*INSUFFICIENT DATA*			
			Principal Arterial	Minor Arterial	0.05 - 0.11	0.76 - 0.85	0.08 - 0.14	14	*INSUFFICIENT DATA*			
		2-left, 1-thru, 1-right	Major Collector	Minor Arterial	0.38 - 0.49	0.09 - 0.16	0.37 - 0.50	7	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.33 - 0.51	0.29 - 0.44	0.17 - 0.26	11	*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	0.34 - 0.49	0.19 - 0.24	0.31 - 0.42	6	*INSUFFICIENT DATA*			
		2-left, 2-thru, 1-right	Principal Arterial	Principal Arterial	0.17 - 0.29	0.41 - 0.56	0.18 - 0.40	18	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.48 - 0.56	0.28 - 0.37	0.11 - 0.21	14	*INSUFFICIENT DATA*			
		1-left, 3-thru, 1-right	Principal Arterial	Minor Arterial	0.08 - 0.11	0.71 - 0.81	0.10 - 0.20	27	*INSUFFICIENT DATA*			
		2-left, 2-thru, 2-right	Principal Arterial	Principal Arterial	0.20 - 0.29	0.55 - 0.69	0.09 - 0.19	7	*INSUFFICIENT DATA*			
		2-left, 3-thru, 1-right	Principal Arterial	Principal Arterial	0.09 - 0.18	0.49 - 0.62	0.21 - 0.41	7	*INSUFFICIENT DATA*			
			Principal Arterial	Minor Arterial	0.06 - 0.09	0.67 - 0.76	0.15 - 0.27	10	*INSUFFICIENT DATA*			
			Principal Arterial	Local	0.06 - 0.12	0.71 - 0.92	0.00 - 0.20	4	*INSUFFICIENT DATA*			
*Proportions are a percentage of the approach volume												

The JMP results for one type of lane distribution type from each lane group is presented below in Figures 9 - 12 to display the results calculated and provide a visual of the proportions and outliers. Lane distributions with larger sample sizes are chosen to show best representation of data. From Table 3, statistical analysis for the average values for minor arterial to principal arterial roads with 1-left/thru and 1-thru/right lanes at the approach is presented in Figure 9. Statistical analysis results for principal arterial to major collector roads for 2-thru (1 shared right) lanes are displayed in Figures 10 and 11 from Table 4. Figure 12 also shows the statistical analysis results for principal arterial to minor arterial roads with 1-left, 3-thru, and 1-right lanes from Table 5.

From the JMP results, the summary statistics provides the 95 percent confidence interval for the mean that is translated into proportion ranges for each variable in the category, the mean of the selected variable, and standard deviation. The histogram provides a visual of the spread of the turning proportions used to determine the mean and desired range, which is also documented numerically in the quantiles section. The presence of outliers in some of the data could occur from unusual circumstances from the observation, recording error, or by random chance. It would not be possible to determine the cause of the outliers for the data in this research because they span over multiple years and different sources.

Left



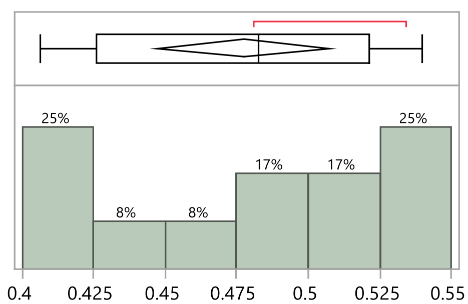
Quantiles

100.0%	maximum	0.397540984
99.5%		0.397540984
97.5%		0.397540984
90.0%		0.3907786888
75.0%	quartile	0.333305044
50.0%	median	0.2550175795
25.0%	quartile	0.229082972
10.0%		0.2114484541
2.5%		0.210843373
0.5%		0.210843373
0.0%	minimum	0.210843373

Summary Statistics

Mean	0.2758339
Std Dev	0.0639224
Std Err Mean	0.0184528
Upper 95% Mean	0.3164482
Lower 95% Mean	0.2352195
N	12

Thru



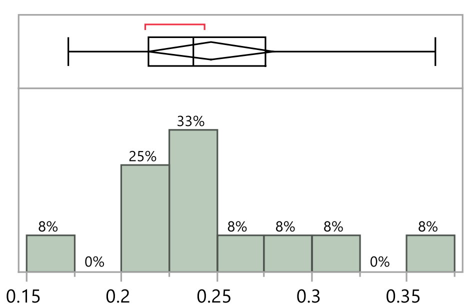
Quantiles

100.0%	maximum	0.539961014
99.5%		0.539961014
97.5%		0.539961014
90.0%		0.5381767913
75.0%	quartile	0.5210765653
50.0%	median	0.4826239765
25.0%	quartile	0.4261060635
10.0%		0.4114533888
2.5%		0.406113537
0.5%		0.406113537
0.0%	minimum	0.406113537

Summary Statistics

Mean	0.477391
Std Dev	0.0470534
Std Err Mean	0.0135831
Upper 95% Mean	0.5072873
Lower 95% Mean	0.4474947
N	12

Right



Quantiles

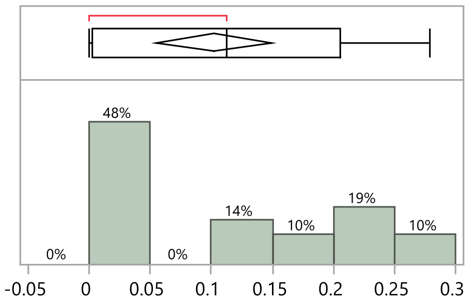
100.0%	maximum	0.364457831
99.5%		0.364457831
97.5%		0.364457831
90.0%		0.3472464659
75.0%	quartile	0.275380463
50.0%	median	0.237434275
25.0%	quartile	0.2143482653
10.0%		0.1808178907
2.5%		0.172131148
0.5%		0.172131148
0.0%	minimum	0.172131148

Summary Statistics

Mean	0.2467751
Std Dev	0.0512913
Std Err Mean	0.0148065
Upper 95% Mean	0.279364
Lower 95% Mean	0.2141862
N	12

Figure 9 JMP analysis results for no exclusive turning lane group of a 4 leg intersection with 1-left/thru and 1-thru/right lanes.

Left



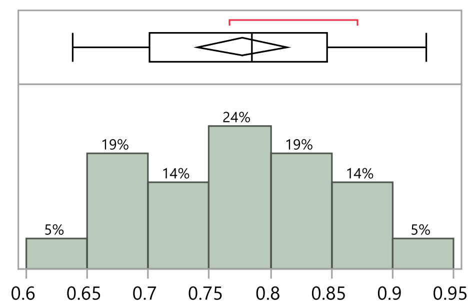
Quantiles

100.0%	maximum	0.278382582
99.5%		0.278382582
97.5%		0.278382582
90.0%		0.2591578838
75.0%	quartile	0.205362463
50.0%	median	0.11223203
25.0%	quartile	0.0032414995
10.0%		0.0002881844
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.101979
Std Dev	0.1036186
Std Err Mean	0.0226114
Upper 95% Mean	0.1491456
Lower 95% Mean	0.0548124
N	21

Thru



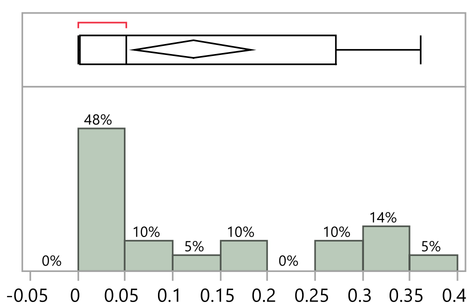
Quantiles

100.0%	maximum	0.927444795
99.5%		0.927444795
97.5%		0.927444795
90.0%		0.8824685662
75.0%	quartile	0.8460340225
50.0%	median	0.784745763
25.0%	quartile	0.701627899
10.0%		0.6733451272
2.5%		0.63832853
0.5%		0.63832853
0.0%	minimum	0.63832853

Summary Statistics

Mean	0.7764995
Std Dev	0.0801681
Std Err Mean	0.0174941
Upper 95% Mean	0.8129916
Lower 95% Mean	0.7400074
N	21

Right



Quantiles

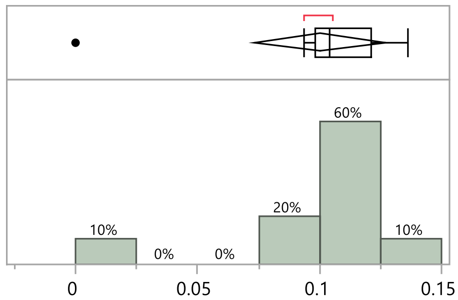
100.0%	maximum	0.360230548
99.5%		0.360230548
97.5%		0.360230548
90.0%		0.3259029932
75.0%	quartile	0.2712911725
50.0%	median	0.050473186
25.0%	quartile	0.0030814225
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.1215215
Std Dev	0.1349177
Std Err Mean	0.0294415
Upper 95% Mean	0.1829353
Lower 95% Mean	0.0601077
N	21

Figure 10 JMP analysis results for partial exclusive and partial shared lane group of a 4 leg intersection with 2-thru (1 shared rt) lanes.

Left



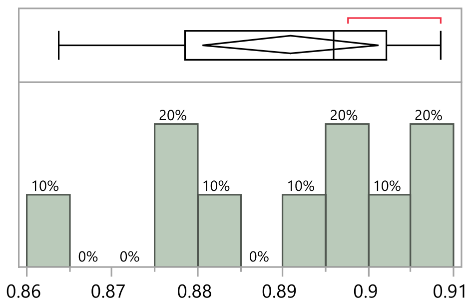
Quantiles

100.0%	maximum	0.136253041
99.5%		0.136253041
97.5%		0.136253041
90.0%		0.1349049646
75.0%	quartile	0.1214058123
50.0%	median	0.104013789
25.0%	quartile	0.0979325085
10.0%		0.0093484419
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.0999947
Std Dev	0.037478
Std Err Mean	0.0118516
Upper 95% Mean	0.1268048
Lower 95% Mean	0.0731846
N	10

Thru



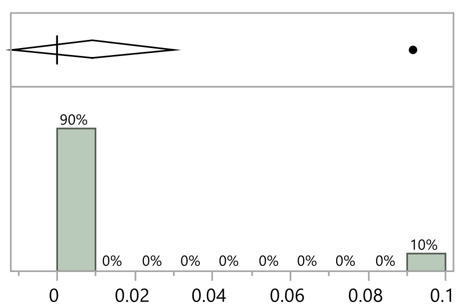
Quantiles

100.0%	maximum	0.90843806
99.5%		0.90843806
97.5%		0.90843806
90.0%		0.90824581
75.0%	quartile	0.90206749
50.0%	median	0.89598621
25.0%	quartile	0.87859419
10.0%		0.86509504
2.5%		0.86374696
0.5%		0.86374696
0.0%	minimum	0.86374696

Summary Statistics

Mean	0.8908491
Std Dev	0.0144345
Std Err Mean	0.0045646
Upper 95% Mean	0.9011749
Lower 95% Mean	0.8805233
N	10

Right



Quantiles

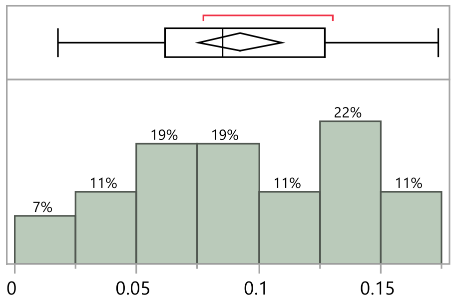
100.0%	maximum	0.091561939
99.5%		0.091561939
97.5%		0.091561939
90.0%		0.0824057451
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.0091562
Std Dev	0.0289544
Std Err Mean	0.0091562
Upper 95% Mean	0.0298689
Lower 95% Mean	-0.011557
N	10

Figure 11 JMP analysis results for partial exclusive and partial shared of a 3 leg intersection with 2-thru (1 shared rt) lanes.

