# Development of Queue Length Models at Two-way STOP Controlled Intersection:

## *A Surrogate Method*

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**October 2010**

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# Executive Summary

This study aims at developing queue length models at two-way STOP controlled intersections. A significant amount of research on the estimation of capacity, delay, and queue lengths at unsignalized intersection has resulted in a variety of models ranging from empirical to simulation models. Most agencies are following methods like the Two-Minute Rule, Highway Capacity Manual Method, and the Harmelink Curves to estimate queue lengths. But, these methods are yielding inconsistence estimates and questions often arise as to the correct method to use. This study documents the inconsistency among these methods and takes further steps to improve queue length estimates by developing surrogate models.

Data at 15 two-way STOP controlled intersections covering various functional classifications of highways, geometric configurations, and geographic regions were collected by using video tapes. Data was processed to meet the requirements of the methods. Queue length estimations from each method were noted. Later, models were compared for their performance in estimating 95$^{th}$ percentile queue lengths. It was shown that the Highway Capacity Manual method consistently underestimates queues. The two-minute rule estimated fairly closer queue lengths except for major left turn movements, due to not considering opposing volumes. The Harmelink curves are applicable only for major left turns. Queue length estimation equations developed by John T. Gard showed better results, but the variation among observed and estimated queue lengths was still high.

Data processed for comparison was used to estimate the models. First, looking at the data clearly indicated that random phenomena prevail among queue lengths and the associated explanatory variables. Exhaustive statistical analysis was conducted to understand queue behavior on both major and minor approach lane groups. Poisson regression models were fitted to explain the random process. A model comparison showed significantly improved performance of the new models in predicting maximum queue lengths.

Further, field data at 25 intersections was collected covering wide array of condition to test the developed model consistency. More than 70 % of the predicted queue lengths were close to observed queue length estimates. In addition, model sensitivity analysis was performed to assess the stability of the model. When the major and minor approach volumes are within limits of MUTCD signal warrant volumes, acceptable ranges of queue lengths are predicted. Beyond the MUTCD suggested volume ranges, marginal increase in input variable substantiates queue lengths.

This report is organized in seven chapters. Various methods are reviewed in Chapter 1. Problems identified in each method, objectives, scope and methodology are discussed. Chapter 2 is dedicated to data collection and analysis efforts. Chapter 3 compares the methods and highlights their differences. Chapter 4 explains the basic philosophy of developing Poisson regression models. Detailed statistical analysis, including data description, model selection, variable selection and model statistics are included. Data validation steps are presented in chapter 5. Chapter 6 deals with the stability analysis of the model through sensitivity tests. Chapter 7 gives the summary, conclusions, and scope for future study.

# 1 Introduction

A significant amount of research on the estimation of capacity, delay, and queue lengths at unsignalized intersection has resulted in the development of a variety of models ranging from empirical to simulation. A literature review of all available models is beyond the scope of this project, but unsignalized intersection theory chapter in the Traffic Flow Theory1 gives a good start. In particular, the philosophies behind the methods like, Two-Minute Rule, Highway Capacity Manual Method, the Harmelink Curves, and equations given by John T. Gard are discussed.

This chapter introduces the above mentioned methods briefly. Next, problems associated with each method are explained. This leads to the definition of the problem. Finally, the step-by-step process used for the study is presented.

## *1.1 Methodologies*

### 1.1.1 Two-Minute Rule[2]

The Two-Minute Rule is a rule of thumb methodology that estimates queue lengths for major street left turns and minor street movements by using the queue that would result from a two-minute stoppage of the turning demand volume. This method does not consider the magnitudes and impacts of the conflicting flows on the size of the queue. The calculation of the 95th percentile queue using the two-minute rule methodology shall use the following equation:

S = (v) (t) (L)

Where:

S = the 95th percentile queue storage length (feet)

v = the average left-turn volume arriving in a 2-minute interval

t = a variable representing the ability to store all vehicles; usually 1.75 to 2.0 (Use Table 1-1)

L = average length of the vehicles being stored and the gap between vehicles; 25 ft. for cars. This value can be increased where a significant number of trucks are present

[1] R.J.Troutbeck., and Brilon, W. "*Unsignalised Intersection Theory*", Traffic Flow Theory, TRB Special Report 165, Washington D.C.

[2] Chapter 7: Intersection Analysis, "*Analysis Procedure Manual* ", Updated: May 2010, Pg:237

**Table 1-1 Selection of "t" values (*source: APM*)**

**Exhibit 7-29 Selection of "t" Values**

| Minimum "t" Value | Percentile |
|---|---|
| 2.0 | 98 % |
| 1.85 | 95 % |
| 1.75 | 90 % |
| 1.0 | 50 % |

It should also be noted that the value of 25-feet used in the equation represents the average storage length required for a passenger car. If a significant number of trucks are present in the turning volumes, the average storage length per vehicle should be increased according to Table 1-2. This adjustment is only for the manual methods; software packages may require a different adjustment.

**Table 1- 2 Storage Length Adjustments for Trucks (*source: APM)***

**Exhibit 7-30 Storage Length Adjustments for Trucks**

| Percent Trucks in Turning Volume | Average Vehicle Storage Length |
|---|---|
| < 2% | 25 ft |
| 5% | 27 ft |
| 10% | 29 ft |

While both the nomograph given in the Analysis Procedure Manual and the rule of thumb equation are intended for use in estimating vehicle queue lengths for single-lane left turn movements, the vehicle queue lengths for double left turn lanes can be estimated by dividing the results of these methods by 1.8. This value represents the assumption that queued vehicles will not be evenly distributed between the turn lanes.

### 1.1.2 Harmelink Curves[3]

M.D. Harmelink , in a paper that was published in 1967, provided the foundation for many current left-turn guidelines. Harmelink based his work on a queuing model in which arrival and service rates are assumed to follow negative exponential distributions. He stated that the probability of a through vehicle arriving behind a stopped, left-turning vehicle should not exceed 0.02 for 40 mph (64 km/h), 0.015 for 50 mph (80 km/h), and 0.01 for 60 mph (96 km/h). He presented his criteria in the form of graphs, 18 in all. To use his graphs, the advancing volume, opposing volume, operating speed, and left-turn percentage

[3] M.D.Harmelink, "*Volume Warrants for Left-Turn Storage Lanes at Unsignalized Grade Intersections*", Highway Research Record 211, 1967

need to be known. Graphs for speeds of 40, 50, and 60 mph (64, 80, and 96 km/h) are given, as well as 5, 10, 15, 20, 30, and 40 percent left-turn volumes.

### 1.1.3 Highway Capacity Manual[4]

HCM 2000 relies on refined models developed in Germany based on both gap acceptance and empirical models which describe the interaction of the minor or stop controlled approach with drivers on the major street. The following figure shows the computational steps to calculate the queue lengths for two-way stop controlled approaches.

$$Q_{95} \approx 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{150T}}\right]\left(\frac{c_{m,x}}{3600}\right) \qquad (17\text{-}37)$$

where

$Q_{95}$ = 95th-percentile queue (veh),
$v_x$ = flow rate for movement x (veh/h),
$c_{m,x}$ = capacity of movement x (veh/h), and
$T$ = analysis time period (h) (T = 0.25 for a 15-min period).

95th percentile queue lengths are calculated by the above equation 17-37 of the HCM. For varying volume-to-capacity ratios, expected maximum number of vehicles in queue are obtained from Figure 1-1.

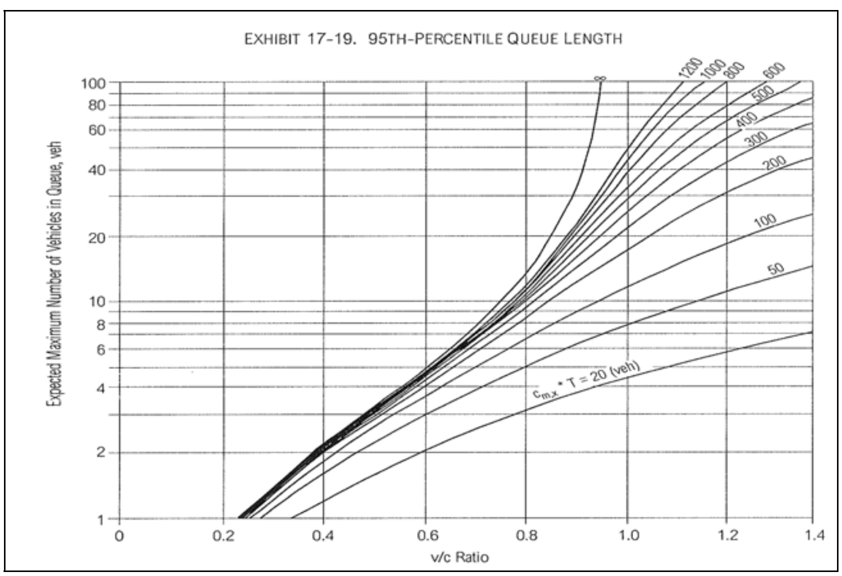



**Figure 1-1 Expected maximum number of vehicles in Queue by HCM**

[4] "Chapter 17- Unsignalized intersections", *2000 Highway Capacity Manual*, Transportation Research Board, Washington, D.C.

### 1.1.4 Gard's Equation[5]

John T. Gard developed regression equations for the prediction of queue lengths for major-street left turn, minor street left turn, minor street right turn, and minor street shared left/through/right turn configurations through a study of 15 unsignalized intersections in Sacramento, CA. Queue length represents the maximum number of vehicles in the queue. Table 1-3 describes the study intersections and Table 1-4 gives a summary of regression equations. $R^2$ values of the equations vary from 0.65 to 0.80.

**Table 1-3 Description of Gard's Study Intersections[5]**

**Table 1. Description of study intersections.**

| | Major street | | | | Minor street | |
|---|---|---|---|---|---|---|
| Intersection | Roadway type | Posted speed limit | Traffic signal within one-quarter mile? | Two-way left-turn lane? | Roadway type | Lane configuration |
| 1 | 2-lane collector | 30 mph | Yes | No | 2-lane collector | Exclusive left & right lanes |
| 2 | 2-lane arterial | 45 mph | Yes | Yes | 2-lane collector | Shared left/right lane |
| 3 | 2-lane arterial | 55 mph | No | No | 2-lane arterial | Shared left/right lane |
| 4 | 2-lane arterial | 50 mph | No | No | 2-lane arterial | Exclusive left & right lanes |
| 5 | 2-lane arterial | 45 mph | No | No | 2-lane collector | Shared left/right lane |
| 6 | 2-lane highway | 55 mph | No | No | 2-lane collector | Shared left/right lane |
| 7 | 2-lane highway | 50 mph | No | No | 2-lane arterial | Exclusive left & right lanes |
| 8 | 4-lane arterial | 45 mph | Yes | No | Hospital driveway | Exclusive left/through & right lanes |
| 9 | 4-lane arterial | 45 mph | Yes | No | Shopping center driveway | Shared left/right lane |
| 10 | 4-lane arterial | 40 mph | Yes | Yes | Office complex driveway | Exclusive left/through & right lanes |
| 11 | 4-lane arterial | 45 mph | No | Yes | 2-lane collector | Exclusive left & right lanes |
| 12 | 4-lane arterial | 45 mph | Yes | Yes | Shopping center driveway | Exclusive left & right lanes |
| 13 | 4-lane arterial | 45 mph | Yes | Yes | 2-lane collector | Shared left/through & exclusive right lanes |
| 14 | 6-lane arterial | 35 mph | Yes | No | Shopping center driveway | Exclusive right lane |
| 15 | 6-lane arterial | 45 mph | Yes | No | Shopping center driveway | Exclusive right lane |

*Note: All turning movements are permitted at intersections 1–13. Left-turn ingress and right-turn movements are permitted at intersections 14 and 15.*

**Table 1-4 Gard's Regression Equations[5]**

**Table 4. Regression equations.**

| Movement | Condition | Equation |
|---|---|---|
| Major-street left turn | Approach volume ≤ 100 VPH/PHF | Max. Queue = –2.042 + 1.167 ln(AppVol) + 0.975*TS |
| | Approach volume > 100 VPH/PHF | Max. Queue = +4.252 – 1.23*Lanes + 0.07996*Speed + 1.412*TS – 374.028/AppVol + 0.00001144*AppVol *ConflVol |
| Minor-street left turn | Approach volume ≤ 60 VPH/PHF | Max. Queue = +0.958 + 0.00111*(AppVol)^2 + 0.000333* (ConflVol) |
| | Approach volume > 60 VPH/PHF | Max. Queue = +6.174 – 2.313*TS + 0.03307*Speed – 1201.644/ConflVol + 0.00006549 (AppVol)^2 |
| Minor-street right turn | Approach volume ≤ 100 VPH/PHF | Max. Queue = –19.822 + 0.688ln(AppVol) + 1.886*TS + 0.369*(Lanes)^2 + 0.000000288* (ConflVol) ^2 + 0.401*Speed |
| | Approach volume > 100 VPH/PHF | Max. Queue = –26.23 + 0.132*Speed + 0.000000603* (ConflVol) ^2 + 4.909ln(AppVol) |
| Minor-street shared left/through/right | All conditions | Max. Queue = –12.916 + 3.225ln(AppVol) +0.00569*(ConflVol for LTs & THs) – 0.000177*(ConflVol for RTs) – 2.109*(RT %) – 3.157*TS |

Where

[5] John T. Gard. "*Estimation of Maximum Queue Lengths at Unsignalized Intersection*", ITE Journal, November 2001, Pg: 26-34

AppVol = hourly traffic volume divided by peak-hour factor (PHF) for subject movement

ConflVol = hourly traffic volume divided by PHF that conflicts with subject movement (refer to the Highway Capacity Manual to identify movements that conflict with subject approach)

TS = a dummy variable with a value of 1 if a traffic signal is located on the major street within one-quarter mile of the subject intersection and 0 otherwise

Lanes = number of through lanes occupied by conflicting traffic

Speed = posted speed limit on major street (in miles per hour)

RT % = Percentage of vehicles on shared left/through/right minor street approach that turn right

In his comparison, Gard found that the 2000 HCM method showed a tendency to underestimate the queues. The Two-Minute Rule was successfully predicting 8 out 10 cases, with in one vehicle variation. According to the author, in 49 out of 51 comparisons, the regression equation provided maximum queue-length estimates that were as accurate as or more accurate than other methods used in this study.

## *1.2 Problem*

The problem for this work is defined as reasonably estimating the 95$^{th}$ percentile queue length, the length of the queue that has a probability of 5 percent or less of being exceeded during the peak hour, which is critical to the operational success and safety of the intersection.

## *1.3 Purpose*

This study describes the maximum queue length model development and validation for two-way stop control. It further checks the consistency of queue length predictions among the widely used methods.

## *1.4 Study Methodology*

The first step in the development of a model is data collection. Data collection requires prior effort in the form of: identifying the parameters influencing queue behavior, checking the sample size, location, season and duration of data collection. After collection, data is processed to get the required inputs. Then, model comparison is performed to identify the deficiencies among the existing models. This leads to model formulation and statistical analysis of data to predicted the maximum number of vehicles in the stopped queue. Next, model validation is conducted to check the model accuracy. Finally, sensitivity analysis will identify the limits to the value of input variables. The step-by-step procedure is shown in Figure 1-2.

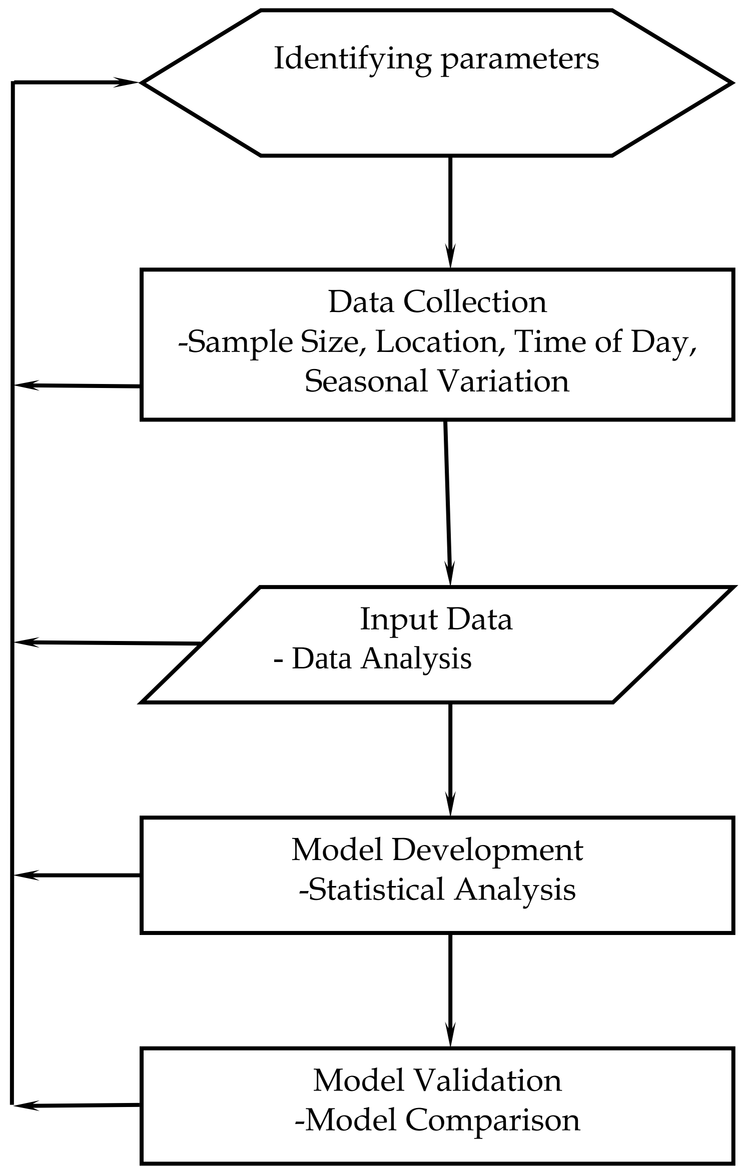



**Figure 1-2 Study Methodology**

## *1.5 Summary*

This chapter briefly explains the current adopted methods to estimate the queue lengths at two-way STOP controlled intersections. Not every model is representing a true condition, so this study was directed to get a closer solution to the problem. The methodology explained above outlines the study process.

# 2 Data Collection & Analysis

Data plays a key role in model development, validation and comparing competitive models for consistency. This chapter focuses on the data collection procedure, data synthesis, and preparation of data sets for various lane groups. Data collection technologies are not discussed here.

## *2.1 Data collection*

Intersections were chosen to cover a range of lane configurations, geographic regions, functional classifications, and traffic conditions. In total, 15 intersections shown in Appendix B, Table B1 were used for data collection.

Out of 15 intersections: 7 of are from region 2, 5 are from region 3, one from region 4, and the remaining 2 from region 5. 10 (67%) are within the urban growth boundary, and the remainder 5 (33%) are rural. 13 intersections have either OR or US route as the major approach. Three of the intersections have an upstream signal within 1000 ft. Six intersections have either an exclusive or two-way left turn lane. More than half of the intersections, totaling 9, have skewed approaches. Three intersection approaches are off-set from the major approach. Nearly half of the intersections are 3 legged (7 or 47%). Finally, three intersections major approaches have flaredness.

Appendix B, Table B2 represents the time frame of the data collection. All the data collected belong to either year 2010 or year 2009. Where the data is available, both AM and PM peak periods are covered.

## *2.2 Data Analysis*

For each approach, information regarding the geometry, lane groups and associated movements, turn lane information, and traffic volume by movement is noted.

Queue data is collected through video logs provided by the Transportation Data Section. Maximum number of vehicles in the stopped queue is noted for every 15 minute interval for both peak periods by taking the maximum value of the observed queue on each lane group. Traffic volume for the same period is obtained from Traffic Count Management (TCM) program used by Transportation Data Section.

Hourly traffic volume is computed by summing the corresponding four 15 min intervals. A peak hour factor is calculated and applied to obtain hourly flow rates. Time periods having only hourly traffic volume are not considered in the analysis period. In the absence of a calculated peak hour factor, default peak hour factors can be taken to prevent data loss. This was not done due to the importance of the study for model comparison and development in order to emulate actual traffic conditions.

The next step is to calculate the conflicting traffic flow rate according the procedure documented in Highway Capacity Manual. An excerpt from the HCM showing the two-way STOP controlled configurations are given in Appendix A, Figure A1 and the calculation of the associated conflicting flow rates for different lane movements are shown in Appendix A, Figure A2. Conflicting flow rates from individual movements in a lane group are added algebraically to obtain the lane group conflicting movements. Similarly, lane group flow rates are obtained by adding individual lane group flow rates.

This methodology adopted disaggregates approaches where individual intersection approaches and individual lane groups within approaches are treated separately. Both geometry of the intersection and the distribution of traffic movements play a key role in segmenting the intersection into lane groups. The following are the excerpts from HCM[6] related to the definitions of various lane groups:

An exclusive left-turn lane or lanes should normally be designated as a separate lane group unless there is also a shared left-through lane present, in which case the proper lane grouping will depend upon the distribution of traffic volume between the movements. The same is true of an exclusive right-turn lane.

On approaches with exclusive left-turn or right-turn lanes, or both, all other lanes on the approach would generally be included in a single lane group. Some example lane groups according to HCM are given in Appendix A, Figure A3.

The following lane groups are considered:

***MNLTR*** is for a minor street on a four legged intersection having a single lane for left, through and right turn movements

***MNLR*** is for a minor street on a three legged intersection having a single lane for left and right turn movements

***MJL*** is for a major left turn movement irrespective of exclusive/median/TWTL configuration

***MNL*** is for an exclusive left turn lane on a minor approach of either a four or three legged intersection

***MNR*** is for an exclusive right turn lane on a four legged intersection minor approach

[6] "Chapter 16- signalized intersections", *2000 Highway Capacity Manual*, Transportation Research Board, Washington, D.C., pg:16-6

The next step is to calculate the hourly observed queue length by taking the maximum of four 15 min interval queue lengths. Estimate queue lengths by the 2 minute rule, HCM methodology, and Gard's equation. This step completes the data set for one intersection on one approach. Repeat the process for all approaches and intersections.

## 2.3 *Summary*

The data collection methodology is explained in this chapter. Then the step by step process for data analysis and the preparation of input data are given. This step leads to the comparison of existing methodologies to check the consistency among the models.

# 3 Comparison of Existing Methodologies

The first part of this study is to check the performance of the 2 minute rule, HCM method and Gard's equation for estimating queue lengths. The following sub sections analyze performance of these models for each lane configuration.

## *3.1 Major Left (MJL)*

Summary statistics are given in Table 3-1. Observed queue length varies from a minimum of 1 vehicle to a maximum of 8 vehicles. At lower volumes, for instance a minimum volume of 1 vehicle, all methods tend to give zero queue lengths corresponding to the observed queue length of 1. If the volume reaches the maximum observed volume of 134 vph, the HCM method seems to be insensitive, only yielding a single vehicle in the stopped queue.

