# CAPACITY OF TWO-SIDED TYPE C WEAVES ON FREEWAYS WITH FOUR LANES

by

Shadi Ghasemi-Majd

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## ABSTRACT


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ON FREEWAYS WITH FOUR LANES

Shadi Ghasemi-Majd, M.S.

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Supervising Professor: Dr. James C. Williams

Weaving segments are categorized based on weaving length, configuration, number of lanes, free flow speed and weaving ratio. All these parameters affect weaving capacity.

One of the objectives of this research was to extend Phong Thanh Vo's dissertation and study the relation between weaving capacity of two-sided type C on freeways with four lanes and any potential variables (mainalane demand, entrance ramp demand, exit ramp demand and weaving ratio). Micro-simulation has been used in order to analyze different capacity scenarios and the VISSIM calibrated model by Vo was used. Also, the effect of each of the VISSIM calibration parameters on weaving capacity has been studied in this research.

In conclusion, the reader will find a few suggestions in better estimating capacities under VISSIM microscopic simulation software.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Freeway Weaving

As the population increases, the demand for new freeways or expansion of old ones to facilitate this increase becomes the focus of the transportation agencies. Since the construction of new freeways is not financially feasible in most cases, transportation agencies are in search of new, innovative ways to address this issue. One of their operational strategies is to implement the new managed-lanes concept to meet travel demand. Weaving sections between a standard, right-side freeway entrance ramp and a left-side managed lane entrance ramp have become a topic of interest to designers and can be considered to be two-sided type C weaving areas in the Highway Capacity Manual. Weaving areas are defined as “the crossing of two or more traffic streams traveling in the same general direction along a significant length of highway without the aid of traffic control devices’’ in the 2000 edition of the Highway Capacity Manual (HCM) [Ref. 1].

In type C weaves, weaving vehicles in one direction may complete a weaving maneuver without making a lane change, whereas other vehicles in the weaving segments must make two or more lane changes to successfully complete a weaving maneuver [Ref. 1].

The main focus of this research is on type C weaving areas, specifically two-sided weaves, shown in Figure 1.1. In this type, vehicles in the main weaving movement, freeway vehicles, do not necessarily need to change lanes, whereas those in the other movement, ramp to ramp, must change two or more lanes to accomplish the maneuver.

There are two movements along weaving segments, weaving and non-weaving: freeway to freeway (A to D) and ramp to ramp (B to C) flows are considered weaving flows, whereas freeway to ramp (A to C) and ramp to freeway (B to D) are non-weaving flows.

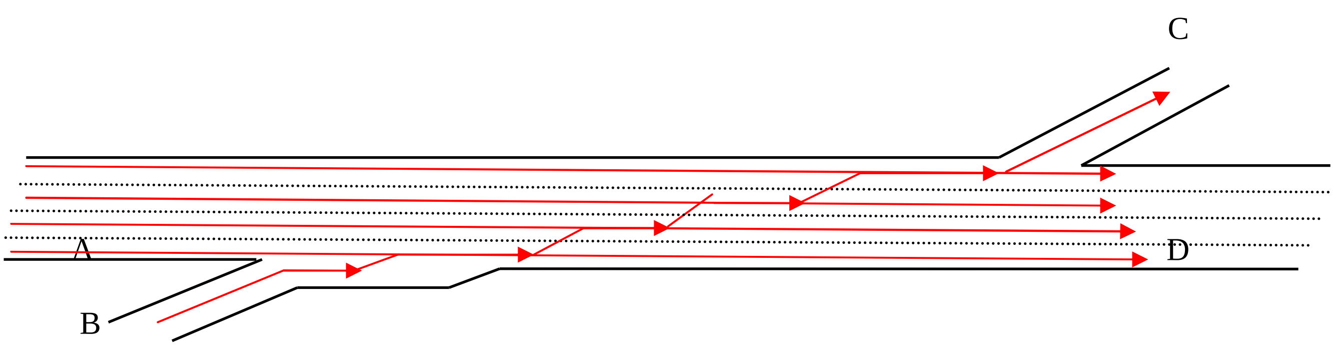



Figure 1.1 Two-sided type C weaving segments [Ref. 1]

## 1.2 Proposed Methodology

This research is fundamentally an extension of Phong Thanh Vo's [Ref. 3] research. Vo's calibrated VISSIM model has been used to analyze the capacity of two-sided type C weaves on freeways with four lanes. In traditional methods, traffic volumes and the network geometry are input into microscopic traffic simulation software, and the speeds from output files are compared with speeds from field data. The traditional methods, which use speed to estimate, weaving area capacity, have the following disadvantages.

1. Speed is not the only capacity indicator since average speed is quite insensitive to flow up to 1,600 passenger cars per hour per lane (pcphpl) [Ref. 4].
2. To compute weaving area capacity in this method, the HCM graphs and tables should be used. In other words, there is no direct equation to compute weaving area capacity.

Vo [Ref.3] considered density, which is the result of both speed and flow, as a congestion indicator in estimating the capacity of type C weaves on freeways with three lanes. Since simulation modeling is an effective approach for quantifying the benefits and limitations of different alternatives [Ref. 6], VISSIM 4.30 is chosen as the microscopic traffic simulation software to analyze traffic behavior in the weaving segments. The study area comprises southbound I-35/410 between the Rittiman entrance and southbound I-410 exit in San Antonio, Texas.

In this thesis, a literature review of Vo's dissertation is presented in Chapter 2, along with an overview of VISSIM and a description of the calibration and validation process of the VISSIM model. Chapter 3 discusses the applied methodology in analyzing the capacity of two-sided type C weaves on freeways with four lanes. Chapter 4 presents the conclusions and recommendations. A summary of simulation runs made in this research is provided in the appendices.

# CHAPTER 2

# LITERATURE REVIEW AND CALIBRATION

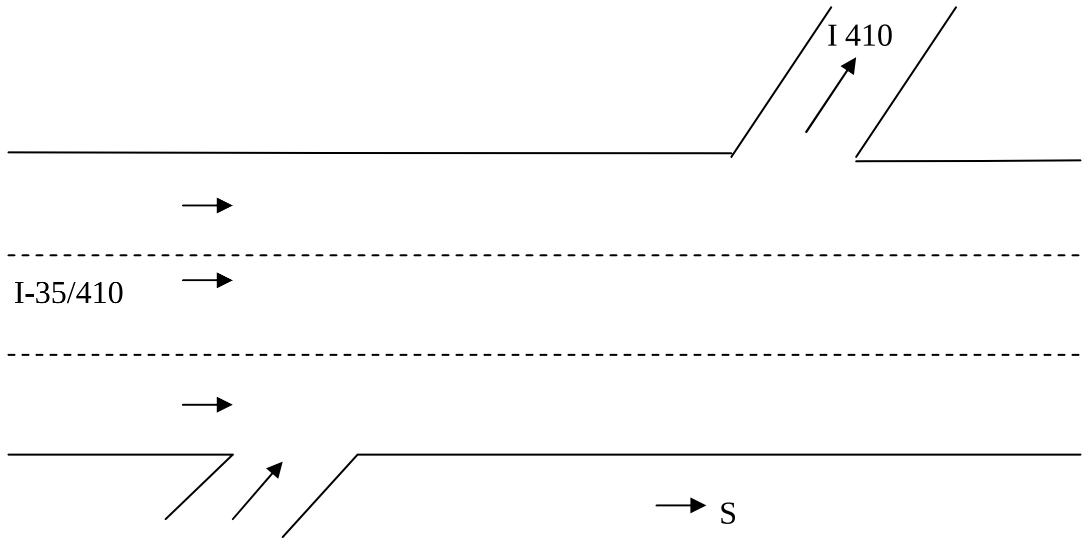
This chapter discusses the methodology used by Vo [Ref.3] in his dissertation to estimate capacity of two-sided type C weaves on freeways with three lanes. The model specified in the current HCM is a speed-based model, whereas the regression model obtained by Vo [Ref.3] in his dissertation estimates weaving capacity for different flow combinations using microscopic simulation software.

This chapter consists of five sections. The first section presents the data collection process in San Antonio, Texas. An overview of the VISSIM software, followed by VISSIM inputs and outputs, needed for the research, are presented in the second section. The third section discusses the calibration process of the simulation model, followed by a discussion of the validation process of the simulation model in the fourth section. The last section presents the regression model for predicting two-sided type C weaving capacity on freeways with three lanes.

## 2.1 Data Collection

The study area is southbound I-35/410 between the Rittiman Road entrance on the right and southbound I-410 exit on the left in San Antonio, Texas. The weaving area, with length of 0.52 mile, is shown in Figure 2.1 [Ref. 3].

In order to calibrate the model, data (speed and volume) were collected every fifteen minutes from 7:30 to 9:30 AM on June 29, 2005. Speed and volume data from 4:00 to 6:00 PM on June 30, 2005, were used to validate the VISSIM model, as explained later in this chapter. In addition to volume and speed data, travel times through the weaving section were also collected.




Entrance Ramp at Rittiman Road

Figure 2.1 I-35/410 Southbound, two-sided weave [Ref. 3]

## 2.2 VISSIM Overview

This section discusses the microscopic traffic simulation software, VISSIM, in detail. VISSIM 4.30 was used to analyze all the simulation runs in the research.

*2.2.1 Introduction*

The traffic flow model in VISSIM is a discrete, stochastic, time step based, microscopic model with driver-vehicle units as single entities. The model contains a psycho-physical car-following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The model is based on the continued work of Wiedemann. It is a powerful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness [Ref. 2]. One of the interesting aspects of VISSIM is that it takes into account the psychological characteristics and driving habits of drivers. Different VISSIM elements used in the research are comprehensively explained in the following section.

*2.2.2 VISSIM inputs*

2.2.2.1 Network geometry

The general inventory of the network geometry can be determined by using any commercially available satellite imagery, i.e., Google maps.

2.2.2.2 Links and connectors

Roadway segments are represented by a system of VISSIM network links and connectors. These links, which are joined together by connectors, have specified directions of flow. Different link types are based on attributes of driving behavior. Since the research is concerned with estimation of weaving capacity on freeways, the link type "freeway" was selected. Connectors have the same link type as the link where they originate.

2.2.2.3 Vehicle inputs and routes

For each individual link and time interval, traffic volumes must be defined in vehicles per hour. Within one time interval, vehicles enter the link on the basis of a Poisson distribution [Ref. 2]. In the research, five time intervals are used, as follows: one 5-minute time period for warm-up, then four 15-minute time periods. Routing decisions are defined by the percentage of the vehicles routed into different directions from each entry point.

2.2.2.4 Vehicle types and traffic compositions

Vehicle type defines a group of vehicles with similar vehicle characteristics (maximum and minimum acceleration, maximum and minimum deceleration, weight, power, and length). Typical vehicle types are car, LGV, HGV (truck), bus, articulated bus, tram, bike, and pedestrian.

The vehicle mix of each input flow to be defined for the VISSIM network is described as traffic composition. In the research, traffic composition is considered to be 98% cars and 2% HGVs (trucks).

A driver will travel at his desired speed. For each vehicle type, stochastic distributions of desired speeds are to be defined. In his research, a speed category number 80 is selected, with minimum speed of 46.6 and maximum speed of 68.4 mph [Ref. 3].

2.2.2.5 Driving behavior

Both the car-following and lane change models in VISSIM use an extensive range of parameters. Some parameters used in the research are explained here.

1- Car-Following Model: the car-following model of Wiedemann consists of ten parameters which use stochastic distributions, as follows [Ref.2]:

● CC0 (Standstill distance) defines the desired distance between stopped cars. The default value is 4.92 ft.

● CC1 (Headway time) is the time that a driver wants to maintain while following another car. The higher the value, the more cautious the driver is. Thus, at a given speed the safety distance dx_safe is computed as:

dx_safe = CC0 + CC1 * v

The default value is 0.90 seconds. The safety distance is defined as the minimum distance a driver will keep while following another car [Ref. 2]

● CC2 (Following variation) defines the maximum distance a driver can go beyond safety distance before moving closer to the front car. The default value of 13.12 ft. is in the stable following process range. The higher the value, the more aggressive the driver is.

● CC3 (Threshold for entering 'Following') defines when a driver needs to accelerate before reaching safety distance. The default value is -8.

● CC4 and CC5 ("Following" thresholds) control the speed differences during the "Following" state. Smaller values result in a more sensitive reaction of drivers to accelerations or decelerations of the preceding car, i.e., the vehicles are more tightly coupled. CC4 is used for negative and CC5 for positive speed differences. The default values are (-0.35, 0.35) [Ref. 2].

● CC6 (Speed dependency of oscillation) describes the effect of distance on speed oscillation in the following process If this parameter sets to zero, the speed oscillation will be independent of the distance to the preceding car. Larger values cause greater speed oscillation with increasing distance. The default value 11.44.

● CC7 (Oscillation acceleration) defines the acceleration during oscillation process. The default value is 0.82 ft/s².

● CC8 (Standstill acceleration) defines the desired acceleration from the standstill situation. The default value is 11.48 ft/s².

● CC9 (Acceleration at 50 mph) defines the desired acceleration at 50 mph. The default value is 4.92 ft/s².

2- Lane change model: the lane change parameters explain the lane change behavior of cars following their routes. Some lane change parameters are described as follows.