Left



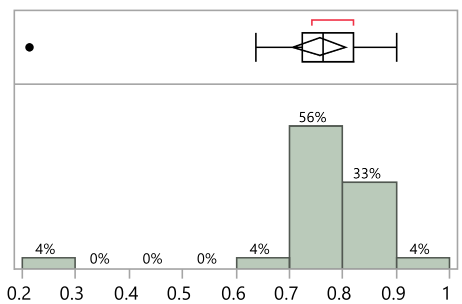
Quantiles

100.0%	maximum	0.1737609329
99.5%		0.1737609329
97.5%		0.1737609329
90.0%		0.1539397012
75.0%	quartile	0.1271186441
50.0%	median	0.0848905499
25.0%	quartile	0.0618345618
10.0%		0.0242366915
2.5%		0.018018018
0.5%		0.018018018
0.0%	minimum	0.018018018

Summary Statistics

Mean	0.0924348
Std Dev	0.0425547
Std Err Mean	0.0081897
Upper 95% Mean	0.1092689
Lower 95% Mean	0.0756007
N	27

Thru



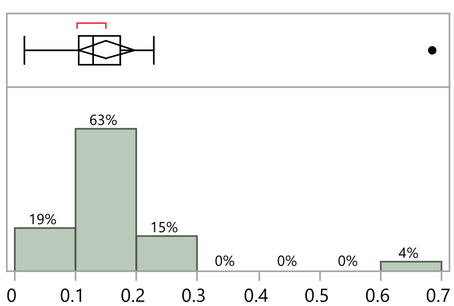
Quantiles

100.0%	maximum	0.9011345219
99.5%		0.9011345219
97.5%		0.9011345219
90.0%		0.8673444414
75.0%	quartile	0.8204301075
50.0%	median	0.763671875
25.0%	quartile	0.7248416608
10.0%		0.6932904847
2.5%		0.2139830508
0.5%		0.2139830508
0.0%	minimum	0.2139830508

Summary Statistics

Mean	0.7565963
Std Dev	0.1235895
Std Err Mean	0.0237848
Upper 95% Mean	0.8054867
Lower 95% Mean	0.7077059
N	27

Right



Quantiles

100.0%	maximum	0.6843220339
99.5%		0.6843220339
97.5%		0.6843220339
90.0%		0.2274073212
75.0%	quartile	0.172923777
50.0%	median	0.1282420749
25.0%	quartile	0.1041110518
10.0%		0.0644383838
2.5%		0.0166567519
0.5%		0.0166567519
0.0%	minimum	0.0166567519

Summary Statistics

Mean	0.1509689
Std Dev	0.1188375
Std Err Mean	0.0228703
Upper 95% Mean	0.1979795
Lower 95% Mean	0.1039584
N	27

Figure 12 JMP analysis results for all exclusive lane group of a 4 leg intersection with 1-left, 3-thru, 1-right lanes.

ACCURACY OF ESTIMATION

Using the proportion range category determined in Tables 3 to 5, turning volumes were estimated for the 26 test intersection volumes with two methods: Hauer's proposed algorithm and a basic proportion distribution calculation.

Hauer's algorithm requires an input of turning proportions (Tables 3 to 5 from this research), traffic volume into the intersection from each approach, traffic volume going out of the intersection from each approach, and total entering/exiting flow (*1*). These values are represented in a traffic flow matrix format. The input values are used to determine iterative factors (A and B) that lead to the final estimation of turning volumes (veh/hr). A_i value is first calculated with traffic volume from approach *i* into the intersection (O_i) and the sum for the entering flow from all approaches (S). Next, B_j is calculated with traffic volume out of the intersection to approach *j* (D_j), turning proportions (p_{ij}), and A_i. A_i is then updated with the turning proportions and the value of B_j to give A_i(new). The difference between A_i(new) and A_i is determined. If the calculated difference is significantly small, then A_i(new) and B_j are used to estimate T_{ij}; otherwise, B_j is recalculated with A_i(new) and the iteration is repeated until the difference is significantly small. The equations for these calculations are presented below (*1*):

$$T_{ij} = p_{ij} A_i B_j$$

$$A_i = \frac{O_i}{\sqrt{S}}$$

$$B_j = \frac{D_j}{\sum_{i=1}^{m} p_{ij} A_i}$$

$$A_i(new) = \frac{O_i}{\sum_{j=1}^{m} p_{ij} B_j}$$

Where:

T_{ij} = Turning volume estimates (veh/hr)

p_{ij} = Turning proportions (%) (Tables 3-5)

A_i, B_j, A_i(new) = iterative factors

D_j = Traffic volume out of the intersection to approach j (veh/hr)

O_i = Traffic volume into the intersection from approach i (veh/hr)

S = Sum of entering flow (veh/hr)

The basic proportion distribution method takes an input of total approach volumes (O_i) and, multiplied by the turning proportions (p_{ij}), calculates the turning volumes distribution (T_{ij}) (veh/hr).

$$T_{ij} = p_{ij}O_i$$

Where

T_{ij} = Turning volume estimates (veh/hr)

p_{ij} = Turning proportions (%) (Tables 3-5)

O_i = Traffic volume into the intersection from approach i (veh/hr)

Table 6 provides an example of the estimated volumes using the two methods and the determined initial turning proportions. Two columns show the difference (Δ) between the observed volumes and the two methods.

Table 6 Comparison of Observed vs Estimated Volumes Using the Two Methods.

	Observed Volume (veh/hr)	Basic Proportion Volume Estimate (veh/hr)	Δ (Basic Proportion - Observed)	Hauer Volume Estimate (veh/hr)	Δ (Hauer - Observed)
Left	10	95	88	18	8
Thru	285	111	-174	281	-4
Right	22	111	89	19	-3
Left	27	89	62	25	-2
Thru	245	104	-141	241	-4
Right	26	104	115	32	6
Left	28	4	-24	20	-8
Thru	20	44	24	19	-1
Right	4	4	0	13	9
Left	17	5	-12	17	0
Thru	31	65	34	24	-7
Right	29	6	-23	35	6

Figures 13 and 14 below presents plots of the observed vs estimated turning movement volume from the test intersections (141 turning movements). The plots are separated by the methods used to calculate the estimated turning volumes. Coefficient of determination values for both methods were determined to be $R^2 = 0.966$ for the basic proportion distribution method and $R^2 = 0.9977$ for the Hauer method. Although both methods have high R^2 values, Hauer's method provides a slightly better explanation for the variability in the data and higher strength in the relationship between the observed vs estimated volumes. This conclusion is also supported by the differences shown in Table 6 above. The difference between Hauer estimates and observed volumes are significantly less than the difference between the basic proportion estimates and observed volumes.

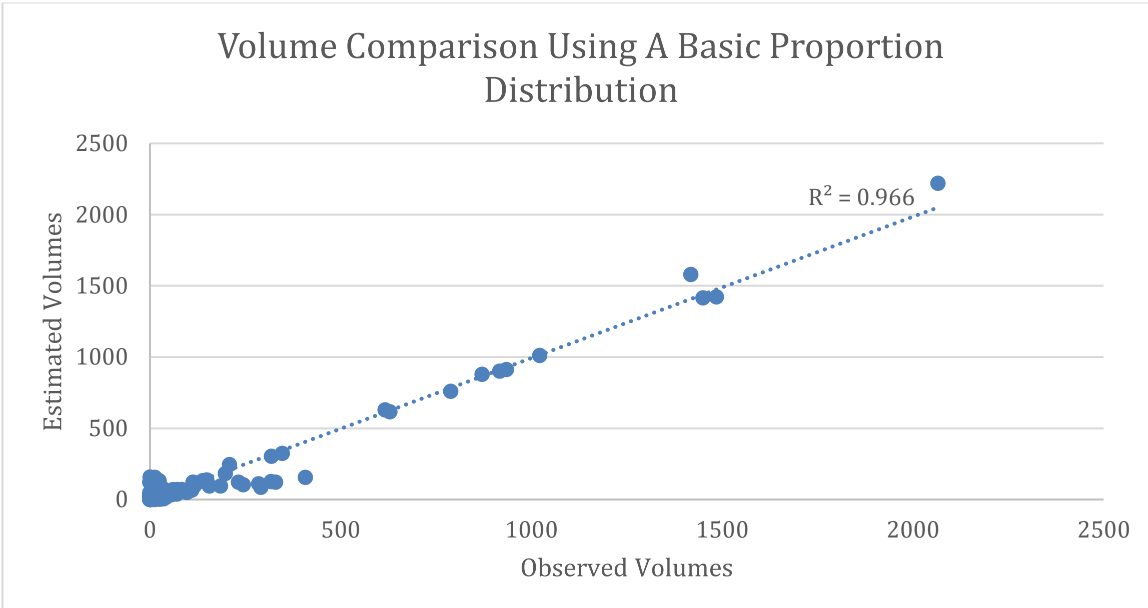


Figure 13 Observed vs estimated volume comparison - basic proportion distribution method.

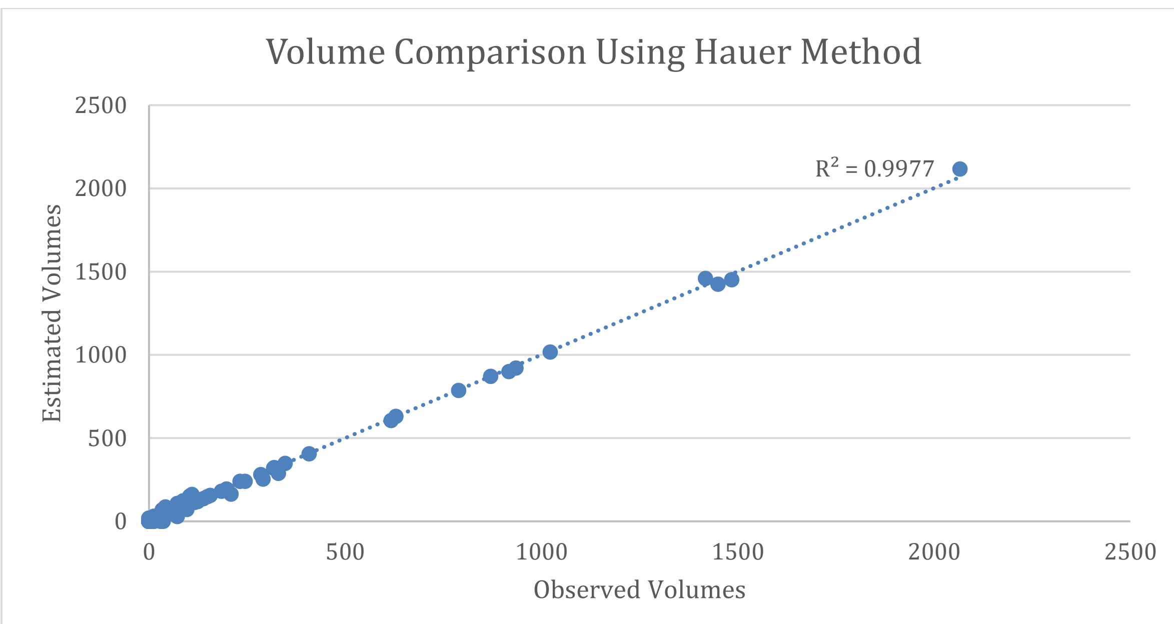


Figure 14 Observed vs estimated volume comparison - Hauer's algorithm method.

VARIABILITY

For three intersections, the variability in the approach volume is determined. Figures 15 - 17 show the variability of traffic volumes arriving at the approach from the raw data. Variability in the approach volumes means there is variability in turning movements for each approach. Variability of the data is checked to validate the use of 25 percent for the error bound when estimating turning movement volumes. Figure 15 displays the variability report for the lower volume intersection at George Bush Dr and Bizzell St/Timber St for the years 2011, 2016, and 2018. The counts were collected for the AM peak periods. Figure 16 shows the variability report for the medium volume intersection of Wellborn Rd and Holleman Dr for the years 2010, 2016, and 2018. The counts were collected for the PM peak periods. Figure 17 shows the variability report for the higher volume intersection of Texas Ave and University Dr for three days of the week, Tuesday, Wednesday, and Thursday. These counts were collected for the PM peak periods. Texas Ave and University Dr intersection represents a higher volume intersection, Wellborn Rd and Holleman Dr a medium volume intersection, and George Bush and Bizzell St/Timber St a lower volume intersection.