**Table 3-1 Summary Statistics for MJL**

| | Observed | Two_min_Rule | HCM_Method | Gards | VOL |
|---|---|---|---|---|---|
| Count | 219 | 219 | 219 | 219 | 219 |
| Average | 2.58904 | 0.931507 | 0.0182648 | 1.73973 | 29.9361 |
| Variance | 2.61933 | 0.843911 | 0.0180135 | 1.48699 | 618.436 |
| Standard deviation | 1.61843 | 0.918646 | 0.134214 | 1.21942 | 24.8684 |
| Minimum | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Maximum | 8.0 | 5.0 | 1.0 | 4.0 | 134.0 |
| Range | 7.0 | 5.0 | 1.0 | 4.0 | 133.0 |
| Stnd. skewness | 6.76384 | 5.8038 | 43.7694 | -0.987539 | 6.45329 |
| Stnd. kurtosis | 3.52603 | 4.16918 | 153.913 | -3.80584 | 3.8392 |

| | CONVOL |
|---|---|
| Count | 219 |
| Average | 506.95 |
| Variance | 60516.9 |
| Standard deviation | 246.002 |
| Minimum | 2.0 |
| Maximum | 972.0 |
| Range | 970.0 |
| Stnd. skewness | -0.729985 |
| Stnd. kurtosis | -1.97501 |

A scatter diagram of both observed and estimated queue lengths of the 219 data points is shown in Figure 3-1. The horizontal axis shows the observation number and the vertical axis represents the model predicted maximum number of vehicles in the stopped queue. Table 3-2 compares the relative performance of each model. The queue length given by Gard's equations for the MJL lane configuration matches 32% of observations, which is highest among these methods. Only 8% are matched by the Two-Minute rule. If the queue length matching criterion is relaxed to predict ± 1 vehicle, 53% are matched by the Two-Minute rule and 76% by Gard's equation. The Two-Minute rule is out-performed here due to the fact that it does not consider the opposing traffic volume.

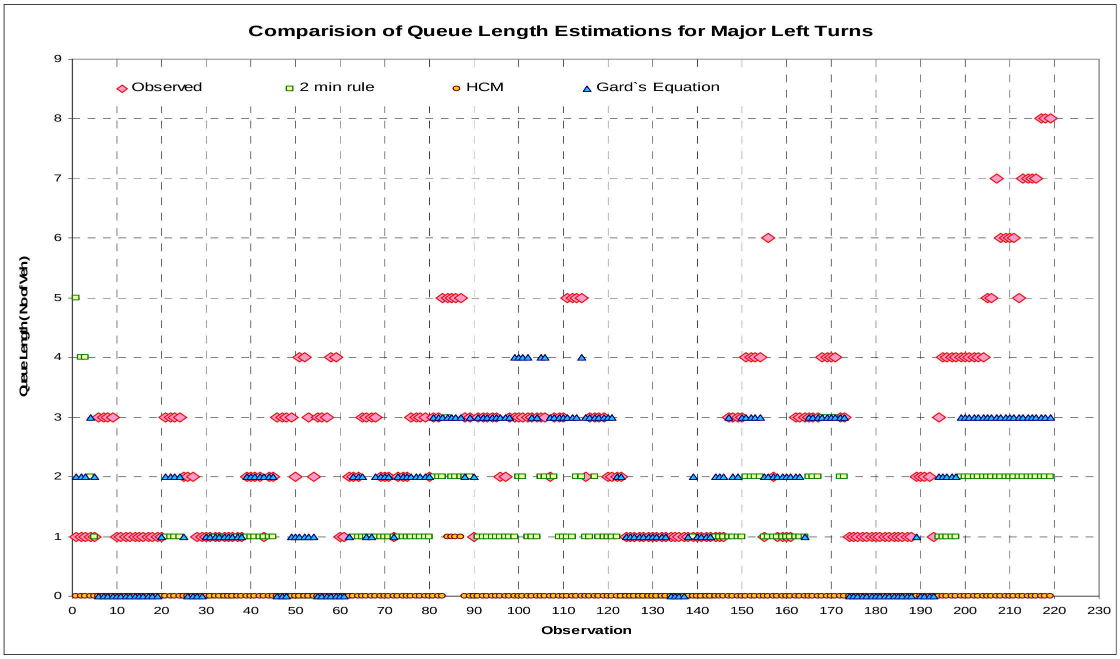



**Figure 3-1 Scatter plot of all methods for MJL**

**Table 3-2 Difference between Observed and Model Outputs for MJL**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule % of Obs | Observed - 2 min rule Cum. % of Obs | Observed - HCM method % of Obs | Observed - HCM method Cum. % of Obs | Observed - Gard's Equation % of Obs | Observed - Gard's Equation Cum. % of Obs |
|---|---|---|---|---|---|---|---|
| Over Estimated | -5 | 0% | 1% | 0% | 0% | 0% | 0% |
| | -4 | 0% | | 0% | | 0% | |
| | -3 | 1% | | 0% | | 0% | |
| | -2 | 0% | | 0% | | 0% | |
| Acceptable | -1 | 0% | 53% | 0% | 35% | 12% | 76% |
| | 0 | 8% | | 0% | | 32% | |
| | 1 | 44% | | 35% | | 32% | |
| Under Estimated | 2 | 26% | 46% | 16% | 65% | 11% | 24% |
| | 3 | 11% | | 28% | | 7% | |
| | 4 | 5% | | 12% | | 4% | |
| | 5 | 3% | | 4% | | 1% | |
| | 6 | 1% | | 2% | | 0% | |
| | 7 | 0% | | 2% | | 0% | |
| | 8 | 0% | | 1% | | 0% | |
| | 9 | 0% | | 0% | | 0% | |
| | 10 | 0% | | 0% | | 0% | |

## *3.2 Minor, Share LTR (MNLTR)*

The scatter plot matrix in Figure 3-2 clearly shows that an increase in both volume and conflicting volume has positive impact on the number of vehicles in queue. Table 3-3 shows the summary statistics for each of the selected data variables. It includes measures of central tendency, measures of variability, and measures of shape. As Volume increase, a nearly linear relation is observed between queue length and volume. A similar relation is observed for Gard's equation for increasing conflicting volume. The HCM method yields almost constant queue lengths up to a point, beyond which even a small increment in conflicting volume triggers an exponential increase in queue length.

The scatter plot of queue lengths for different models is shown in Figure 3-2 and Figure 3-3. It seems the Two-Minute Rule relatively closely follows the observed trend. To explore further, the differences between observed queue lengths and predicted queue lengths are tabulated in Table 3-4. The Two-Minute Rule shows 22% of the predictions exactly matched observations. The Two-Minute Rule attains 65% predictability within ± 1 vehicle. For the same instance, 36% are matched by the HCM method.

**Table 3-3 Summary Statistics for MJL**

| | VOL | CONVOL | OBSERVED | Two min Rule | HCM |
|---|---|---|---|---|---|
| Count | 143 | 143 | 143 | 143 | 143 |
| Average | 80.1119 | 2159.78 | 2.55944 | 2.67832 | 2.01399 |
| Variance | 9690.61 | 936297.0 | 3.19186 | 11.1775 | 25.2252 |
| Standard deviation | 98.4409 | 967.625 | 1.78658 | 3.34327 | 5.02247 |
| Minimum | 3.0 | 897.0 | 1.0 | 0.0 | 0.0 |
| Maximum | 396.0 | 4016.0 | 8.0 | 13.0 | 21.0 |
| Range | 393.0 | 3119.0 | 7.0 | 13.0 | 21.0 |
| Stnd. skewness | 8.73745 | 3.07341 | 6.83757 | 8.43334 | 12.4561 |
| Stnd. kurtosis | 5.4864 | -2.00372 | 3.77464 | 5.02124 | 12.931 |

| | Gards |
|---|---|
| Count | 143 |
| Average | 8.8951 |
| Variance | 57.672 |
| Standard deviation | 7.59421 |
| Minimum | 0.0 |
| Maximum | 24.0 |
| Range | 24.0 |
| Stnd. skewness | 4.16384 |
| Stnd. kurtosis | -1.2633 |

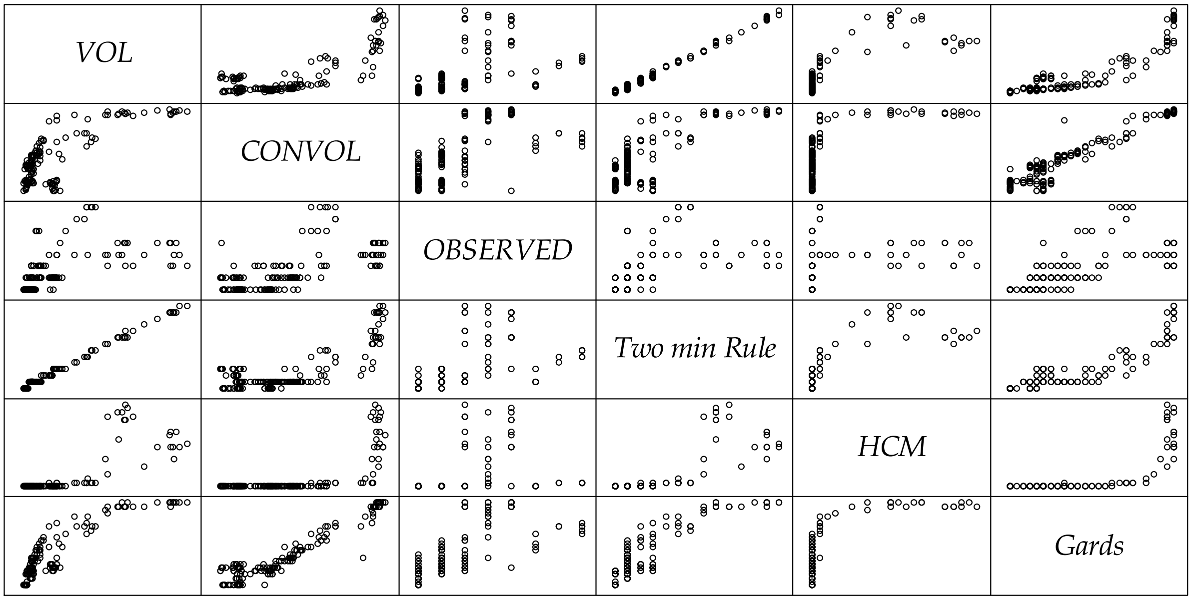



**Figure 3-2 Scattered plot of VOL, CONVOL, & Queue Lengths**

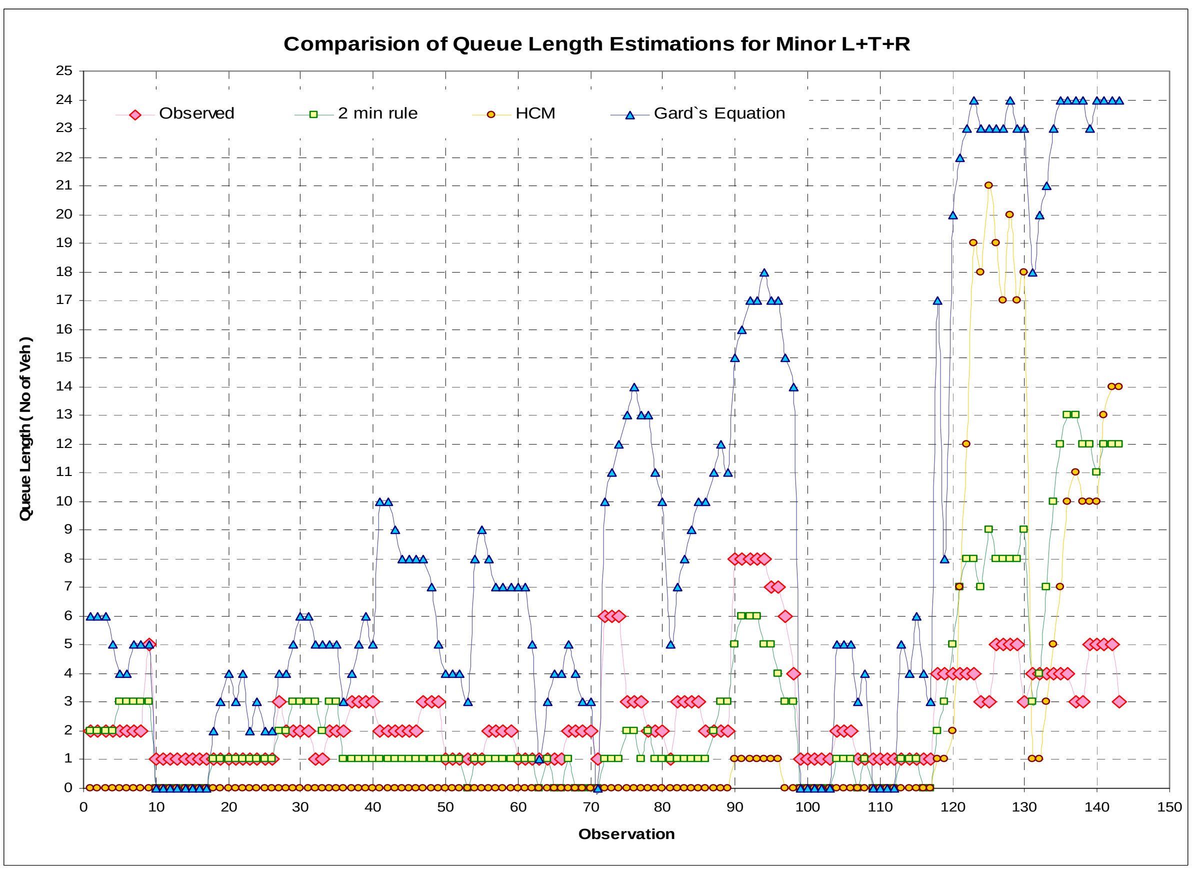



**Figure 3-3 Scatter plot of all methods for MNLTR**

**Table 3-4 Difference between Observed and Model Outputs for MNLTR**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | |
|---|---|---|---|---|---|---|---|
| | | % of Obs | Cum. % of Obs | % of Obs | Cum. % of Obs | % of Obs | Cum. % of Obs |
| Over Estimated | < -10 | 0% | 15% | 6% | 13% | 19% | 80% |
| | -10 | 1% | | 0% | | 5% | |
| | -9 | 2% | | 1% | | 4% | |
| | -8 | 1% | | 2% | | 4% | |
| | -7 | 2% | | 1% | | 3% | |
| | -6 | 3% | | 1% | | 6% | |
| | -5 | 0% | | 1% | | 5% | |
| | -4 | 2% | | 0% | | 10% | |
| | -3 | 4% | | 1% | | 15% | |
| | -2 | 1% | | 0% | | 10% | |
| Acceptable | -1 | 9% | 65% | 1% | 36% | 6% | 20% |
| | 0 | 22% | | 0% | | 1% | |
| | 1 | 34% | | 36% | | 13% | |
| Under Estimated | 2 | 15% | 20% | 28% | 50% | 0% | 0% |
| | 3 | 3% | | 13% | | 0% | |
| | 4 | 0% | | 1% | | 0% | |
| | 5 | 2% | | 1% | | 0% | |
| | 6 | 0% | | 4% | | 0% | |
| | 7 | 0% | | 3% | | 0% | |
| | 8 | 0% | | 0% | | 0% | |
| | 9 | 0% | | 0% | | 0% | |
| | 10 | 0% | | 0% | | 0% | |

## *3.3 MNLR*

A minimum queue length of a single vehicle to a maximum of 7 vehicles in the queue is observed for MNLR lane configuration. The Two-Minute Rule estimated a maximum of 7 vehicles, while the HCM predicts a maximum of 3 vehicles in queue for the similar prevailing conditions. Gard's equation tends to overestimate the queues as shown in Table 3-6. The data description is given in Table 3-5 and shown in Figure 3-4 and Figure 3-5.

Around 33% are exactly matched with observed values by the Two-Minute Rule which performs far better than other models. If the difference between the observed and estimated queue lengths is relaxed to ±1, 84% are matched for the Two-Minute Rule, while 46% is matched for Gard's equation.

## Table 3-5 Summary Statistics for MNLR

| | VOL | CONVOL | Observed | Two_min_Rule | HCM |
|---|---|---|---|---|---|
| Count | 81 | 81 | 81 | 81 | 81 |
| Average | 66.7654 | 1490.32 | 2.39506 | 2.23457 | 0.259259 |
| Variance | 2683.03 | 282928.0 | 1.96698 | 2.73179 | 0.519444 |
| Standard deviation | 51.798 | 531.909 | 1.40249 | 1.65281 | 0.720725 |
| Minimum | 12.0 | 802.0 | 1.0 | 0.0 | 0.0 |
| Maximum | 224.0 | 2489.0 | 7.0 | 7.0 | 3.0 |
| Range | 212.0 | 1687.0 | 6.0 | 7.0 | 3.0 |
| Stnd. skewness | 5.40679 | 1.60496 | 5.77836 | 5.02874 | 11.2284 |
| Stnd. kurtosis | 3.87235 | -1.99022 | 5.03514 | 2.94678 | 16.0452 |

| | Gards |
|---|---|
| Count | 81 |
| Average | 4.23457 |
| Variance | 7.68179 |
| Standard deviation | 2.7716 |
| Minimum | 0.0 |
| Maximum | 9.0 |
| Range | 9.0 |
| Stnd. skewness | 0.768588 |
| Stnd. kurtosis | -1.66468 |

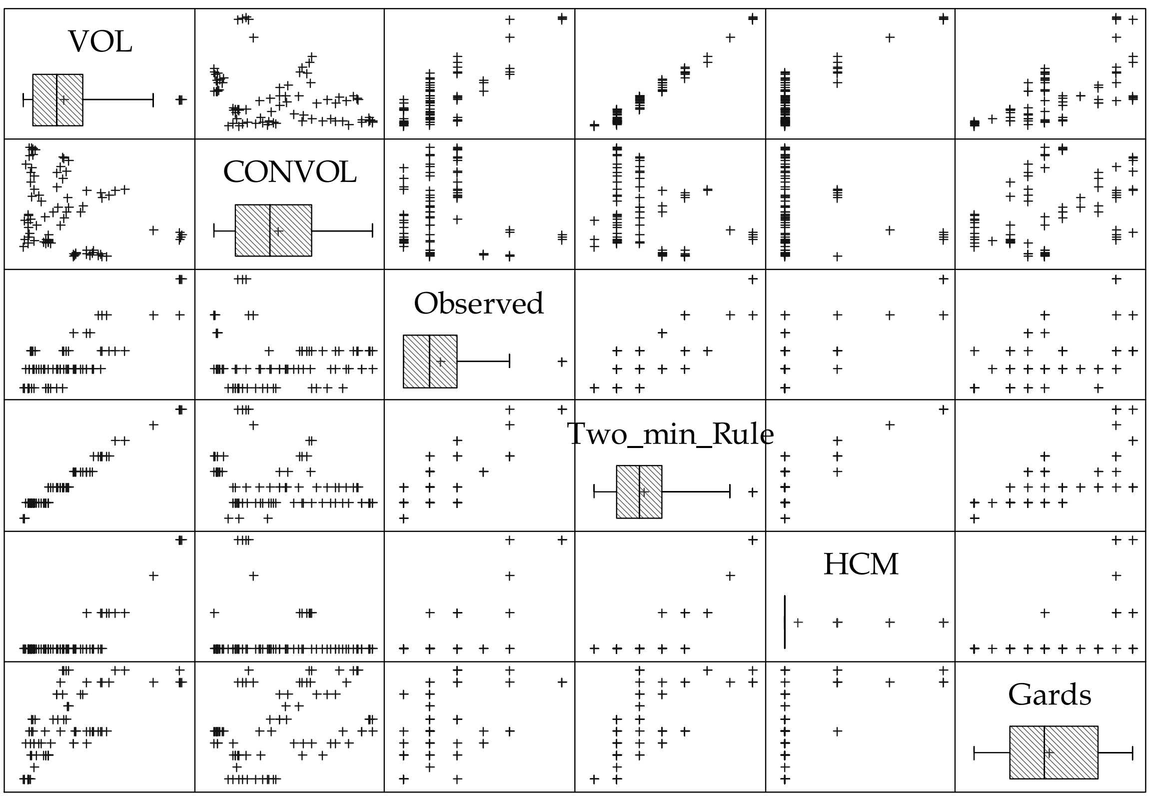



**Figure 3-4 Scattered plot of VOL, CONVOL, & Queue Lengths for MNLR**

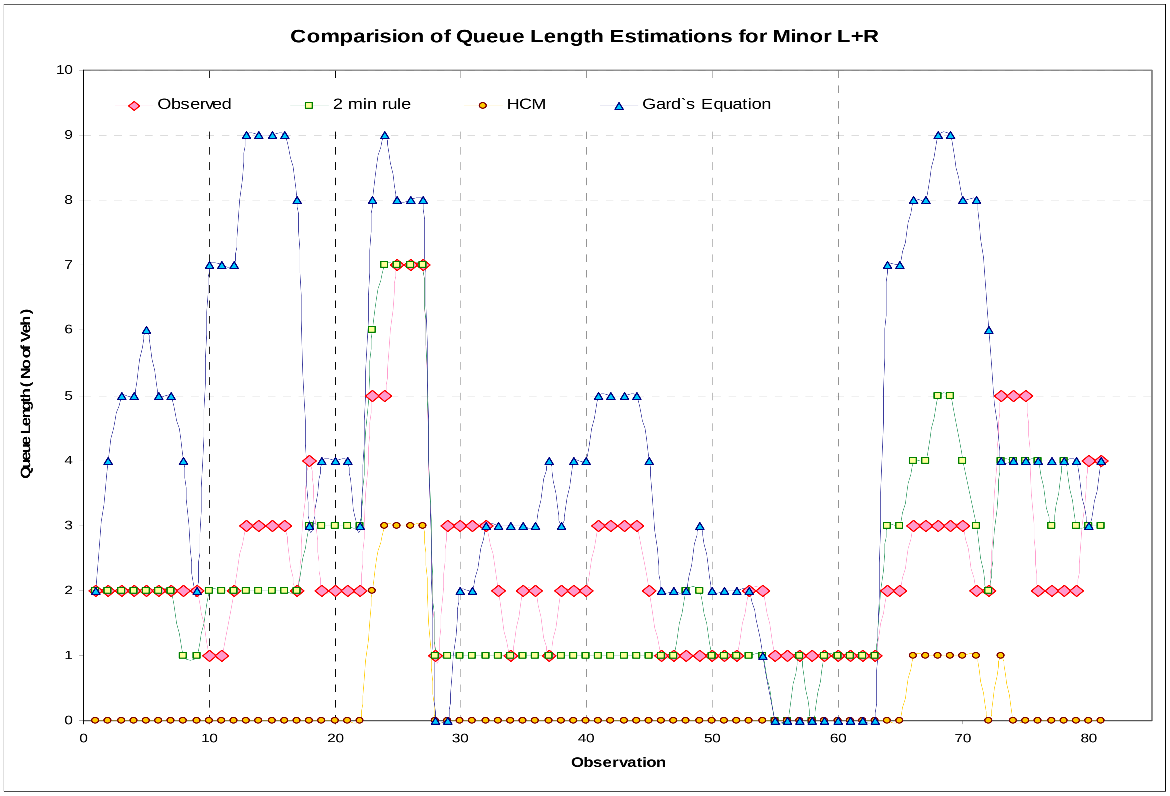



**Figure 3-5 Scatter plots of all methods for MNLR**

**Table 3-6 Difference between Observed and Model Outputs for MNLR**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | |
|---|---|---|---|---|---|---|---|
| | | % Obs | Cum % of Obs | % Obs | Cum % of Obs | % Obs | Cum % of Obs |
| Over Estimated | -6 | 0% | 6% | 0% | 0% | 12% | 53% |
| | -5 | 0% | | 0% | | 7% | |
| | -4 | 0% | | 0% | | 4% | |
| | -3 | 0% | | 0% | | 7% | |
| | -2 | 6% | | 0% | | 22% | |
| Acceptable | -1 | 21% | 84% | 0% | 27% | 17% | 46% |
| | 0 | 33% | | 0% | | 6% | |
| | 1 | 30% | | 27% | | 22% | |
| Under Estimated | 2 | 10% | 10% | 46% | 73% | 0% | 1% |
| | 3 | 0% | | 16% | | 1% | |
| | 4 | 0% | | 9% | | 0% | |
| | 5 | 0% | | 2% | | 0% | |
| | 6 | 0% | | 0% | | 0% | |
| | 7 | 0% | | 0% | | 0% | |
| | 8 | 0% | | 0% | | 0% | |
| | 9 | 0% | | 0% | | 0% | |

## 3.4 MNL

All models consistently underestimate the MNL queue length. Only the Two-Minute Rule predictions show a consistent trend with increasing volumes. This group has the lowest number of observations, 38. A maximum queue length of 11 vehicles is observed in queue. The description of the data is shown in Table 3-7. Scatter plots of the observed data and the distribution of the queue length predictions are shown in Figure 3-6 and 3-7 respectively.