● Waiting time before diffusion: The maximum amount of time a vehicle can wait for a gap, in order to change lanes to stay on its route is defined by the time a vehicle waits before it diffused. When this time is reached, the vehicle is eliminated from the model and written to the error file. The default value is 60 seconds.

● Minimum headway: Minimum headway (front/rear) defines the minimum distance to the vehicle in front that must be available for a lane change in standstill condition. The default value is 1.64 ft.

● Lane change distance: Lane change distance defines the distance at which vehicles will begin to attempt to change lanes. The default value is 656.6 ft.

● Emergency stop: Emergency stop defines the last possible position for a vehicle to change lanes. It is measured upstream from the start of the connector. The default value is 16.4 ft [Ref.2]. The last three parameters mentioned are attributes of connectors in VISSIM.

*2.2.3 VISSIM outputs*

VISSIM outputs used in the research were link evaluation and travel time files, which are explained below.

1-Link evaluation: The link evaluation feature allows the user to collect simulation results (link name, link number, speed, density, volume, lost time, coordinates, etc) from each link. The simulation results are written in a link evaluation file (*.STR). These results are also available per lane in order to analyze lane flow differences.

2- Travel time: During a simulation run, VISSIM can evaluate average travel times. The average travel time (including waiting or dwell times) is determined as the time it takes a vehicle to cross from point A to point B in the network. It is written to text file (*.RSZ) [Ref. 2].

## 2.3 Calibration

Calibration is the process of modifying the input parameters to a model until the output from the model matches an observed set of data. In other words, the calibrated model should replicate real traffic characteristics. It is important to understand how well the model represents the measured data. The VISSIM model by Vo [Ref.3] was not calibrated for the purpose of this research, because it was used to extend Vo' s work for freeways with four lanes.

### *2.3.1 Calibration parameters*

In order to calibrate the model, the data collected every 15 minutes from 7:30 to 9:30 AM on June 29, 2005, was used. The following VISSIM parameters were used in the calibration process, as explained in the previous section.

1. Length of Acceleration. The length of the acceleration lane changed from 100 ft to 250 ft.

2. Lane Change Distance: The default value in VISSIM is 656.2 ft. The lane change distance changed from 2,000 ft to 3,000 ft in the model.

3. Emergency Stopping Distance. The default value of 16.4 ft was used.

4. Waiting Time before Diffusion. The default value of 60 seconds was used.

5. Minimum Headway: Minimum headway of 3 ft was used in place of the default value of 1.6 ft.

6. Car-Following Parameters. The ranges of the car-following model parameters in the research are shown in Table 2.1.

Table 2.1 Calibration of car-following model parameters

| Parameters | Value |
|---|---|
| CC0 | 1.5 to 1.7 ft |
| CC1 | 1.0 to 1.3 sec |
| CC2 | 13.12 ft (default) |
| CC3 | -8 (default) |
| CC4 | -0.35 to -2 |
| CC5 | 0.35 to 2 |
| CC6 | 11.44 (default) |
| CC7 | .82 $ft/s^2$ (default) |
| CC8 | 11.48 $ft/s^2$ (default) |
| CC9 | 4.92 $ft/s^2$ (default) |

*2.3.2 Simulation parameters*

1- Simulation running time: The simulation running time was 3,900 seconds, including 300 seconds for a warm-up period.

2- Simulation resolution: Simulation resolution, which is the number of times the vehicle's position is calculated within one simulated second [Ref.2], was set to 5.

3- Random seed: this parameter initializes the random number generator. Simulation runs with identical input files and random seeds generate identical results. To get a good statistical confidence on MOEs, it is necessary to run the simulation model for different random seeds. The number of simulation runs at different random seed depends on statistical confidence level (95% or 99%). It was assumed that the variables used was normally distributed. Therefore, the required number of iteration was calculated from the following equation:

$$n = \left( \frac{Z \times \sigma}{e} \right)^2 \tag{2.1}$$

Where n = number of simulation runs required for each observation point

Z = normal score

$\sigma$ = standard deviation

e = tolerance

The standard deviation was calculated from multiple runs. Seven runs were conducted to obtain standard deviation. The tolerance for volumes and speed were 20 vph and 2 mph [Ref.3]. Considering these values in equation 2.1, the number of iterations was found. The results showed that one simulation run is needed for calibration in most cases, but three runs were conducted and the mean value of these three runs was used.

*2.3.3 Calibration process*

As stated before, the volume and speed values collected every fifteen minutes from 7:30 to 9:30 AM were used to calibrate the model. At this stage, different combinations of selected VISSIM parameters were used in order to obtain the best-fit model. Main lane volumes, entry ramp volume, exit ramp volume, and travel speeds from merge gore to diverge gore on each freeway lane were compared with their field values. Seven models were built based on different selected parameter sets.

In order to select the best model, a multi-criteria analysis process was conducted using the Simple Additive Weighting (SAW) method. The two models with the highest score were selected for validation.

## 2.4 Validation

Validation is the process of determining that a calibrated model is an accurate representation of the real situation.

### *2.4.1 Validation process*

In the previous section, two models were selected to be validated. Speeds and volumes from 4:00 to 6:00 PM on June 30, 2005, were compared with VISSIM output values. The required simulation runs were also calculated from the equation 2.1. Three runs were conducted and the mean value was used. As a result, the model with the following parameters was found to be the best calibrated model:

1. Lane change distance: 2,500 ft from exit ramp
2. Acceleration lane length: 200 ft
3. Minimum headway: 3 ft

   CC0 = 1.7 ft, CC1 = 1.1 sec, CC4 = -2, CC5 = 2

## 2.5 Regression Model for Predicting Weaving Capacity of Type C

This section discusses Vo's [Ref.3] methodology for examining the relation between selected parameters and weave capacity. In each stage, each potential variable was changed and the other parameters were kept constant.

### *2.5.1 Correlation between capacity of a weaving section and entrance ramp demand*

To determine the relationship between capacity of a weaving section and entrance ramp volume, different scenarios, including various combinations of mainlane volumes and entrance ramp volumes, were conducted, resulting in the following [Ref. 3]:

1- Both entrance ramp capacity and lane 1 capacity are 1,000 vph if mainlane demand exceeds 4,500 vph.

2- The network reaches capacity at a point somewhere just below 5,000 vph on the mainlane.

### *2.5.2 Correlation between capacity of a weaving section and R-R flow*

In order to examine the relationship between capacity of a weaving section and R-R flow, two models were considered, one with entrance ramp at capacity (1,000 vph) and the other one under capacity (500 vph). Volumes of mainlane, R-R and exit ramp were changed. From these two models, the conclusions are as follows [Ref. 3]:

1- At capacity, as R-R volume increases, total volume decreases.

2- As exit ramp demand increases, total volume also decreases because more vehicles from entrance ramp try to reach the left lane to exit. This creates more weaving activity in the system.

3- The sum of lane 1 and entrance ramp flow is approximately 2,000 vph, which is the capacity of one lane of a freeway recommended by the 2000 HCM.

*2.5.3 Regression model*

Regression analysis was performed using the results of simulation runs to determine a relationship between weaving capacity and any potential variables (exit ramp, mainlane, entrance ramp, weaving ratio, and R-R ratio). The best regression model to estimate two-sided type C weaves on freeway with three lanes was obtained as follows: [Ref. 3]

$$C_w = 5113 + 0.187 * V_{ML} - 0.317 * V_{EX} - 0.262 * V_{RR}$$

Where

$C_w$ = Weaving Capacity

$V_{ML}$ = Main Lane Volume (vph) and $4,500 \leq V_{ML} \leq 6,500$

$V_{EX}$ = Exit Ramp Volume (vph) and $800 \leq V_{EX} \leq 2,000$

$V_{RR}$ = R-R Flow and $100 \leq V_{RR} \leq 1,000$

The ranges for each variable represent the data used to estimate the model. This model has some limitations, as described below [Ref.3].

- 0.52 mile weaving section
- With 98% passenger cars and 2% trucks (traffic mix)

# CHAPTER 3

## SIMULATION RUNS AND RESULTS

This chapter presents applied methodology to assess the relation between capacity of two-sided type C weaves on freeways with four lanes and any potential variables (entrance ramp flow, mainlane flow, ramp to ramp, R-R ratio, weaving ratio and exit ramp flow). This chapter consists of two sections. The first section investigates the correlation between weaving capacity and entrance ramp flow. The second section examines the correlation between capacity of a weaving section and, R-R flow.

Because one of the principal objectives was to extend Vo's model for four lanes, all calibrated parameters, as explained in chapter 2, remained the same.

The number of required runs was calculated from the following equation:

$$n = \left( \frac{Z \times \sigma}{e} \right)^2$$

Z = 1.96 corresponding z value -% 95 confidence interval

e = 5% of total demand

σ = standard deviation

In order to find the least number of needed runs, one scenario with mainlane demand of 6000 vph, entrance ramp demand of 600 vph, exit ramp demand of 800 vph, R-R 10%, was run 10 times and "n" is calculated from the above equation. Table 3.1

shows the result of VISSIM runs. The results showed that one run is needed for lane 1, lane 2, lane 3, lane 4 and exit ramp and four runs is needed for the entrance ramp. However, each VISSIM scenario was run five times with different random seed numbers to achieve statistically sound results.

Table 3.1 Lane volumes for different random seed for the above scenario

| Random Seed | Exit Ramp Volume | Lane 1 Volume | Lane 2 Volume | Lane 3 Volume | Lane 4 Volume | Entrance Ramp Volume |
|---|---|---|---|---|---|---|
| RS1 | 802 | 1392 | 1608 | 1688 | 1815 | 572 |
| RS 2 | 743 | 1410 | 1550 | 1672 | 1797 | 509 |
| RS 3 | 785 | 1412 | 1622 | 1710 | 1801 | 595 |
| RS 4 | 761 | 1439 | 1613 | 1684 | 1767 | 586 |
| RS 5 | 794 | 1414 | 1617 | 1692 | 1804 | 580 |
| RS 6 | 789 | 1455 | 1605 | 1706 | 1792 | 595 |
| RS 7 | 754 | 1358 | 1543 | 1676 | 1775 | 534 |
| RS 8 | 797 | 1421 | 1622 | 1702 | 1812 | 594 |
| RS 9 | 807 | 1456 | 1639 | 1670 | 1788 | 595 |
| RS 10 | 792 | 1409 | 1603 | 1687 | 1800 | 574 |
| Standard Deviation | 21.8 | 29.3 | 31.2 | 14.0 | 15.2 | 32.8 |
| Tolerance | 40 | 75 | 75 | 75 | 75 | 30 |
| z | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 |
| n | 1.1 | 0.6 | 0.7 | 0.1 | 0.2 | 3.7 |

D. Ni, K. Strickland and C. Feng also, used five runs in their I-85 traffic study [Ref. 8]. In addition, B. Park and H. Qi used five iterations for their freeway work zone studies [Ref.11].

In order to investigate the relation between weaving capacity, four models were built. Models 1 and 2 assess the relation between weaving capacity and entrance ramp demand and Models 3 and 4 show the relation between weaving capacity and ramp to ramp, R-R flow.

## 3.1 Correlation between Capacity of Two-Sided Weaves and Entrance Ramp Flow

Entrance ramp demand affects capacity of two-sided weaves on freeways. Two models are introduced here.

### *3.1.1 Correlation between weaving capacity and entrance ramp flow when there is no exit ramp*

Model 1: The objective of this step is to find the maximum entrance ramp demand, which can be processed when there is not any weaving activity on the freeway. Therefore, the exit ramp is eliminated from the network. Figure 3.1 shows a 4-lane freeway with single entrance ramp. Vehicles are traveling toward the bottom of this figure.

For each given mainlane volume, entrance ramp demand is increased until the actual entrance ramp flow is lower than its demand. Therefore, for each given mainlane volume, the entrance ramp capacity can be found. Three scenarios are introduced here.

Scenario 1: In this scenario, the total mainlane volume is 5000 vph, and the entrance ramp volume varies from 200 to 2000 vph. Figure 3.2 shows the relationship between the entrance ramp demand and entrance ramp flow. Here demand refers to the number of vehicles, which are supplied to VISSIM as an input and flow is the actual number of vehicles which can be processed by the network. The latter is extracted from VISSIM link evaluation files.