The variability reports in the figures below show significant variability at approaches over the years, for different days of the week, and for different peak periods. The peak 15 minute flow rate is used as representative of the peak hour flow and compared over time. For the higher volume intersections, the highest notable change in flow rate over the days is a change in approach flow of 300 veh/hr (change of 50 percent). The medium volume intersection had the highest change in approach flow of 97 veh/hr (change of 33 percent). The lower volume intersections had the highest change in approach flow of 77 veh/hr (change of 50 percent). Therefore, having up to 25 percent change in estimated vs observed turning proportion is a valid range for the error bounds chosen when the turning proportion range tables were determined.

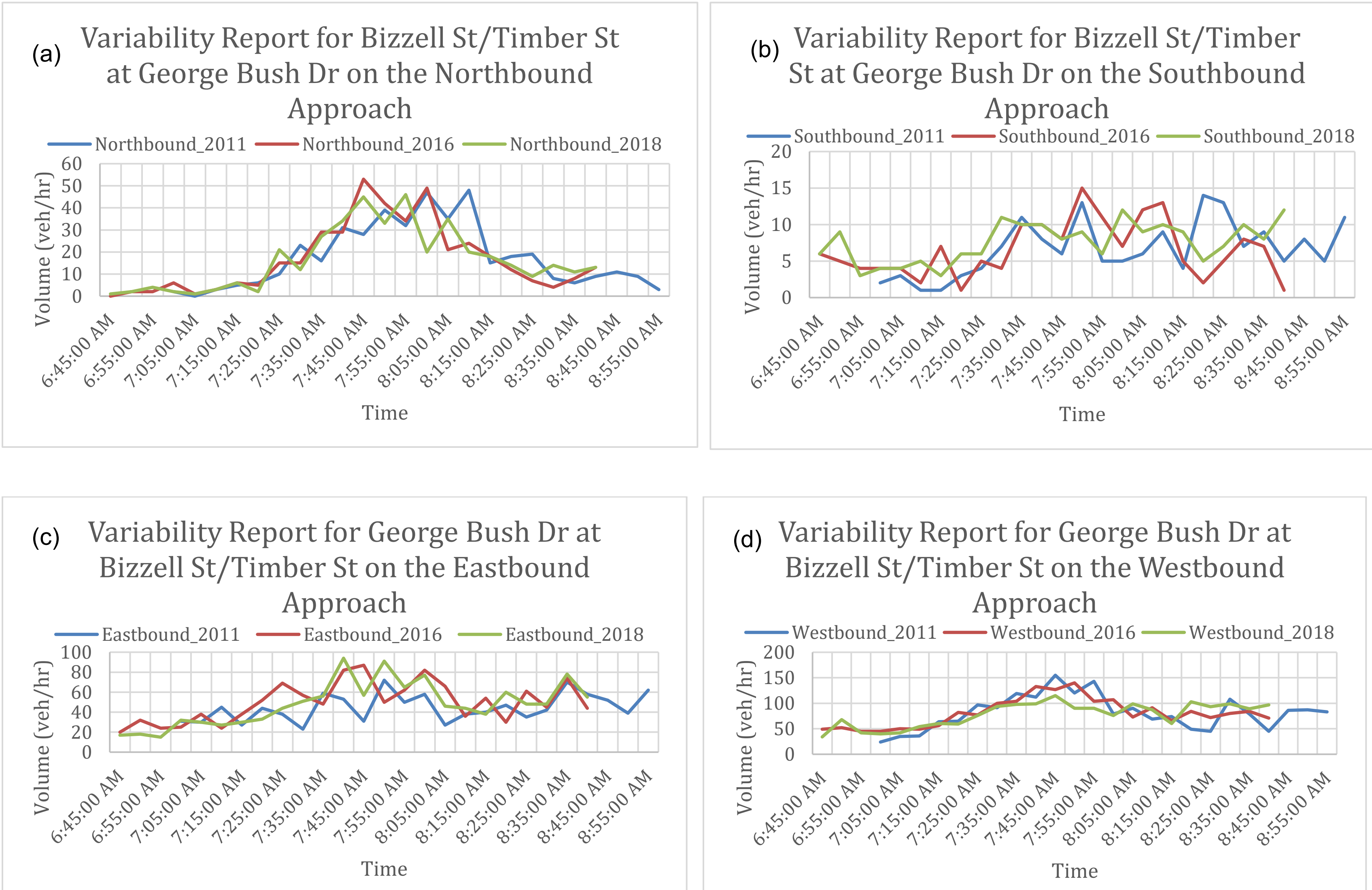


Figure 15 Variability report for each direction (a-d) at George Bush Dr and Bizzell St/Timber St.

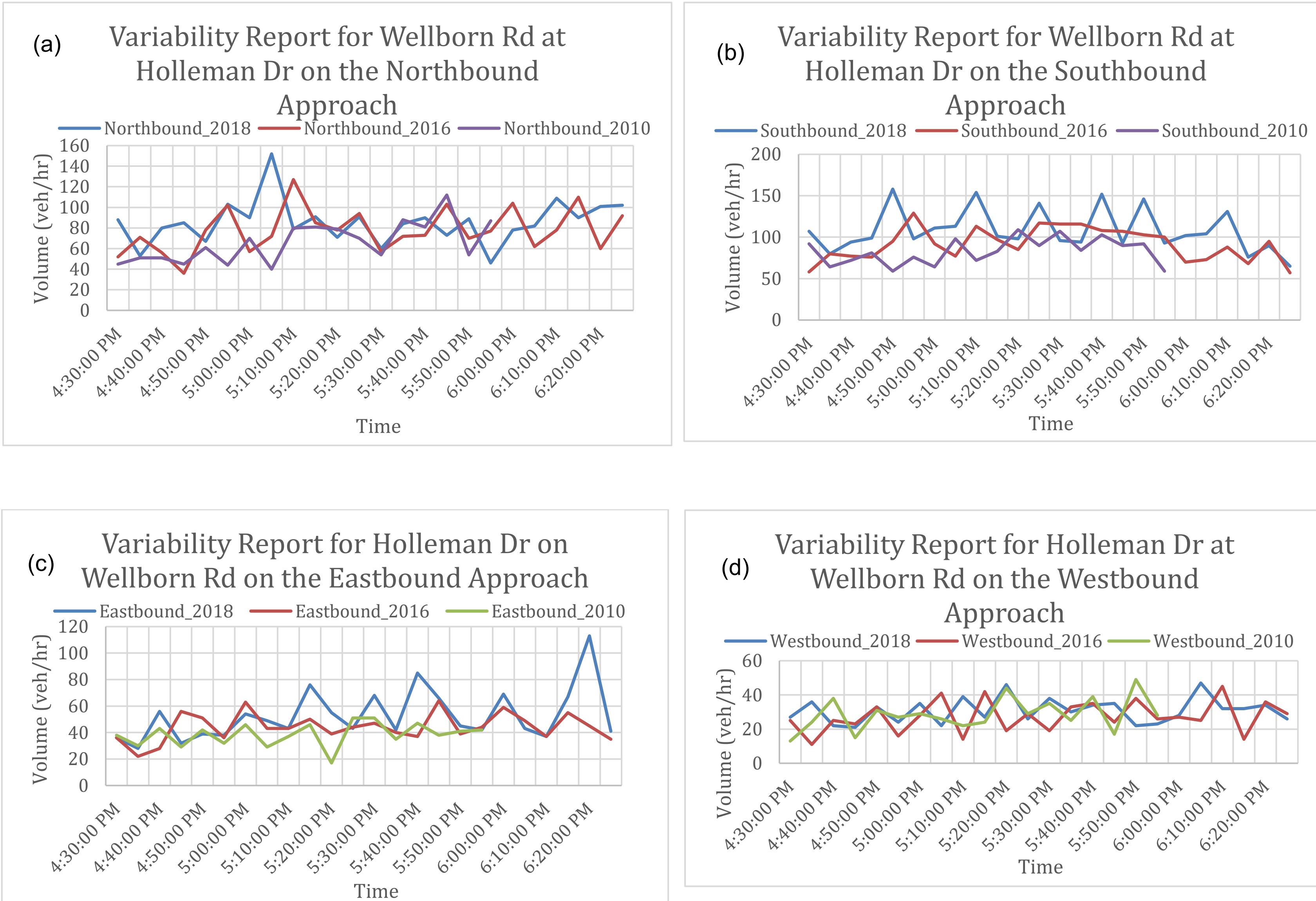


Figure 16 Variability report for each direction (a-d) at Wellborn Rd and Holleman Dr.

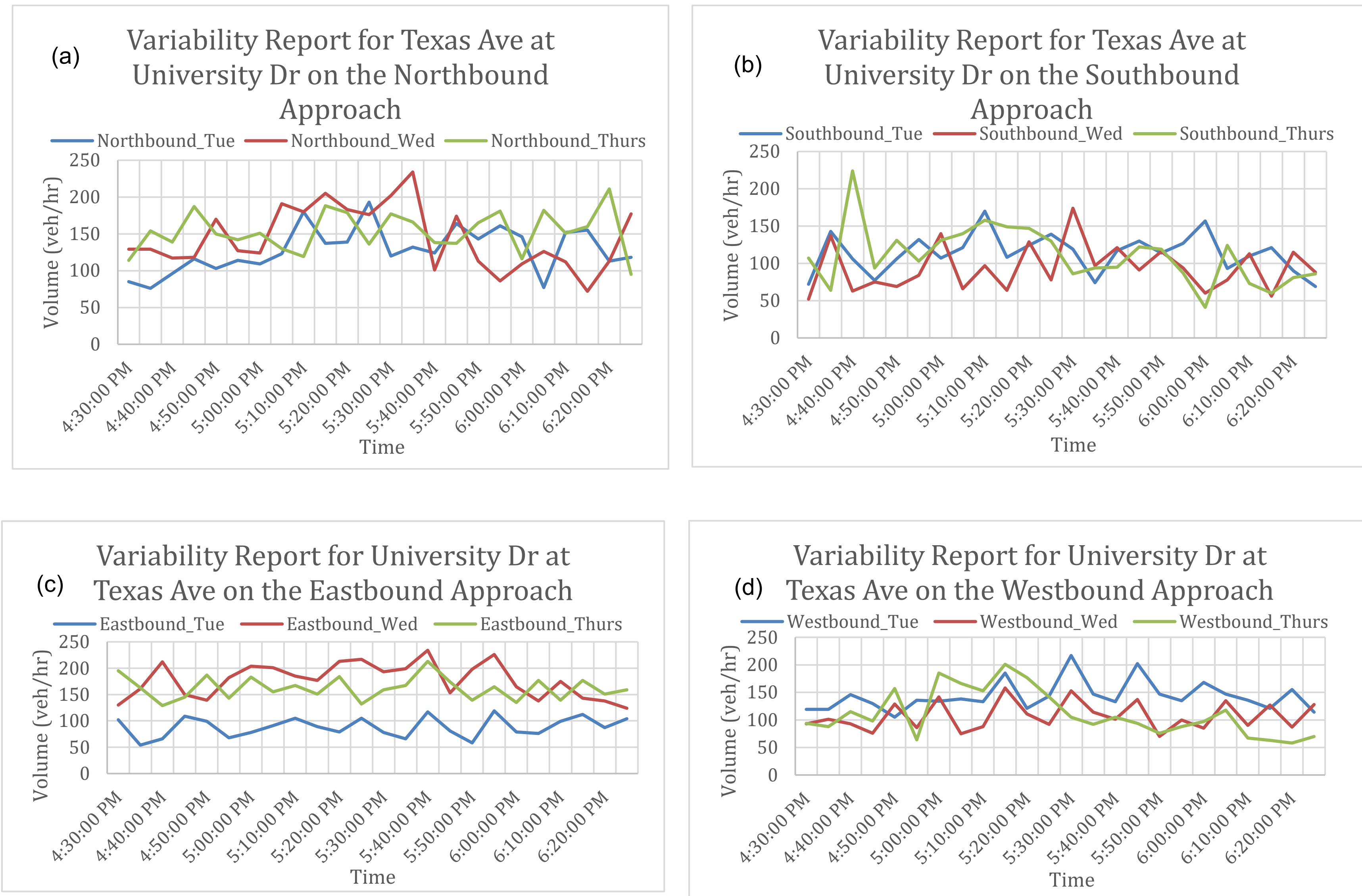


Figure 17 Variability report for each direction (a-d) at Texas Ave and University Dr.