The Two-Minute Rule predicts 18% of the observed values. Predictions improved to nearly 40% with a tolerance of a single vehicle. Gard's equation predicts 32% as shown in Table 3-8.

**Table 3-7 Summary Statistics for MNL**

| | VOL | CONVOL | Observed | Two_min_Rule | HCM |
|---|---|---|---|---|---|
| Count | 38 | 38 | 38 | 38 | 38 |
| Average | 70.0 | 928.132 | 4.44737 | 2.26316 | 0.526316 |
| Variance | 1469.95 | 62556.9 | 7.33499 | 1.60455 | 0.472262 |
| Standard deviation | 38.3399 | 250.114 | 2.70832 | 1.26671 | 0.687213 |
| Minimum | 7.0 | 457.0 | 1.0 | 0.0 | 0.0 |
| Maximum | 132.0 | 1286.0 | 11.0 | 4.0 | 2.0 |
| Range | 125.0 | 829.0 | 10.0 | 4.0 | 2.0 |
| Stnd. skewness | -0.189789 | -0.58707 | 3.24311 | -0.691012 | 2.4046 |
| Stnd. kurtosis | -1.37725 | -1.66867 | 1.94871 | -1.15355 | -0.306799 |

| | Gards |
|---|---|
| Count | 38 |
| Average | 4.92105 |
| Variance | 5.58819 |
| Standard deviation | 2.36394 |
| Minimum | 0.0 |
| Maximum | 7.0 |
| Range | 7.0 |
| Stnd. skewness | -2.88054 |
| Stnd. kurtosis | 0.120273 |

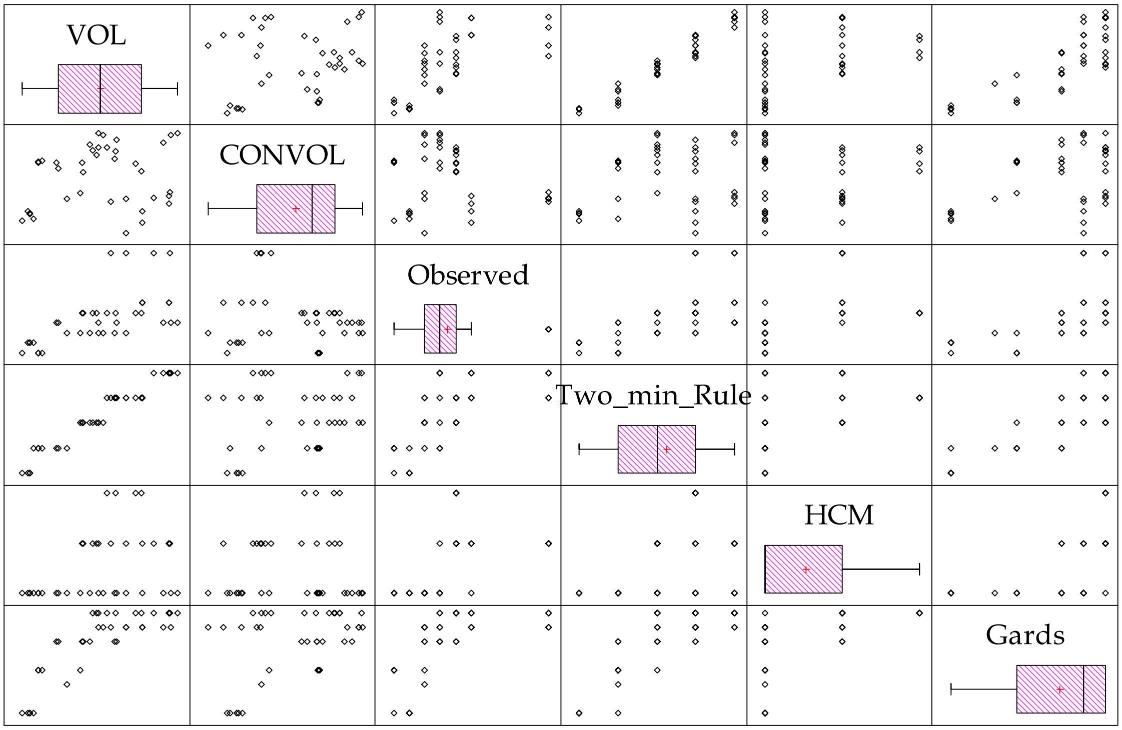



**Figure 3-6 Scattered plot of VOL, CONVOL, & Queue Lengths for MNL**

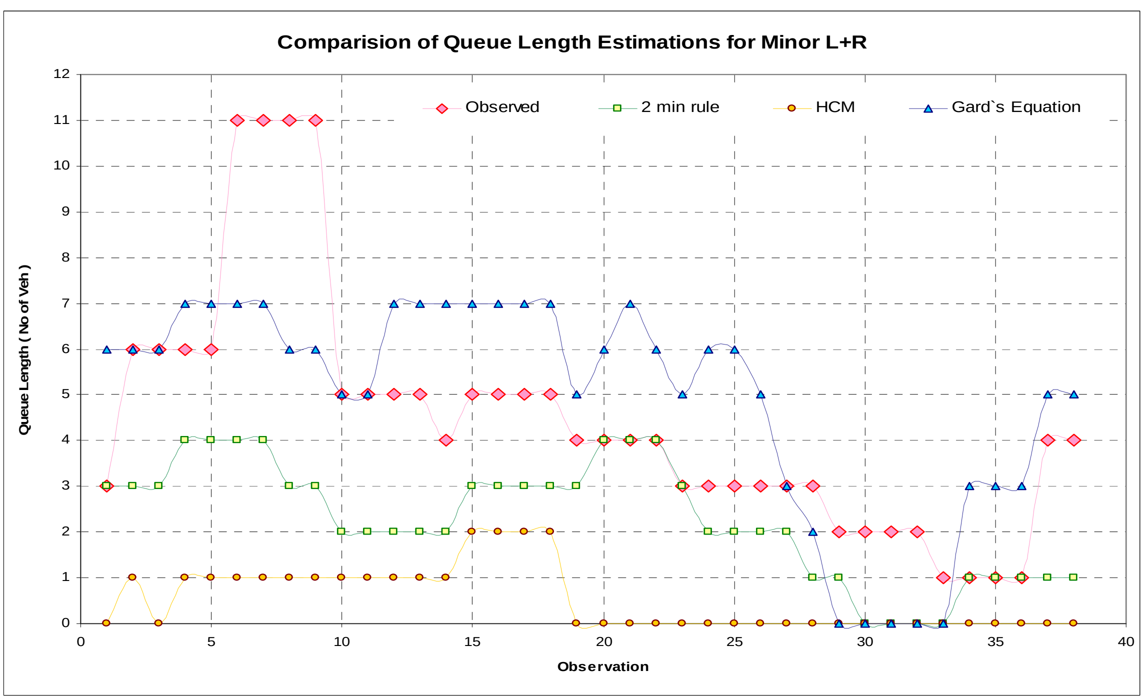



**Figure 3-7 Scatter plot of all methods for MNL**

**Table 3-8 Difference between Observed and Model Outputs for MNL**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | |
|---|---|---|---|---|---|---|---|
| | | % Obs | Cum. % Obs | % Obs | Cum. % Obs | % Obs | Cum. % Obs |
| Over Estimated | -5 | 0% | 0% | 0% | 0% | 0% | 47% |
| | -4 | 0% | | 0% | | 0% | |
| | -3 | 0% | | 0% | | 13% | |
| | -2 | 0% | | 0% | | 34% | |
| Acceptable | -1 | 0% | 39% | 0% | 11% | 13% | 32% |
| | 0 | 21% | | 0% | | 13% | |
| | 1 | 18% | | 11% | | 5% | |
| Under Estimated | 2 | 29% | 61% | 11% | 89% | 11% | 21% |
| | 3 | 21% | | 32% | | 0% | |
| | 4 | 0% | | 26% | | 5% | |
| | 5 | 0% | | 8% | | 5% | |
| | 6 | 0% | | 3% | | 0% | |
| | 7 | 5% | | 0% | | 0% | |
| | 8 | 5% | | 0% | | 0% | |
| | 9 | 0% | | 0% | | 0% | |
| | 10 | 0% | | 11% | | 0% | |

## 3.5 *Summary*

Analysis related to the relative performances of the Two-Minute Rule, Highway Capacity Manual Method, and John T. Gard's equations in predicting the queue lengths at two-way STOP controlled intersections are presented in the chapter. For Major Left Turn (MJL) lane configurations Gard's equation performs well. For the remaining lane configurations, the Two-Minute Rule predicts the best. On average, the performance of matching with ± one vehicle variation does not exceed 70 percent. This triggers the effort to build a model to assess the queue length in consistent manner. The model development procedure is presented in the next chapter.

# 4 Model Development

Model development plays a key role for predicting vehicles in stopped queue. A well formulated model significantly explains the changes to the dependent variable for variations in the independent variable. Though a variety of models ranging from simple regression to complex simulation exists today, this study is limited to development of a regression model. This is intuitive because of the simple model structure and easy usage. Not only are regression models straight forward to understand, but also the model user can study model sensitivity by changing the values of the independent variables.

This chapter explains the model development process. First, the factors influencing the queue behavior for different lane configuration movements at unsignalized intersections are identified. Then, a scatter diagram of the observed data is analyzed to identify the appropriate regression model. Next, for the chosen regression model the combinations of influenced variables are identified to incorporate into the model. After that the model is formulated and developed for each lane configuration movement. Finally, statistical tests are performed to check the model reasonableness.

## *4.1 Factors Influencing Queue Behavior*

Primarily geometry, operations, traffic flow, and human travel characteristics influence the queue behavior. Over the past decade, numerous models have been developed taking into consideration one or a combination of these characteristics. Influencing factors are listed in Table 4-1.

It is very difficult to capture the effects of all parameters. Instead, it is assumed that lane configuration, major and minor approach volume, number of conflicting lanes, volumes and speed on the conflicting lanes, presence of turn lanes, right turn channelization, flared right turn lanes, and presence of traffic signal within 1000ft of the study intersections are the most influencing parameters.

**Table 4-1 Factors Influencing Queue Behavior**

| Category | List of Factors |
|---|---|
| Geometry | Number of approaches<br>Number of lanes on both major and minor approaches<br>Lane configuration (shared/separate)<br>Chanallization / Flared approaches<br>Median Type<br>Grade<br>Sight Distance<br>Intersection Skewness |
| Operations | Traffic flow speed<br>Upstream Signal |
| Traffic Flow | Approach volume<br>Conflicting volume<br>Arrival type<br>Turning volume<br>Percent of heavy vehicles<br>Gap and follow-up times<br>Time of day / seasonal variation |
| Human Factors | Reaction time |

It is a fact that traffic movements will behave uniquely for the given lane configuration. Lane groups are identified according the definitions provided in the 2000 Highway Capacity Manual. This chapter reiterates the lane groups considered in this study as shown below and from this point forward models are designated with the lane group codes shown below.

- ***MNLTR*** is for minor street on four legged intersection having a single lane for left, through and right turn movements
- ***MNLR*** is for minor street on three legged intersection having a single lane for left, and right turn movements
- ***MJL*** is for a Major left turn movement irrespective of exclusive/median/TWTL configuration
- ***MNL*** is for an exclusive left turn lane on minor approach of either four or three legged intersection
- ***MNR*** is for an exclusive right turn lane on four legged intersection minor approach

The data collection and analysis chapter explains the preparation of the data sets for modeling purposes. Scatter plots for different lane group configurations are drawn to get the outlook of the data trend and type of model to choose. As such, the trends of the queue lengths (denoted as QL, is the maximum number of vehicles in the stopped queue for the same time unit of volume measurement) with respect to the changes in volume (VOL) and conflicting volume (CONVOL) were evaluated. Following sub-sections describe the findings for various lane group models.

## 4.2 *Poisson Regression Model*

A general description of the Poisson Regression Model is given as it is the model which is best suited for the study conditions. Number of vehicles in the queue is of count type, often called discrete type, taking only a finite number of values. The probability distribution that is specifically suited for count data is the Poisson probability distribution. An interesting feature of the Poisson distribution: its variance is the same as its mean value.

The Poisson regression model may be written as:

$$\mathrm{Ln}(Y) = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + \beta n \times X_n$$

Where

Ln = Natural LogarithmY = Dependent Variable

$X_1$,$X_2$,……$X_n$ = Independent or Explanatory Variables

$\beta_0$ = Constant

$\beta_1$ , $\beta_2$ , $\beta_3$ = Model coefficients corresponds $X_1$,$X_2$,……$X_n$

## 4.3 *Major Left Turn (MJL) Model*

Table 4-2 shows summary statistics for each of the selected data variables. It includes measures of central tendency, measures of variability, and measures of shape. Of particular interest here are the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of -2 to +2 indicate significant departures from normality, which would tend to invalidate many of the statistical procedures normally applied to this data. In this case, the variables show standardized skewness values outside the expected range are QL, VOL and VOLCONVOL. QL and VOL variables show standardized kurtosis values outside the expected range. QL value varies from 1 to 8 vehicles.

**Table 4-2 Summary Statistics of Major Left Turn Data**

| | QL | VOL | CONVOL | VOLCONVOL |
|---|---|---|---|---|
| Count | 219 | 219 | 219 | 219 |
| Average | 2.58904 | 29.9361 | 506.95 | 17163.2 |
| Variance | 2.61933 | 618.436 | 60516.9 | 3.03245E8 |
| Standard deviation | 1.61843 | 24.8684 | 246.002 | 17413.9 |
| Minimum | 1.0 | 1.0 | 2.0 | 51.0 |
| Maximum | 8.0 | 134.0 | 972.0 | 65715.0 |
| Range | 7.0 | 133.0 | 970.0 | 65664.0 |
| Stnd. skewness | 6.76384 | 6.45329 | -0.729985 | 7.04459 |
| Stnd. kurtosis | 3.52603 | 3.8392 | -1.97501 | 1.19911 |

Transformations are one of the methods to make the variables more normal. A scattered matrix plot among the variables shows no definite pattern between QL and explanatory variables VOL, CONVOL, and their product.


**Figure 4-1 Scattered Matrix Plot between the variables for MJL**

Though many variables listed in Table 4-1 adequately explain the queue behavior, only VOL, CONVOL, presence of upstream signal within 1000 ft distance from intersection (SIGNAL), and presence of exclusive left turn lane (Coded as LT, either median left turn lane or two-way left turn lane-TWTL) are selected, based upon lowest Mean Squared Error, highest R-squared value, and lowest Cp Statistics[7]. Results of this analysis are shown in Table 4-3.

After selecting the variables, analysis needs to be performed to identify the correlation among the independent variables. Table 4-4 shows Spearman rank correlations between each pair of variables. These correlation coefficients range between -1 and +1 and measure the strength of the association between the variables. In contrast to the more common Pearson correlations, the Spearman coefficients are computed from the ranks of the data values rather than from the values themselves. Consequently, they are less sensitive to outliers than the Pearson coefficients. Also shown in parentheses is the number of pairs of data values used to compute each coefficient. The third number in each location of the table is a P-value which tests the statistical significance of the estimated correlations. P-values below 0.05 indicate statistically significant "non-zero" correlations at the 95% confidence level.

[7] Mallows' Cp statistic is a measure of the bias in a model, based on a comparison of total mean squared error to the true error variance. Unbiased models have an expected value of approximately p, where p is the number of coefficients in the fitted model including constant

## Table 4-3 Selection of Independent Variable for MJL Model

Regression Model Selection

Dependent variable: QL
Independent variables:
A=VOL
B=CONVOL
C=VOLCONVOL
D=SIGNAL
E=TWTL

Number of complete cases: 219
Number of models fit: 32

Model Results

| MSE | R-Squared | Adjusted R-Squared | Cp | Included Variables |
|---|---|---|---|---|
| 2.61933 | 0.0 | 0.0 | 502.988 | |
| 1.70135 | 35.3442 | 35.0463 | 250.514 | A |
| 1.97238 | 25.0443 | 24.6989 | 324.672 | B |
| 1.04799 | 60.1737 | 59.9902 | 71.7446 | C |
| 2.6145 | 0.642103 | 0.184232 | 500.365 | D |
| 2.15002 | 18.2936 | 17.9171 | 373.277 | E |
| 1.43358 | 45.7712 | 45.2691 | 177.441 | AB |
| 1.05279 | 60.1756 | 59.8068 | 73.7312 | AC |
| 1.7088 | 35.3602 | 34.7617 | 252.399 | AD |
| 1.53786 | 41.8265 | 41.2879 | 205.842 | AE |
| 1.00842 | 61.8539 | 61.5007 | 61.6472 | BC |
| 1.94017 | 26.6084 | 25.9288 | 315.411 | BD |
| 1.21427 | 54.0672 | 53.6419 | 117.711 | BE |
| 1.02662 | 61.1654 | 60.8058 | 66.6044 | CD |
| 0.822207 | 68.898 | 68.61 | 10.9306 | CE |
| 1.85755 | 29.7336 | 29.0829 | 292.91 | DE |
| 0.992793 | 62.619 | 62.0974 | 58.1386 | ABC |
| 1.40365 | 47.1491 | 46.4117 | 169.52 | ABD |
| 1.04388 | 60.6953 | 60.1469 | 71.9892 | ABE |
| 1.03133 | 61.1682 | 60.6264 | 68.5844 | ACD |
| 0.808386 | 69.5624 | 69.1377 | 8.14724 | ACE |
| 1.44915 | 45.4362 | 44.6748 | 181.853 | ADE |
| 1.0039 | 62.2008 | 61.6733 | 61.1501 | BCD |
| 0.824137 | 68.9693 | 68.5363 | 12.4173 | BCE |
| 1.16617 | 56.0909 | 55.4783 | 105.14 | BDE |
| 0.808903 | 69.5429 | 69.1179 | 8.28729 | CDE |
| 0.991387 | 62.8456 | 62.1511 | 58.5075 | ABCD |
| 0.811127 | 69.6012 | 69.033 | 9.86749 | ABCE |
| 1.02763 | 61.4872 | 60.7673 | 68.2879 | ABDE |
| 0.792048 | 70.3162 | 69.7614 | 4.7195 | ACDE |
| 0.811509 | 69.5869 | 69.0184 | 9.97064 | BCDE |
| 0.793088 | 70.4162 | 69.7217 | 6.0 | ABCDE |

## Table 4-4 Spearman Rank Correlation Matrix

| | QL | VOL | CONVOL | SIGNAL | TWTL |
|---|---|---|---|---|---|
| QL | | 0.6551 | 0.4673 | 0.1529 | -0.4519 |
| | | ( 219) | ( 219) | ( 219) | ( 219) |
| | | 0.0000 | 0.0000 | 0.0239 | 0.0000 |
| VOL | 0.6551 | | 0.4411 | 0.2112 | -0.2724 |
| | ( 219) | | ( 219) | ( 219) | ( 219) |
| | 0.0000 | | 0.0000 | 0.0018 | 0.0001 |
| CONVOL | 0.4673 | 0.4411 | | 0.3937 | 0.1713 |
| | ( 219) | ( 219) | | ( 219) | ( 219) |
| | 0.0000 | 0.0000 | | 0.0000 | 0.0114 |
| SIGNAL | 0.1529 | 0.2112 | 0.3937 | | 0.4983 |
| | ( 219) | ( 219) | ( 219) | | ( 219) |
| | 0.0239 | 0.0018 | 0.0000 | | 0.0000 |
| TWTL | -0.4519 | -0.2724 | 0.1713 | 0.4983 | |
| | ( 219) | ( 219) | ( 219) | ( 219) | |
| | 0.0000 | 0.0001 | 0.0114 | 0.0000 | |

Correlation
(Sample Size)
P-Value

The model for predicting the maximum number of vehicles in the stopped queue is formulated as a Poisson regression equation with volume, conflicting volume, presence of upstream signal, and presence of left turn lane as the independent or explanatory variables.

$$\mathrm{Ln}(\mathrm{QL}_{\mathrm{MJL}}) = \beta_0 + \beta_1 \times \mathrm{VOL}_{\mathrm{MJL}} + \beta_2 \times \mathrm{CONVOL}_{\mathrm{MJL}} + \beta_3 \times SIGNAL + \beta_4 \times LT$$

Where

Ln = Natural Logarithm

VOL = Approach volume for MJL lane configuration

CONVOL = Conflicting volume for MJL

SIGNAL = Presence of upstream signal within 1000 ft of the intersection (1 if there is a signal, otherwise 0)

LT = Presence of left turn lane (1 if there is an exclusive left turn lane/median left turn lane/ two-way left turn lane, otherwise 0)

$\beta_0$ = Constant

$\beta_1$, β2, β3, β4 = Model coefficients corresponds to VOL, CONVOL, SIGNAL, and LT variables

The developed model with coefficient values and corresponding statistical tests are explained below:

$$\mathbf{Ln(QL) = 0.3925 + 0.0059 \times VOL + 0.00104 \times CONVOL + 0.49 * SIGNAL - 0.81 * LT}$$

$$QL = e^{(\mathbf{0.3925 + 0.0059 \times VOL + 0.00104 \times CONVOL + 0.49 * SIGNAL - 0.81 * LT})}$$

**Percentage of deviance explained by model = 66.959**

As the volume and conflicting volume increases, QL increases. Presence of an upstream signal within 1000 feet from the intersection increases QL. Moreover, presence of a separate left turn lane decreases QL as compared to not having a turn lane. These signs indicate the reasonableness of the model. Statistical analysis of the model is shown in Table 4-5.