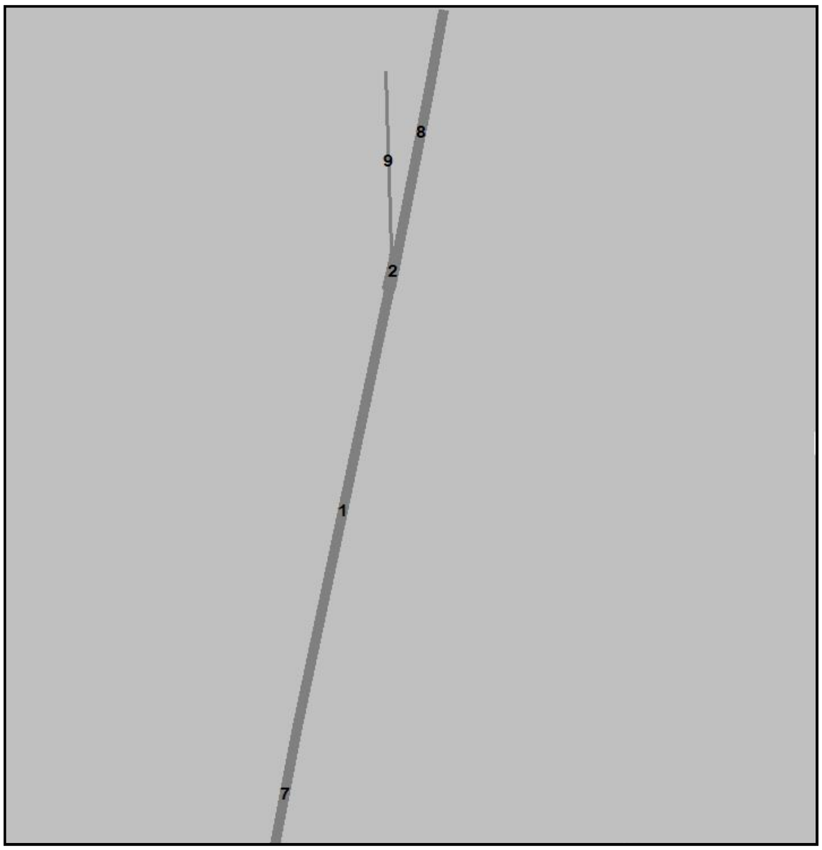



Figure 3.1 VISSIM network – no exit ramp (North is up)

In this scenario, the value of entrance ramp flow is equal to the entrance ramp demand until its demand reaches 900 vph. In other words, the capacity of entrance ramp is about 900 vph when the mainlanes volume is 5000 vph.

Figure 3.3 shows the relationship between total volume (mainlane + entrance ramp) and entrance ramp demand. The throughput flow is equal to its corresponding demand until entrance ramp demand reaches 1200 vph. After this point, the throughput flows are smaller than demand, which indicates that the system reaches capacity. The capacity of the mainlane is just under 6000 vph in this scenario.

Scenario 2: In this scenario, the total mainlane volume is 6000 vph, and the entrance ramp volume varies from 200 to 2000 vph.

Figure 3.4 shows the relationship between the entrance ramp demand and the entrance ramp flow for scenario 2. The entrance ramp capacity has drastically decreased compared to the previous scenario (from about 900 vph to 600 vph).

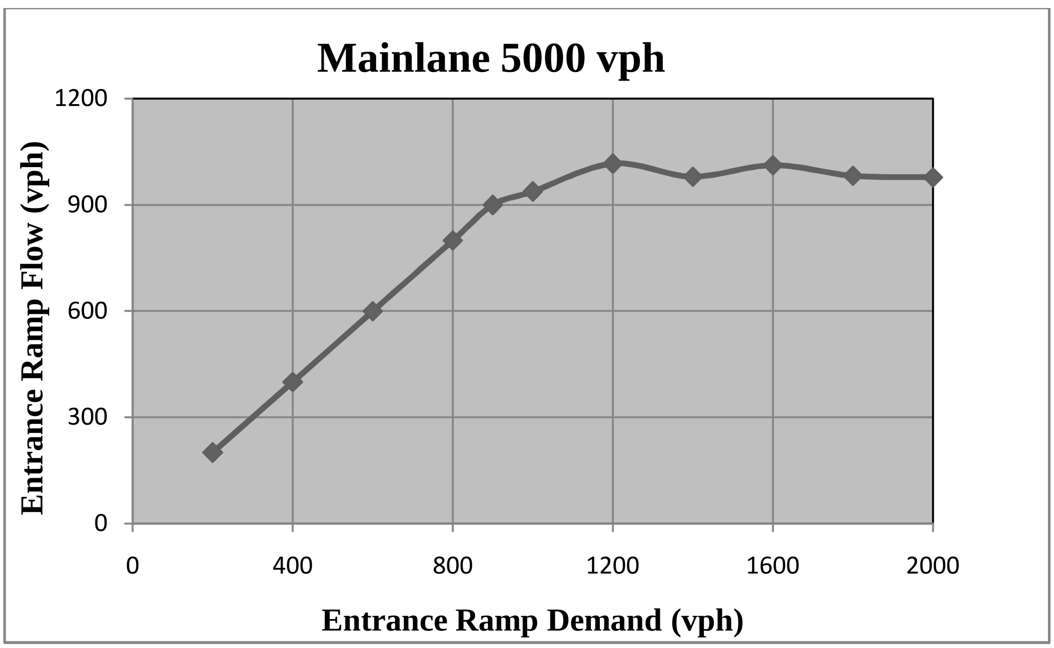



Figure 3.2 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 1 Model 1

Also, the relation between the total volume and the entrance ramp demand is shown in Figure 3.5. The capacity of the mainlanes is around 6500 vph in this scenario.

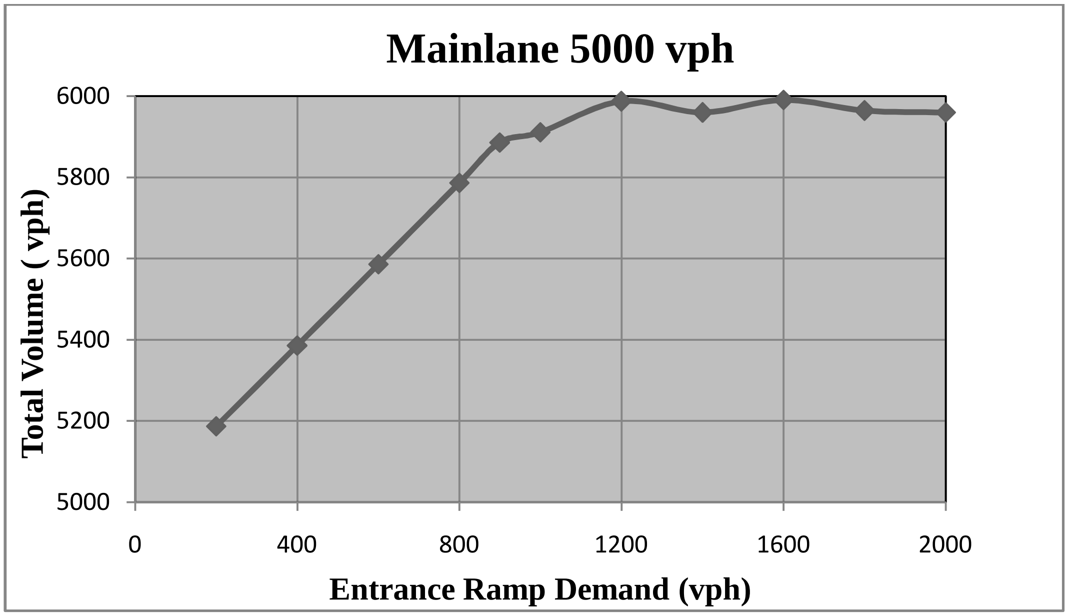



Figure 3.3 Entrance Ramp Demand vs. Total Volume for scenario 1 Model 1

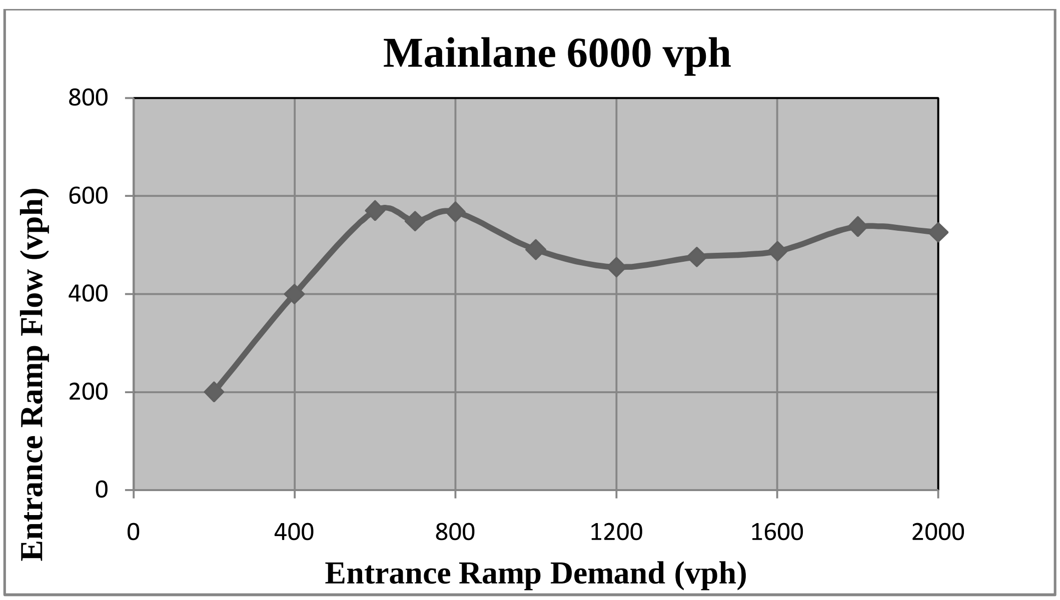



Figure 3.4 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 2 Model 1

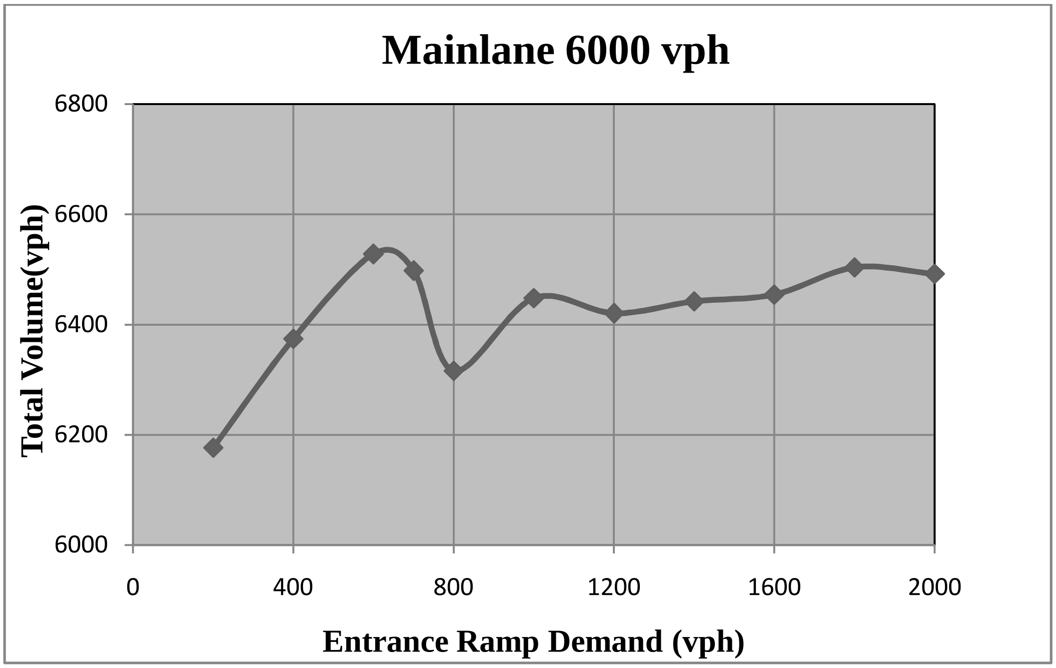



Figure 3.5 Entrance Ramp Demand vs. Total Volume for scenario 2 Model 1

Scenario 4: In this scenario, the total mainlane volume is 8000 vph, and the entrance ramp volume varies from 200 to 2000 vph. Figure 3.6 shows the entrance ramp demand and entrance ramp flow for scenario 3. In this scenario, another decrease in entrance ramp capacity can be seen (400 vph compared to 600 vph).

Figure 3.7 shows the relation between entrance ramp demand and total volume for scenario 4. The throughput volume is equal to its demand (8400 vph) until entrance ramp demand reaches 400 vph. As entrance ramp demand increases, the mainlane flow decreases significantly so that one can conclude that the mainlane capacity is around 8300 vph. The entrance ramp capacity value for each mainlane volume is bolded in

Table 3.2. As mainlane volume increases, the entrance ramp capacity decreases (From 900 vph to 400 vph).Table 3.2 summarizes all of the scenarios in Model 1.