LEVEL OF SERVICE (LOS)

Level of Service (LOS) provides a qualitative measure of the conditions of a stream of traffic on a roadway. It determines how well the facility is operating and can be defined by the average delay for vehicles on the road. The average delay is based on effects of several factors, such as signal phasing, traffic volume, intersection capacity, etc. on a section of roadway. Intersection LOS ranges from A - F, with A having the best traffic flow (free flow) and F having the worst (congestion and queues). Case studies were performed to analyze the effects a big difference (up to 25 percent change) in turning volume has on LOS using one of the test intersections. Because a range is presented for the turning proportions, a difference in percentage may change the LOS of an intersection. An HCM software, HCS7, was used to perform the LOS analysis. The same default values were used for inputs like Peak Hour Factor (PHF), while the signal timing information was changed to the configuration shown in Figure 18.

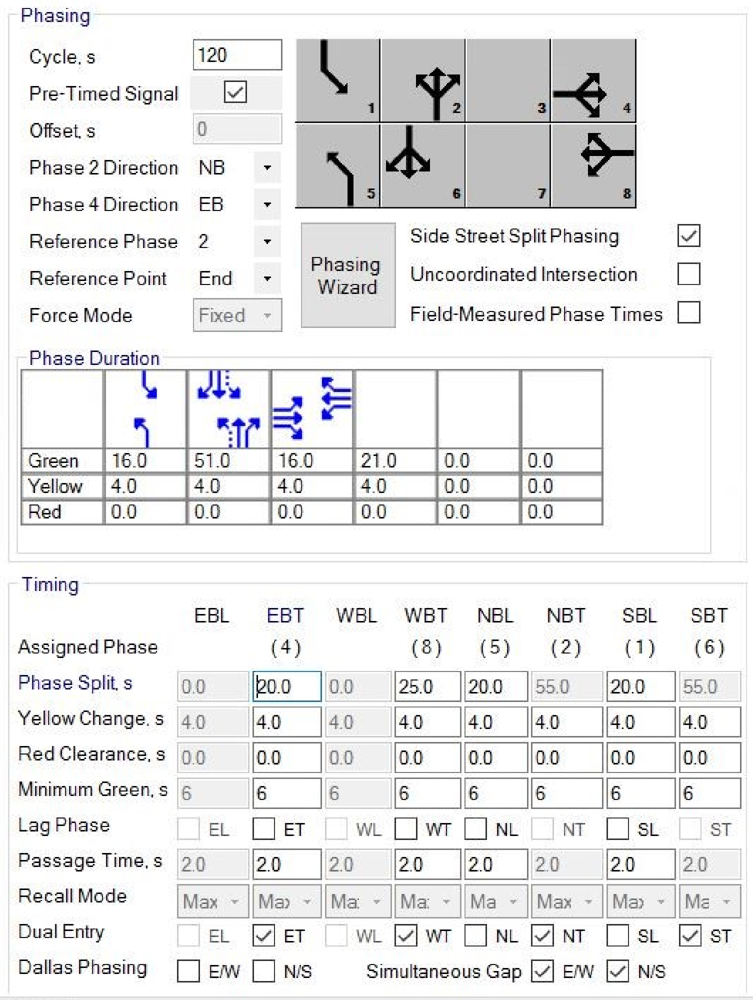


Figure 18 Configuration for timing signal phasing in LOS analysis.

The proportion ranges used in the case studies were for three different types of intersections (five separate intersections). The first intersection type presented a high volume (> 2500 veh/hr) principal arterial and major collector signalized intersection with 1-left and 2-thru (1 shared right turn) lanes on two approaches, and 1-left and 1-thru/right lanes on the other two approaches. The second intersection type consisted of a medium volume (> 1000 veh/hr) principal arterial and local signalized intersection with 1-left and 2-thru (1 shared right turn) lanes on two approaches, 1-left/thru/right shared lane on one approach, and 1-left/thru shared and 1-right lane on the fourth approach of the intersection. The third intersection type was a low volume (< 1000 veh/hr) stop controlled intersection of two major collector roads with 1-left and 1-thru/right lanes on two approaches, and 1-left/thru/right shared lane on the other two approaches of the intersection.

Three turning proportions for each turning movement were chosen, the corresponding turning volumes were estimated, and the resulting LOS and delay were determined. The criteria for proportion values within the range chosen were based on proportion with consideration for the peak direction, proportion in the off-peak direction, and a mean proportion within the range. For proportion based on peak direction, the peak direction was determined for the intersections and the left, thru, and right proportions were adjusted for the peak. The off-peak direction basis considered the chance that the peak direction was incorrectly selected, and the proportions were determined for the off-peak direction as the peak at the intersection. The mean basis selected the average value from the proportion range for the intersection. This way of analysis also picks values for the left, thru, and right turning proportions from the range such that they add up to 100 percent.

Tables 7 and 8 presents the proportions that were used for the three values in the range. The low volume road had to be represented twice because the major and minor roads for one of the intersections did not correspond with the other intersections in the category. Tables 9 shows the LOS and delay results for one instance of the high, medium, and low volume roads. The delay for the intersection approach is presented. Table 10 also displays the calculated absolute change in delay for the intersection approaches between the observed and estimated peak, mean, and off-peak volumes, and the corresponding average absolute change in proportions.

Table 7 Selected Proportion Values for High and Medium Volume Intersections

		High Volume			Medium Volume		
		Left	**Thru**	**Right**	**Left**	**Thru**	**Right**
Peak Direction Proportion	Northbound	0.04	0.89	0.07	0.19	0.8	0.01
	Southbound	0.13	0.83	0.04	0.01	0.82	0.17
	Eastbound	0.48	0.2	0.32	0.22	0.11	0.67
	Westbound	0.33	0.17	0.5	0.58	0.07	0.35
Mean Proportion	Northbound	0.08	0.86	0.06	0.1	0.82	0.08
	Southbound	0.08	0.86	0.06	0.09	0.82	0.09
	Eastbound	0.41	0.18	0.41	0.42	0.1	0.48
	Westbound	0.41	0.18	0.41	0.47	0.06	0.47
Off-peak Direction Proportion	Northbound	0.13	0.83	0.04	0.01	0.82	0.17
	Southbound	0.04	0.89	0.07	0.19	0.8	0.01
	Eastbound	0.33	0.17	0.5	0.62	0.08	0.3
	Westbound	0.48	0.2	0.32	0.35	0.05	0.6
*Proportions are a percentage of the approach volume							

Table 8 Selected Proportion Values for Low Volume Intersections

		Low Volume 1			Low Volume 2		
		Left	**Thru**	**Right**	**Left**	**Thru**	**Right**
Peak Direction Proportion	Northbound	0.37	0.36	0.27	0.04	0.82	0.14
	Southbound	0.23	0.33	0.44	0.13	0.82	0.05
	Eastbound	0.13	0.83	0.04	0.37	0.36	0.27
	Westbound	0.04	0.81	0.15	0.23	0.33	0.44
Mean Proportion	Northbound	0.3	0.35	0.35	0.09	0.82	0.09
	Southbound	0.3	0.35	0.35	0.09	0.82	0.09
	Eastbound	0.09	0.82	0.09	0.3	0.35	0.35
	Westbound	0.09	0.82	0.09	0.3	0.35	0.35
Off-peak Direction Proportion	Northbound	0.23	0.33	0.44	0.13	0.82	0.05
	Southbound	0.37	0.36	0.27	0.04	0.82	0.14
	Eastbound	0.04	0.81	0.15	0.23	0.33	0.44
	Westbound	0.13	0.83	0.04	0.37	0.36	0.27
*Proportions are a percentage of the approach volume							

Table 9 Comparison of Intersection LOS and Delay Results at Different Volume Levels

High Volume Intersection								
	Observed		Estimated Peak		Estimated Mean		Estimated Off-peak	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS
NB	66.6	E	61.20	E	60.10	E	59.30	E
SB	30.5	C	30.90	C	30.80	C	30.70	C
EB	53.9	D	54.60	D	54.30	D	54.20	D
WB	49.2	D	49.60	D	49.60	D	49.70	D
Medium Volume Intersection								
	Observed		Estimated Peak		Estimated Mean		Estimated Off-peak	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS
NB	34.2	C	34.10	C	34.20	C	34.20	C
SB	28.7	C	28.80	C	28.90	C	28.80	C
EB	28.1	C	27.90	C	28.30	C	29.60	C
WB	27	C	27.10	C	26.90	C	27.00	C
Low Volume Intersection								
	Observed		Estimated Peak		Estimated Mean		Estimated Off-peak	
	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS	Delay (s/veh)	LOS
NB	0.2	B	0.40	B	0.40	B	0.40	B
SB	0.7	A	0.80	A	0.80	A	0.70	A
EB	14.2	B	13.30	B	13.50	B	14.00	B
WB	13.9	B	13.70	B	13.20	B	12.90	B

Table 10 Change in Proportion vs Change of Delay for Intersections at Different Volume Levels

	High					
	Peak		**Mean**		**Off-peak**	
	Change in Proportion	**Change in Delay**	**Change in Proportion**	**Change in Delay**	**Change in Proportion**	**Change in Delay**
NB	0.03	5.4	0.05	6.5	0.07	7.3
SB	0.07	0.4	0.05	0.3	0.03	0.2
EB	0.09	0.7	0.13	0.4	0.19	0.3
WB	0.18	0.4	0.12	0.4	0.09	0.5
	Medium					
	Peak		**Mean**		**Off-peak**	
	Change in Proportion	**Change in Delay**	**Change in Proportion**	**Change in Delay**	**Change in Proportion**	**Change in Delay**
NB	0.11	0.1	0.08	0.0	0.09	0.0
SB	0.10	0.1	0.10	0.2	0.12	0.1
EB	0.11	0.2	0.12	0.2	0.26	1.5
WB	0.18	0.1	0.18	0.1	0.19	0.0
	Low					
	Peak		**Mean**		**Off-peak**	
	Change in Proportion	**Change in Delay**	**Change in Proportion**	**Change in Delay**	**Change in Proportion**	**Change in Delay**
NB	0.05	0.2	0.05	0.2	0.07	0.2
SB	0.03	0.1	0.00	0.1	0.04	0.0
EB	0.13	0.9	0.18	0.7	0.24	0.2
WB	0.05	0.2	0.05	0.7	0.10	1.0
*Proportions are a percentage of the approach volume						

For the high volume intersections, the largest change in delay for the intersection was 7.3 s/veh for estimation using the off-peak basis. The largest change in delay for the medium volume intersections was 1.5 s/veh using the off-peak basis and 1.3 s/veh for low volume intersections using the off-peak basis. Off-peak direction basis for determination of turning movement proportions resulted in the largest difference between the delay for the observed and estimated volumes. Peak direction and mean proportion basis generally offer better estimations for turning movement volumes when used to select turning proportion from the proportion range tables.