## Table 4-5 Statistical Analysis of MJL Model

```
Poisson Regression

Dependent variable: QL
Factors:
   VOL
   CONVOL
   SIGNAL
   TWTL

Estimated Regression Model (Maximum Likelihood)
-------------------------------------------------------------
                                      Standard    Estimated
Parameter                 Estimate       Error    Rate Ratio
-------------------------------------------------------------
CONSTANT                  0.392535     0.119829
VOL                     0.00586284   0.00187515      1.00588
CONVOL                   0.0010416  0.000187399      1.00104
SIGNAL                     0.48999      0.16482       1.6323
TWTL                     -0.811879     0.140689     0.444023
-------------------------------------------------------------

              Analysis of Deviance
----------------------------------------------------
Source          Deviance            Df      P-Value
----------------------------------------------------
Model           137.162              4       0.0000
Residual        67.6827            214       1.0000
----------------------------------------------------
Total (corr.)   204.845            218

Percentage of deviance explained by model = 66.959
Adjusted percentage = 62.0772

Likelihood Ratio Tests
----------------------------------------------------------
Factor                    Chi-Square         Df   P-Value
----------------------------------------------------------
VOL                       9.22746             1    0.0024
CONVOL                    33.0217             1    0.0000
SIGNAL                    8.98112             1    0.0027
TWTL                      37.2249             1    0.0000
----------------------------------------------------------

Residual Analysis
---------------------------------
      Estimation       Validation
n     219
MSE   2.78244
MAE   0.761339
MAPE  33.5926
ME    0.0189021
MPE   -16.1152
```

Because the P-value for the model in the Analysis of Deviance table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. In addition, the P-value for the residuals is greater than or equal to 0.10, indicating that the model is not significantly worse than the best possible model for this data at the 90% or higher confidence level. The percentage of deviance in QL explained by the model equals 66.959%. This statistic is similar to the usual R-Squared statistic. The adjusted percentage, which is more suitable for comparing models with different numbers of independent variables, is 62.0772%.

In determining whether the model can be simplified, notice that the highest P-value for the likelihood ratio tests is 0.0027, belonging to SIGNAL. Because the P-value is less than 0.01, that term is statistically significant at the 99% confidence level. Consequently, it is not advisable to remove any variables from the model.

Table 4-6 shows estimated correlations between the coefficients in the fitted model. These correlations can be used to detect the presence of serious multicollinearity, i.e., correlation amongst the predictor variables. In this case, there is 1 correlation with an absolute value greater than 0.5.

**Table 4-6 Correlation Matrix for Estimated Coefficients for MJL Model**

Correlation matrix for coefficient estimates

| | CONSTANT | VOL | CONVOL | SIGNAL |
|---|---|---|---|---|
| CONSTANT | 1.0000 | -0.3962 | -0.6333 | 0.3000 |
| VOL | -0.3962 | 1.0000 | -0.3402 | -0.1638 |
| CONVOL | -0.6333 | -0.3402 | 1.0000 | -0.2150 |
| SIGNAL | 0.3000 | -0.1638 | -0.2150 | 1.0000 |
| TWTL | -0.3673 | 0.3793 | -0.0517 | -0.7019 |

| | TWTL |
|---|---|
| CONSTANT | -0.3673 |
| VOL | 0.3793 |
| CONVOL | -0.0517 |
| SIGNAL | -0.7019 |
| TWTL | 1.0000 |

The plot of the fitted model with 95% confidence limits (shown as red lines), predicted QL Vs Observed QL, and the Residual plot for QL, are shown in Figures 4-2 and 4-3, respectively. The Residual plot for QL shows most of the predictions have an error of ± 1 vehicle, due to rounding off to the nearest integer.

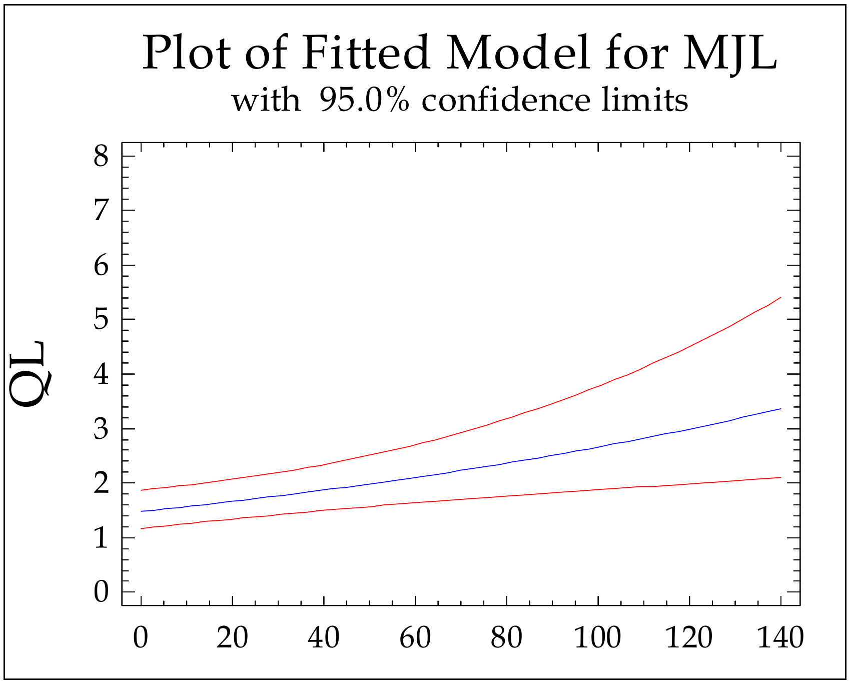



**Figure 4-2 Plot of Fitted Model for MJL**

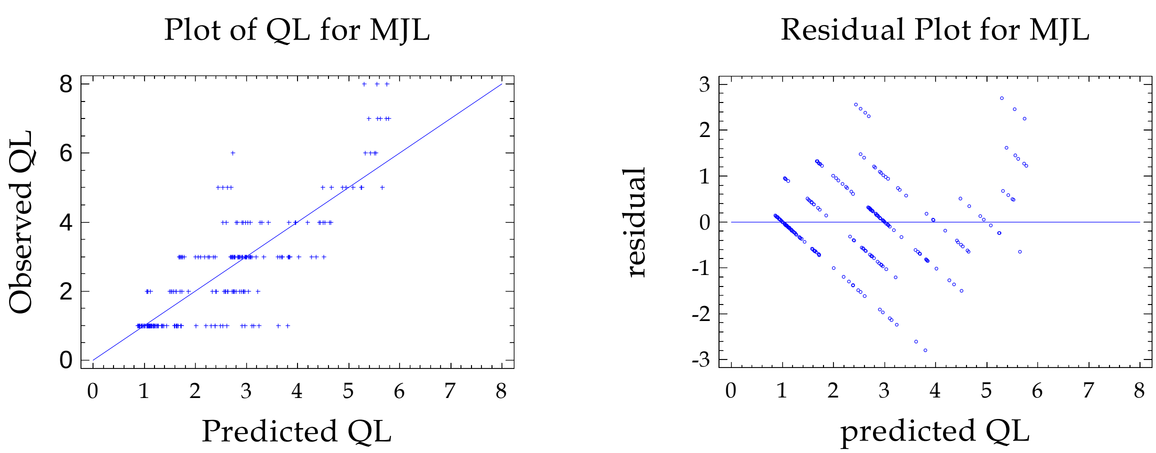



**Figure 4-3 Residual Plot for MJL**

## 4.4 *Minor, Shared LTR (MNLTR)*

There are 143 observations for this lane group category. Scatter plots are shown in Figure 4-4.

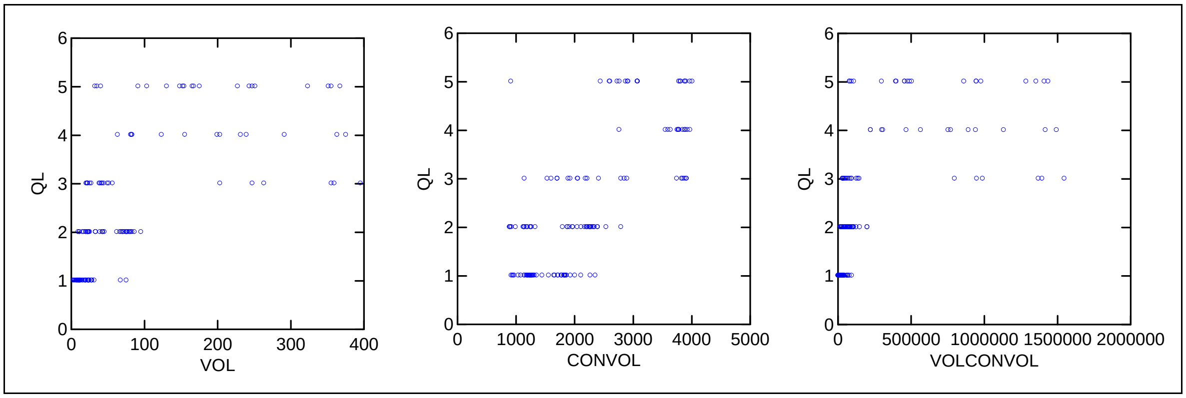



**Figure 4-4 Scattered Plot of QL Vs VOL, CONVOL, and VOL*CONVOL for MNLTR**

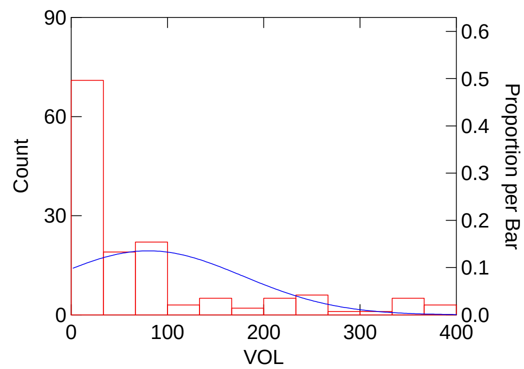
There exists no definite pattern among the variables, which shows the requirement of the transformation of the explanatory variables. This may be due to the random arrival of the minor street movements, which will influence the queue formation to be random. Various combinations of transformations are analyzed to recognize the patterns in the data, but none are explaining the queue behavior properly.

The distributions of volume, conflicting volume, product of these volumes, and queue lengths are following gamma distribution as listed in Table 4-7. In the Shapiro-Wilk test statistic for normality, the P-value for each distribution is less than the alpha value of 0.05. It is concluded that the data are not from the normally distribution population. So, VOL and CONVOL are not normally distributed.

It is assumed that the queue lengths tend to follow the random vehicle arrivals and therefore the Poisson regression model is tested. Before going further into the model development it is worthwhile to get a snap shot of the summary statistics for each variable in the model.

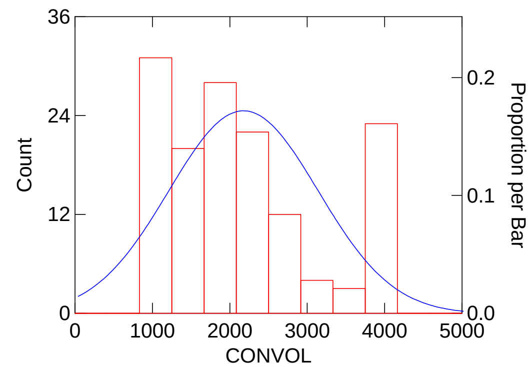
## Table 4-7 Fitting Distributions for MNLTR Data

FITTED DISTRIBUTION



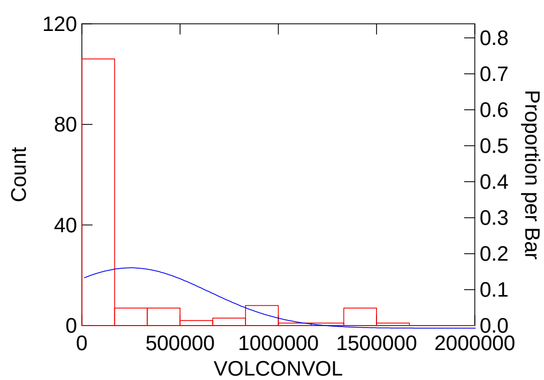

Distribution: Gamma
Kolmogorov-Smirnov test statistic = 0.246430
Lilliefors Probability (2-tail) = 0.000000
Shapiro-Wilk test statistic for normality = 0.714618
p-value = 0.000000
Estimated Shape (alpha) = 0.666946
Scale (beta) = 120.117511
Chi-square test statistic = 30.032026
df = 5, p-value = 0.000015

FITTED DISTRIBUTION



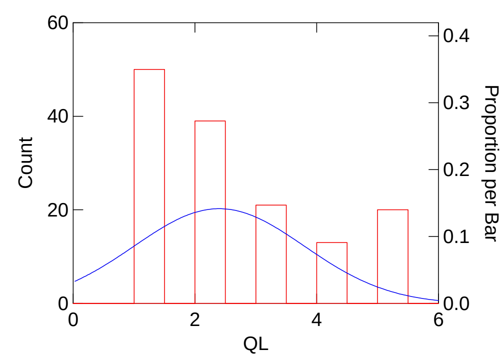

Distribution: Gamma
Kolmogorov-Smirnov test statistic = 0.118544
Lilliefors Probability (2-tail) = 0.000041
Shapiro-Wilk test statistic for normality = 0.895070
p-value = 0.000000
Estimated: Shape (alpha) = 5.017084
Estimated: Scale (beta) = 430.484357
Chi-square test statistic = 68.746965
df = 8, p-value = 0.000000

FITTED DISTRIBUTION




Distribution: Gamma
Kolmogorov-Smirnov test statistic = 0.339958
Lilliefors Probability (2-tail) = 0.000000
Shapiro-Wilk test statistic for normality = 0.620258
p-value = 0.000000
Variable Name: VOLCONVOL
Estimated: Shape (alpha) = 0.387296
Estimated: Scale (beta) = 636926.604762
Chi-square test statistic = 61.330933
df = 4 p-value = 0.000000

FITTED DISTRIBUTION




Distribution: Gamma
Kolmogorov-Smirnov test statistic = 0.234447
Lilliefors Probability (2-tail) = 0.000000
Shapiro-Wilk test statistic for normality = 0.831541
p-value = 0.000000
Variable Name: QL
Estimated: Shape (alpha) = 2.935354
Estimated: Scale (beta) = 0.817142
Chi-square test statistic = 192.914128
df = 8 p-value = 0.000000

As given in Table 4-8, the maximum queue length observed is 5 with minimum of 1 vehicle in the queue. Volumes range from 3 vehicles per hour to 396 vehicles with a mean arrival rate of 80 vph. A mean conflicting flow rate of 2160 vph is observed. The distribution of the product of volume and conflicting volume is skewed more to the right side, and all data sets are showing a trend that is not normally distributed.

**Table 4-8 Summary Statistics for MNLTR data**

| Item | VOL | CONVOL | VOLCONVOL | QL |
|---|---|---|---|---|
| N of cases | 143 | 143 | 143 | 143 |
| Minimum | 3.000 | 897.000 | 3600.000 | 1.000 |
| Maximum | 396.000 | 4016.000 | 1550149.000 | 5.000 |
| Range | 393.000 | 3119.000 | 1546549.000 | 4.000 |
| Sum | 11456.000 | 308848.000 | 3.52752E+07 | 343.000 |
| Median | 34.000 | 1935.000 | 69315.000 | 2.000 |
| Mean | 80.112 | 2159.776 | 246679.392 | 2.399 |
| 95% CI upper | 96.385 | 2319.734 | 312434.895 | 2.631 |
| 95% CI lower | 63.839 | 1999.819 | 180923.888 | 2.166 |
| Std. Error | 8.232 | 80.917 | 33263.424 | 0.117 |
| Standard Dev | 98.441 | 967.625 | 397772.702 | 1.405 |
| Variance | 9690.607 | 936297.414 | 1.58223E+11 | 1.974 |
| C.V. | 1.229 | 0.448 | 1.613 | 0.586 |
| Skewness(G1) | 1.790 | 0.630 | 2.002 | 0.697 |
| SE Skewness | 0.203 | 0.203 | 0.203 | 0.203 |
| Kurtosis(G2) | 2.248 | -0.821 | 2.846 | -0.808 |
| SE Kurtosis | 0.403 | 0.403 | 0.403 | 0.403 |
| SW Statistic | 0.715 | 0.895 | 0.620 | 0.832 |
| SW P-Value | 0.000 | 0.000 | 0.000 | 0.000 |

The next step after choosing the model is to select the appropriate independent variable(s) from the pool of identified influencing variables. The combinations of the variables are tested and chosen based upon the largest $R^2$ Value[8], lowest Mallow`s Cp statistic [9] value, and lowest Mean Square Error (MSE). The analysis results are shown in Table 4-9. Analysis indicates that VOL, CONVOL, and the product of VOL and CONVOL may explain the queue behavior significantly. This step leads to the basic model formulation and development.

---

[8] The adjusted R-Squared statistic measures the proportion of the variability in QL which is explained by the model.

9 Mallows' Cp statistic is a measure of the bias in a model, based on a comparison of total mean squared error to the true error variance. Unbiased models have an expected value of approximately p, where p is the number of coefficients in the fitted model including constant

**Table 4-9 Selection of Dependent Variables for Poisson Regression**

Regression Model Selection

Dependent variable: QL
Independent variables:
A=VOL
B=CONVOL
C=RATIO
D=CONLANES
E=CONSPEED
F=VOLCONVOL

Number of complete cases: 143
Number of models fit: 63

Model Results

| MSE | R-Squared | Adjusted R-Squared | Cp | Included Variables |
|---|---|---|---|---|
| 0.611827 | 69.6575 | 69.0026 | 1.439 | ABF |
| 0.614559 | 69.7412 | 68.8642 | 3.06236 | ABDF |
| 0.615163 | 69.7115 | 68.8336 | 3.19602 | ABEF |
| 0.615628 | 69.6886 | 68.81 | 3.29892 | ABCF |
| 0.618901 | 69.7483 | 68.6442 | 5.03076 | ABCDF |
| 0.618946 | 69.7461 | 68.6419 | 5.04066 | ABDEF |
| 0.619454 | 69.7212 | 68.6162 | 5.15227 | ABCEF |
| 0.76147 | 62.2362 | 61.4212 | 34.8098 | BCE |
| 0.762063 | 62.4787 | 61.3911 | 35.7194 | ABCE |
| 0.764151 | 61.8306 | 61.2853 | 34.6337 | BC |
| 0.765162 | 62.3261 | 61.2341 | 36.4056 | BCDE |
| 0.765886 | 62.0172 | 61.1974 | 35.7946 | BCD |
| 0.766978 | 61.963 | 61.1421 | 36.0382 | ABC |
| 0.767159 | 62.5015 | 61.1329 | 37.617 | ABCDE |
| 0.768823 | 61.8715 | 61.0486 | 36.4495 | BCF |
| 0.770255 | 62.3501 | 60.976 | 38.2975 | BCDEF |
| 0.848438 | 57.6204 | 57.015 | 53.5652 | AB |
| 0.877404 | 56.1736 | 55.5475 | 60.0711 | BD |
| 0.884581 | 55.4995 | 55.1839 | 61.1023 | B |
| 0.885017 | 55.7933 | 55.1618 | 61.7809 | BF |
| 0.88622 | 55.7332 | 55.1008 | 62.0512 | BE |
| 1.08969 | 45.1812 | 44.7924 | 107.5 | A |
| 1.16248 | 41.5195 | 41.1047 | 123.965 | F |
| 1.44374 | 27.3698 | 26.8546 | 187.591 | C |
| 1.85577 | 6.64192 | 5.9798 | 280.797 | D |
| 1.9738 | 0.0 | 0.0 | 308.663 | |

A correlation matrix between QL and the independent variables is given in Table 4-10. A correlation coefficient of either +1 or -1 shows perfect correlation in positive or negative manner. A 0 correlation coefficient shows that independent variables can not explain queue behavior sufficiently. A positive sign in the matrix represents a positive correlation which indicates that QL increases as the independent or explanatory variable increases. Moreover, all explanatory variables are correlated with QL. There exists correlation between VOL and CONVOL. This may be due to the fact that CONVOL and VOL are volumes on different lanes, and as VOL increase from the off-peak period to the peak period, CONVOL may increase in volume to represent the peak condition. Finally, the correlation between the product of VOL and CONVOL with VOL and CONVOL will be expected as the product comes from both VOL and CONVOL. Though consideration of all three explanatory variables seems to dampen the model performance as a result of correlation, the comparison of models with various combinations of variables as shown in Table 4-11 indicates that these variables perform better for the observed data. The other reason to consider the product term is to capture the QL for the corresponding pair of VOL and CONVOL.

**Table 4-10 Correlation Matrix of Variables for MNLTR Model**

| Variable | VOL | CONVOL | VOLCONVOL | QL |
|---|---|---|---|---|
| VOL | 1.000 | 0.780 | 0.986 | 0.672 |
| CONVOL | 0.780 | 1.000 | 0.824 | 0.745 |
| VOLCONVOL | 0.986 | 0.824 | 1.000 | 0.644 |
| QL | 0.672 | 0.745 | 0.644 | 1.000 |

The model for predicting the maximum number of vehicles in the stopped queue is formulated as a Poisson regression equation with volume, conflicting volume, and their product as independent or explanatory variables.

$$\mathrm{Ln}(QL_{MNLTR}) = \beta_0 + \beta_1 \times VOL_{MNLTR} + \beta_2 \times CONVOL_{MNLTR} + \beta_3 \times (VOL_{MNLTR} * CONVOL_{MNLTR})$$

Where

Ln = Natural Logarithm

VOL = Approach volume for MNLTR lane configuration

CONVOL = Conflicting volume for MNLTR

$\beta_0$ = Constant

$\beta_1$ , $\beta_2$ , $\beta_3$ = Model coefficients corresponds to VOL, CONVOL, and VOL*CONVOL

The Poisson Regression model with coefficient values and corresponding statistical tests are explained below:

$$\mathbf{Ln(QL) = -0.7844 + 0.01636 \times VOL + 0.0006 \times CONVOL - 0.0000043 \times (VOL * CONVOL)}$$

$$QL = e^{(-0.7844 + 0.01636 \times VOL + 0.0006 \times CONVOL - 0.0000043 \times (VOL * CONVOL))}$$

**Percentage of Deviation Explained by Model = 71.643**

Signs of the independent variables show reasonableness in the models, as a positive change in the VOL and CONVOL results in increasing QL. But the occurrence of VOL and the corresponding CONVOL as a product triggers a decrease in QL, due to the fact that lower approach volume may not yield larger queue lengths, rather more waiting time in the stopped queue. As approach volumes increase to capacity, the approach volume has a greater higher impact on queue than the conflicting volume.

**Table 4-11 Possion Regression Model for MNLTR**

Poisson Regression
Dependent variable: QL
Factors: VOL, CONVOL, VOLCONVOL
Estimated Regression Model (Maximum Likelihood)

| Parameter | Estimate | Standard Error | Estimated Rate Ratio |
|---|---|---|---|
| CONSTANT | -0.784374 | 0.247345 | |
| VOL | 0.0163606 | 0.00357521 | 1.0165 |
| CONVOL | 0.000598612 | 0.000102971 | 1.0006 |
| VOLCONVOL | -0.0000043145 | 9.55645E-7 | 0.999996 |

Analysis of Deviance

| Source | Deviance | Df | P-Value |
|---|---|---|---|
| Model | 80.5605 | 3 | 0.0000 |
| Residual | 31.8861 | 139 | 1.0000 |
| Total (corr.) | 112.447 | 142 | |

Percentage of deviance explained by model = 71.6433
Adjusted percentage = 64.5289
Likelihood Ratio Tests

| Factor | Chi-Square | Df | P-Value |
|---|---|---|---|
| VOL | 19.6951 | 1 | 0.0000 |
| CONVOL | 33.5012 | 1 | 0.0000 |
| VOLCONVOL | 19.6016 | 1 | 0.0000 |

Residual Analysis

| | Estimation | Validation |
|---|---|---|
| n | 143 | |
| MSE | 1.53264 | |
| MAE | 0.581838 | |
| MAPE | 24.0153 | |
| ME | -0.00423549 | |
| MPE | -9.38096 | |

Statistical significance is given in Table 4-11. The model accounts for 71.6 percent of deviance[10] explained in QL. Because the P-value for the model in the Analysis of Deviance table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. In addition, the P-value for the residuals is greater than or equal to 0.10, indicating that the model is not significantly worse than the best possible model for this data at the 90% or higher confidence level.