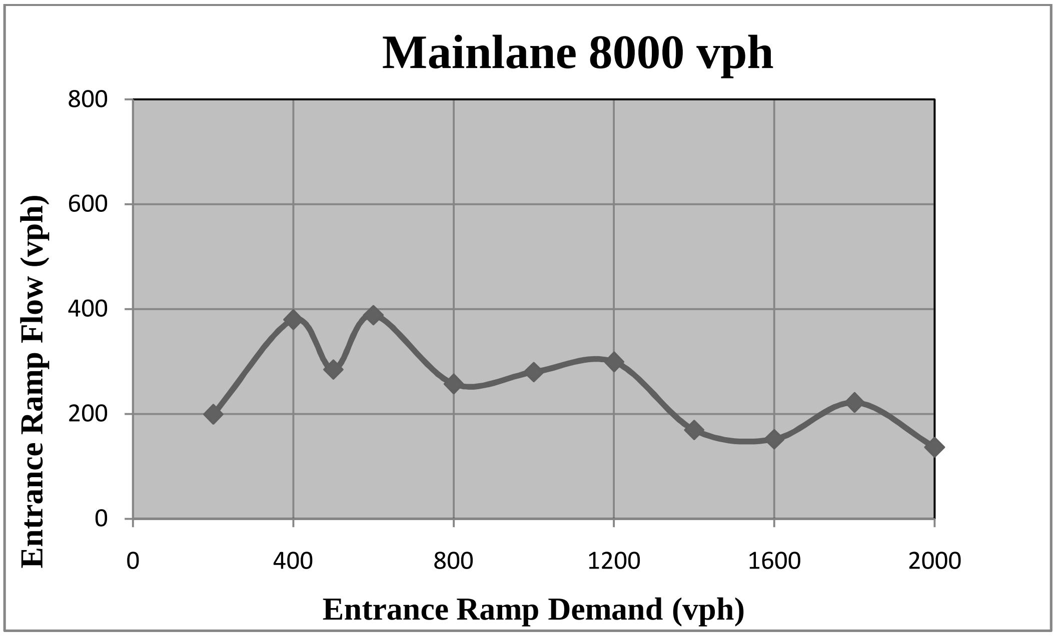



Figure 3.6 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 4 Model 1

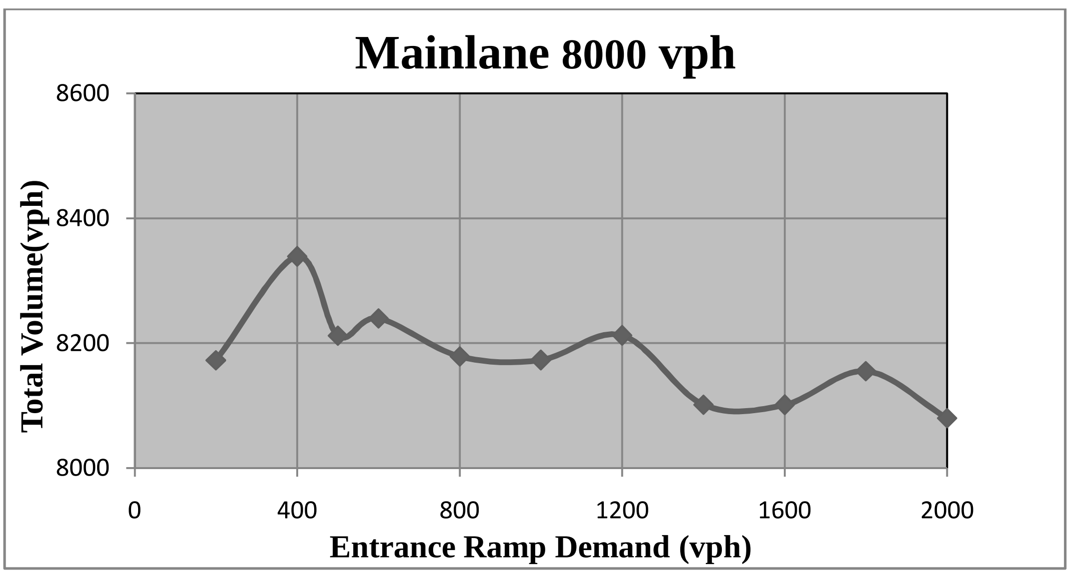



Figure 3.7 Entrance Ramp Demand vs. Total Volume for scenario 4 Model 1

Table 3.2 Summary of all scenarios for Model 1

| Scenarios | Runs | Demand (vph) | | | Flow(vph) | |
|---|---|---|---|---|---|---|
| | | Entrance Ramp | Mainlanes | Total Volume | Entrance Ramp | Total Volume |
| 1 | 1 | 200 | 5000 | 5200 | 200 | 5187 |
| | 2 | 400 | 5000 | 5400 | 400 | 5386 |
| | 3 | 600 | 5000 | 5600 | 599 | 5586 |
| | 4 | 800 | 5000 | 5800 | 799 | 5787 |
| | 5 | ***900*** | 5000 | 5900 | 899 | 5886 |
| | 6 | 1000 | 5000 | 6000 | 937 | 5911 |
| | 7 | 1200 | 5000 | 6200 | 1016 | 5987 |
| | 8 | 1400 | 5000 | 6400 | 980 | 5960 |
| | 9 | 1600 | 5000 | 6600 | 1012 | 5991 |
| | 10 | 1800 | 5000 | 6800 | 982 | 5965 |
| | 11 | 2000 | 5000 | 7000 | 978 | 5960 |
| 2 | 1 | 200 | 6000 | 6200 | 200 | 6176 |
| | 2 | 400 | 6000 | 6400 | 400 | 6374 |
| | 3 | ***600*** | 6000 | 6600 | 570 | 6528 |
| | 4 | 800 | 6000 | 6800 | 567 | 6316 |
| | 5 | 1000 | 6000 | 7000 | 490 | 6448 |
| | 6 | 1200 | 6000 | 7200 | 455 | 6420 |
| | 7 | 1400 | 6000 | 7400 | 476 | 6442 |
| | 8 | 1600 | 6000 | 7600 | 488 | 6454 |
| | 9 | 1800 | 6000 | 7800 | 537 | 6504 |
| | 10 | 2000 | 6000 | 8000 | 526 | 6492 |
| 3 | 1 | 200 | 7000 | 7200 | 200 | 7181 |
| | 2 | ***400*** | 7000 | 7400 | 374 | 7342 |
| | 3 | 600 | 7000 | 7600 | 483 | 7433 |
| | 4 | 800 | 7000 | 7800 | 263 | 7204 |
| | 5 | 1000 | 7000 | 8000 | 218 | 7170 |
| | 6 | 1200 | 7000 | 8200 | 204 | 7157 |
| | 7 | 1400 | 7000 | 8400 | 199 | 7152 |
| | 8 | 1600 | 7000 | 8600 | 215 | 7168 |
| | 9 | 1800 | 7000 | 8800 | 212 | 7167 |
| | 10 | 2000 | 7000 | 9000 | 212 | 7170 |
| 4 | 1 | 200 | 8000 | 8200 | 199 | 8173 |
| | 2 | ***400*** | 8000 | 8400 | 380 | 8339 |
| | 3 | 600 | 8000 | 8600 | 388 | 8240 |
| | 4 | 800 | 8000 | 8800 | 257 | 8179 |
| | 5 | 1000 | 8000 | 9000 | 280 | 8173 |
| | 6 | 1200 | 8000 | 9200 | 299 | 8212 |
| | 7 | 1400 | 8000 | 9400 | 169 | 8102 |
| | 8 | 1600 | 8000 | 9600 | 152 | 8101 |
| | 9 | 1800 | 8000 | 9800 | 222 | 8155 |
| | 10 | 2000 | 8000 | 10000 | 136 | 8080 |

The reason for low entrance ramp capacity values is that the VISSIM model was calibrated under low volume inputs. The effects of calibrated parameters on the results are explained as follows.

- Minimum headway: as defined in chapter 2, minimum headway is the minimum distance to the vehicle in front needed for lane change. Greater values cause the vehicles from the entrance ramp to wait longer in order to find a gap.
- CC0: Another parameter, which might result in low entrance ramp capacity values, is CC0. As explained in chapter 2, CC0, is the desired distance between stopped vehicles. Therefore, the lower that CC0 is the lower the chance of vehicles from the entrance ramp finding enough gaps to merge into the freeway.
- CC1: in addition to CC0, CC1 also affects entrance ramp capacity values. Based on its definition, CC1 is the time driver wants to keep while following another vehicle. In case of high volumes, CC1 becomes the value with the strongest influence on capacity as it significantly changes the mean of the headways [Ref.7].

  Safety Distance = CC0+v CC1, Where v is the speed of the trailing vehicle. Larger values of CC1 cause the drivers to act more conservatively, meaning they leave larger gaps. Therefore, it would seem that the larger values of CC1 would allow for some of vehicle to enter the freeway.

- CC4 and CC5: these dimensionless parameters show drivers sensitivity to the vehicle in front. Increasing these parameters will lead to reductions in freeway and entrance ramp capacity values.

  The effect of CC1 and CC4/CC5 on the capacity has been studied by Nicholas Lownes and Randy Machemehl [Ref.10]. Figure 3.8 shows the relationship between capacity and CC1 and CC4/CC5 values. For a given sensitivity (CC4/CC5), the higher that CC1 is, the lower the average capacity. Also for a given CC1, an increase in CC4/CC5 causes a slight reduction in capacity. Figure 3.9, as illustrated by Nicholas Lownes and Randy Machemehl, shows that an increase in the CC1 values results in a reduction on capacity. For example, when CC1 increased from 1 second to 1.5 seconds, the capacity reduced by %15[Ref.13].

  Another study by Xiaotian Sun shows that increasing CC1 and increasing the magnitudes of the CC4/CC5 pair will lead to a reduction in freeway capacity [Ref.12].

- Time before diffusion: Time before diffusion is the maximum amount of time a vehicle can wait for a gap, in order to change lanes to stay on its route. In addition to car-following parameters, entrance ramp vehicles have 60 seconds to stay on the merge area, provided as ‘’time before diffusion’’ in the VISSIM network, until they find a large gap to merge on to the freeway and that is the reason why there is a queue in the merge area in most scenarios. An increase of time before diffusion may result in an increase in the wait time for vehicles entering the freeway.

Each of the above parameters has a negative effect on maximum entrance ramp volume but once compounded, they will have a greater impact

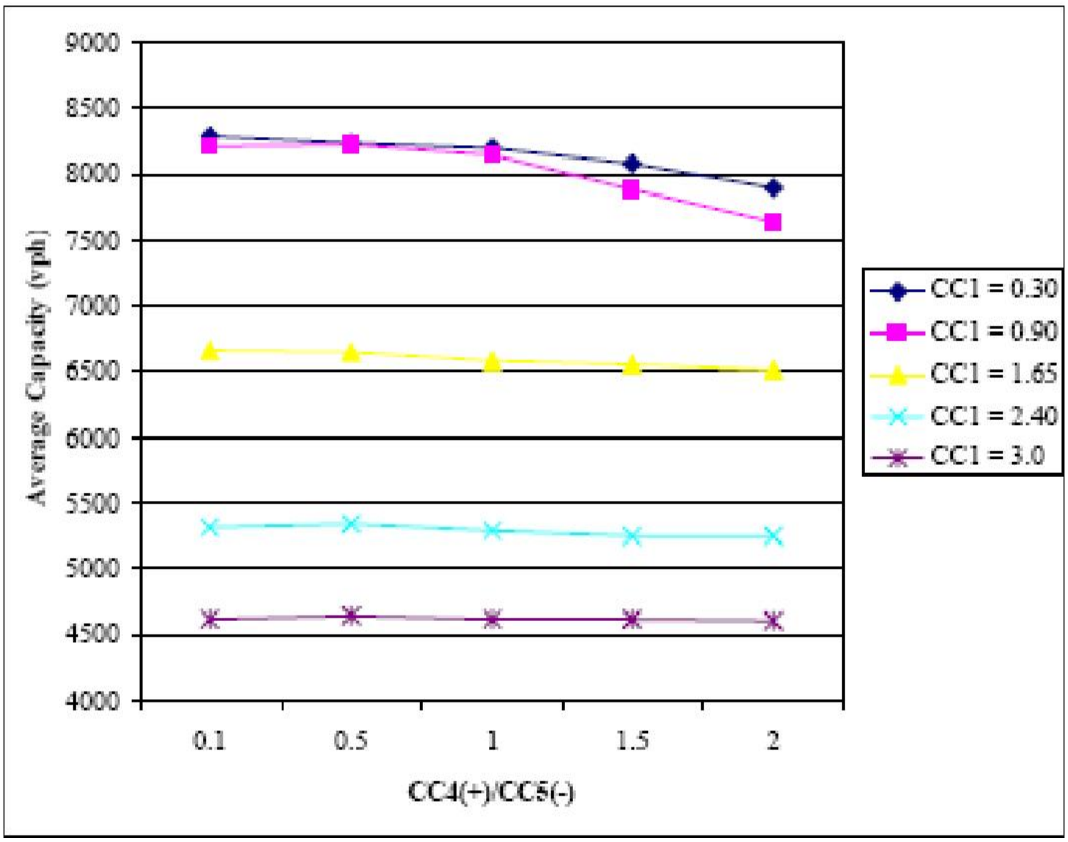



Figure 3.8 Average capacity values vs. CC1 and CC4/CC5 [Ref.12]

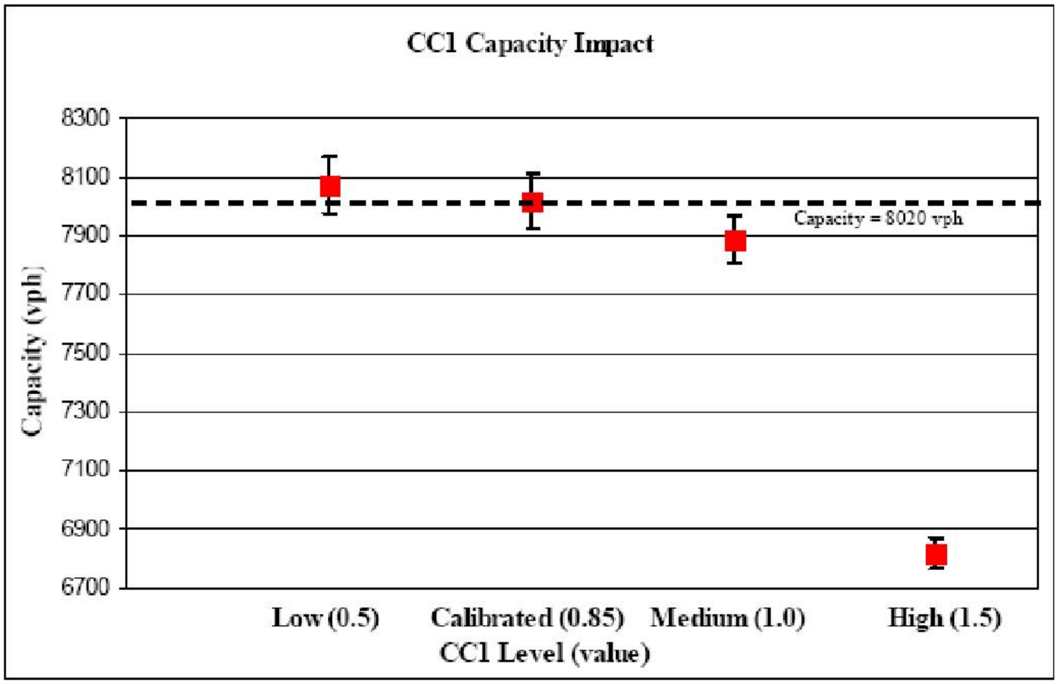



Figure 3.9 Average capacity vs. CC1 [Ref. 13]

*3.1.2 Correlation between weaving capacity and entrance ramp flow in the actual network*

Model 2: This model examines the relationship between entrance ramp demand and weaving capacity in the actual network. Figure 3.10 shows a four-lane freeway with single entrance ramp. Weaving length is 0.52 miles. As specified in chapter 2, there are 98% passenger cars and 2% trucks in this model.