SUMMARY

This chapter goes through the data analyses that were performed for the turning movement counts and the results from the analyses. First, the established categories were defined, compared, and the selected category used as basis for initial turning proportions was lane group + functional classification. Next, the initial turning proportion range tables were created using a 95 percent confidence interval for the mean and separated into tables based on their lane groupings. Some examples of the JMP results were presented to show the presence of outliers that might affect the mean and ranges. Then, turning movement volumes were estimated using Hauer's method and a basic proportion distribution method. Hauer's method provided more accurate estimation of turning movement volumes than the basic method and was chosen as the algorithm to work with the initial turning proportions.

Variability test was performed and showed that vehicle arrival at the approach was variable over time and validated the use of 25 percent error bound. Finally, the results from the LOS/delay analysis proved that choosing any proportion value within the turning proportion range does not have a significant impact on the LOS or delay results of the estimates when compared to observed volumes.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

This chapter provides a discussion on the results of the research conducted and provides a summary of recommendations. The main goal of this research was to determine initial turning proportion ranges that can be used to make estimations about turning movement volumes. This was achieved by analyzing several turning movement counts provided for the Bryan/College Station area. Nine subcategories were considered as basis for the proportion determination, all based on definable roadway characteristics. The HCM manual provides suggestions for turning proportions that are too general to be reliable, and previous research focused on turning volume estimation. This study provides a refined initial turning proportion that can be used to estimate turning volumes when little additional information is available beyond the AADT volumes.

DISCUSSION

The subcategory that was selected as the appropriate proportion range was based on a combination of lane group and functional classification. These two factors work well together in prediction because number of lanes are part of the definition of a road’s functional classification. When determining the proportion range for the selected category, a conservative maximum error bound of 25 percent was used to give reliable predictions and a 95 percent confidence interval was selected, as is typical in practice. Some of the data that fell out of the range for the maximum error bounds were added, while others were labeled insufficient data. The decision to keep and eliminate data were made after observation of the results from the JMP analysis. Data was either too spread out to make conclusive predictions, or the sample size was small, less than four. It will be difficult to make predictions on the model that best fits the histogram result for a majority of the data. This can be attributed to the fact that the data spans a 10-year period and the way in which it was collected differs.

Several conclusions can be drawn from the presented average proportion ranges from the tables.

- Through movement volumes were generally larger on a major road when it intersected a minor, while left and right movements carry the larger percentage of the volume on the minor road counterpart.
- When roadways with the same functional classification intersect, there is a more even distribution of proportion with through movement slightly higher.
- In a little over half of the proportion ranges, right turn proportions were observed to be higher than left turns. This is especially evident in the all exclusive, exclusive right, and fully shared lane groups. Left turns showed higher percentages than right turns in the exclusive left turn lane group.

Hauer's algorithm is the main estimation considered for this research because it incorporates the use of initial turning proportions, the main focus of this research. A second method was introduced to compare to Hauer's algorithm and to see if better estimation can be made. As shown in the previous chapter, Hauer's algorithm proves to provide a better explanation of the data and a stronger relationship between observed and estimated volumes. From analysis of the data, a conclusion can be drawn that the algorithm, along with the turning proportions, provides estimations for turning movement volumes within 25 percent of the actual values for 90 percent of the tested data for the high, medium and low volume intersection levels.

The LOS analysis performed in the previous chapter compared the resulting LOS and delay of three estimated intersection volume types (high, medium, and low) to the corresponding observed volumes. Intersection approach delays were the main tool for comparison. The intersection approach delays were calculated as the weighted averages of the average delay for all the lane groups and are based on the amount of volumes in each of the lane groups. For high volume intersections, the largest difference in delay between the estimated and observed was 7.3 s/veh. The medium volume intersections had the largest change in delay at 1.5 s/veh, and the low volume intersection the largest change in delay at 1.3 s/veh. These results reveal that the effects of the determined turning movement proportions on LOS are small enough to fall within defined density thresholds. The established density thresholds are presented in Figure 19. Changes in turning movement volumes for high, medium, and low volume intersections are then concluded to not have too significant an impact on the LOS.

LOS	Control Delay per vehicle (seconds per vehicle)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

Figure 19 Thresholds for LOS and Delay. Reprinted from (9).

The variability section of this thesis served as a justification for the use of 25 percent error bound during the analysis. The test for the accuracy of estimation showed that Hauer's method and the turning proportion range tables were able to estimate the turning movement volumes for 108 turning movements within 25 percent of the actual value with 95 percent accuracy for high volume intersections, 90 percent accuracy for medium volume intersections, and 97 percent accuracy for low volume intersections. To determine if 25 percent error bound is valid, variability is checked at high, medium, and low volume intersections over different years, days of the week, and peak periods. The analysis resulted in changes in approach volumes up to 50 percent for the intersections. From this, a conclusion can be drawn that having an error bound of 25 percent in the estimation is validated.

LIMITATIONS

Limitations associated with this research are introduced below:

- The major limitation for this project is the data that was available. Counts were collected from different sources, so the time periods and methods of collection were inconsistent.
- Conclusive interpretations cannot be drawn for some of the variable in the proportion range tables because there was not enough sample size to work with
- Because the data ranges over 10 years, there could be some inconsistencies with some of the values obtained, like signal control, lane group, or functional classification for an intersection. This led to the elimination of several counts from the analysis.
- For the average proportions based on lane group and functional classification, it does not distinguish between turning proportion in the peak and non-peak directions, which could alter the results of the proportions.

RECOMMENDATION

When making preliminary engineering decisions for an intersection, the proportion range tables are proposed to be consulted to determine the appropriate turning movement percentages based on the desired roadway characteristics. For each range, the peak direction is recommended to provide the most accurate estimation for turning movement volumes. If this information is unavailable, then the mean proportion can be used. With Hauer's algorithm, the proportion estimates can be used to predict turning movement volumes from AADT with some accuracy. As more information regarding the roadway becomes available, the proportions can be updated accordingly for a better estimation. Appendix A expands further on the recommended process for using the initial turning proportion range tables and Hauer's algorithm to estimate turning movement volumes.

FUTURE WORK

Further research that can be done to improve on the findings in this research include:

- An analysis on using category based on location in an area and attractions surrounding the intersection to predict the turning volumes.
- Increasing the sample size of the variable ranges that had low sample sizes or insufficient data report to increase accuracy of predictions.
- Analyze the effects of including bike, pedestrian and other modes of transportation volumes on estimated turning proportions and volumes.
- Use different software in analysis and confidence interval determination to see effects of bias on predictions.
- Add signal phasing to the analysis and explore relationship between turning proportions and turn signal phasing.

This thesis set out to provide a basis for determining "good" initial turning proportion to be used with algorithms that estimate turning movement volumes at intersections. This was accomplished by introducing recommended initial turning proportions tables based on lane groupings and functional classifications, and an algorithm that can be used to provide an accurate estimation for turning movement volumes. Justification is provided through a variability test and LOS/delay analysis for the initial turning proportions.

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APPENDIX A

RECOMMENDED PROCESS FOR ESTIMATING TURNING MOVEMENT VOLUME FROM AADT USING INITIAL TURNING PROPORTIONS

Turning movement volumes are important variables in traffic analysis. They provide the basic inputs used in traffic studies, forecasting, operational performance analysis, etc. The more common method of obtaining turning movement counts is through manual counting. This, however, can be an expensive and exhaustive task. This research provides a process to estimate hourly turning movement volumes from Annual Average Daily Traffic (AADT), when limited information is presented for the roadway, to make preliminary engineering decisions. The recommended process converts AADT volumes to estimated turning movement volumes using Hauer's method and turning proportion range tables. To use the turning proportion range tables the basic roadway characteristics that need to be known are lane group/number of lanes and the roadway's functional classification.

RECOMMENDED PROCESS

Three major steps to estimate turning movement volumes from AADT are presented below:

1. Convert Annual Average Daily Traffic (AADT) to Directional Design-Hour Volume (DDHV)
2. Select turning proportion from the proportion range tables
3. Estimate hourly turning volumes using Hauer's algorithm, DDHV, and turning proportion

Converting AADT to DDHV

The first step in the process of estimating turning movement volumes is to convert Annual Average Daily Traffic (AADT) to Directional Design-Hour Volume (DDHV). AADT provides an estimate of the average volume of traffic for all days in a year for a segment of roadway (*10*). DDHV represents the volume of traffic as a proportion of AADT in the peak direction. AADT can be converted to DDHV using K-factor and D-factor. K-factor is the proportion of AADT occurring during the peak hour and D-factor is the proportion of traffic moving in the higher volume direction during the peak hour. The equation is provided below.

$$DDHV = AADT * K * D$$

The DDHV will need to be calculated for both sides of the leg of the intersection, departure out of and arrival into the intersection. This distinction is made with the D-factor. Volume into the intersection is calculated with D and assigned the variable O, while volume out of the intersection is calculated with 1 – D and assigned the variable D.

Selecting Turning Proportions

The next step is to select the turning proportion to be used in estimating turning volumes from the turning proportion range tables. Turning proportions average values were determined based on two roadway characteristics, lane group/number of lanes and functional classification, and ranges were calculated for each category with a 95 percent confidence interval. Information on the peak direction is important when using the turning proportion range tables. When the peak direction is determined, the left and right movement proportions to use within the range can be selected with adjustments made for peak direction of traffic. If the peak direction is unknown, the mean of the turning proportion ranges can be used for the turning volume estimation.

Estimating Turning Volumes

The final step is to estimate the turning volumes using Hauer's algorithm, the turning proportions and the calculated DDHV values. Hauer's algorithm utilizes a flow matrix method to convert traffic flow into and out of an intersection and turning proportions to estimated turning volumes. The equations that make up the algorithm are listed below (*1*):

$$T_{ij} = p_{ij} A_i B_j$$

$$A_i = \frac{O_i}{\sqrt{S}}$$

$$B_j = \frac{D_j}{\sum_{i=1}^{m} p_{ij} A_i}$$

$$A_i(new) = \frac{O_i}{\sum_{j=1}^{m} p_{ij} B_j}$$

Where:

T_{ij} = Turning volume estimates (veh/hr)
p_{ij} = Turning proportions (%) (Tables 3-5)
A_i, B_j, A_i(new) = iterative factors
D_j = Traffic volume out of the intersection to approach j (veh/hr)
O_i = Traffic volume into the intersection from approach i (veh/hr)
S = Sum of entering flow (veh/hr)

The process for using this algorithm is to first calculate A_i with the previously determined volumes into the intersection from each approach, O_i, and the total sum of vehicles entering the intersection from all approaches, S. Then calculate B_j with the departure volumes out of the intersection, D_j, the calculated A_i, and the turning proportions from the proportion range tables, p_{ij}. Next, recalculate the A value, A_i(new) with the volumes entering the intersection, O_i, the turning proportions p_{ij}, and the calculated B_j. Determine the difference between A_i and A_i(new). If the largest difference is significantly small, then use A_i(new), B_j and p_{ij} to estimate the turning movement volumes, T_{ij}. If the difference is not significantly small, then A_i is replaced with A_i(new) and the steps are repeated from the calculation of B_j. (The smaller the difference the more accurate the estimation).

CALCULATING HOURLY TURNING VOLUMES FROM AADT

Putting it all together, this section shows calculation of hourly turning movement volumes from AADT. When provided with AADT, the volume can be reduced to turning volumes at an intersection using the turning proportion tables from this research and Hauer's method. An example is provided below, and the results are compared to the observed values for a similar intersection configuration with slightly different volumes.

Suppose the turning volumes need to be determined for preliminary intersection analysis in an urban area. The functional classification of the roads at the intersection are principal arterial (North/South) and minor arterial (East/West). The north and south approaches have 1-left, 3-thru, and 1-right lanes (all exclusive lanes) in each direction. The east and west approaches have 1-left and 2-thru lanes (1 shared right turn) in each direction (partial exclusive/shared lanes). AADT volumes were determined to be 31,000 veh/day, 36,000 veh/day, 15,000 veh/day and 13,000 veh/day for the north, south, east, and west legs respectively (TxDOT, 2020).