[10] The percentage of deviance statistic is similar to the usual R-Squared statistic.

The adjusted percentage, which is more suitable for comparing models with different numbers of independent variables, is 64.5289%. In determining whether the model can be simplified, notice that the highest P-value for the likelihood ratio tests is 0.0000, belonging to VOLCONVOL. Because the P-value is less than 0.01, that term is statistically significant at the 99% confidence level. Consequently, it is not advisable to remove any variables from the model. The plot of predicted QL and Observed QL is shown in Figure 4-5. The Residual plot for QL given in Figure 4-6 shows most of the predictions have an error of ± 1 vehicle, due to rounding-off error to the nearest integer.

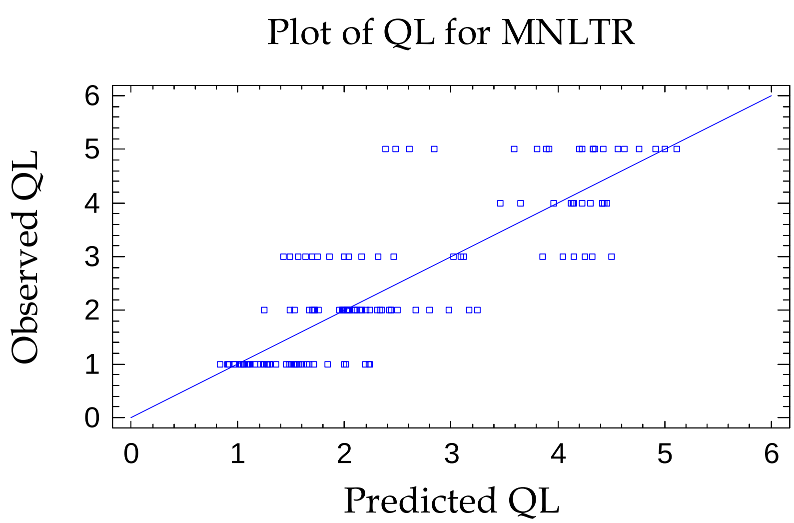



**Figure 4-5 Plot of Predicted QL and Observed QL for MNLTR Model**

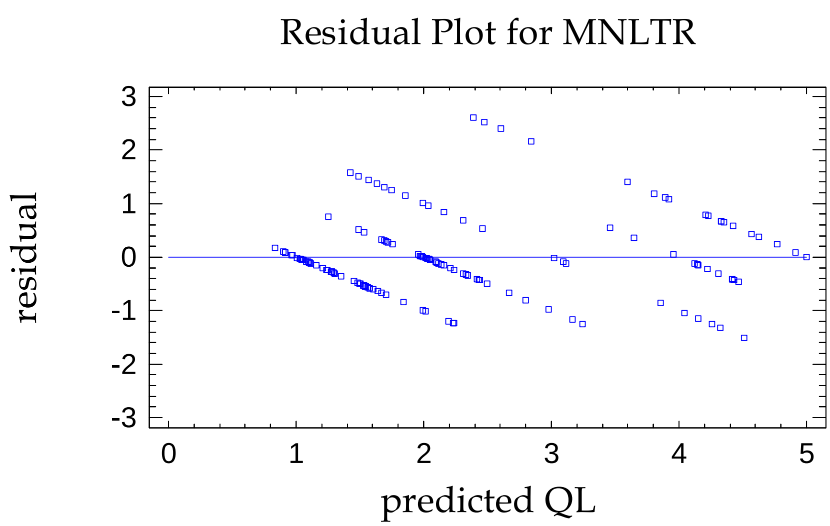



**Figure 4-6 Residual Plot of Predicted QL and Observed QL for MNLTR Model**

## *4.5 Minor, LR (MNLR)*

This section explains model development for minor approach queue length estimation for a T-intersection where there exists a single lane for both left and right turn movements. There are 81 data point for model development. Summary statistics of the observed data corresponding to VOL, CONVOL, and their product is given in Table 4-12.

**Table 4-12 Summary Statistics for MNLR lane group**

| | VOL | CONVOL | VOLCONVOL | QL |
|---|---|---|---|---|
| Count | 81 | 81 | 81 | 81 |
| Average | 66.7654 | 1490.32 | 91333.1 | 2.39506 |
| Variance | 2683.03 | 282928.0 | 4.53467E9 | 1.96698 |
| Standard deviation | 51.798 | 531.909 | 67340.0 | 1.40249 |
| Minimum | 12.0 | 802.0 | 11250.0 | 1.0 |
| Maximum | 224.0 | 2489.0 | 273273.0 | 7.0 |
| Range | 212.0 | 1687.0 | 262023.0 | 6.0 |
| Stnd. skewness | 5.40679 | 1.60496 | 4.51837 | 5.77836 |
| Stnd. kurtosis | 3.87235 | -1.99022 | 1.18442 | 5.03514 |

The observed maximum number of vehicles in the stopped queue (QL) varies from a minimum of 1 to a maximum of 7. Standardized skewness and standardized kurtosis statistics outside the range of -2 to +2 indicate significant departures from normality. So, QL is believed to be not from a Normal Distribution. Also VOL and VOLCONVOL show standardized skewness values outside the expected range. Standardized kurtosis values for VOL are also outside the expected range. Transformations may make these variables to be normal.

Analysis of the scatter plot between QL and VOL, and CONVOL shows the possible relation among variables. A box-and-whisker diagram or plot [11] is shown as the diagonal of the matrix in Figure 4-7. No definite pattern is observed among these plots. Therefore QL is assumed to follow the random process of vehicle arrivals. A Poisson regression model is tested as the initial step in model development.

[11] is a convenient way of graphically depicting groups of numerical data through their five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). A boxplot may also indicate which observations, if any, might be considered outliers.

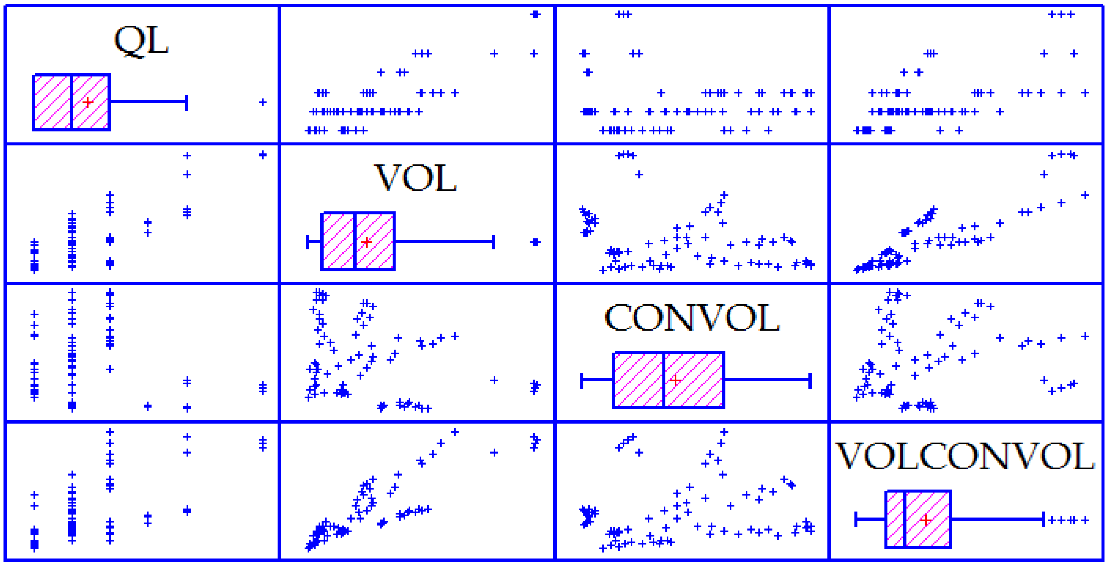



**Figure 4-7 Scattered Matrix Plot for MNLR Lane Group Data**

The next step is to choose appropriate set of variables from the identified list of variables from Table 4-13. Based on the lowest MSE, highest R-squared, and lowest Cp Statistic, VOL, CONVOL, and the product of VOL and CONVOL are considered in the model.

Variable selection leads to the step of correlation analysis to check for the serial correlation among the independent variables. Due to the fact that VOL and CONVOL are simply volume occurring on different lanes, there may be some correlation between them. Likewise, the product term has either VOL or CONVOL which will trigger the correlation. This has an impact on the model, but they can not be excluded to capture the impact on QL. The correlation matrix is shown in Table 4-14.

**Table 4-14 Pearson Correlation Matrix of Variables in MNLR Model**

| Variable | QL | VOL | CONVOL | VOLCONVOL |
|---|---|---|---|---|
| QL | 1.000 | 0.771 | -0.064 | 0.643 |
| VOL | 0.771 | 1.000 | -0.300 | 0.869 |
| CONVOL | -0.064 | -0.300 | 1.000 | 0.123 |
| VOLCONVOL | 0.643 | 0.869 | 0.123 | 1.000 |

**Table 4-13 Variables Selection for MNLR Model**

```
Regression Model Selection

Dependent variable: QL
Independent variables:
   A=VOL
   B=CONVOL
   C=RATIO
   D=VOLCONVOL

Number of complete cases: 81
Number of models fit: 16

Model Results
```

| MSE | R-Squared | Adjusted R-Squared | Cp | Included Variables |
|---|---|---|---|---|
| 1.96698 | 0.0 | 0.0 | 220.885 | |
| 0.806398 | 59.5156 | 59.0031 | 44.4064 | A |
| 1.96698 | 1.25 | 0.0 | 221.638 | B |
| 1.77722 | 10.7766 | 9.64718 | 190.567 | C |
| 1.16805 | 41.3593 | 40.617 | 98.8545 | D |
| 0.755034 | 62.5741 | 61.6145 | 37.2345 | AB |
| 0.625702 | 68.9849 | 68.1896 | 18.0095 | AC |
| 0.810442 | 59.8276 | 58.7975 | 45.4708 | AD |
| 1.74266 | 13.6189 | 11.404 | 184.044 | BC |
| 1.14078 | 43.4533 | 42.0034 | 94.5747 | BD |
| 1.18154 | 41.433 | 39.9313 | 100.633 | CD |
| 0.633765 | 68.988 | 67.7797 | 20.0002 | ABC |
| 0.526761 | 74.224 | 73.2197 | 4.29828 | ABD |
| 0.604781 | 70.4063 | 69.2533 | 15.7471 | ACD |
| 1.03289 | 49.4574 | 47.4882 | 78.5694 | BCD |
| 0.524729 | 74.6569 | 73.3231 | 5.0 | ABCD |

The model for predicting the maximum number of vehicles in the stopped queue is formulated as a Poisson regression equation with volume, conflicting volume, and their product as independent or explanatory variables.

$$Ln(QL_{MNLR}) = \beta_0 + \beta_1 \times VOL_{MNLR} + \beta_2 \times CONVOL_{MNLR} + \beta_3 \times (VOL_{MNLR} * CONVOL_{MNLR})$$

Where

Ln = Natural Logarithm

VOL = Approach volume for MNLR lane configuration

CONVOL = Conflicting volume for MNLR

$\beta_0$ = Constant

$\beta_1$ , $\beta_2$ , $\beta_3$ = Model coefficients corresponds to VOL, CONVOL, and VOL*CONVOL

The developed model with coefficient values and corresponding statistical tests are explained below:

$$\mathbf{Ln(QL) = -0.6319 + 0.0173 \times VOL + 0.00066 \times CONVOL - 0.000007913\,(VOL * CONVOL)}$$

$$QL = e^{\left(\mathbf{-0.6319 + 0.0173 \times VOL + 0.00066 \times CONVOL - 0.000007913\,(VOL * CONVOL)}\right)}$$

**Percentage of deviance explained by model = 69.25**

The signs of the independent variables show reasonableness in the models, as a positive change in the VOL and CONVOL results in increasing QL. But the occurrence of VOL and the corresponding CONVOL as a product triggers a decrease in QL, due to the fact that lower approach volume may not yield larger queue lengths, rather increase waiting time in the stopped queue. As volumes increase to capacity, the approach volume has a higher impact on queue than the conflicting volume. The statistics of model development are given in Table 4-15.

The model accounts for 69.25 percent of deviance[12] explained in QL. Because the P-value for the model in the Analysis of Deviance table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. In addition, the P-value for the residuals is greater than or equal to 0.10, indicating that the model is not significantly worse than the best possible model for this data at the 90% or higher confidence level.

**Table4-15 Poisson Regression Model for MNLR Data**

[12] The percentage of deviance statistic is similar to the usual R-Squared statistic.

```
Poisson Regression

Dependent variable: QL
Factors:
   VOL
   CONVOL
   VOLCONVOL

Estimated Regression Model (Maximum Likelihood)
------------------------------------------------------------
                                         Standard    Estimated
Parameter                Estimate           Error   Rate Ratio
------------------------------------------------------------
CONSTANT                -0.631869        0.399069
VOL                     0.0172923      0.00455457      1.01744
CONVOL                0.000662669     0.000246615      1.00066
VOLCONVOL         -0.00000791327  0.00000352853     0.999992
------------------------------------------------------------

              Analysis of Deviance
---------------------------------------------------
Source          Deviance            Df       P-Value
---------------------------------------------------
Model           39.7281              3        0.0000
Residual        17.6416             77        1.0000
---------------------------------------------------
Total (corr.)   57.3698             80

Percentage of deviance explained by model = 69.2492
Adjusted percentage = 55.3046

Likelihood Ratio Tests
---------------------------------------------------------
Factor                   Chi-Square          Df   P-Value
---------------------------------------------------------
VOL                      14.5754              1    0.0001
CONVOL                   6.88596              1    0.0087
VOLCONVOL                5.17992              1    0.0228
---------------------------------------------------------

Residual Analysis
---------------------------------
      Estimation       Validation
n     81
MSE   1.55813
MAE   0.618471
MAPE  26.7428
ME    -0.0326626
MPE   -9.84617
```

The adjusted percentage of deviance, which is more suitable for comparing models with different numbers of independent variables, is 55.3%. In determining whether the model can be simplified, notice that the highest P-value for the likelihood ratio tests is 0.0228, belonging to VOLCONVOL. Because the P-value is less than 0.05, that term is statistically significant at the 95% confidence level. Consequently, it is not advisable to remove any variables from the model. The plot of predicted QL and Observed QL is shown in Figure 4-8. The Residual plot for QL given in Figure 4-9 shows most of the predictions have an error of ± 1 vehicle, due to rounding-off error to the nearest integer.

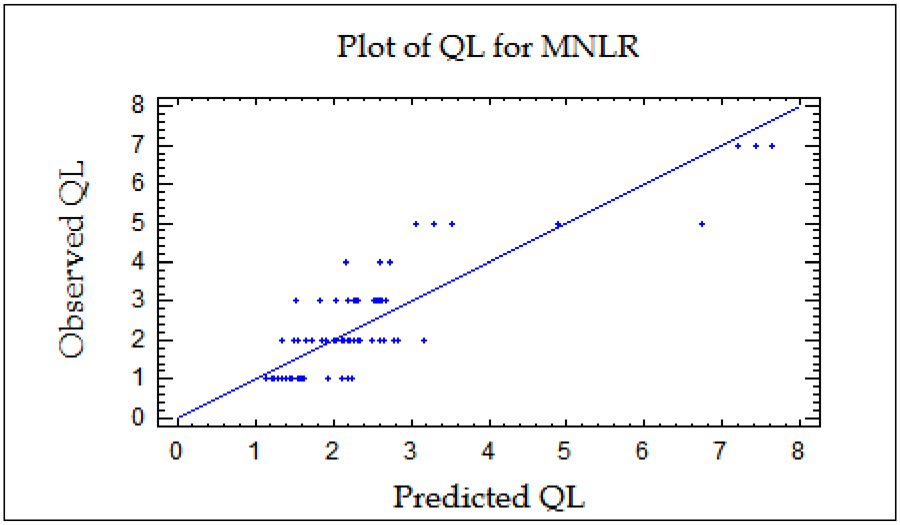



**Figure 4-8 Plot of QL between Predicted Vs Observed QL for MNLR**

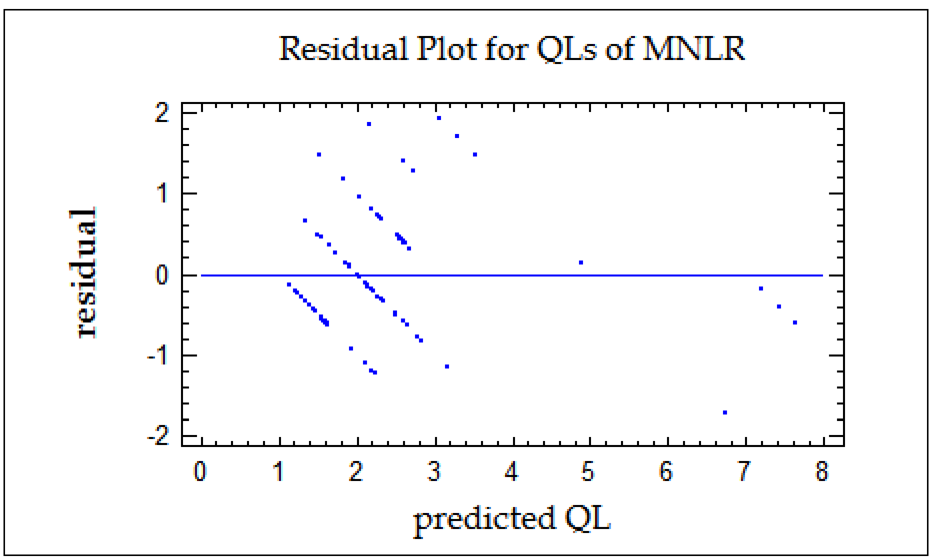



**Figure 4-9 Residual Plot between Predicted QL and Residual for MNLR**

## 4.6 *Minor Left (MNL)*

There are 34 data point available for model development. Table 4-16 shows the maximum QL observed ranges from one vehicle to 6 vehicles. Sample QL, VOL and CONVOL come from a normal distribution except the ratio of conflicting volume to the approach volume (designated as RATIO). Intuition for taking RATIO as the explanatory variable is partly explained through the scattered diagram shown in Figure 4-10, where a pattern is observed between QL and RATIO.

**Table 4-16 Summary Statistics of MNL Data**

| | QL | VOL | CONVOL | RATIO |
|---|---|---|---|---|
| Count | 34 | 34 | 34 | 34 |
| Average | 3.67647 | 66.2353 | 949.412 | 23.2288 |
| Variance | 2.40731 | 1467.16 | 65609.0 | 350.695 |
| Standard deviation | 1.55155 | 38.3035 | 256.143 | 18.7268 |
| Minimum | 1.0 | 7.0 | 457.0 | 5.03 |
| Maximum | 6.0 | 132.0 | 1286.0 | 83.35 |
| Range | 5.0 | 125.0 | 829.0 | 78.32 |
| Stnd. skewness | -0.589831 | 0.183785 | -1.09969 | 3.62622 |
| Stnd. kurtosis | -1.08621 | -1.27444 | -1.42946 | 2.37195 |

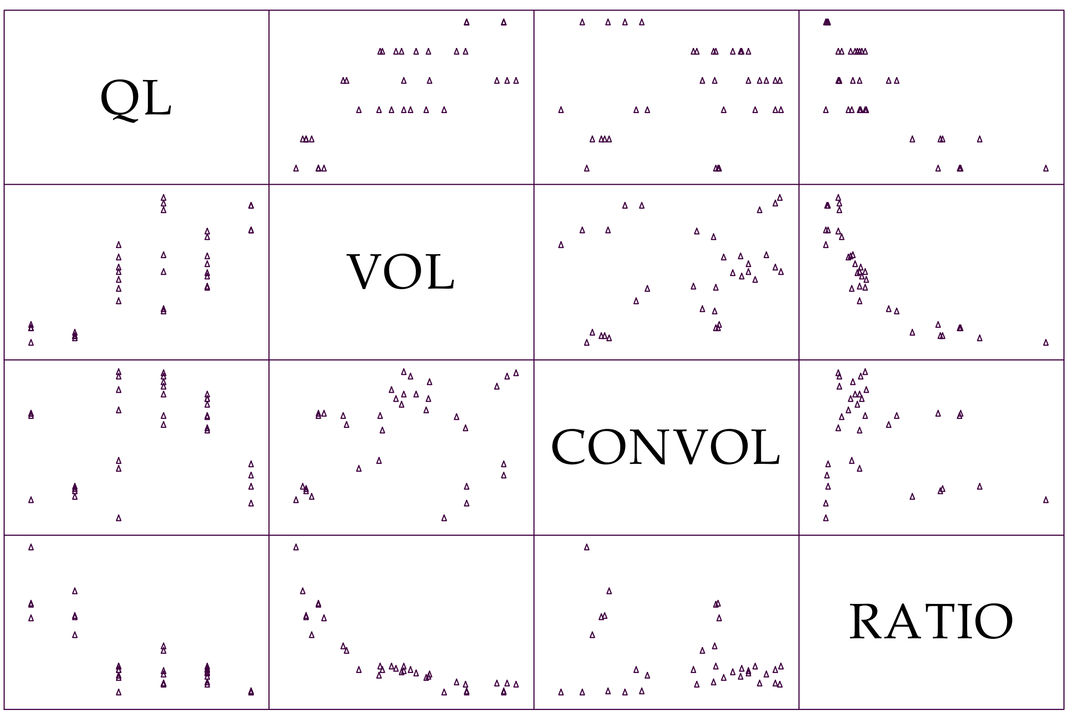



**Figure 4-10 Scattered Matrix Plot of Variables for MNLR**

Table 4-17 shows the results of fitting various multiple regression models to describe the relationship between QL and 4 predictor variables. Models have been fit containing all combinations of from 0 to 4 variables. The statistics tabulated include the mean squared error (MSE), the adjusted and unadjusted R-Squared values, and Mallows' Cp statistic. Models are determined to be best according to lowest values for all three criteria.

**Table 4-17 Selection of Independent Variables for MNL Model**

```
Regression Model Selection

Dependent variable: QL
Independent variables:
   A=VOL
   B=CONVOL
   C=VOLCONVOL
   D=RATIO

Number of complete cases: 34
Number of models fit: 16

Model Results
--------------------------------------------------------------------
                           Adjusted                    Included
MSE          R-Squared     R-Squared     Cp            Variables
--------------------------------------------------------------------
2.40731      0.0           0.0           57.7769
1.10936      55.3133       53.9169       10.1183       A
2.40731      3.0303        0.0           58.6512       B
1.69847      31.5832       29.4452       31.4225       C
0.91006      63.3415       62.196        2.91082       D
1.12208      56.2137       53.3888       11.31         AB
1.04489      59.2256       56.595        8.60595       AC
0.89479      65.083        62.8303       3.34741       AD
1.49105      41.8154       38.0616       24.2363       BC
0.910698     64.4622       62.1695       3.90472       BD
0.939369     63.3434       60.9784       4.90918       CD
1.01232      61.7708       57.9479       8.321         ABC
0.887672     66.4781       63.126        4.09488       ABD
0.861009     67.485        64.2336       3.19092       ACD
0.921012     65.2191       61.741        5.22521       BCD
0.884873     67.6977       63.2422       5.0           ABCD
--------------------------------------------------------------------
```

Table 4-18 shows Spearman rank correlations between each pair of variables. These correlation coefficients range between -1 and +1 and measure the strength of the association between the variables. In contrast to the more common Pearson correlations, the Spearman coefficients are computed from the ranks of the data values rather than from the values themselves. Consequently, they are less sensitive to outliers than the Pearson coefficients. Also shown in parentheses is the number of pairs of data values used to compute each coefficient. The third number in each location of the table is a P-value which tests the statistical significance of the estimated correlations. P-values below 0.05 indicate statistically significant non-zero correlations at the 95% confidence level. The following pairs of variables have P-values below 0.05: QL and VOL, QL and RATIO, and VOL and RATIO.