Similar to Model 1, all inputs but the entrance ramp demands are kept constant. Entrance ramp demand is increased gradually until the entrance ramp flow is lower than the entrance ramp demand. For this model, R-R ratio (R-R ratio is a percentage of entrance ramp volume) and exit ramp demand is considered between 10-25% and 800-

1200 vph, respectively. Two scenarios are introduced here. Appendix B shows all scenarios for this model.

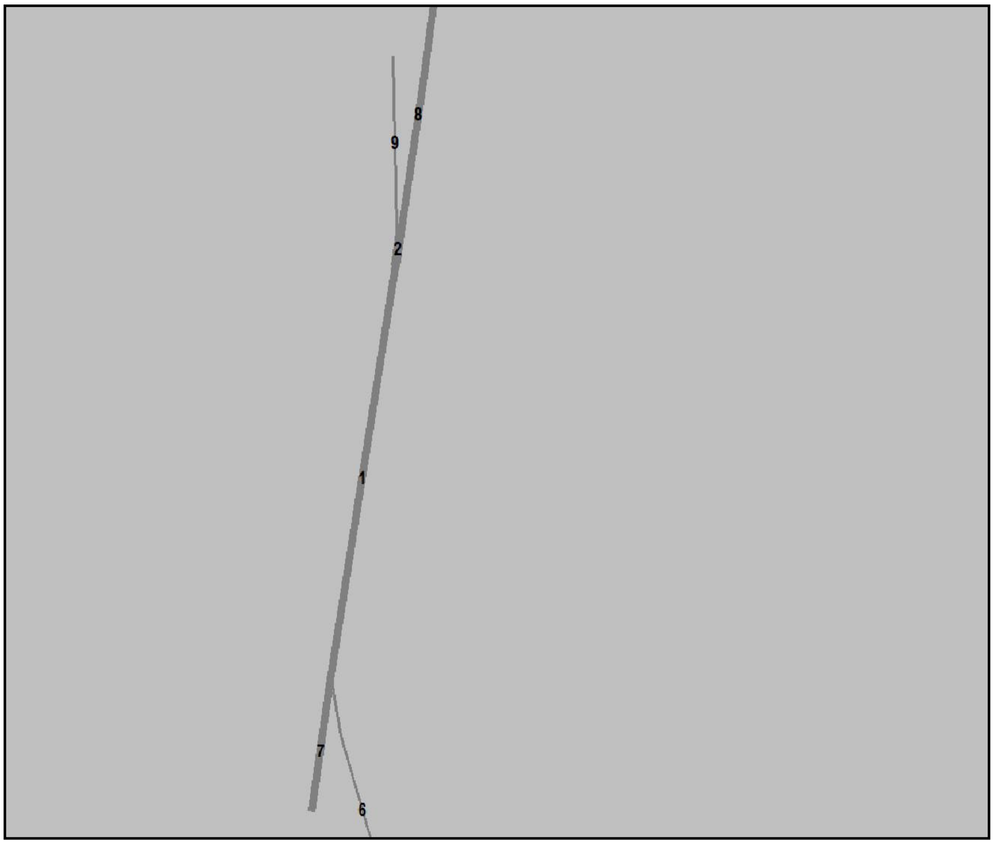



Figure 3.10 VISSIM network – North is up

Scenario 2: In this scenario, the mainlanes volume is 6000 vph, the exit ramp has a volume of 800 vph, 25% of the entrance ramp volume is the R-R demand, and entrance ramp volume varies from 100 to 2000 vph.

In this scenario, the entrance ramp flow is equal to entrance ramp demand until its demand reaches 600 vph. So, the capacity of entrance ramp is about 600 vph when the mainlanes volume is 6000 vph.

Figure 3.11 shows the relationship between entrance ramp demand and entrance ramp flow. Figure 3.12 also shows the relationship between entrance ramp demand and the total volume for scenario 2. The freeway capacity is around 6500 vph for this scenario.

Figure 3.13 shows the relation between entrance ramp demand and lane flows. In Figure 3.13, increasing entrance ramp demand causes lane 2 volumes to increase due to entering vehicles from lane 1. The lane 4 volume is the highest of the four lanes because the lane change distance was set at 2500 feet before the exit ramp. In other words, soon after the entrance ramp vehicles merge into the freeway, they should cross three lanes in order to reach the left lane and exit freeway. This situation will increase the volume in lane 4 for low freeway volumes. Also, lane 4 has the highest volume in the case of high freeway volumes since lane 4 has the least weaving activity of vehicles.

The exit ramp lane's flow remains unchanged until entrance ramp demand reaches 600 vph. After this point, the exit ramp flow drastically decreases (from 800 vph to 400 vph) because most of the vehicles from the entrance ramp do not have the chance to cross three lanes in such a short distance and most of the exit ramp flow is coming from entrance ramp.

Scenario 4: In this scenario, the mainlanes volume is 8000 vph, the exit ramp has a volume of 1200 vph, 25% of entrance ramp volume is R-R demand, and entrance ramp volume varies from 100 to 2000 vph. Figure 3.14 shows the relationship between entrance ramp demand and entrance ramp flow. The entrance ramp capacity decreases from 600 vph to 500 vph when mainlane volume increases from 6000 to 8000 vph. Figure 3.15 shows the relationship between entrance ramp demands and total volume for scenario2. The freeway capacity is around 8100 vph for this scenario. All scenarios for this model are summarized in Table 3.3. The entrance capacity values are bolded.