The first step is to convert the AADT volumes to DDHV. TxDOT roadway design manual states that K-factors generally range from 8-12 percent for urban facilities and D-factors of 60-70 percent generally occur (*14*). So, a K-factor of 10 percent and D-factor of 65 percent is chosen for this scenario. Using the DDHV equation described, the calculated entrance and departure volumes are shown in Table A.2. Applying Hauer's algorithm and the proportion ranges shown in Table A.1, the turning movement volumes can be calculated (For this example, the peak directions were determined to be eastbound and northbound, and the turning proportions were adjusted to match those directions). The input values for Hauer's algorithm and resulting turning movement volumes are presented in Tables A.2 and A.3 respectively. Observed and estimated turning movement proportions are compared in Figure A.1.

Table A.1 Proportion Range for the Specified Roadway Characteristics (From Tables 4 and 5)

	Left (%)		**Thru (%)**		**Right (%)**	
	Range	**Selection**	**Range**	**Selection**	**Range**	**Selection**
Northbound	0.08~0.11	0.08	0.71~0.81	0.72	0.1~0.2	0.2
Southbound	0.08~0.11	0.11	0.71~0.81	0.79	0.1~0.2	0.1
Eastbound	0.18~0.24	0.24	0.57~0.66	0.61	0.15~0.2	0.15
Westbound	0.18~0.24	0.18	0.57~0.66	0.62	0.15~0.2	0.2
*Proportions are a percentage of the approach volume						

Table A.2 Input and Calculated Values for Example Scenario

		AADT (veh/day)	**K**	**D**	**DDHV**		
Direction	**Road Characteristics**				**O_i (veh/hr)**	**D_j (veh/hr)**	**S (veh/hr)**
Northbound	principal arterial, 1-left, 3-thru, 1-right	31000	0.1	0.65	2015	1085	
Southbound	principal arterial, 1-left, 3-thru, 1-right	36000	0.1	0.65	2340	1260	
Eastbound	minor arterial, 1-left, 2-thru	15000	0.1	0.65	975	525	
Westbound	minor arterial, 1-left, 2-thru	13000	0.1	0.65	845	455	
							6175

Table A.3 Estimated vs Observed Turning Movement Volumes Compared

	Estimated			**Observed**		
	Left	**Thru**	**Right**	**Left**	**Thru**	**Right**
Northbound (veh/hr)	153	1556	302	176	1009	81
Southbound (veh/hr)	174	1965	201	232	1415	205
Eastbound (veh/hr)	282	500	193	175	347	130
Westbound (veh/hr)	176	490	179	135	352	150
Intersection Total (veh/hr)	6175			4407		

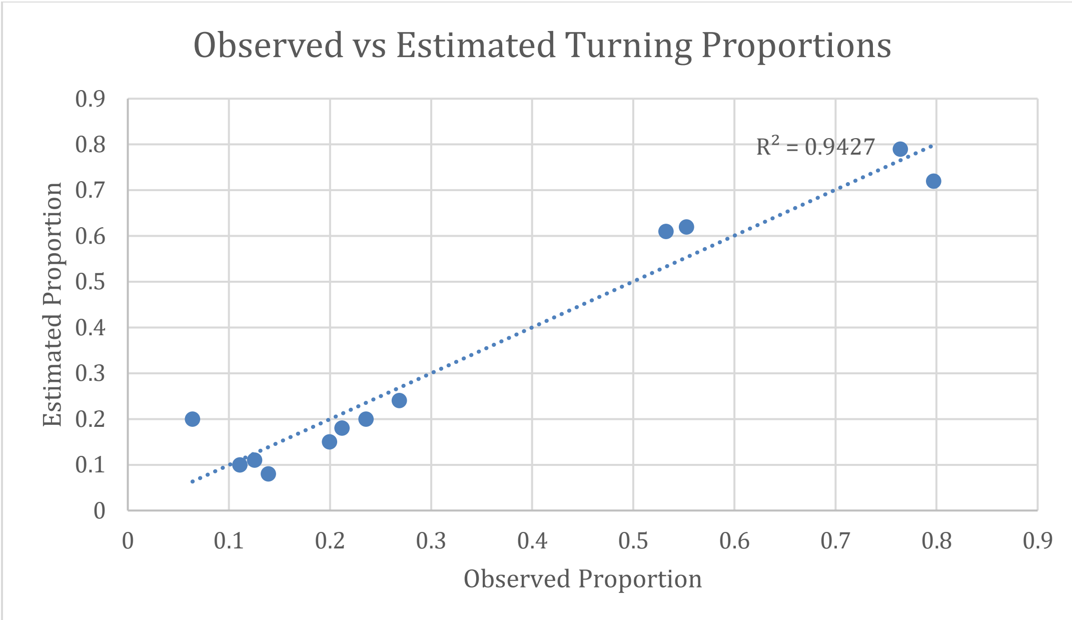

Figure A.1 Estimated vs observed turning movement proportions.

The results from this example show the accuracy of the turning movement proportions ranges within a 95 percent confidence interval. The figure comparing the observed and estimated turning proportions of the results give an R^2 value of 0.9427. This proves that there is a strong relationship between the estimated and observed proportions. The turning proportion ranges are able to estimate turning volumes within 25 percent of the actual proportion ranges. The observed counts were collected from the same year as the AADT but represent a different day in that year, so that provide an explanation for the changes in the delay for some of the approaches. In conclusion, hourly turning movement volumes can be accurately calculated from AADT by using the following steps: 1) Convert AADT to DDHV, 2) Select turning proportion from the proportion range table, and 3) Appl Hauer's algorithm. A hypothetical scenario was also presented to support the use of the three steps and the results show the accuracy of the estimation.

APPENDIX B

AVERAGE RESULTS FOR EACH CATEGORY

This section includes tables of the results for average turning proportions calculated for each variable in the nine categories. The averages are divided by left, thru, and right movements at an intersection. Each table also contains averages for only 3 leg intersections, only 4 leg intersections, and a combination of 3 and 4 leg intersections. For the categories that deal with time, the calculation is done for proportion in the peak directions during the peak periods. Table B.1 presents the average proportion for the functional classification only category. Table B.2 shows the average for the functional classification + time category, and Table B.3 shows the averages for the functional classification + day of the week + time category. The average for lane group only is shown in Table B.4. The averages for lane group + time and for lane group + functional classification are also shown in Tables B.5 and B.6 respectively. Finally, Tables B.7 – B.9 show the average proportion results for intersection control only, intersection control + time, and intersection control + functional classification + time categories respectively.

Table B.1 Average Results for the Functional Classification Only Category

Category			3+4 leg			4 leg			3 leg		
			Proportion								
	From	To	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Functional Classification Only	Major Collector	Major Collector	0.16	0.54	0.30	0.19	0.58	0.22	0.01	0.34	0.65
	Principal Arterial	Principal Arterial	0.21	0.55	0.24	0.21	0.55	0.24	0.24	0.55	0.21
	Principal Arterial	Local	0.06	0.88	0.05	0.07	0.88	0.06	0.02	0.93	0.05
	Local	Principal Arterial	0.42	0.13	0.45	0.42	0.11	0.47	0.55	0.00	0.45
	Minor Arterial	Major Collector	0.14	0.76	0.10	0.16	0.73	0.11	0.14	0.79	0.07
	Major Collector	Minor Arterial	0.34	0.31	0.35	0.32	0.35	0.33	0.45	0.07	0.48
	Minor Arterial	Local	0.23	0.49	0.27	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Local	Minor Arterial	0.40	0.11	0.49	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Major Collector	Principal Arterial	0.38	0.23	0.39	0.34	0.30	0.36	0.52	0.00	0.48
	Principal Arterial	Major Collector	0.09	0.83	0.09	0.10	0.81	0.09	0.04	0.86	0.10
	Minor Arterial	Minor Arterial	0.23	0.59	0.19	0.20	0.61	0.19	0.27	0.55	0.18
	Minor Arterial	Principal Arterial	0.30	0.43	0.28	0.29	0.46	0.25	0.36	0.00	0.64
	Principal Arterial	Minor Arterial	0.15	0.74	0.11	0.15	0.73	0.11	0.13	0.78	0.08
	Major Collector	Local	0.37	0.44	0.19	0.39	0.43	0.19	*INSUFFICIENT DATA*		
	Local	Major Collector	0.15	0.52	0.33	0.14	0.51	0.35	*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

Table B.2 Average Results for the Functional Classification + Time Category

Category				3+4 leg			4 leg			3 leg		
				Proportion (Peak Direction)								
	From	**To**	**Time**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**
Functional Classification + Time	Major Collector	Major Collector	AM + PM	0.12	0.49	0.39	0.20	0.58	0.21	0.01	0.34	0.65
	Principal Arterial	Principal Arterial	AM + PM	0.21	0.50	0.29	0.20	0.51	0.29	0.31	0.38	0.31
	Principal Arterial	Local	AM + PM	0.06	0.92	0.02	0.06	0.92	0.03	0.05	0.95	0.00
	Local	Principal Arterial	AM + PM	0.44	0.08	0.49	0.42	0.09	0.49	0.54	0.00	0.46
	Minor Arterial	Major Collector	AM + PM	0.19	0.74	0.07	0.19	0.73	0.08	0.21	0.77	0.02
	Major Collector	Minor Arterial	AM + PM	0.37	0.27	0.36	0.34	0.33	0.33	0.47	0.07	0.46
	Minor Arterial	Local	AM + PM	0.11	0.40	0.49	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Local	Minor Arterial	AM + PM	0.75	0.02	0.23	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Major Collector	Principal Arterial	AM + PM	0.45	0.14	0.41	0.43	0.23	0.34	0.49	0.00	0.51
	Principal Arterial	Major Collector	AM + PM	0.08	0.83	0.09	0.09	0.82	0.09	0.04	0.87	0.09
	Minor Arterial	Minor Arterial	AM + PM	0.29	0.51	0.20	0.22	0.59	0.19	0.37	0.42	0.21
	Minor Arterial	Principal Arterial	AM + PM	0.32	0.35	0.32	0.32	0.40	0.28	0.37	0.00	0.63
	Principal Arterial	Minor Arterial	AM + PM	0.13	0.78	0.09	0.14	0.77	0.10	0.12	0.82	0.06
	Major Collector	Local	AM + PM	0.35	0.55	0.10	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Local	Major Collector	AM + PM	0.14	0.61	0.25	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
*Proportions represented are a percentage of the approach volume												

Table B.3 Average Results for the Functional Classification + Time + Day of the Week Category

Category				3+4 leg			4 leg			3 leg		
				Proportion (Peak Direction)								
	From	To		Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Functional Classification + Peak + Day of the week	Major Collector	Major Collector	Tuesday	0.14	0.50	0.36	0.23	0.60	0.17	0.01	0.34	0.65
			Thursday	0.17	0.51	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Principal Arterial	Principal Arterial	Tuesday	0.19	0.43	0.38	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Wednesday	0.20	0.49	0.31	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Thursday	0.26	0.51	0.23	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Principal Arterial	Local	Tuesday	0.07	0.91	0.03	0.06	0.91	0.03	0.09	0.89	0.01
			Wednesday	0.03	0.92	0.04	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Thursday	0.12	0.82	0.05	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Local	Principal Arterial	Tuesday	0.48	0.07	0.51	0.42	0.07	0.51	0.69	0.05	0.26
			Wednesday	0.46	0.04	0.50	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Thursday	0.42	0.12	0.45	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Minor Arterial	Major Collector	Monday	0.17	0.81	0.02	0.13	0.84	0.03	0.25	0.75	0.00
			Tuesday	0.13	0.83	0.05	0.13	0.82	0.05	0.12	0.88	0.00
			Wednesday	0.10	0.82	0.08	0.15	0.74	0.10	0.02	0.93	0.04
			Thursday	0.20	0.73	0.08	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Major Collector	Minor Arterial	Monday	0.48	0.25	0.28	0.45	0.33	0.21	0.54	0.00	0.46
			Tuesday	0.33	0.23	0.44	0.32	0.26	0.42	0.41	0.00	0.59
			Wednesday	0.37	0.19	0.44	0.29	0.31	0.40	0.50	0.00	0.50
			Thursday	0.35	0.33	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Minor Arterial	Local	Tuesday	0.03	0.34	0.63	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Local	Minor Arterial	Tuesday	0.74	0.02	0.24	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Major Collector	Principal Arterial	Monday	0.60	0.17	0.23	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Tuesday	0.46	0.14	0.41	0.41	0.18	0.41	0.60	0.00	0.40
			Wednesday	0.44	0.19	0.38	0.41	0.33	0.27	0.48	0.00	0.52
			Thursday	0.47	0.13	0.39	0.44	0.24	0.32	0.52	0.00	0.48
	Principal Arterial	Major Collector	Monday	0.08	0.80	0.12	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Tuesday	0.09	0.82	0.10	0.10	0.83	0.07	0.02	0.76	0.21
			Wednesday	0.12	0.79	0.09	0.15	0.77	0.08	0.04	0.82	0.14
			Thursday	0.08	0.84	0.09	0.09	0.82	0.09	0.05	0.86	0.09