**Table4-18 Spearman Rank Correlation Matrix for MNL Variables**

Spearman Rank Correlations

| | QL | VOL | CONVOL | RATIO |
|---|---|---|---|---|
| QL | | 0.7117<br>( 34)<br>0.0000 | 0.0560<br>( 34)<br>0.7478 | -0.7294<br>( 34)<br>0.0000 |
| VOL | 0.7117<br>( 34)<br>0.0000 | | 0.3265<br>( 34)<br>0.0607 | -0.9276<br>( 34)<br>0.0000 |
| CONVOL | 0.0560<br>( 34)<br>0.7478 | 0.3265<br>( 34)<br>0.0607 | | -0.0393<br>( 34)<br>0.8215 |
| RATIO | -0.7294<br>( 34)<br>0.0000 | -0.9276<br>( 34)<br>0.0000 | -0.0393<br>( 34)<br>0.8215 | |

Correlation
(Sample Size)
P-Value

The model for predicting the maximum number of vehicles in the stopped queue is formulated as a Poisson regression equation with volume and conflicting volume as independent or explanatory variables.

$$\mathbf{Ln}\left(\mathbf{QL_{MNL}}\right) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} \times \left(\boldsymbol{CONVOL_{MNL}/VOL_{MNL}}\right)$$

Where

Ln = Natural Logarithm

QL = Maximum number of vehicles in the stopped queue

VOL = Approach volume for MNL lane configuration

CONVOL = Conflicting volume for MNL

$\beta_0$ = Constant

$\beta_1$ = Model coefficients corresponds to RATIO (CONVOL/VOL)

The Poisson regression model developed with coefficient values and corresponding statistical tests are explained below:

$$\mathbf{Ln}\left(\mathbf{QL}\right) = \mathbf{1.7934 - 0.025} \times \left(\boldsymbol{CONVOL/VOL}\right)$$

$$QL = e^{\left(1.7934 - 0.025 \times \left(CONVOL/VOL\right)\right)}$$

**Percentage of deviance explained by model = 69.404**

Because the P-value for the model in the Analysis of Deviance table shown in Table 4-19 is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. In addition, the P-value for the residuals is greater than or equal to 0.10, indicating that the model is not significantly worse than the best possible model for this data at the 90% or higher confidence level.

**Table 4-19 Estimated Regression Model for MNL Data**

```
Poisson Regression

Dependent variable: QL
Factors:
   RATIO

Estimated Regression Model (Maximum Likelihood)
------------------------------------------------------------
                                        Standard    Estimated
Parameter                Estimate          Error   Rate Ratio
------------------------------------------------------------
CONSTANT                  1.79343        0.14742
RATIO                  -0.0247881     0.00684342     0.975517
------------------------------------------------------------

              Analysis of Deviance
---------------------------------------------------
Source          Deviance            Df      P-Value
---------------------------------------------------
Model           16.7513              1       0.0000
Residual        7.38449             32       1.0000
---------------------------------------------------
Total (corr.)   24.1357             33

Percentage of deviance explained by model = 69.4043
Adjusted percentage = 52.8314

Likelihood Ratio Tests
---------------------------------------------------------
Factor                   Chi-Square          Df   P-Value
---------------------------------------------------------
RATIO                    16.7513              1    0.0000
---------------------------------------------------------

Residual Analysis
---------------------------------
      Estimation       Validation
n     34
MSE   3.41565
MAE   0.820284
MAPE  23.642
ME    -0.00104352
MPE   -6.81105
```

The above Table also shows that the percentage of deviance in QL explained by the model equals 69.4043%. This statistic is similar to the usual R-Squared statistic. The adjusted percentage, which is more suitable for comparing models with different numbers of independent variables, is 52.8314%.

In determining whether the model can be simplified, notice that the highest P-value for the likelihood ratio tests is 0.0000, belonging to RATIO. Because the P-value is less than 0.01, that term is statistically significant at the 99% confidence level. Consequently, it is not advisable to remove any variables from the model. Plots of the predicted vs observed QL and their residuals are shown in Figure 4-11 and 4-12.

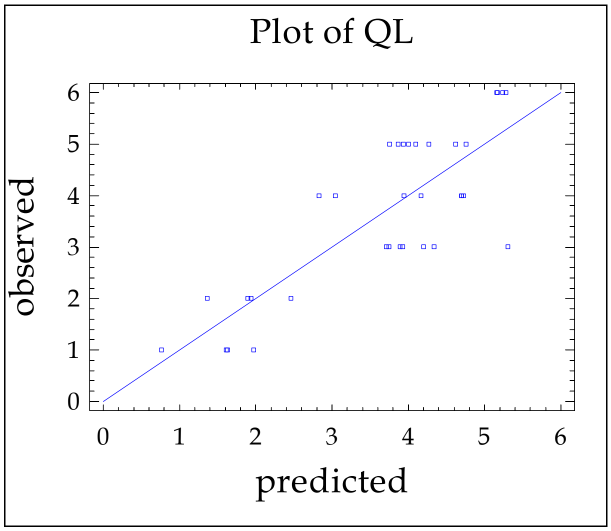



**Figure 4-11 Plot of QL between Predicted Vs Observed QL for MNL**

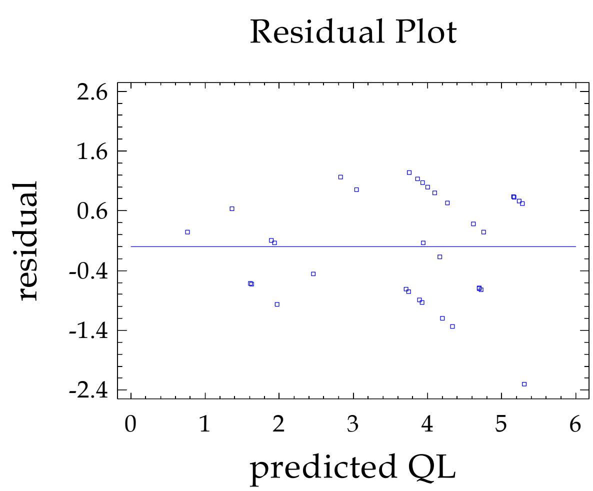



**Figure 4-12 Residual Plot between Predicted QL and Residual for MNL**

## 4.7 *Minor Right (MNR)*

Unfortunately, there are only 18 data points available for model development. A minimum of 2 vehicle in the queue and maximum of 5 vehicles are observed for this lane configuration. Table 4-20 shows summary statistics of data.

**Table 4-20 Summary Statistics of MNR Data**

| | QL | VOL | CONVOL | VOLCONVOL |
|---|---|---|---|---|
| Count | 18 | 18 | 18 | 18 |
| Average | 3.22222 | 56.1667 | 304.167 | 17124.6 |
| Variance | 1.12418 | 77.9118 | 7107.79 | 2.75093E7 |
| Standard deviation | 1.06027 | 8.82676 | 84.3077 | 5244.94 |
| Minimum | 2.0 | 44.0 | 141.0 | 6166.0 |
| Maximum | 5.0 | 71.0 | 412.0 | 23323.0 |
| Range | 3.0 | 27.0 | 271.0 | 17157.0 |
| Stnd. skewness | 0.871404 | 0.273118 | -0.594507 | -1.09394 |
| Stnd. kurtosis | -0.702281 | -0.991707 | -0.862272 | -0.426578 |

Only the developed model is shown with out further explanation of the model. This model is not tested for validation, as more data is required to obtain a significant model.

The model for predicting the maximum number of vehicles in the stopped queue is formulated as a Poisson regression equation with onlythe product of volume and conflicting volume as the independent or explanatory variable.

$$\mathrm{Ln}(\mathrm{QL}_{\mathrm{MNR}}) = \beta_0 + \beta_1 \times (VOL^*CONVOL)_{MNR}$$

Where

Ln = Natural Logarithm

QL = Maximum number of vehicles in the stopped queue

VOL = Approach volume for MNR lane configuration

CONVOL = Conflicting volume for MNR

$\beta_0$ = Constant

$\beta_1$ = Model coefficients corresponds to CONVOL

Poisson Regression is shown below:

$$\mathbf{Ln(QL) = 0.225058 + 0.00005316 \times (VOL * CONVOL)}$$

$$\mathbf{QL = e^{(0.225058 + 0.00005316 \times (VOL^*CONVOL))}}$$

$$\mathbf{Percentage\ of\ deviance\ explained\ by\ model = 64.7485}$$

## *4.8 Summary*

This chapter summarizes the step by step procedure in the development of a model. It is not practically possible to consider all explanatory variables in the model development. Only volume, conflicting volume, either their product or ratio between them, presence of a signal, and presence of a separate turn lane are assumed to have a significant impact on queue. Scatter diagrams of these identified variables show the random phenomenon which triggers the development of Poisson regression models. Model development steps are presented in a detailed manner for each lane configuration except for minor right turn configuration (MNR), due to presence of only 18 data points. Accuracy of these models is validated through data validation presented in the next chapter.

# 5 Model Validation

Validation gives the estimation of the model accuracy in predicting the maximum number of vehicles in the stopped queue. Validation can be done by using the subset of data prepared for model development process but not used for model building. If there is a possibility to collect separate data under similar conditions where the model is developed, those data will be preferred.

This chapter explains the data collection efforts for model validation. Collected raw data need to be processed to be used in model. For each model category, observed queue lengths are compared with predicted queues to check the consistency. Later, this step is extended to compare other methods with the existing methodology.

## *5.1 Data Collection*

Intersections are chosen to cover good proportions of various lane configurations, geographic regions, functional classifications, and traffic conditions. In total, 25 intersections shown in Table C1 in the Appendix C are used for data collection.

Out of 25 intersections: 17 of them are from Region 1, and 8 are from Region 2. 12 (48%) are within the urban growth boundary, and the remaining 13 (52%) are rural. 24 intersections have either OR or US route as the major approach. Ten of the intersections have an upstream signal within 1000 ft. Thirteen intersections have either an exclusive or two-way left turn lane. Only 7 of the intersections have skewed approaches. None of the intersection approaches are off-set from the major approach. 17 intersections are 3 legged (68%), and 8 of them are 4 legged intersections. Finally, two intersections major approaches have flaredness.

Table C2 represents the time frame of the data collection. All the data were collected in 2010, on typical weekdays of either last week of August or the first week of September, but before the Labor Day Weekend.

## 5.2 *MJL*

There are 41 data points available for validation. Although there are many indicators of the strength of the model in predicting the intended behavior, residual analysis is primarily to document the accuracy. The difference between the observed and model predicted value is used to assess the model performance. The following Table 5-1 shows the difference between various models. 39% of observed values are exactly predicted by the new model. Gard's equation and the Two-Minute Rule are behind the new model with 22% and 20% matching. If the error is relaxed to either +1 or -1 vehicles, 79% are matched by the new model and nearly the same percentage of match by Gard's and Two-Minute Rule. HCM consistently yields lower estimates. None of the model outputs underestimate queue length by more than 3 vehicles.

**Table 5-1 Comparison of Queue Length Estimation Differences for MJL**

| Type of Estimation | Difference (against Observed) | **Observed - 2 min rule** | | **Observed - HCM method** | | **Observed - Gard's Equation** | | **Observed - Model** | |
|---|---|---|---|---|---|---|---|---|---|
| | | % Obs | Cum % of Obs | % Obs | Cum % of Obs | % Obs | Cum % of Obs | % Obs | Cum % of Obs |
| Over Estimated | < = -5 | 0% | 2% | 0% | 0% | 0% | 12% | 5% | 17% |
| | -4 | 0% | | 0% | | 0% | | 0% | |
| | -3 | 0% | | 0% | | 7% | | 2% | |
| | -2 | 2% | | 0% | | 5% | | 10% | |
| Acceptable | -1 | 20% | **61%** | 0% | **29%** | 20% | **56%** | 20% | **78%** |
| | 0 | **20%** | | **0%** | | **22%** | | **39%** | |
| | 1 | 22% | | 29% | | 15% | | 20% | |
| Under Estimated | 2 | 17% | 37% | 29% | 71% | 10% | 32% | 5% | 5% |
| | 3 | 12% | | 12% | | 15% | | 0% | |
| | 4 | 0% | | 17% | | 2% | | 0% | |
| | > = 5 | 7% | | 12% | | 5% | | 0% | |

## 5.3 *MNLTR*

Overall 15 observations are available for this category. 33% of predicted queue lengths are exactly matched with the observed values. Two-Minute rule matched 13% of the observations. The new model matches 60% with a variation of a single vehicle on both sides. For the same variation 53% are matches for the Two-Minute Rule. Gard's equation is overestimating the queues, while the HCM is under predicting. The variation of the error is shown through both Table 5-2.

**Table 5-2 Comparison of Queue Length Estimation Differences for MNLTR**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | | Observed - Model | |
|---|---|---|---|---|---|---|---|---|---|
| | | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs |
| Over Estimated | < = -5 | 0% | 0% | 0% | 0% | 60% | 73% | 0% | 20% |
| | -4 | 0% | | 0% | | 0% | | 0% | |
| | -3 | 0% | | 0% | | 7% | | 7% | |
| | -2 | 0% | | 0% | | 7% | | 13% | |
| Acceptable | -1 | 7% | 53% | 7% | 7% | 13% | 20% | 0% | 60% |
| | 0 | 13% | | 0% | | 0% | | 33% | |
| | 1 | 33% | | 0% | | 7% | | 27% | |
| Under Estimated | 2 | 13% | 47% | 27% | 93% | 7% | 7% | 13% | 20% |
| | 3 | 33% | | 47% | | 0% | | 7% | |
| | 4 | 0% | | 13% | | 0% | | 0% | |
| | > = 5 | 0% | | 7% | | 0% | | 0% | |

## 5.4 *MNLR*

Only 25% of predicted queue lengths are exactly matched with the observed queues, while 42% are matched by the Two-Minute Rule. With a variation of 1 vehicle, almost 92% are matched by Two-Minute Rule. For the same situation, 67% are matched by the developed model. The HCM method is matching 58% of the time and 33% are matched by Gard's equation. The results are shown inTable 5-3. The predicted model seems to be underestimating. One reason may be only 12 data points are available for data validation purpose. As the sample size increases, there is a good chance of model convergence with the observed values.

**Table 5-3 Comparison of Queue Length Estimation Differences for MNLR**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | | Observed - Model | |
|---|---|---|---|---|---|---|---|---|---|
| | | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs |
| Over Estimated | < = -5 | 0% | 0% | 8% | 8% | 50% | 58% | 0% | 0% |
| | -4 | 0% | | 0% | | 0% | | 0% | |
| | -3 | 0% | | 0% | | 0% | | 0% | |
| | -2 | 0% | | 0% | | 8% | | 0% | |
| Acceptable | -1 | 0% | 92% | 8% | 58% | 17% | 33% | 25% | 67% |
| | 0 | 42% | | 8% | | 8% | | 25% | |
| | 1 | 50% | | 42% | | 8% | | 17% | |
| Under Estimated | 2 | 8% | 8% | 25% | 33% | 8% | 8% | 25% | 33% |
| | 3 | 0% | | 0% | | 0% | | 0% | |
| | 4 | 0% | | 0% | | 0% | | 8% | |
| | > = 5 | 0% | | 8% | | 0% | | 0% | |

## 5.5 *MNL*

Only 10 observations are available for the MNL lane configuration. 50% are exactly matched for the developed model with 90% for one vehicle variation. 70% are matched by Two-Minute Rule, and 60% by Gard's Equation. The HCM methodology underestimates the queue lengths. Error distribution is shown in Table 5-4.

**Table 5-4 Comparison of Queue Length Estimation Differences for MNR**

| Type of Estimation | Difference (against Observed) | Observed - 2 min rule | | Observed - HCM method | | Observed - Gard's Equation | | Observed - Model | |
|---|---|---|---|---|---|---|---|---|---|
| | | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs | % of Obs | Cum % of Obs |
| Over Estimated | < = -5 | 0% | 0% | 0% | 0% | 0% | 40% | 0% | 10% |
| | -4 | 0% | | 0% | | 0% | | 0% | |
| | -3 | 0% | | 0% | | 40% | | 0% | |
| | -2 | 0% | | 0% | | 0% | | 10% | |
| Acceptable | -1 | 0% | 70% | 0% | 0% | 20% | 60% | 40% | 90% |
| | 0 | 10% | | 0% | | 20% | | 50% | |
| | 1 | 60% | | 0% | | 20% | | 0% | |
| Under Estimated | 2 | 20% | 30% | 30% | 100% | 0% | 0% | 0% | 0% |
| | 3 | 10% | | 50% | | 0% | | 0% | |
| | 4 | 0% | | 20% | | 0% | | 0% | |
| | > = 5 | 0% | | 0% | | 0% | | 0% | |

## 5.6 *Summary*

The developed models are predicting consistently closer values. Although error varies from one lane group model to other, the percent of matching varies from 60% to 90% with error of ±1 vehicle. Importantly, the data set available for most of the lane groups is not sufficient for analysis. As more data is made available, the predictions should be closer.

# 6 Model Sensitivity Analysis

The sensitivity of the model with respect to changes in the independent or explanatory variables gives an idea how well models will perform for varying conditions. As such, one can check the model reasonableness by the sign of the change of dependent variable for the corresponding change in the explanatory variables. The magnitude of the change will also be obtained. In addition, one can check the limit(s) or range(s) of the independent variables where the model will adequately explain the queue behavior.

This chapter presents the explanations for sensitivity of the models developed in Chapter 4. For each model, limits are set for the independent variables based on the outcome of the model queue lengths which indicate the model stability.

## *6.1 MJL*

Volume (VOL), conflicting volume (CONVOL), presence of upstream signal within 1000 feet of the intersection (SIGNAL), and presence of left turn lane (LT) are considered for modeling queue lengths for major left turns. The developed model is shown below:

$$\mathbf{Ln(QL) = 0.3925 + 0.0059 \times VOL + 0.00104 \times CONVOL + 0.49 * SIGNAL - 0.81 * LT}$$

$$QL = e^{\left(\mathbf{0.3925 + 0.0059 \times VOL + 0.00104 \times CONVOL + 0.49 * SIGNAL - 0.81 * LT}\right)}$$

**Percentage of deviance explained by model = 66.959**

As VOL and CONVOL increases, QL increases. Presence of an upstream signal increases QL due to vehicle arrivals in platoon. If there is a separate left turn lane, either exclusive or two-way left turn lane, it decreases queue length compared to a shared left turn lane. The bounds for VOL and CONVOL are set by drawing a 2-D contour map of the QL.

As shown in Figure 6-1, as the VOL and CONVOL pair reaches MUTCD 2009 edition warranted volumes given in Table A1, for condition A (Minimum vehicular volume for 2 or more lanes on major street and 2 or more lanes on minor street), a maximum of fifteen vehicles are predicted to be in the stopped queue. For condition B (interruption of continuous traffic condition for the same lane configuration), eleven vehicles at maximum are in the stopped queue condition.

Volumes exceeding these points trigger a substantial increase in queue lengths. As such, unacceptable queue lengths are obtained for volumes greater than 300 VPH and corresponding conflicting volumes of 2000 VPH. Beyond these points the model is unstable for queue length prediction. Caution - the outcomes shown in Figure 6-1 are obtained by assuming an upstream signal and shared left turn lane, which will test the worst possible scenario.

## 6.2 *MNLTR*

QL on a single shared left, through, and right turn movement on minor approach is affected by volume, conflicting volume, and their product.

$$\mathbf{Ln(QL) = -0.7844 + 0.01636 \times VOL + 0.0006 \times CONVOL - 0.0000043 \times (VOL * CONVOL)}$$

$$QL = e^{(-0.7844+0.01636\times VOL+0.0006\times CONVOL-0.0000043\times(VOL*CONVOL))}$$

**Percentage of Deviation Explained by Model = 71.643**

Signs of the independent variables show reasonableness in the models, as a positive change in the VOL and CONVOL increases QL. But the occurrence of VOL and the corresponding CONVOL as a product triggers a decrease in QL, due to the fact that a lower approach volume may not yield larger queue lengths, rather triggers more waiting time in the stopped queue.

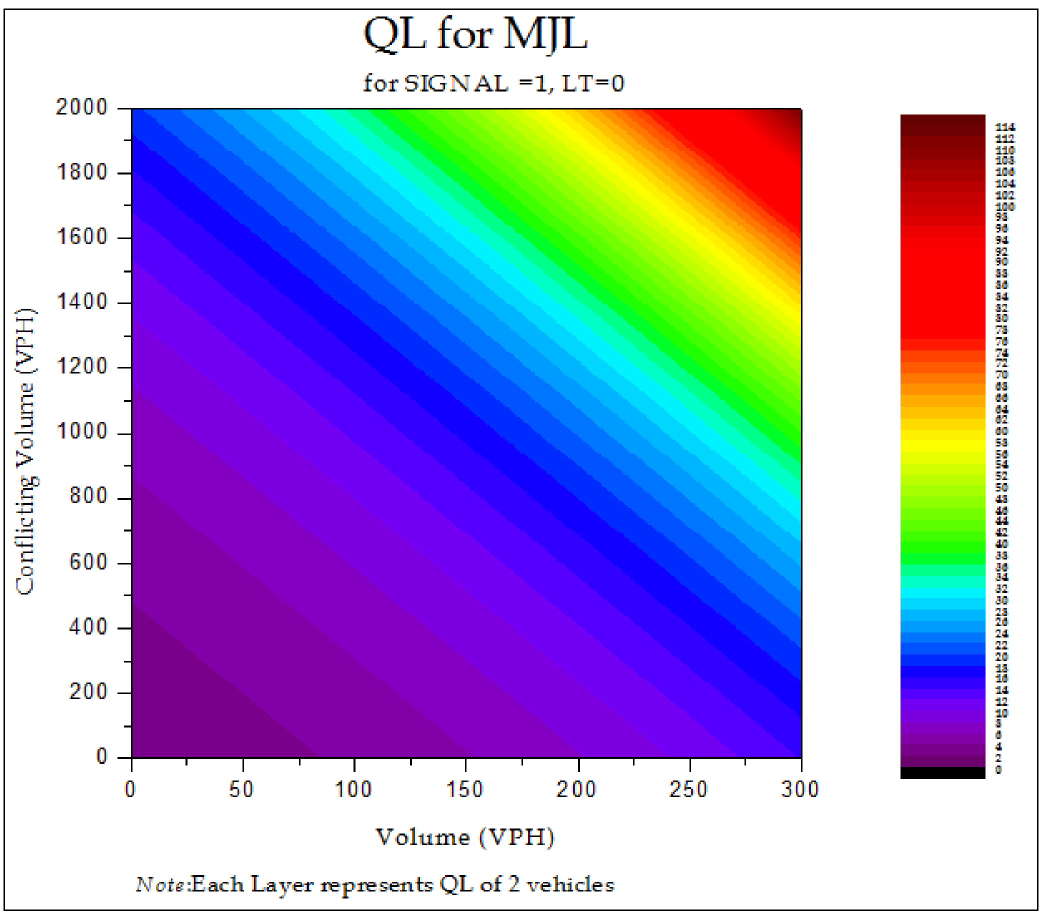



**Figure 6-1 Plot of QL for VOL and CONVOL at Major Left Turn (MJL)**

As approach volume increase to capacity, approach volume has a higher impact on queue than the conflicting volume. This behavior can be seen in Figure 6-2. As Highway Capacity Manual (HCM) limits the maximum 95th percentile queue lengths to be 100, the limits for VOL and CONVOL are set such that predicted queue length is not exceeding 100 vehicles. This is not a bad idea because, if the volume on the subject approach and the corresponding volume on major street reach the MUTCD Chapter 4C, section 4C.02 thresholds, it will warrant the installation of a signal.