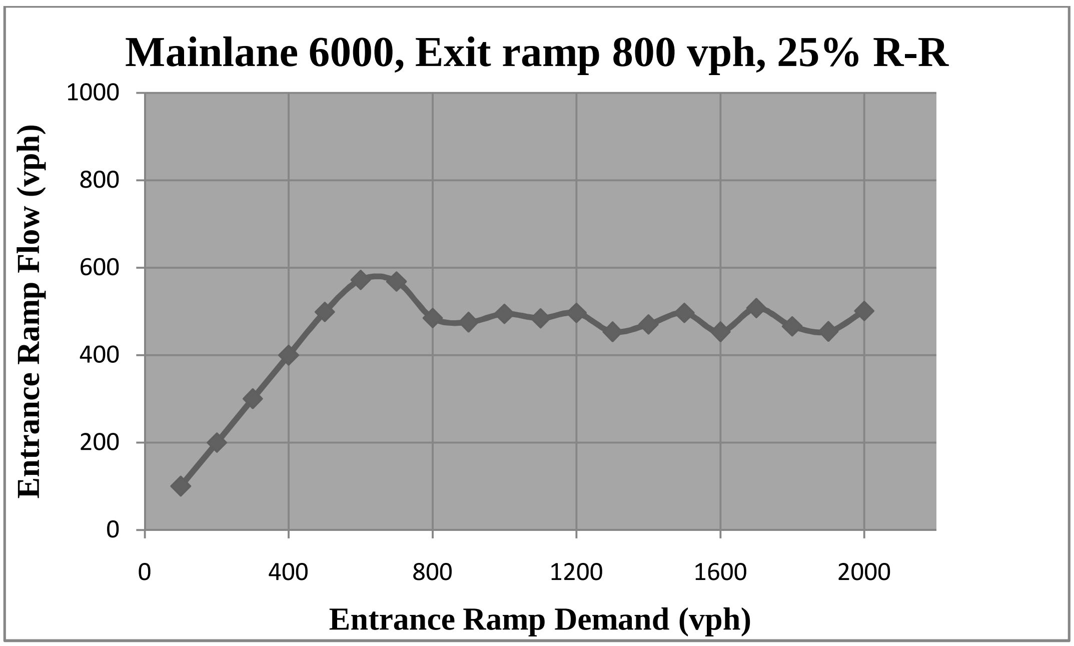



Figure 3.11 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 2Model 2

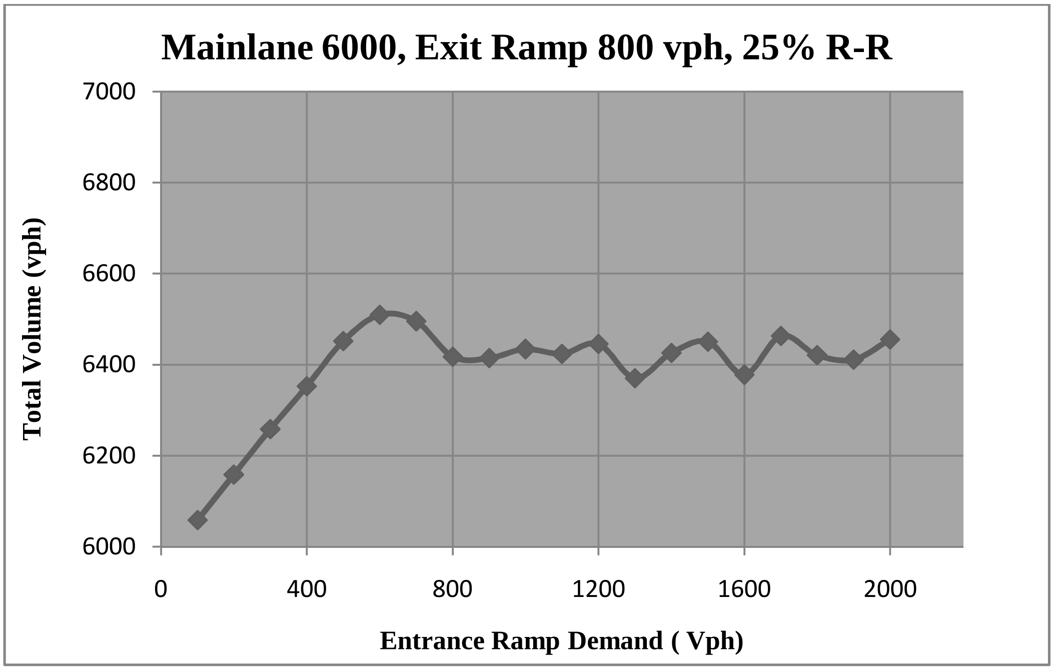



Figure 3.12 Entrance Ramp Demand vs. Total Volume for scenario 2 Model 2

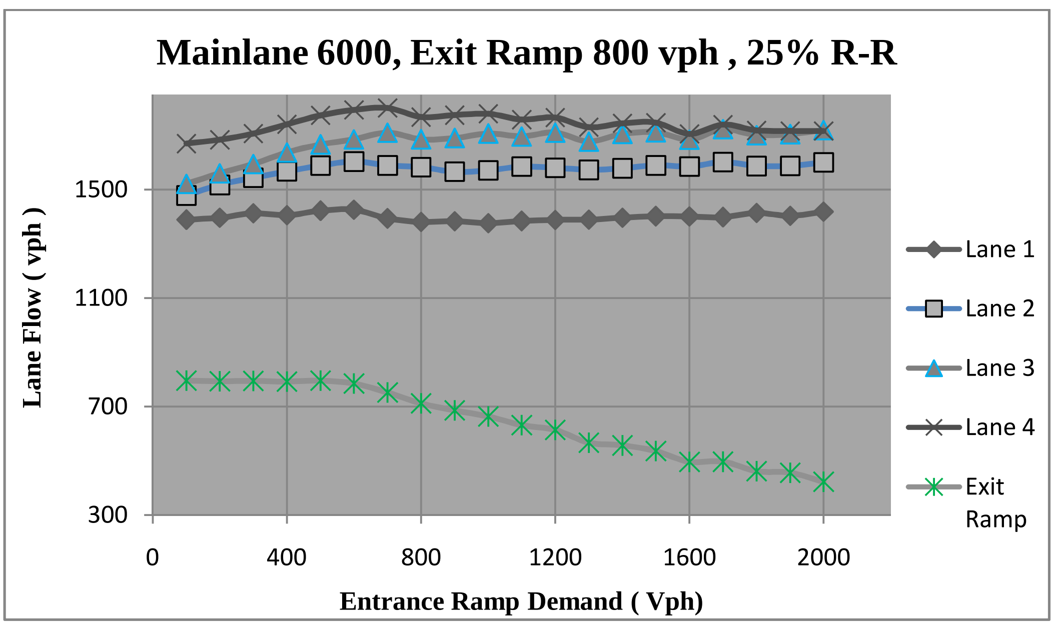



Figure 3.13 Entrance Ramp Demand vs. Lane Flow for scenario 2 Model 2

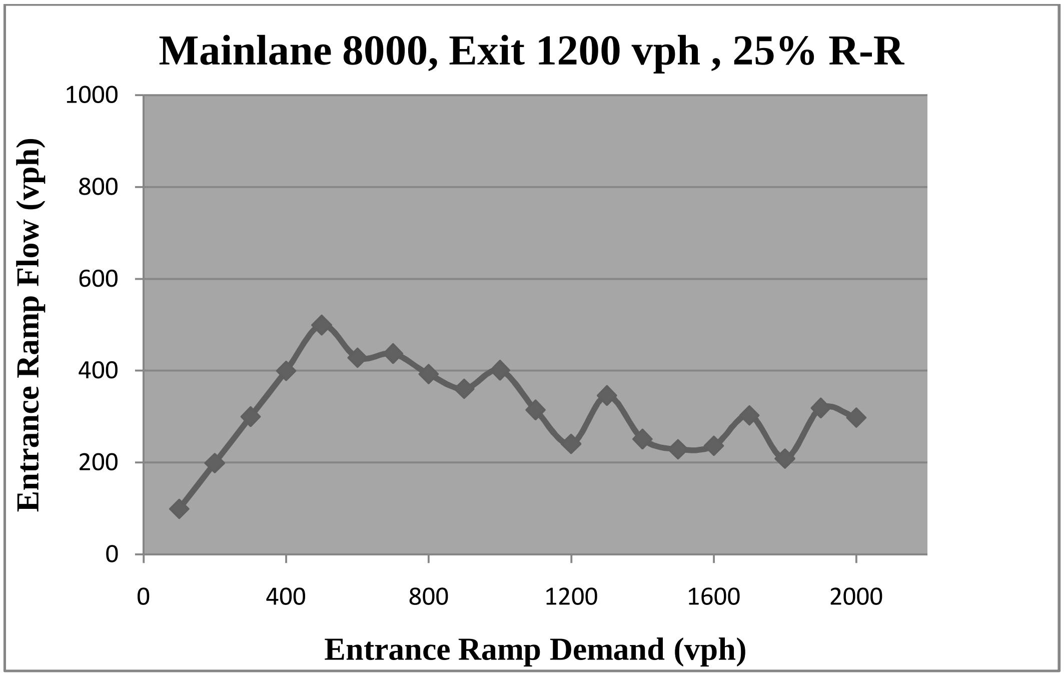



Figure 3.14 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario4 Model 2

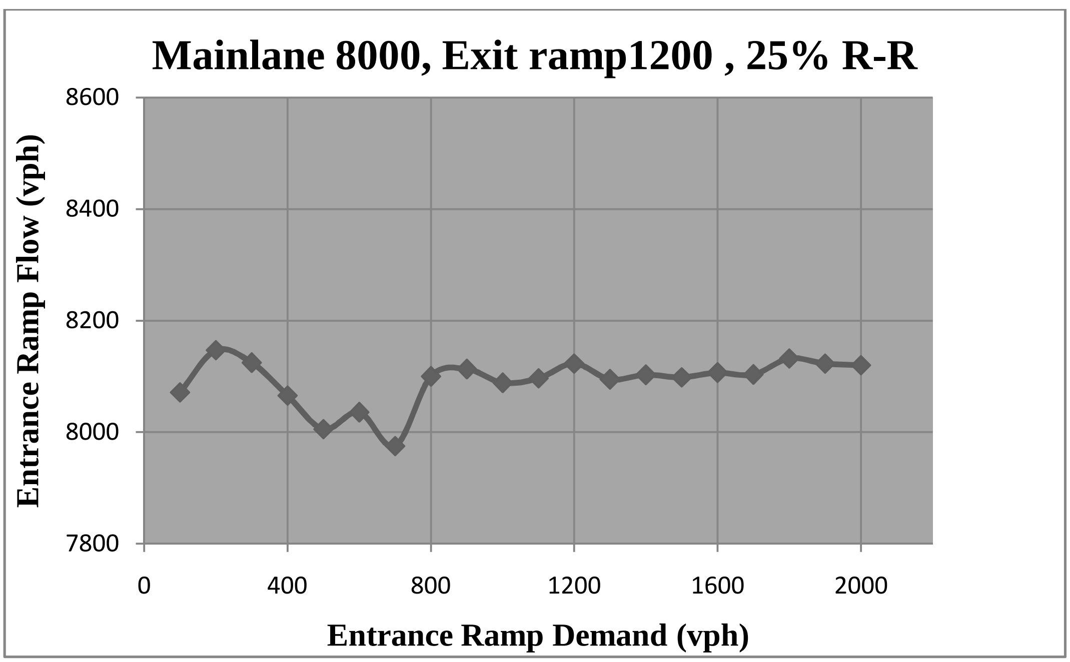



Figure 3.15 Entrance Ramp Demand vs. Total Volume for scenario 4 Model 2

Table 3.3 Summary of all scenarios for Model 2

| Scenarios | runs | Exit Ramp | R-R % | Demand (vph) Entrance Ramp | Demand (vph) Mainlanes | Demand (vph) Total Volume | Flow(vph) Entrance Ramp | Flow(vph) Total Volume |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 800 | 10% | 100 | 4500 | 4600 | 100 | 4591 |
| | 2 | | | 200 | 4500 | 4700 | 199 | 4692 |
| | 3 | | | 300 | 4500 | 4800 | 298 | 4792 |
| | 4 | | | 400 | 4500 | 4900 | 398 | 4891 |
| | 5 | | | 500 | 4500 | 5000 | 499 | 4991 |
| | 6 | | | 600 | 4500 | 5100 | 599 | 5091 |
| | 7 | | | 700 | 4500 | 5200 | 695 | 5190 |
| | 8 | | | 800 | 4500 | 5300 | 799 | 5291 |
| | 9 | | | 900 | 4500 | 5400 | 899 | 5392 |
| | 10 | | | 1000 | 4500 | 5500 | 999 | 5489 |
| | 11 | | | 1100 | 4500 | 5600 | 1099 | 5591 |
| | 12 | | | 1200 | 4500 | 5700 | 1199 | 5692 |
| | 13 | | | 1300 | 4500 | 5800 | 1297 | 5785 |
| | 14 | | | ***1400*** | 4500 | 5900 | 1379 | 5857 |
| | 15 | | | 1500 | 4500 | 6000 | 1380 | 5855 |
| | 16 | | | 1600 | 4500 | 6100 | 1382 | 5874 |
| | 17 | | | 1700 | 4500 | 6200 | 1331 | 5817 |
| | 18 | | | 1800 | 4500 | 6300 | 1344 | 5839 |
| | 19 | | | 1900 | 4500 | 6400 | 1337 | 5824 |
| | 20 | | | 2000 | 4500 | 6500 | 1390 | 5875 |
| 2 | 1 | 800 | 25% | 100 | 6000 | 6100 | 100 | 6059 |
| | 2 | | | 200 | 6000 | 6200 | 200 | 6159 |
| | 3 | | | 300 | 6000 | 6300 | 300 | 6259 |
| | 4 | | | 400 | 6000 | 6400 | 400 | 6353 |
| | 5 | | | 500 | 6000 | 6500 | 499 | 6452 |
| | 6 | | | ***600*** | 6000 | 6600 | 572 | 6510 |
| | 7 | | | 700 | 6000 | 6700 | 569 | 6495 |
| | 8 | | | 800 | 6000 | 6800 | 485 | 6418 |
| | 9 | | | 900 | 6000 | 6900 | 475 | 6415 |
| | 10 | | | 1000 | 6000 | 7000 | 495 | 6434 |

Table 3.3 - continued

| Scenario | Runs | Exit Ramp | R-R % | Demand (vph) | | | Flow(vph) | |
|---|---|---|---|---|---|---|---|---|
| | | | | Entrance Ramp | Mainlanes | Total Volume | Entrance Ramp | Total Volume |
| | 11 | 800 | 25% | 1100 | 6000 | 7100 | 484 | 6424 |
| | 12 | | | 1200 | 6000 | 7200 | 497 | 6446 |
| | 13 | | | 1300 | 6000 | 7300 | 453 | 6371 |
| | 14 | | | 1400 | 6000 | 7400 | 470 | 6426 |
| | 15 | | | 1500 | 6000 | 7500 | 497 | 6451 |
| | 16 | | | 1600 | 6000 | 7600 | 453 | 6378 |
| | 17 | | | 1700 | 6000 | 7700 | 508 | 6463 |
| | 18 | | | 1800 | 6000 | 7800 | 466 | 6421 |
| | 19 | | | 1900 | 6000 | 7900 | 454 | 6411 |
| | 20 | | | 2000 | 6000 | 8000 | 501 | 6456 |
| 3 | 1 | 1200 | 25% | 100 | 7000 | 7100 | 99 | 7081 |
| | 2 | | | 200 | 7000 | 7200 | 199 | 7180 |
| | 3 | | | 300 | 7000 | 7300 | 298 | 7283 |
| | 4 | | | ***400*** | 7000 | 7400 | 380 | 7356 |
| | 5 | | | 500 | 7000 | 7500 | 346 | 7289 |
| | 6 | | | 600 | 7000 | 7600 | 501 | 7465 |
| | 7 | | | 700 | 7000 | 7700 | 359 | 7305 |
| | 8 | | | 800 | 7000 | 7800 | 238 | 7184 |
| | 9 | | | 900 | 7000 | 7900 | 187 | 7137 |
| | 10 | | | 1000 | 7000 | 8000 | 267 | 7225 |
| | 11 | | | 1100 | 7000 | 8100 | 225 | 7176 |
| | 12 | | | 1200 | 7000 | 8200 | 233 | 7191 |
| | 13 | | | 1300 | 7000 | 8300 | 236 | 7194 |
| | 14 | | | 1400 | 7000 | 8400 | 228 | 7185 |
| | 15 | | | 1500 | 7000 | 8500 | 201 | 7158 |
| | 16 | | | 1600 | 7000 | 8600 | 196 | 7150 |
| | 17 | | | 1700 | 7000 | 8700 | 222 | 7184 |
| | 18 | | | 1800 | 7000 | 8800 | 227 | 7186 |
| | 19 | | | 1900 | 7000 | 8900 | 244 | 7199 |
| | 20 | | | 2000 | 7000 | 9000 | 226 | 7184 |

Table 3.3 - continued

| Scenario | Runs | Exit ramp | R-R-% | Demand (vph) | | | Flow(vph) | |
|---|---|---|---|---|---|---|---|---|
| | | | | Entrance Ramp | Mainlanes | Total Volume | Entrance Ramp | Total Volume |
| 4 | 1 | 1200 | 25% | 100 | 8000 | 8100 | 99 | 8071 |
| | 2 | | | 200 | 8000 | 8200 | 199 | 8147 |
| | 3 | | | 300 | 8000 | 8300 | 300 | 8124 |
| | 4 | | | 400 | 8000 | 8400 | 400 | 8066 |
| | 5 | | | ***500*** | 8000 | 8500 | 499 | 8005 |
| | 6 | | | 600 | 8000 | 8600 | 428 | 8035 |
| | 7 | | | 700 | 8000 | 8700 | 437 | 7975 |
| | 8 | | | 800 | 8000 | 8800 | 393 | 8100 |
| | 9 | | | 900 | 8000 | 8900 | 361 | 8113 |
| | 10 | | | 1000 | 8000 | 9000 | 401 | 8088 |
| | 11 | | | 1100 | 8000 | 9100 | 315 | 8097 |
| | 12 | | | 1200 | 8000 | 9200 | 241 | 8123 |
| | 13 | | | 1300 | 8000 | 9300 | 346 | 8094 |
| | 14 | | | 1400 | 8000 | 9400 | 251 | 8103 |
| | 15 | | | 1500 | 8000 | 9500 | 229 | 8098 |
| | 16 | | | 1600 | 8000 | 9600 | 237 | 8106 |
| | 17 | | | 1700 | 8000 | 9700 | 303 | 8103 |
| | 18 | | | 1800 | 8000 | 9800 | 209 | 8132 |
| | 19 | | | 1900 | 8000 | 9900 | 319 | 8123 |
| | 20 | | | 2000 | 8000 | 10000 | 298 | 8120 |

After this stage, the following conclusions are made:

1- As the mainlane volume increases, the entrance ramp capacity decreases.

2- Eliminating the exit ramp does not impact the entrance ramp capacity values in model 1, as the entrance ramp capacity values remain the same in model 2.

## 3.2 Correlation between Capacity of Two-Sided Weaves and R-R Ratio

Another dominant factor that can affect weaving capacity is the ramp to ramp (R-R) demand. The critical situation is when the exit ramp demand is equal or lower than the maximum entrance ramp demand, because, it allows for more vehicles from the mainlanes to stay on their path and therefore, cause an increase in the freeway to freeway volume. So, it is necessary to introduce two models here.