*Proportions represented are a percentage of the approach volume

Table B.3 Continued

Category				3+4 leg			4 leg			3 leg		
				Proportion (Peak Direction)								
	From	**To**		**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**
Functional Classification + Peak + Day of the week	Minor Arterial	Minor Arterial	Monday	0.26	0.51	0.23	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Tuesday	0.22	0.61	0.17	0.19	0.63	0.17	0.37	0.45	0.18
			Wednesday	0.37	0.42	0.22	*INSUFFICIENT DATA*			0.37	0.42	0.22
			Thursday	0.37	0.44	0.19	0.37	0.48	0.15	0.38	0.41	0.21
	Minor Arterial	Principal Arterial	Monday	0.31	0.44	0.26	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Tuesday	0.35	0.29	0.36	0.34	0.36	0.31	0.41	0.00	0.59
			Wednesday	0.32	0.36	0.32	0.31	0.39	0.30	0.41	0.00	0.59
			Thursday	0.29	0.37	0.34	0.30	0.40	0.31	0.25	0.00	0.75
			Friday	0.37	0.29	0.34	0.37	0.35	0.28	0.35	0.00	0.65
	Principal Arterial	Minor Arterial	Monday	0.11	0.78	0.11	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Tuesday	0.11	0.82	0.07	0.11	0.82	0.07	0.14	0.80	0.07
			Wednesday	0.18	0.73	0.08	0.18	0.74	0.09	0.29	0.71	0.00
			Thursday	0.16	0.74	0.10	0.17	0.73	0.10	0.00	0.91	0.09
			Friday	0.11	0.76	0.13	0.14	0.74	0.13	0.00	0.87	0.13

*Proportions represented are a percentage of the approach volume

Table B.4 Average Results for the Lane Group Only Category

Category			3+4 leg			4 leg			3 leg		
			Proportion								
		Number of Lanes/Movement	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Lane Group Only	No Exclusive Lanes	1-left/thru/right	0.29	0.28	0.42	0.33	0.25	0.42	0.20	0.37	0.43
		1-thru/right, 1-left/thru	0.32	0.43	0.26	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-thru/right	0.26	0.30	0.44	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left/thru	0.02	0.82	0.15	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-thru ~ 2-thru (1 shared rt)	0.14	0.70	0.16	0.12	0.74	0.15	0.16	0.67	0.16
		3-thru (1 shared rt)	0.00	0.96	0.03	0.00	0.98	0.02	0.00	0.94	0.06
	Exclusive Left Turn	1-left, 1-thru/right	0.24	0.49	0.26	0.25	0.49	0.26	0.10	0.63	0.27
		1-left, 2-thru (1 shared rt) ~ 1-left, 2-thru	0.19	0.71	0.10	0.20	0.69	0.12	0.14	0.85	0.02
		2-left, 3-thru (1 shared rt)	0.28	0.61	0.12	0.28	0.59	0.13	0.23	0.77	0.00
		1-left, 3-thru (1 shared rt)	0.07	0.88	0.05	0.08	0.87	0.05	0.06	0.90	0.04
		1-left, 4-thru (1 shared rt)	0.03	0.96	0.01	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Right Turn	1-left/thru, 1-right	0.26	0.28	0.45	0.27	0.30	0.43	0.24	0.00	0.76
		1-left, 1-right	0.56	0.00	0.44	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		3-thru, 1-right	0.00	0.86	0.14	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Left/Thru/Right	1-left, 1-thru, 1-right	0.35	0.33	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-thru, 2-right	0.45	0.55	0.00	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 2-thru, 1-right	0.13	0.62	0.25	0.12	0.63	0.25	0.76	0.16	0.08
		1-left, 1-left/thru, 1-right	0.42	0.13	0.44	0.43	0.11	0.46	0.40	0.20	0.40
		1-left, 1-left/thru, 1-thru, 1-right	0.38	0.30	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 1-thru, 1-right	0.44	0.23	0.33	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 1-right	0.35	0.41	0.23	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 3-thru, 1-right	0.10	0.76	0.14	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 2-right	0.24	0.62	0.14	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 3-thru, 1-right	0.10	0.69	0.21	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

Table B.5 Average Results for the Lane Group + Time Category

Category				3+4 leg			4 leg			3 leg		
				Proportion (Peak Direction)								
		Number of Lanes/Movement	Time	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Lane Group + Time	No Exclusive Lanes	1-left/thru/right	AM + PM	0.30	0.23	0.47	0.36	0.20	0.43	0.22	0.26	0.52
		1-thru/right, 1-left/thru	AM + PM	0.27	0.47	0.27	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-thru/right	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left/thru	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-thru ~ 2-thru (1 shared rt)	AM + PM	0.10	0.70	0.20	0.12	0.75	0.12	0.06	0.67	0.27
		3-thru (1 shared rt)	AM + PM	0.00	0.96	0.04	0.00	0.97	0.03	0.00	0.93	0.07
	Exclusive Left Turn	1-left, 1-thru/right	AM + PM	0.30	0.44	0.26	0.31	0.43	0.26	0.08	0.54	0.38
		1-left, 2-thru (1 shared rt) ~ 1-left, 2-thru	AM + PM	0.15	0.78	0.07	0.18	0.73	0.09	0.07	0.92	0.01
		2-left, 3-thru (1 shared rt)	AM + PM	0.25	0.61	0.14	0.25	0.60	0.15	0.27	0.73	0.00
		1-left, 3-thru (1 shared rt)	AM + PM	0.08	0.87	0.05	0.08	0.87	0.06	0.09	0.89	0.02
		1-left, 4-thru (1 shared rt)	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Right Turn	1-left/thru, 1-right	AM + PM	0.39	0.09	0.52	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-right	AM + PM	0.57	0.00	0.43	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		3-thru, 1-right	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Left/Thru/Right	1-left, 1-thru, 1-right	AM + PM	0.38	0.28	0.34	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-thru, 2-right	AM + PM	0.45	0.55	0.00	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 2-thru, 1-right	AM + PM	0.12	0.58	0.29	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-left/thru, 1-right	AM + PM	0.40	0.15	0.45	0.41	0.12	0.48	0.40	0.20	0.40
		1-left, 1-left/thru, 1-thru, 1-right	AM + PM	0.38	0.30	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 1-thru, 1-right	AM + PM	0.47	0.23	0.30	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 1-right	AM + PM	0.37	0.40	0.24	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 3-thru, 1-right	AM + PM	0.10	0.80	0.10	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 2-right	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 3-thru, 1-right	AM + PM	0.09	0.73	0.17	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

Table B.6 Average Results for the Lane Group + Functional Classification Category

Category					3+4 leg			4 leg			3 leg		
					Proportion								
		Number of Lanes/Movement	From	To	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Lane Group + Functional Class	No Exclusive Lanes	1-left/thru/right	Major Collector	Major Collector	0.21	0.35	0.44	0.30	0.35	0.35	0.01	0.34	0.65
			Local	Principal Arterial	0.46	0.05	0.48	0.46	0.05	0.48	*INSUFFICIENT DATA*		
			Major Collector	Principal Arterial	0.37	0.12	0.52	0.34	0.14	0.52	0.50	0.00	0.50
		1-thru/right, 1-left/thru	Minor Arterial	Principal Arterial	0.28	0.48	0.25	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Minor Arterial	0.31	0.43	0.26	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-thru/right	Major Collector	Minor Arterial	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Principal Arterial	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left/thru	Major Collector	Principal Arterial	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-thru ~ 2-thru (1 shared rt)	Principal Arterial	Major Collector	0.10	0.81	0.09	0.10	0.78	0.12	0.10	0.89	0.01
			Minor Arterial	Major Collector	0.22	0.68	0.11	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Minor Arterial	0.00	0.80	0.20	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Minor Arterial	0.00	0.84	0.16	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		3-thru (1 shared rt)	Principal Arterial	Local	0.00	0.97	0.03	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Major Collector	0.01	0.96	0.03	0.00	0.96	0.04	0.02	0.96	0.03
	Exclusive Left Turn	1-left, 1-thru/right	Major Collector	Major Collector	0.09	0.82	0.09	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Principal Arterial	0.40	0.19	0.41	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Minor Arterial	0.18	0.66	0.17	0.19	0.63	0.18	0.09	0.79	0.12
		1-left, 2-thru (1 shared rt) ~ 1-left, 2-thru	Principal Arterial	Minor Arterial	0.18	0.73	0.09	0.17	0.73	0.10	0.28	0.72	0.00
			Minor Arterial	Principal Arterial	0.21	0.62	0.18	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Local	0.05	0.87	0.08	0.08	0.83	0.09	0.03	0.89	0.08
			Principal Arterial	Major Collector	0.07	0.89	0.04	0.08	0.86	0.06	0.02	0.96	0.01
			Major Collector	Principal Arterial	0.39	0.50	0.12	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Major Collector	0.21	0.70	0.09	0.19	0.70	0.11	0.35	0.65	0.00
			Minor Arterial	Minor Arterial	0.17	0.70	0.13	0.19	0.62	0.19	0.13	0.87	0.00

*Proportions represented are a percentage of the approach volume

Table B.6 Continued

Category					3+4 leg			4 leg			3 leg		
					Proportion								
Lane Group + Functional Class		Number of Lanes/Movement	From	To	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
	Exclusive Left Turn	2-left, 3-thru (1 shared rt)	Principal Arterial	Principal Arterial	0.23	0.56	0.20	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Minor Arterial	0.31	0.66	0.02	0.33	0.64	0.03	0.23	0.77	0.00
		1-left, 3-thru (1 shared rt)	Principal Arterial	Local	0.06	0.91	0.03	0.05	0.92	0.03	0.09	0.87	0.04
			Principal Arterial	Major Collector	0.06	0.89	0.06	0.07	0.87	0.06	0.03	0.95	0.02
			Principal Arterial	Minor Arterial	0.14	0.78	0.07	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 4-thru (1 shared rt)	Principal Arterial	Local	0.03	0.96	0.01	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Right Turn	1-left/thru, 1-right	Minor Arterial	Principal Arterial	0.16	0.54	0.30	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Local	Principal Arterial	0.39	0.08	0.53	0.42	0.10	0.48	0.24	0.00	0.76
			Local	Minor Arterial	0.09	0.19	0.72	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-right	Major Collector	Principal Arterial	0.64	0.00	0.36	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Minor Arterial	0.65	0.00	0.35	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Principal Arterial	0.32	0.00	0.68	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		3-thru, 1-right	Principal Arterial	Minor Arterial	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Exclusive Left/Thru/Right	1-left, 1-thru, 1-right	Local	Principal Arterial	0.16	0.48	0.36	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Principal Arterial	0.33	0.37	0.30	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Minor Arterial	0.23	0.43	0.34	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Local	Minor Arterial	0.74	0.02	0.24	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-thru, 2-right	Principal Arterial	Principal Arterial	0.45	0.55	0.00	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 2-thru, 1-right	Principal Arterial	Principal Arterial	0.15	0.51	0.34	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Principal Arterial	0.14	0.54	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Major Collector	0.02	0.84	0.14	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Principal Arterial	0.15	0.58	0.27	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Minor Arterial	0.08	0.81	0.11	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-left/thru, 1-right	Local	Principal Arterial	0.49	0.16	0.36	0.49	0.16	0.36	0.40	0.20	0.40
			Minor Arterial	Principal Arterial	0.37	0.15	0.48	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 1-left/thru, 1-thru, 1-right	Minor Arterial	Principal Arterial	0.38	0.30	0.32	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
*Proportions represented are a percentage of the approach volume													