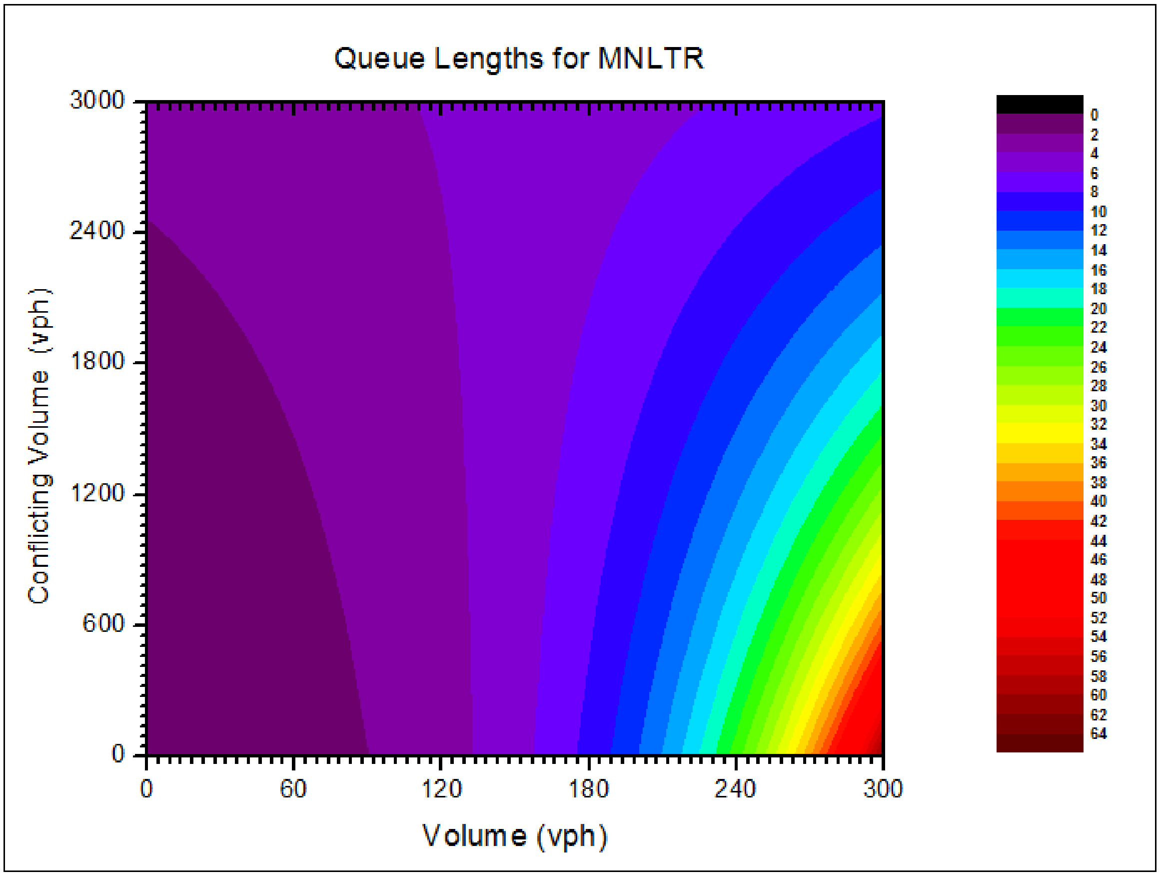



**Figure 6-2 Plot of QL for VOL and CONVOL at Minor LTR (MNLTR)**

## *6.3 MNLR*

QL on a single shared left, through, and right turn movement on minor approach is affected by volume, conflicting volume, and their product.

$$\mathbf{Ln(QL) = -0.6319 + 0.0173 \times VOL + 0.00066 \times CONVOL - 0.000007913\,(VOL * CONVOL)}$$

$$QL = e^{(-0.6319 + 0.0173 \times VOL + 0.00066 \times CONVOL - 0.000007913\,(VOL * CONVOL))}$$

**Percentage of deviance explained by model = 69.25**

Signs of the independent variables show reasonableness in the models, as a positive change in the VOL and CONVOL increases QL. But the occurrence of VOL and the corresponding CONVOL as a product triggers a decrease in QL, due to the fact that lower approach volume may not yield larger queue lengths, rather triggers more waiting time in the stopped queue. As approach volume increase to capacity, approach volume has higher impact on queue than the conflicting volume. This behavior can be seen in Figure 6-3. As Highway Capacity Manual (HCM) limits the maximum 95$^{th}$ percentile queue lengths to be 100, the limits for VOL and CONVOL are set such that predicted queue length is not exceeding 100 vehicles. This is not a bad idea because, if the volume on the subject approach and the corresponding volume on major street reach the MUTCD Chapter 4C, section 4C.02 thresholds, it will warrant the installation of a signal.

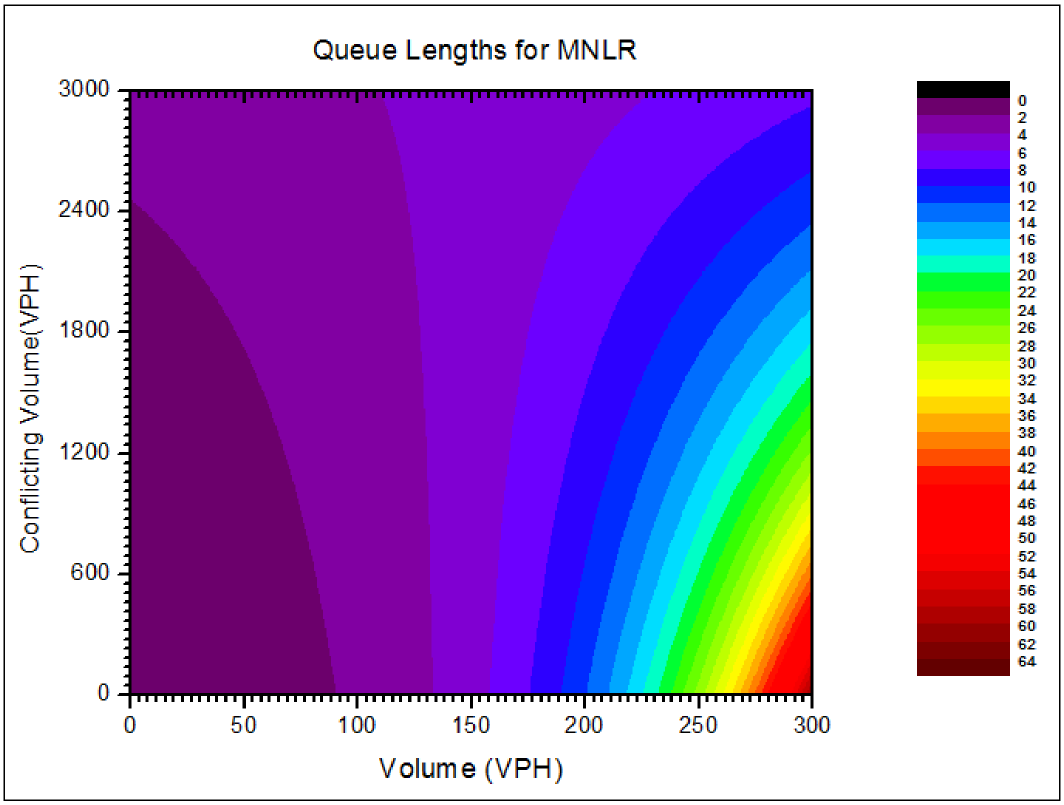



**Figure 6-3 Plot of QL for VOL and CONVOL at Minor LR (MNLR)**

## *6.4 MNL*

Poisson Regression developed is shown below:

$$\mathbf{Ln(QL) = 1.7934 - 0.025 \times} (CONVOL / VOL)$$

$$QL = e^{(1.7934 - 0.025 \times (CONVOL/VOL))}$$

**Percentage of deviance explained by model = 69.404**

As the volume and conflicting volume increases, QL increases as shown in Figure 6-4. Beyond the volume of 300 VPH and conflicting volume of 3000 VPH, queue lengths are not realistically represented by the model. These are used as the limits for the models. MNL model is developed using only 34 data points, which may limit the strength of the model. This is evident from MNL model form, which has 1.7934[13] as a constant. So, the output is greatly affected by a constant value rather than variation of explanatory variables. MNL model needs to be improved by collecting more data.

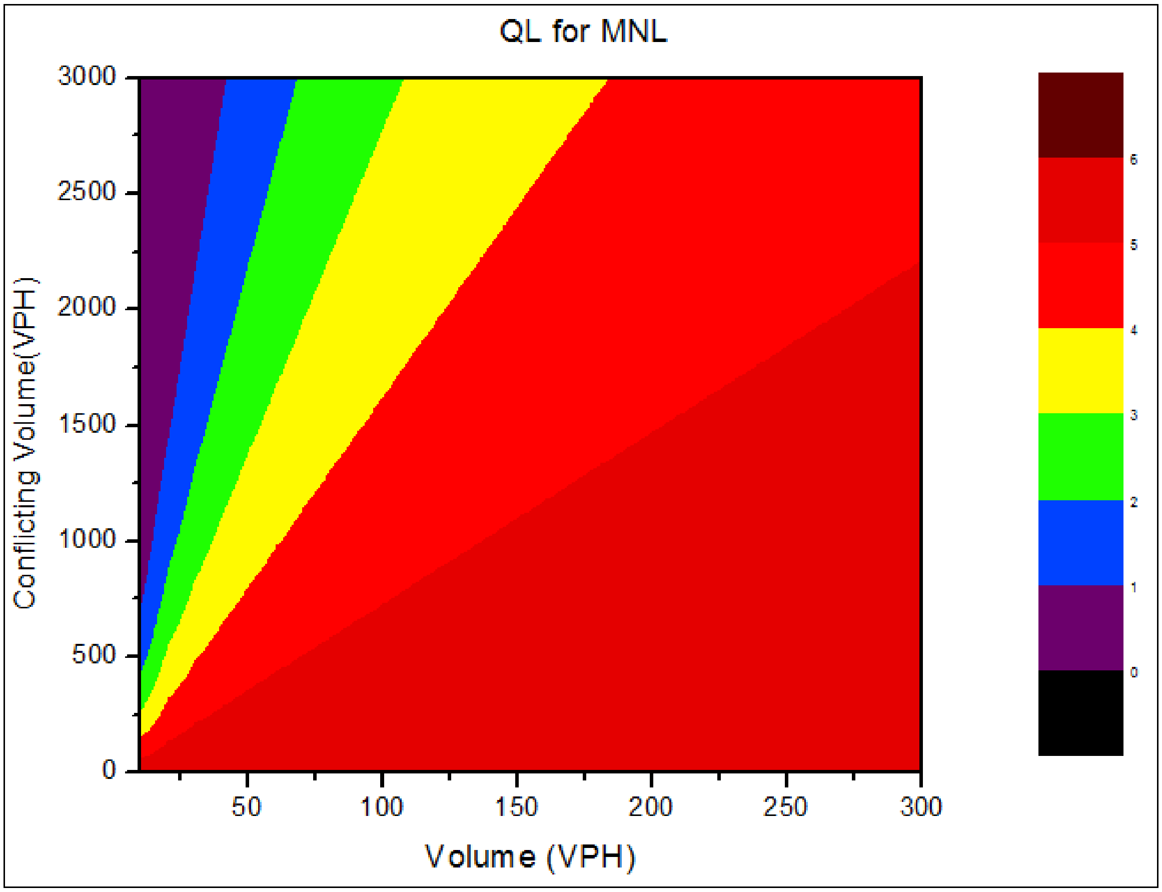



**Figure 6-4 Plot of QL for VOL and CONVOL at Minor Left (MNL)**

## *6.5 Summary*

Sensitivity Analysis is used to test the model for the all possible ranges of the input variables. During the model development only certain range for input variables are represented. Sensitivity analysis gives an opportunity, as explained in the above sections, to test the model behavior for most of the combinations of inputs. Following table summaries models for each lane groups with the limitation to the input variables.

---

[13] In the absence of VOL, and CONVOL , QL = $e^{1.7934} \equiv 6$ vehicles

# 7 Summary, Conclusions & Scope for Future Study

## 7.1 Summary

The following table summarizes the developed models, the applicable ranges for input data, and the percentage of deviation for each model:

VOL = Traffic flow rate on the subject approach in vehicles per hour

CONVOL = Conflicting traffic flow rate calculated according HCM methodology, expressed as vehicles per hour

SIGNAL = Presence of Upstream Signal with in 1000 ft of the intersection, Applicable for Major Left Turn only, 1 if there is a signal, otherwise 0

LT = Presence of a separate left turn lane, Applicable for Major Left Turn only (1 if there is an exclusive left turn lane/median left turn lane/ two-way left turn lane, otherwise 0)

| Lane Group | Model Equation & Ranges | Percent of Deviation |
|---|---|---|
| MJL | $QL = e^{(0.3925+0.0059\times VOL+0.00104\times CONVOL+0.49*SIGNAL-0.81*LT)}$<br>VOL = (0, 300] ; CONVOL = (0,2000]<br>SIGNAL = 0 or 1 ; LT = 0 or 1 | 66.96 |
| MNLTR | $QL = e^{(-0.7844+0.01636\times VOL+0.0006\times CONVOL-0.0000043\times(VOL*CONVOL))}$<br>VOL = (0, 300] ; CONVOL = (0,3000] | 71.64 |
| MNLR | $QL = e^{(-0.6319+0.0173\times VOL+0.00066\times CONVOL-0.000007913\times(VOL*CONVOL))}$<br>VOL = (0, 300] ; CONVOL = (0,3000] | 69.25 |

## 7.2 Conclusions

Following conclusions are made from this study:

- The Two-Minute Rule performs better than other existing methods except for the Major Left Turn (MJL) configuration where Gard's Equation does better for the reason that the Two-Minute Rule does not include opposing volume.
- Existing methods are not exactly predicting queue lengths for more than 50 percent of the cases.
- A Poisson regression model is developed to improve the queue length estimations.
- The developed models accurately predict more than 65 percent of the cases.

- Improvements to the model predictions may achieved by expanding the data sample size.
- As presented these models are a proto type, one may not adopt this model until they are validated for a wide range of conditions.

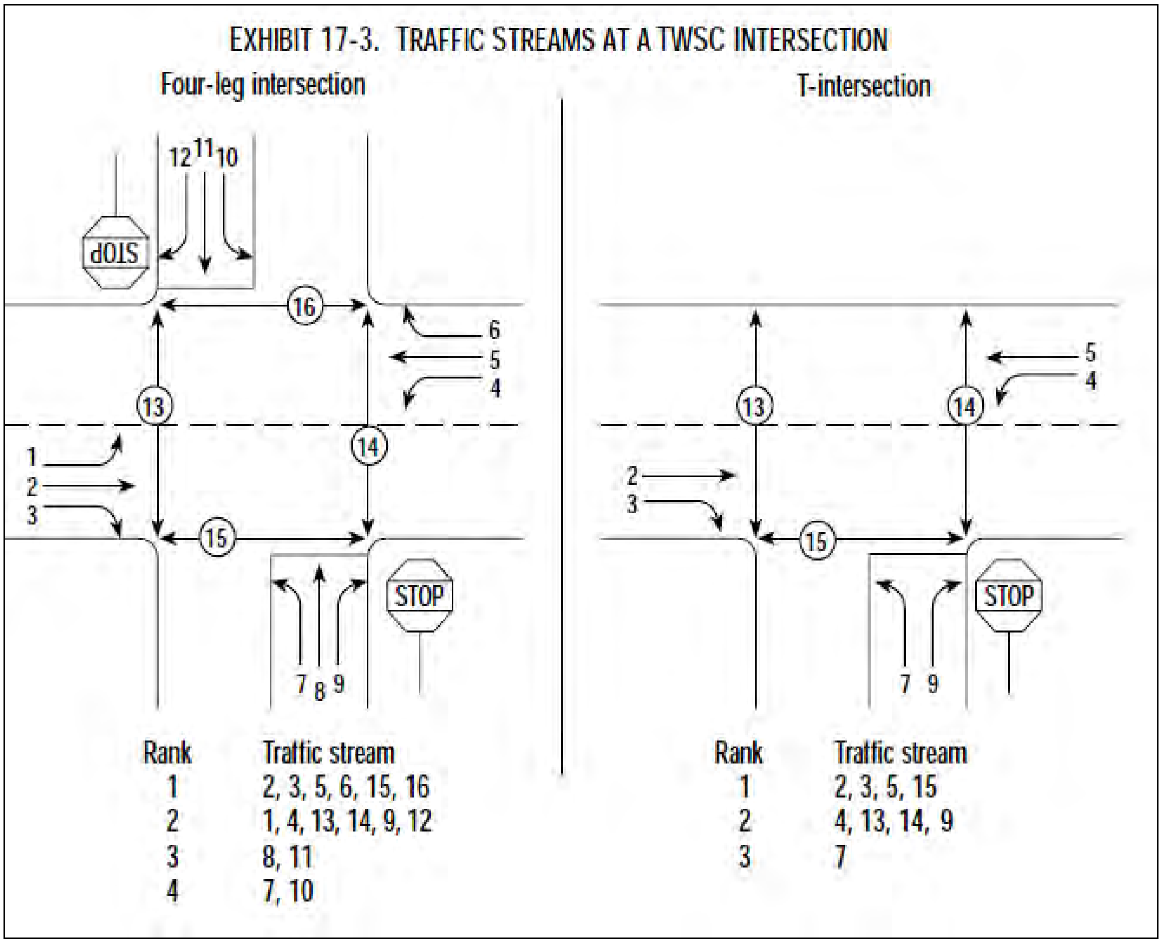
## *7.3 Future Study Scope*

It is a well known fact that model development is an iterative process, as such there is always room for improvement.

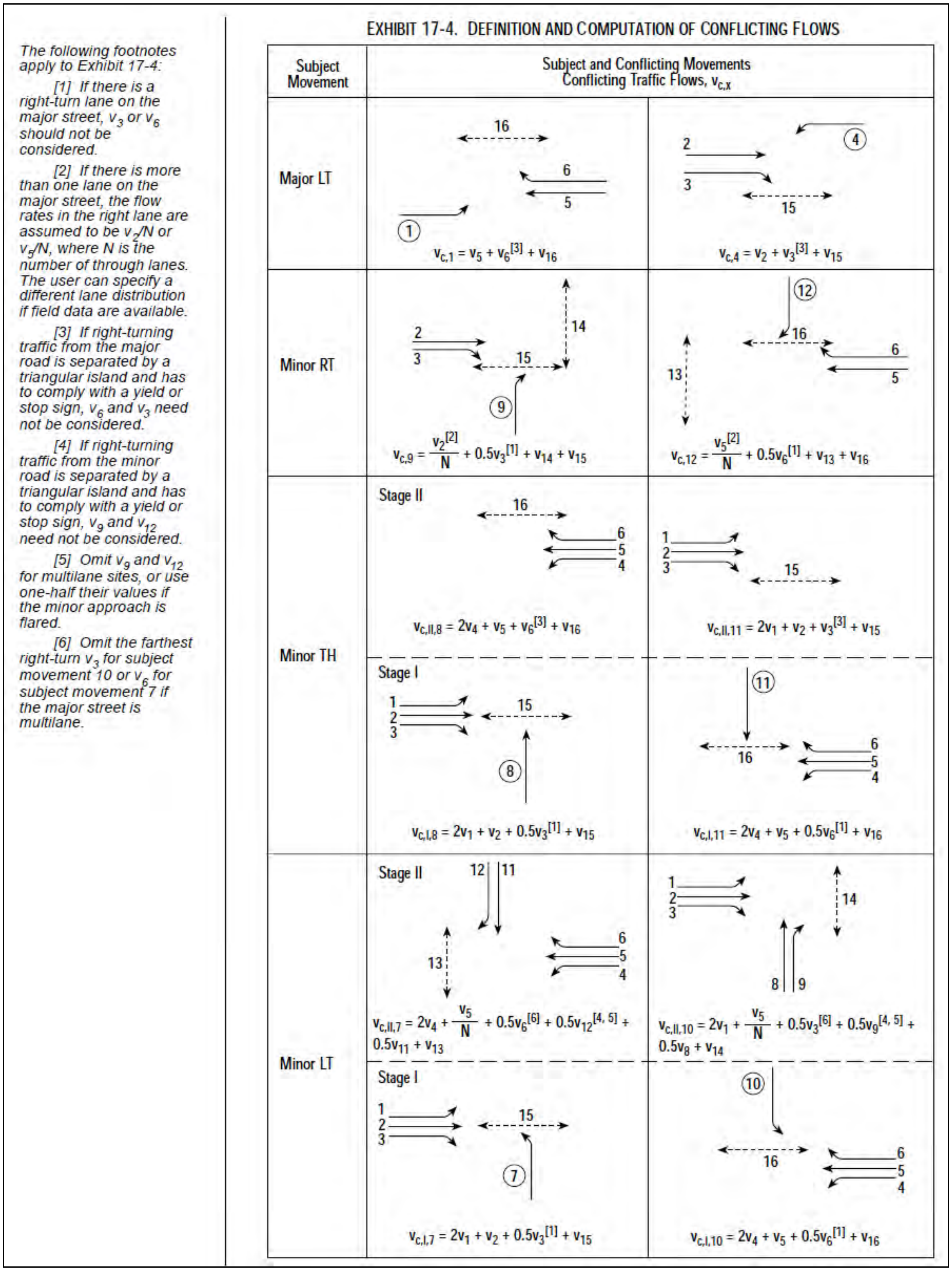
- The current study may be elaborated with expanded data sets. Special attention need to be given to collect MNL lane configuration data to refine the model performance.
- A good proportion of data groups are adopted for study, but expansion to different geographic regions, highway networks, traffic loads as time of day and seasonal variations, multi-year data sets is possible
- The model form may be scoped to suit various traffic and queue conditions
- The methods of model development may be varied to capture dynamics of queues
- Even explanatory variables and their combination may be studied

# Appendix A – HCM & MUTCD Exhibits

**Figure A1 Traffic Streams at a Two-Way STOP Controlled Intersection**
**(*Source: HCM, Exhibit 17-3*)**



## Figure A2 Method for Computing Lane Group Conflicting Flow Rates (*Source: HCM, Exhibit 17-4*)



*The following footnotes apply to Exhibit 17-4:*

*[1] If there is a right-turn lane on the major street, $v_3$ or $v_6$ should not be considered.*