In the third model, exit ramp demands are kept lower or equal to entrance ramp capacity, and the second model examines the relation between weaving capacity and R-R demand when exit ramp demand is larger than entrance ramp capacity.

### *3.2.1 Correlation between weaving capacity and R-R ratio when exit ramp demand is equal to entrance ramp capacity*

Model 3: Now that the entrance ramp capacity values are found for each mainlane volume, different scenarios based on maximum entrance ramp demand for each mainlane (from Model 2) and exit ramp are conducted. R-R demand is increased gradually until R-R flow is lower than R-R demand. Two scenarios are introduced here. All scenarios for this model are summarized in Table 3.4.

Scenario 2: in this scenario, mainlane volume is 6000 vph, the entrance ramp volume has a volume of 600 vph, the exit ramp has a volume of 500 vph and R-R demand is increased until R-R flow is lower than R-R demand. In this scenario, R-R varies from 0 to 500 vph. Figure 3.16 shows the relationship between R-R demand and R-R flow. The maximum R-R volume that this network can process is 100 vph while the mainlanes demand is 6000 vph. Therefore, the maximum R-R ratio that can be processed in this scenario is 20% which shows that the assumption that R-R ratio at 10-25% in model 2, is a logical assumption.

Figure 3.17 shows the relation between R-R demand and total volume. As is apparent in the Figure, the mainlane capacity in this scenario is around 6,500 vph. Moreover, lane flows are compared to each other in Figure 3.18. Like scenario 2 of model 2, lane 1 has the lowest flow as vehicles avoide conflict with the entering vehicles. Also, as R-R demand increases, the exit ramp flow decreases because as R-R increases, a greater fraction of the exit ramp demand is coming from the R-R flow. If the R-R flow hits capacity and cannot increase, the exit ramp flow is decreased. Appendix C shows all scenarios for this model.

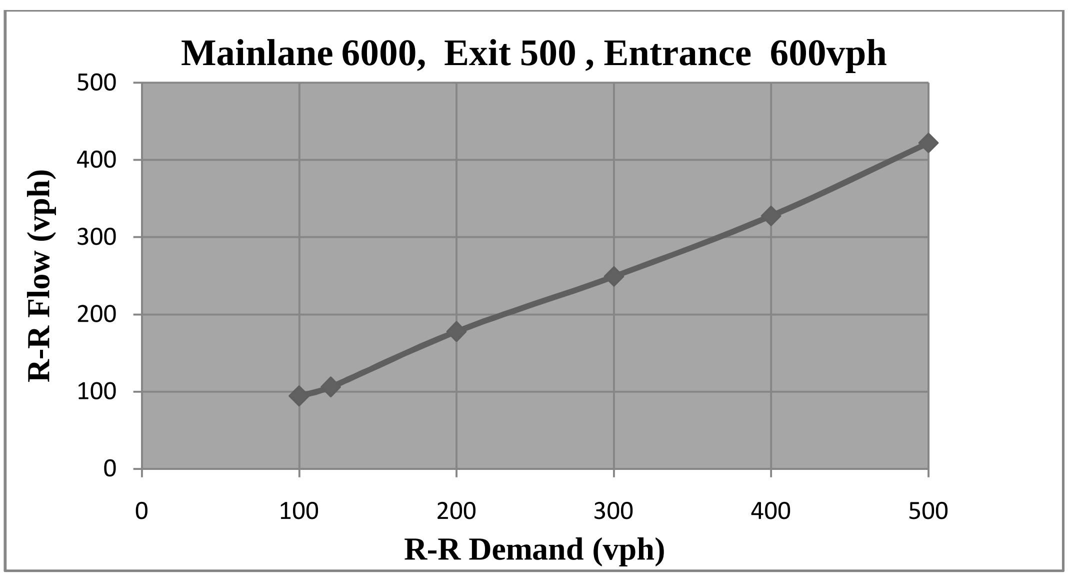



Figure 3.16 R-R Demand vs. R-R Flow for scenario 2 Model 3

Scenario 4: in this scenario, mainlane volume, entrance ramp volume and exit ramp volume are 8000, 400 and 400 vph, respectively, and the R-R volume varies from 0 to 400 vph. Figure 3.19 shows the relation between R-R demands and the R-R flow. Similar to scenario 1, maximum R-R ratio that can be processed is 20%. Figure 3.20 shows the relation between R-R demand and total volume. The mainlane capacity in this scenario is around 8,300 vph.

Table 3.4 Summary of all scenarios for Model 3

| Scenarios | Runs | Demand (vph) | | | | Flow (vph) | | |
|---|---|---|---|---|---|---|---|---|
| | | Entrance Ramp | Mainlanes | Exit Ramp | R-R | Entrance Ramp | V | R-R |
| 1 | 1 | 900 | 5000 | 900 | 200 | 899 | 5881 | 197 |
| | 2 | 900 | 5000 | 900 | 400 | 896 | 5879 | 390 |
| | 3 | 900 | 5000 | 900 | 600 | 878 | 5856 | 573 |
| | 4 | 900 | 5000 | 900 | 800 | 894 | 5874 | 784 |
| | 5 | 900 | 5000 | 900 | ***900*** | 898 | 5880 | 884 |
| 2 | 1 | 600 | 6000 | 500 | ***100*** | 571 | 6537 | 94 |
| | 2 | 600 | 6000 | 500 | 200 | 554 | 6518 | 178 |
| | 3 | 600 | 6000 | 500 | 300 | 531 | 6497 | 249 |
| | 4 | 600 | 6000 | 500 | 400 | 521 | 6487 | 328 |
| | 5 | 600 | 6000 | 500 | 500 | 535 | 6507 | 422 |
| 3 | 1 | 400 | 7000 | 400 | ***80*** | 372 | 7340 | 78 |
| | 2 | 400 | 7000 | 400 | 100 | 373 | 7341 | 92 |
| | 3 | 400 | 7000 | 400 | 200 | 373 | 7341 | 177 |
| | 4 | 400 | 7000 | 400 | 300 | 377 | 7347 | 270 |
| | 5 | 400 | 7000 | 400 | 400 | 383 | 7346 | 358 |
| 4 | 1 | 400 | 8000 | 400 | ***80*** | 400 | 8353 | 80 |
| | 2 | 400 | 8000 | 400 | 100 | 379 | 8316 | 94 |
| | 3 | 400 | 8000 | 400 | 200 | 385 | 8310 | 186 |
| | 4 | 400 | 8000 | 400 | 300 | 344 | 8244 | 238 |
| | 5 | 400 | 8000 | 400 | 400 | 397 | 8317 | 384 |