Table B.6 Continued

Category					3+4 leg Left	3+4 leg Thru	3+4 leg Right	4 leg Left	4 leg Thru	4 leg Right	3 leg Left	3 leg Thru	3 leg Right
		Number of Lanes/Movement	From	To	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Lane Group + Functional Class	Exclusive Left/Thru/Right	2-left, 1-thru, 1-right	Major Collector	Minor Arterial	0.44	0.13	0.44	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Principal Arterial	0.42	0.36	0.22	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Major Collector	Principal Arterial	0.41	0.22	0.37	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 1-right	Principal Arterial	Principal Arterial	0.23	0.48	0.29	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Minor Arterial	Principal Arterial	0.52	0.33	0.16	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		1-left, 3-thru, 1-right	Principal Arterial	Minor Arterial	0.09	0.76	0.15	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 2-thru, 2-right	Principal Arterial	Principal Arterial	0.24	0.62	0.14	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
		2-left, 3-thru, 1-right	Principal Arterial	Principal Arterial	0.14	0.55	0.31	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Minor Arterial	0.08	0.72	0.21	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
			Principal Arterial	Local	0.09	0.81	0.10	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

Table B.7 Average Results for the Intersection Control Only Category

Category			3+4 leg Left	3+4 leg Thru	3+4 leg Right	4 leg Left	4 leg Thru	4 leg Right	3 leg Left	3 leg Thru	3 leg Right
	From	To	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Signal Control Only	Signalized	Signalized	0.23	0.56	0.22	0.23	0.56	0.22	0.23	0.55	0.22
	Stop Controlled	Non signalized	0.31	0.22	0.47	0.24	0.43	0.33	0.48	0.00	0.52
	Non signalized	Stop Controlled	0.08	0.79	0.13	0.11	0.73	0.15	0.05	0.84	0.11
	Stop Controlled	Stop Controlled	0.21	0.51	0.28	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Non signalized	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

Table B.8 Average Results for the Intersection Control + Time Category

				3+4 leg			4 leg			3 leg		
Category				**Proportion**								
Signal Control + Time	**From**	**To**		**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**
	Signalized	Signalized	AM + PM	0.24	0.53	0.23	0.23	0.55	0.22	0.30	0.43	0.27
	Stop Controlled	Non signalized	AM + PM	0.36	0.11	0.53	0.22	0.23	0.55	0.48	0.00	0.52
	Non signalized	Stop Controlled	AM + PM	0.06	0.78	0.16	0.08	0.70	0.22	0.06	0.79	0.15
	Stop Controlled	Stop Controlled	AM + PM	0.21	0.53	0.26	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Non signalized	AM + PM	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
*Proportions represented are a percentage of the approach volume												

Table B.9 Average Results for the Intersection Control + Functional Classification + Time Category

Category					3+4 leg			4 leg			3 leg		
					Proportion								
Signal Control + Functional Class	**From**	**To**	**From**	**To**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**	**Left**	**Thru**	**Right**
	Signalized	Signalized	Principal Arterial	Local	0.06	0.92	0.02	0.06	0.91	0.03	0.03	0.97	0.00
	Signalized	Signalized	Local	Principal Arterial	0.39	0.08	0.53	0.42	0.09	0.49	0.24	0.00	0.76
	Signalized	Signalized	Minor Arterial	Major Collector	0.21	0.72	0.08	0.19	0.73	0.08	0.35	0.63	0.02
	Signalized	Signalized	Major Collector	Minor Arterial	0.36	0.31	0.33	0.34	0.33	0.33	0.53	0.16	0.32
	Signalized	Signalized	Major Collector	Principal Arterial	0.40	0.23	0.37	0.43	0.23	0.34	0.66	0.00	0.34
	Signalized	Signalized	Principal Arterial	Major Collector	0.08	0.82	0.10	0.09	0.82	0.09	0.05	0.81	0.13
	Signalized	Signalized	Minor Arterial	Minor Arterial	0.28	0.53	0.19	0.22	0.59	0.19	0.37	0.43	0.21
	Signalized	Signalized	Principal Arterial	Principal Arterial	0.21	0.50	0.29	0.20	0.51	0.29	0.31	0.38	0.31
	Signalized	Signalized	Principal Arterial	Minor Arterial	0.13	0.78	0.09	0.14	0.77	0.10	0.12	0.82	0.06
	Signalized	Signalized	Minor Arterial	Principal Arterial	0.32	0.35	0.32	0.32	0.40	0.28	0.37	0.00	0.63
	Stop Controlled	Non signalized	Major Collector	Major Collector	0.24	0.26	0.51	0.32	0.38	0.30	0.01	0.00	0.99
	Stop Controlled	Non signalized	Local	Principal Arterial	0.65	0.02	0.34	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Stop Controlled	Non signalized	Major Collector	Principal Arterial	0.30	0.06	0.63	0.52	0.48	0.00	0.31	0.00	0.69
	Stop Controlled	Non signalized	Major Collector	Minor Arterial	0.44	0.00	0.56	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Stop Controlled	Major Collector	Major Collector	0.06	0.77	0.18	0.08	0.81	0.11	0.00	0.68	0.32
	Non signalized	Stop Controlled	Principal Arterial	Local	0.05	0.92	0.03	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Stop Controlled	Principal Arterial	Major Collector	0.06	0.92	0.03	0.14	0.82	0.04	0.03	0.95	0.02
	Non signalized	Stop Controlled	Minor Arterial	Major Collector	0.11	0.87	0.02	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Non signalized	Principal Arterial	Local	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		
	Non signalized	Non signalized	Local	Principal Arterial	*INSUFFICIENT DATA*			*INSUFFICIENT DATA*			*INSUFFICIENT DATA*		

*Proportions represented are a percentage of the approach volume

APPENDIX C

PROPORTION RANGES FOR TWO CATEGORIES

Included in this section are the two category tables compared with the selected category to determine the optimal proportion range. Each table shows the determined proportion ranges of the left, thru, and right movements for each variable in the category. These proportion ranges were determined with a 95 percent confidence interval. Also displayed are the sample size for the variables that had sufficient data. The sections listed as "INSUFFICIENT DATA" did not have enough data to accurately present a proportion range that could reliably estimate turning movement volumes with a 25 percent error bound and significance level of 0.05. Each table is divided into 4 leg intersections and 3 leg intersections to represent the types of roadways present. Table C.1 displays the proportion range for the functional classification + time category and Table C.2 presents the proportion range for the determined for the intersection control + functional classification + time category.

Table C.1 Proportion Range Table for Functional Classification + Time Category

			4 leg				3 leg			
	From	To	Left	Thru	Right	Sample Size	Left	Thru	Right	Sample Size
Functional Classification + Time	Major Collector	Major Collector	0.09 - 0.31	0.43 - 0.74	0.11 - 0.32	12	*INSUFFICIENT DATA*			
	Principal Arterial	Principal Arterial	0.15 - 0.24	0.44 - 0.59	0.20 - 0.38	32	*INSUFFICIENT DATA*			
	Principal Arterial	Local	0.03 - 0.08	0.89 - 0.94	0.02 - 0.04	27	0.00 - 0.11	0.89 – 1.00	0.00 - 0.00	4
	Local	Principal Arterial	0.35 - 0.49	0.05 - 0.13	0.41 - 0.57	26	*INSUFFICIENT DATA*			
	Minor Arterial	Major Collector	0.10 - 0.30	0.63 - 0.83	0.05 - 0.10	20	*INSUFFICIENT DATA*			
	Major Collector	Minor Arterial	0.28 - 0.39	0.25 - 0.42	0.24 - 0.42	20	*INSUFFICIENT DATA*			
	Minor Arterial	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Local	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Major Collector	Principal Arterial	0.36 - 0.51	0.14 - 0.31	0.24 - 0.45	27	0.35 - 0.62	0.00 - 0.00	0.38 - 0.65	16
	Principal Arterial	Major Collector	0.07 - 0.14	0.75 - 0.85	0.06 - 0.13	40	0.01 - 0.06	0.79 - 0.95	0.00 - 0.18	15
	Minor Arterial	Minor Arterial	0.10 - 0.30	0.63 - 0.83	0.05 - 0.10	20	*INSUFFICIENT DATA*			
	Minor Arterial	Principal Arterial	0.27 - 0.36	0.36 - 0.45	0.25 - 0.31	48	*INSUFFICIENT DATA*			
	Principal Arterial	Minor Arterial	0.11 - 0.16	0.73 - 0.80	0.08 - 0.11	54	*INSUFFICIENT DATA*			
	Major Collector	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Local	Major Collector	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
*Proportions represented are a percentage of the approach volume										

Table C.2 Proportion Range Table for Intersection Control + Functional Classification + Time Category

Signal Control + Functional Class					4 leg				3 leg			
	From	**To**	**From**	**To**	**Left**	**Thru**	**Right**	**Sample Size**	**Left**	**Thru**	**Right**	**Sample Size**
	Signalized	Signalized	Principal Arterial	Local	0.03 - 0.08	0.89 - 0.95	0.01 - 0.04	25	*INSUFFICIENT DATA*			
			Local	Principal Arterial	0.34 - 0.49	0.05 - 0.14	0.40 - 0.58	24	*INSUFFICIENT DATA*			
			Minor Arterial	Major Collector	0.10 - 0.30	0.63 - 0.83	0.05 - 0.10	20	*INSUFFICIENT DATA*			
			Major Collector	Minor Arterial	0.28 - 0.39	0.25 - 0.42	0.24 - 0.42	20	*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	0.37 - 0.52	0.13 - 0.31	0.23 - 0.44	25	*INSUFFICIENT DATA*			
			Principal Arterial	Major Collector	0.07 - 0.14	0.75 - 0.85	0.06 - 0.13	40	0.02 - 0.08	0.71 - 0.94	0.00 - 0.26	10
			Minor Arterial	Minor Arterial	0.18 - 0.26	0.50 - 0.69	0.11 - 0.26	16	0.18 - 0.55	0.17 - 0.67	0.11 - 0.31	14
			Principal Arterial	Principal Arterial	0.15 - 0.24	0.44 - 0.59	0.20 - 0.38	32	*INSUFFICIENT DATA*			
			Principal Arterial	Minor Arterial	0.11 - 0.16	0.73 - 0.80	0.08 - 0.11	54	*INSUFFICIENT DATA*			
			Minor Arterial	Principal Arterial	0.27 - 0.36	0.36 - 0.45	0.25 - 0.31	48	*INSUFFICIENT DATA*			
			Minor Arterial	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Local	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Major Collector	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Local	Major Collector	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Stop Controlled	Non signalized	Major Collector	Major Collector	0.13 - 0.33	0.40 - 0.67	0.14 - 0.34	15	*INSUFFICIENT DATA*			
			Local	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Major Collector	Principal Arterial	*INSUFFICIENT DATA*			2	*INSUFFICIENT DATA*			
			Major Collector	Minor Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Non signalized	Stop Controlled	Major Collector	Major Collector	0.09 - 0.27	0.50 - 0.77	0.09 - 0.27	15	*INSUFFICIENT DATA*			
			Principal Arterial	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Principal Arterial	Major Collector	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Minor Arterial	Major Collector	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
	Non signalized	Non signalized	Principal Arterial	Local	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			
			Local	Principal Arterial	*INSUFFICIENT DATA*				*INSUFFICIENT DATA*			

*Proportions represented are a percentage of the approach volume