*[2] If there is more than one lane on the major street, the flow rates in the right lane are assumed to be $v_2/N$ or $v_5/N$, where N is the number of through lanes. The user can specify a different lane distribution if field data are available.*

*[3] If right-turning traffic from the major road is separated by a triangular island and has to comply with a yield or stop sign, $v_6$ and $v_3$ need not be considered.*

*[4] If right-turning traffic from the minor road is separated by a triangular island and has to comply with a yield or stop sign, $v_9$ and $v_{12}$ need not be considered.*

*[5] Omit $v_9$ and $v_{12}$ for multilane sites, or use one-half their values if the minor approach is flared.*

*[6] Omit the farthest right-turn $v_3$ for subject movement 10 or $v_6$ for subject movement 7 if the major street is multilane.*

EXHIBIT 17-4. DEFINITION AND COMPUTATION OF CONFLICTING FLOWS

| Subject Movement | Subject and Conflicting Movements Conflicting Traffic Flows, $v_{c,x}$ | |
|---|---|---|
| Major LT | $v_{c,1} = v_5 + v_6^{[3]} + v_{16}$ | $v_{c,4} = v_2 + v_3^{[3]} + v_{15}$ |
| Minor RT | $v_{c,9} = \frac{v_2^{[2]}}{N} + 0.5v_3^{[1]} + v_{14} + v_{15}$ | $v_{c,12} = \frac{v_5^{[2]}}{N} + 0.5v_6^{[1]} + v_{13} + v_{16}$ |
| Minor TH | Stage II: $v_{c,II,8} = 2v_4 + v_5 + v_6^{[3]} + v_{16}$ | $v_{c,II,11} = 2v_1 + v_2 + v_3^{[3]} + v_{15}$ |
| | Stage I: $v_{c,I,8} = 2v_1 + v_2 + 0.5v_3^{[1]} + v_{15}$ | $v_{c,I,11} = 2v_4 + v_5 + 0.5v_6^{[1]} + v_{16}$ |
| Minor LT | Stage II: $v_{c,II,7} = 2v_4 + \frac{v_5}{N} + 0.5v_6^{[6]} + 0.5v_{12}^{[4, 5]} + 0.5v_{11} + v_{13}$ | $v_{c,II,10} = 2v_1 + \frac{v_5}{N} + 0.5v_3^{[6]} + 0.5v_9^{[4, 5]} + 0.5v_8 + v_{14}$ |
| | Stage I: $v_{c,I,7} = 2v_1 + v_2 + 0.5v_3^{[1]} + v_{15}$ | $v_{c,I,10} = 2v_4 + v_5 + 0.5v_6^{[1]} + v_{16}$ |

## Figure A3 Lane Groups (*Source: HCM, Exhibit 16-5*)

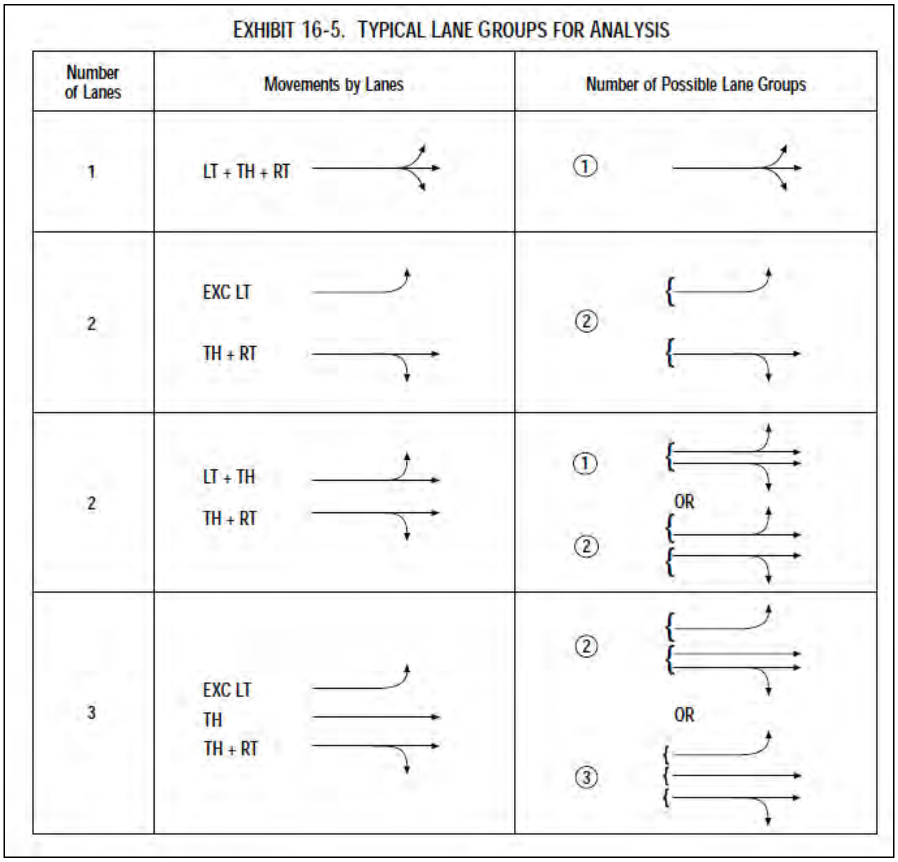


EXHIBIT 16-5. TYPICAL LANE GROUPS FOR ANALYSIS

| Number of Lanes | Movements by Lanes | Number of Possible Lane Groups |
|---|---|---|
| 1 | LT + TH + RT | ① |
| 2 | EXC LT<br>TH + RT | ② |
| 2 | LT + TH<br>TH + RT | ①<br>OR<br>② |
| 3 | EXC LT<br>TH<br>TH + RT | ②<br>OR<br>③ |

**Table A1 MUTCD Warrant 1 Table (Source*: 2009 MUTCD, section 4C.02*)**

## Table 4C-1. Warrant 1, Eight-Hour Vehicular Volume

### Condition A—Minimum Vehicular Volume

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | | Vehicles per hour on higher-volume minor-street approach (one direction only) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 56%[d] | 100%[a] | 80%[b] | 70%[c] | 56%[d] |
| 1 | 1 | 500 | 400 | 350 | 280 | 150 | 120 | 105 | 84 |
| 2 or more | 1 | 600 | 480 | 420 | 336 | 150 | 120 | 105 | 84 |
| 2 or more | 2 or more | 600 | 480 | 420 | 336 | 200 | 160 | 140 | 112 |
| 1 | 2 or more | 500 | 400 | 350 | 280 | 200 | 160 | 140 | 112 |

### Condition B—Interruption of Continuous Traffic

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | | Vehicles per hour on higher-volume minor-street approach (one direction only) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 56%[d] | 100%[a] | 80%[b] | 70%[c] | 56%[d] |
| 1 | 1 | 750 | 600 | 525 | 420 | 75 | 60 | 53 | 42 |
| 2 or more | 1 | 900 | 720 | 630 | 504 | 75 | 60 | 53 | 42 |
| 2 or more | 2 or more | 900 | 720 | 630 | 504 | 100 | 80 | 70 | 56 |
| 1 | 2 or more | 750 | 600 | 525 | 420 | 100 | 80 | 70 | 56 |

[a] Basic minimum hourly volume

[b] Used for combination of Conditions A and B after adequate trial of other remedial measures

[c] May be used when the major-street speed exceeds 40 mph or in an isolated community with a population of less than 10,000

[d] May be used for combination of Conditions A and B after adequate trial of other remedial measures when the major-street speed exceeds 40 mph or in an isolated community with a population of less than 10,000

# Appendix B – Data Collection Sites for Model Development

## Table B1 Description of Study Intersection Used for Model Development

| Sl. No | Name | City | Region | Geographic Area(R/U) | No of Legs (3/4) | Presence of Skewness/ Presence of curve at the intersection | Presence of Offset on Minor Approaches | No of Lanes on Major Street (2/3/4/5) | Functional Classification of the Major ST | Functional Classification of the Minor ST | Major Approach: Approach Speed | Major Approach: Presence of Upstream Signal | Major Approach: Presence of TWLT Lane/ Median Left Turn Lane | Major Approach: Presence of Right Turn Lane | Major Approach: Presence of Flared Right Turn Lane |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Nevada ST and Oak ST | Ashland | 3 | U | 4 | 0 | 0 | 2 | C | L | 25 | 0 | 0 | 0 | 0 |
| 2 | Tolman Creek Rd. and Mistletoe Rd + Takelma Wy | Ashland | 3 | U | 4 | 1 | 0 | 2 | C | L | 25 | 0 | 0 | 0 | 0 |
| 3 | OR 99 E and NE Carl Rd | Woodburn | 2 | U | 3 | 1 | 0 | 5 | OR | C | 45 | 0 | 1 | 0 | 0 |
| 4 | US 101 and 20th ST | Reedsport | 3 | U | 4 | 0 | 0 | 4 | US | C | 30 | 0 | 0 | 0 | 0 |
| 5 | US 730 and Umatilla River Rd | Umatilla | 5 | U | 3 | 0 | 0 | 3 | US | C | 25 | 0 | 1 | 0 | 0 |
| 6 | OR 99 E and E Cleveland ST | Woodburn | 2 | U | 4 | 1 | 1 | 4 | OR | C | 35 | 0 | 0 | 0 | 0 |
| 7 | OR 214 / OR 211 and Lawson Avenue | Woodburn | 2 | U | 3 | 0 | 0 | 3 | OR | C | 30 | 1 | 1 | 0 | 0 |
| 8 | OR 99 E with Industrial Ave and Mc Laren School Rd NE | Woodburn | 2 | R | 4 | 1 | 0 | 5 | OR | L | 45 | 1 | 1 | 0 | 1 |
| 9 | US 97 vs Lakeport Blvd | Klamath Falls | 4 | R | 3 | 1 | 0 | 3 | US | L | 50 | 0 | 1 | 0 | 0 |
| 10 | OR 99 E and Food Services Road | Woodburn | 2 | R | 3 | 1 | 0 | 2 | OR | L | 45 | 0 | 0 | 0 | 0 |
| 11 | US 20 and 17th ST | Philomath | 2 | U | 4 | 0 | 0 | 4 | US/OR | C | 30 | 1 | 0 | 0 | 0 |
| 12 | OR 20 and Dead Indian Memorial Road | Ashland | 3 | R | 3 | 1 | 0 | 2 | OR | C | 35 | 0 | 0 | 0 | 1 |
| 13 | US 395 and Power City Rd | Umatilla | 5 | R | 4 | 1 | 1 | 5 | US/OR | C | 50 | 0 | 1 | 0 | 1 |
| 14 | OR 99 and (W Hersey Road & Wimer ST) | Ashland | 3 | U | 4 | 1 | 1 | 4 | OR | C | 25 | 0 | 0 | 0 | 0 |
| 15 | US 20 (OR 34) and ( S 7th ST & N 7th ST) | Philomath | 2 | U | 3 | 0 | 0 | 2 | US | C | 35 | 0 | 0 | 0 | 0 |

*Note: U=Urban, R=Rural, OR= Oregon Route, US = US Route, C= Collector, L=Local, C/L = Collector/Local, N/A = Not available, 0/1 = Flag showing Yes/No*

## Table B2 Periods of Data Collection Used for Model Development

| Sl. No | Name | City | Region | Data Collection Date | Data Collection Day | Data Collection Time | Data Collection Duration (Hrs) |
|---|---|---|---|---|---|---|---|
| 1 | Nevada ST and Oak ST | Ashland | 3 | 9/14/2009 | Monday | 3 - 6 PM | 3 |
| 2 | Tolman Creek Rd. and Mistletoe Rd + Takelma Wy | Ashland | 3 | 9/16/2009 | Wednesday | 4 - 6 PM; 7-8 AM | 3 |
| 3 | OR 99 E and NE Carl Rd | Woodburn | 2 | 2/23/2010 | Tuesday | 3 - 6 PM ; 6-9 AM | 6 |
| 4 | US 101 and 20th ST | Reedsport | 3 | 11/4/2009 | Wednesday | 3 - 6 PM ; 7:30-9 AM | 4.5 |
| 5 | US 730 and Umatilla River Rd | Umatilla | 5 | 1/13/2010 | Wednesday | 3 - 6 PM ; 7:30-9 AM | 4.5 |
| 6 | OR 99 E and E Cleveland ST | Woodburn | 2 | 2/23/2010 | Tuesday | 3 - 6 PM ; 6-9 AM | 6 |
| 7 | OR 214 / OR 211 and Lawson Avenue | Woodburn | 2 | 3/1/2010 | Monday | 3 - 6 PM ; 6-9 AM | 6 |
| 8 | OR 99 E with Industrial Ave and Mc Laren School Rd NE | Woodburn | 2 | 2/22/2010 | Monday | 3 - 6 PM ; 6-9 AM | 6 |
| 9 | US 97 vs Lakeport Blvd | Klamath Falls | 4 | 4/7/2010 | Wednesday | 3 - 6 PM | 3 |
| 10 | OR 99 E and Food Services Road | Woodburn | 2 | 2/22/2010 | Monday | 3 - 6 PM ; 6-9 AM | 6 |
| 11 | US 20 and 17th ST | Philomath | 2 | 3/9/2010 | Tuesday | 3 - 6 PM ; 6-9 AM | 6 |
| 12 | OR 20 and Dead Indian Memorial Road | Ashland | 3 | 9/15/2009 | Tuesday | 3 - 6 PM | 3 |
| 13 | US 395 and Power City Rd | Umatilla | 5 | 1/19/2010 | Tuesday | 3 - 6 PM ; 6-9 AM | 6 |
| 14 | OR 99 and (W Hersey Road & Wimer ST) | Ashland | 3 | 9/14/2009 | Monday | 2 - 6 PM | 4 |
| 15 | US 20 (OR 34) and ( S 7th ST & N 7th ST) | Philomath | 2 | 3/9/2009 | Tuesday | 3 - 6 PM ; 6-9 AM | 6 |

# Appendix C - Data Collection Sites for Model Validation

## Table C1 Description of Study Intersections Used for Data Validation

| Sl.No | Name | Region | No of Legs (3/4) | Presence of Skewness/ Presence of curve | Presence of Offset on Minor Approaches | Geographic Area(R/U/SU) | No of Lanes on Major Street (2/4/4/5) | Functional Classification of the Major ST | Functional Classification of the Minor ST | Major Approach: Approach Speed | Presence of Upstream Signal | Presence of TWLT / Exclusive Left | Presence of Right Turn Lane | Presence of Flared Right Turn Lane |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | US 30 and NE 185th Ave | 1 | 3 | 1 | 0 | U | 4 | US | C | 40 | 1 | 0 | 0 | 0 |
| 2 | NE 185th Ave and NE Portal Way | 1 | 4 | 1 | 0 | U | 4 | C | L | 40 | 0 | 1 | 0 | 1 |
| 3 | US 30 and NE 172ND PL | 1 | 3 | 0 | 0 | U | 4 | US | L | N/A | 0 | 0 | 0 | 0 |
| 4 | US 26 and SE 79th Ave | 1 | 4 | 0 | 0 | U | 5 | US | C/L | 35 | 1 | 1 | 0 | 0 |
| 5 | US 26 / SE 99th Ave | 1 | 3 | 0 | 0 | U | 2 | US | L | 35 | 1 | 0 | 0 | 0 |
| 6 | US 26 / SE 130th Ave | 1 | 3 | 0 | 0 | U | 2 | US | L | 35 | 1 | 0 | 0 | 0 |
| 7 | OR 99 E / SE HULL AVE | 1 | 4 | 0 | 0 | U | 5 | OR | C | 40 | 1 | 1 | 0 | 0 |
| 8 | OR 99 E / SE VINEYARD RD | 1 | 4 | 0 | 0 | U | 5 | OR | C | 40 | 1 | 1 | 0 | 0 |
| 9 | OR 99 E / SE HOLLY AVE | 1 | 3 | 0 | 0 | U | 5 | OR | L | 40 | 1 | 1 | 0 | 0 |
| 10 | OR 224 & OR 212 / SE 106th ST | 1 | 3 | 0 | 0 | U | 5 | OR | L | N/A | 1 | 1 | 0 | 0 |
| 11 | OR 224 & OR 212 / SE 114th AVE | 1 | 3 | 0 | 0 | U | 5 | OR | L | N/A | 0 | 1 | 0 | 0 |
| 12 | OR 224 & OR 212 / SE 122nd AVE | 1 | 3 | 0 | 0 | U | 5 | OR | C | 45 | 1 | 1 | 0 | 0 |
| 13 | OR 22 W / PERRYDALE RD | 2 | 3 | 1 | 0 | R | 2 | OR | L | N/A | 0 | 1 | 0 | 0 |
| 14 | OR 22 W / DOAKS FERRY RD | 2 | 3 | 1 | 0 | R | 5 | OR | C | N/A | 0 | 1 | 0 | 0 |
| 15 | OR 221 / DOAKS FERRY RD NW | 2 | 3 | 1 | 0 | R | 2 | OR | C | N/A | 1 | 1 | 0 | 0 |
| 16 | OR 221 / SE PALMER CREEK RD | 2 | 3 | 1 | 0 | R | 2 | OR | C | 50 | 0 | 0 | 0 | 0 |
| 17 | OR 219/ SE FARMINGTON RD | 1 | 3 | 0 | 0 | R | 3 | OR | OR | 55 | 0 | 0 | 1 | 0 |
| 18 | OR 219/ SE SCHOLLS FERRY RD(OR 210) | 1 | 3 | 1 | 0 | R | 2 | OR | OR | 45 | 0 | 0 | 0 | 1 |
| 19 | OR 219/ BELL RD / N VALLE RD | 2 | 4 | 0 | 0 | R | 2 | OR | C/L | N/A | 0 | 0 | 0 | 0 |
| 20 | OR 219/ SW UNGER RD | 1 | 3 | 0 | 0 | R | 3 | OR | C | 45 | 0 | 1 | 0 | 0 |
| 21 | OR 219/ Tongue Ln | 1 | 3 | 0 | 0 | R | 4 | OR | C | N/A | 0 | 1 | 0 | 0 |
| 22 | OR 211 / S Kropff Rd or Canby - Marquam Rd | 2 | 4 | 0 | 0 | R | 2 | OR | OR | N/A | 0 | 0 | 1 | 0 |
| 23 | OR 211 / S Meridian Rd | 2 | 4 | 0 | 0 | R | 2 | OR | C | 55 | 0 | 0 | 0 | 0 |
| 24 | OR 214 / Howell Prairie Rd | 2 | 3 | 0 | 0 | R | 2 | OR | C | 40 | 0 | 0 | 0 | 0 |
| 25 | OR 213 / S CARUS RD | 1 | 4 | 0 | 0 | R | 2 | OR | C | 20 | 0 | 0 | 0 | 0 |

*Note:*
*U=Urban, R=Rural, OR= Oregon Route, US = US Route, C= Collector, L=Local, C/L = Collector/Local,*
*N/A = Not available, 0/1 = Flag showing Yes/No*

## Table C2 Duration of Traffic Counts Used for Data Validation

| Sl.No | Name | Region | No of Legs (3/4) | Duration | Date | Day | Time of Day |
|---|---|---|---|---|---|---|---|
| 1 | US 30 and NE 185th Ave | 1 | 3 | 1 Hr | 8/24/2010 | Tuesday | 8:25 AM - 9:25 AM |
| 2 | NE 185th Ave and NE Portal Way | 1 | 4 | 1 Hr | 8/24/2010 | Tuesday | 9:40 AM - 10:41 AM |
| 3 | US 30 and NE 172ND PL | 1 | 3 | 1 Hr | 8/24/2010 | Tuesday | 11:07 AM - 12:07 AM |
| 4 | US 26 and SE 79th Ave | 1 | 4 | 1 Hr | 8/24/2010 | Tuesday | 1:22 PM - 2:22 PM |
| 5 | US 26 / SE 99th Ave | 1 | 3 | 1 Hr | 8/24/2010 | Tuesday | 2:40 PM - 3:40 PM |
| 6 | US 26 / SE 130th Ave | 1 | 3 | 1 Hr | 8/24/2010 | Tuesday | 4:05 PM - 5:05 PM |
| 7 | OR 99 E / SE HULL AVE | 1 | 4 | 1 Hr | 8/25/2010 | Wednesday | 8:20 AM - 9:20 AM |
| 8 | OR 99 E / SE VINEYARD RD | 1 | 4 | 1 Hr | 8/25/2010 | Wednesday | 9:49 AM - 10:49 AM |
| 9 | OR 99 E / SE HOLLY AVE | 1 | 3 | 1 Hr | 8/25/2010 | Wednesday | 11:01 AM - 12:01 AM |
| 10 | OR 224 & OR 212 / SE 106th ST | 1 | 3 | 1 Hr | 8/25/2010 | Wednesday | 1:18 PM - 2:18 PM |
| 11 | OR 224 & OR 212 / SE 114th AVE | 1 | 3 | 1 Hr | 8/25/2010 | Wednesday | 2:49 PM - 3:49 PM |
| 12 | OR 224 & OR 212 / SE 122nd AVE | 1 | 3 | 1 Hr | 8/25/2010 | Wednesday | 4:00 PM - 5:00 PM |
| 13 | OR 22 W / PERRYDALE RD | 2 | 3 | 1 Hr | 8/26/2010 | Thursday | 8:56 AM - 9:56 AM |
| 14 | OR 22 W / DOAKS FERRY RD | 2 | 3 | 1 Hr | 8/26/2010 | Thursday | 10:14 AM - 11:14 AM |
| 15 | OR 221 / DOAKS FERRY RD NW | 2 | 3 | 1 Hr | 8/26/2010 | Thursday | 12:11 PM - 1:26 PM |
| 16 | OR 221 / SE PALMER CREEK RD | 2 | 3 | 1 Hr | 8/26/2010 | Thursday | 1:40 PM - 2:40 PM |
| 17 | OR 219/ SE FARMINGTON RD | 1 | 3 | 2 Hr | 8/31/2010 | Tuesday | 7:45 AM - 9:45 AM |
| 18 | OR 219/ SE SCHOLLS FERRY RD (OR 210) | 1 | 3 | 1 Hr | 8/31/2010 | Tuesday | 10:21 AM - 11:21AM |
| 19 | OR 219/ BELL RD / N VALLE RD | 2 | 4 | 1 Hr | 8/31/2010 | Tuesday | 12:46 PM - 1:46 PM |
| 20 | OR 219/ SW UNGER RD | 1 | 3 | 1 Hr | 8/31/2010 | Tuesday | 2:44 PM - 3:44 PM |
| 21 | OR 219/ Tongue Ln | 1 | 3 | 2 Hr | 8/31/2010 | Tuesday | 4:00 PM - 6:00 PM |
| 22 | OR 211 / S Kropff Rd | 2 | 4 | 1 Hr | 9/1/2010 | Wednesday | 7:10 AM - 8:10 AM |
| 23 | OR 211 / S Meridian Rd | 2 | 4 | 1 Hr | 9/1/2010 | Wednesday | 8:27 AM - 9:27 AM |
| 24 | OR 214 / Howell Prairie Rd | 2 | 3 | 1 Hr | 9/1/2010 | Wednesday | 10:28 AM - 11:28 AM |
| 25 | OR 213 / S CARUS RD | 1 | 4 | 1 Hr | 9/1/2010 | Wednesday | 4:40PM - 5:40 PM |