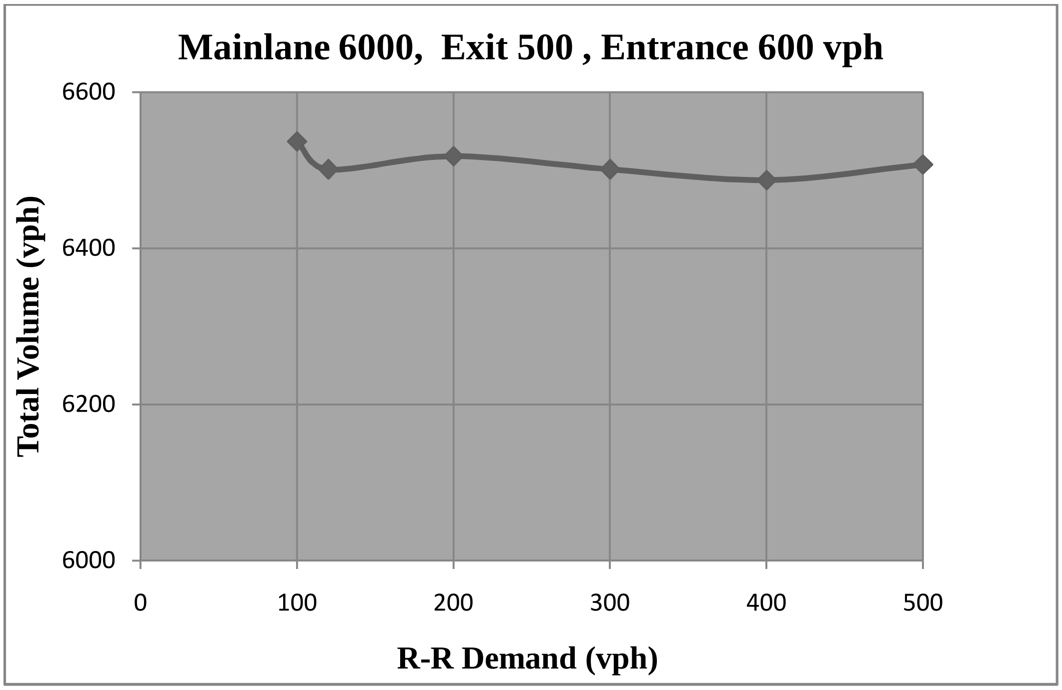



Figure 3.17 R-R Demand vs. Total Volume for scenario 2 Model 3

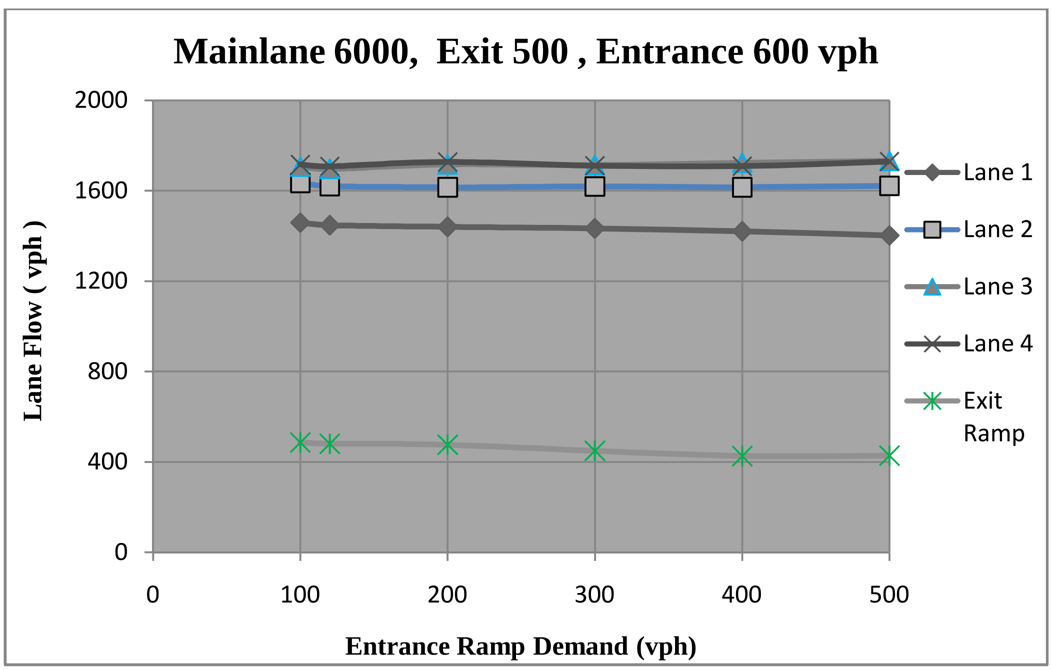



Figure 3.18 R-R Demand vs. Lane Flow for scenario 2 Model 3

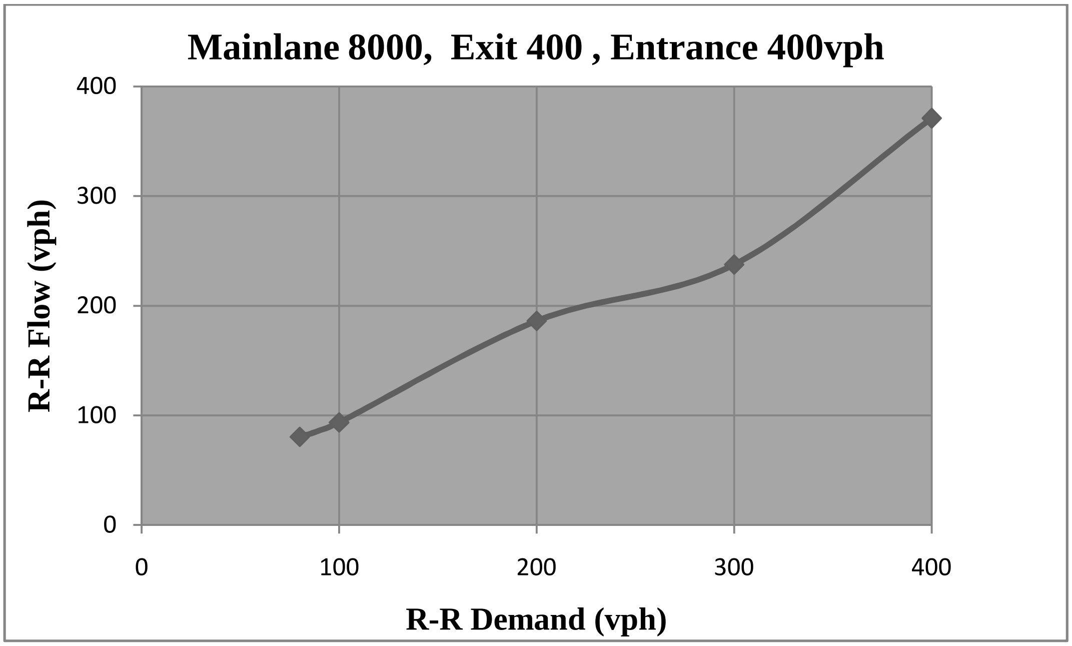



Figure 3.19 R-R Demand vs. R-R Flow for scenario 4 Model 3

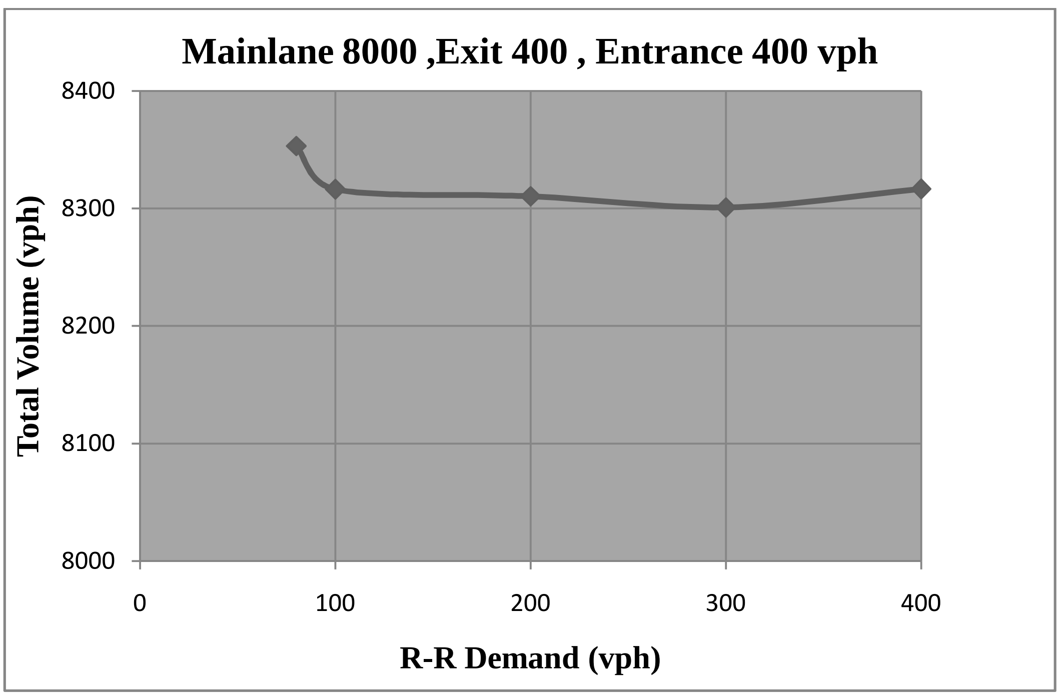



Figure 3.20 R-R Demand vs. Total Volume for scenario 4 Model 3

After this stage, the following conclusions have been formed:

1- The maximum R-R ratio that can be processed is 20-25% when mainlane volume is between 6000 - 8000 vph, entrance ramp at capacity and exit ramp demand is equal to entrance ramp capacity.

2- At capacity, as R-R demand increases, exit ramp flow decreases.

*3.2.2 Correlation between weaving capacity and R-R ratio when exit ramp demand is larger than entrance ramp capacity*

Model 4: At this stage, different scenarios based on the maximum entrance ramp for each mainlane (from Model 2) and exit ramp between 1000- 2000 vph are conducted and R-R is increased gradually until R-R flow is lower than R-R demand.

A summary of all scenarios is shown in Table 3.5. Mainlane demands between 6000 and 8000 vph are used. Entrance ramp demand is equal to corresponding entrance ramp capacity, found in Model 2. Three scenarios are introduced here.

Scenario1: In this scenario, the mainlane volume, entrance ramp volume and exit ramp are 6000, 600 and 1000 vph, respectively, and R-R demand is increased until R-R flow is lower than R-R demand. In this scenario, R-R varies from 200 to 600 vph.

Figure 3.21 shows the relation between R-R demand and R-R flow. In this scenario, 100 % of the R-R demand can be processed. Figure 3.22 also presents the relation between R-R demand and the total flow. As apparent, this scenario has not reached capacity.

Scenario 17: In this scenario, the mainlane volume, entrance ramp demand and exit ramp demand are 8000, 500 and 1500, respectively. The R-R volume changes from 200 to 500 vph.

Figure 3.23 shows the relation between the R-R demand and the R-R flow. The R-R flow is equal to R-R demand until R-R demand reaches 200 vph. As R-R demand increases, R-R flow is less than R-R demand. Figure 3.24 shows the relation between R-R demand and total volume flow. This scenario has reached capacity since the total volume flows are much lower than their demands. As demand R-R increases, the total volume decreases. Appendix D presents all scenarios for this model.

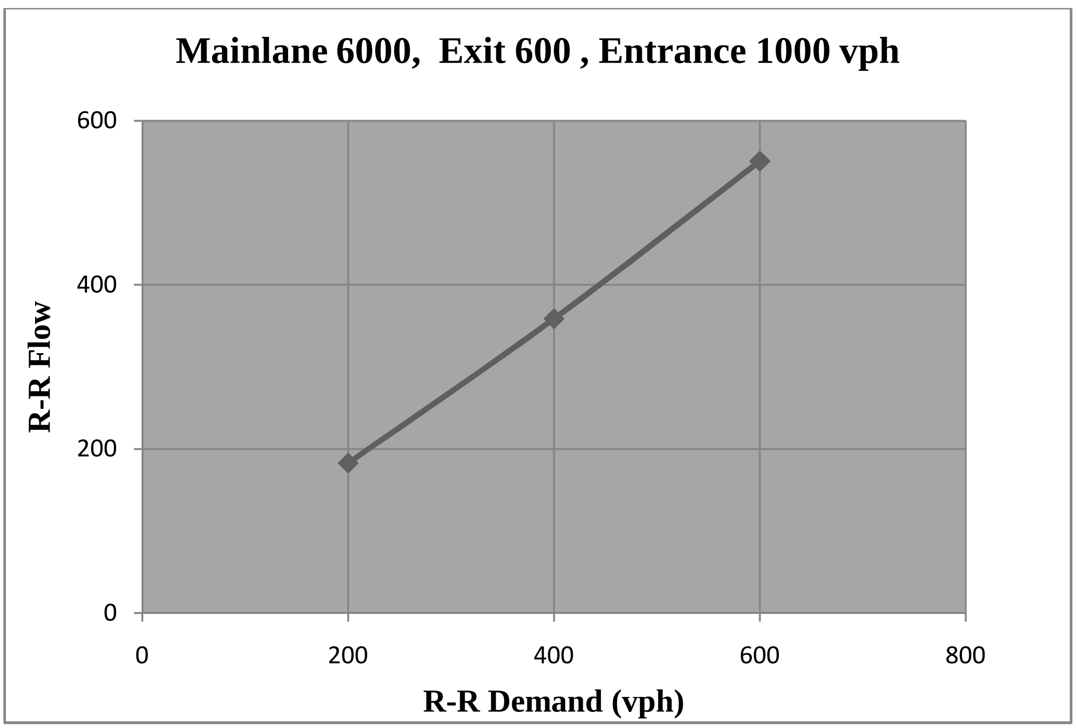



Figure 3.21 R-R Demand vs. R-R Flow for scenario 1 Model 4

Table 3.5 Model 4 inputs

| scenario | entrance ramp | Mainlanes | Exit Ramp | R-R |
|---|---|---|---|---|
| 1 | 600 | 6000 | 1000 | 200-600 |
| 2 | 600 | 6000 | 1500 | 200-600 |
| 3 | 600 | 6000 | 2000 | 200-600 |
| 4 | 500 | 6800 | 1000 | 200-500 |
| 5 | 500 | 6800 | 1500 | 200-500 |
| 6 | 500 | 6800 | 2000 | 200-500 |
| 7 | 500 | 7000 | 1000 | 200-500 |
| 8 | 500 | 7000 | 1500 | 200-500 |
| 9 | 500 | 7000 | 1700 | 200-500 |
| 10 | 500 | 7000 | 1900 | 200-500 |
| 11 | 500 | 7000 | 2000 | 200-500 |
| 12 | 500 | 7200 | 1000 | 200-500 |
| 13 | 500 | 7500 | 1000 | 200-500 |
| 14 | 500 | 7500 | 1500 | 200-500 |
| 15 | 500 | 7500 | 2000 | 200-500 |
| 16 | 500 | 8000 | 1000 | 200-500 |
| 17 | 500 | 8000 | 1500 | 200-500 |
| 18 | 500 | 8000 | 2000 | 200-500 |


Figure 3.22 R-R Demand vs. Total Volume for scenario 1 Model 4

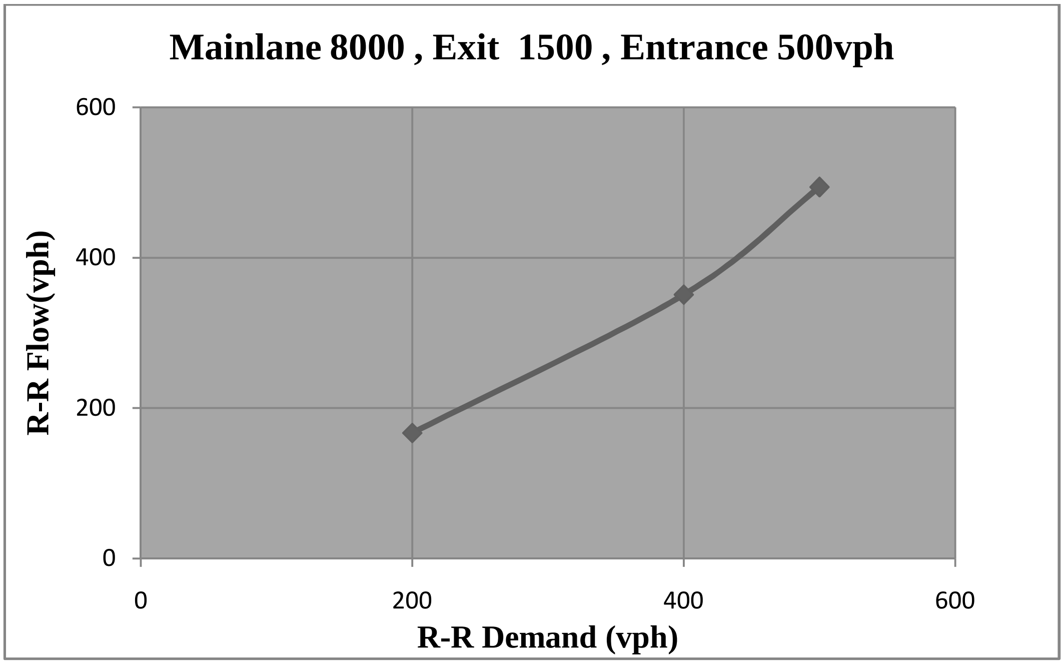



Figure 3.23 R-R Demand vs. R-R Flow for scenario 17 Model 4

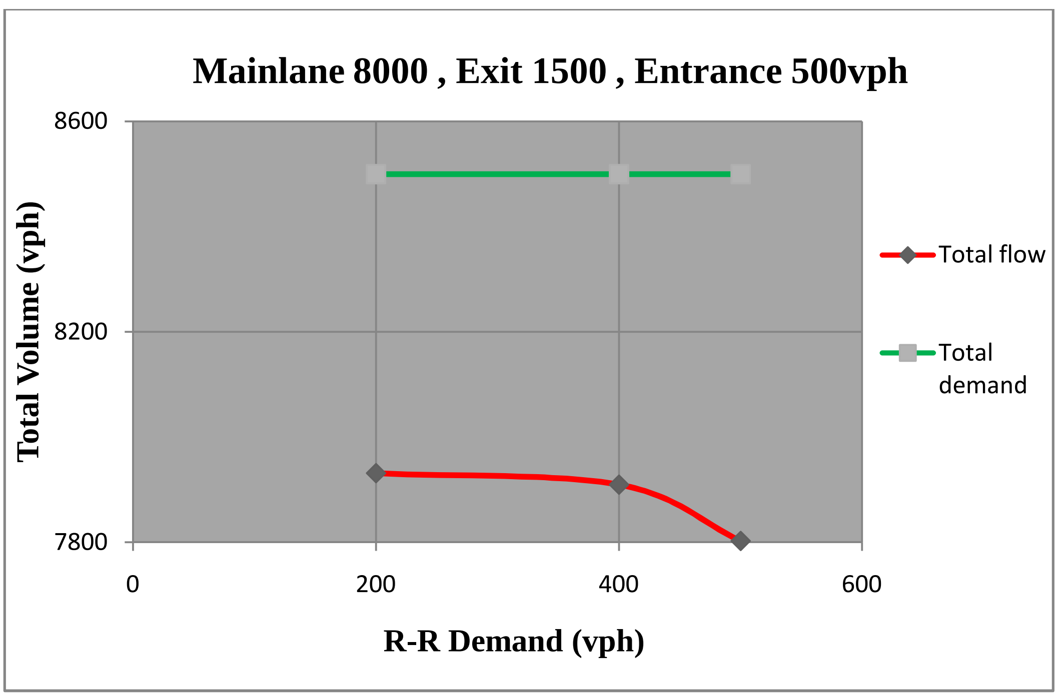



Figure 3.24 R-R Demand vs. Total Volume for scenario 17 Model 4

Scenario 13: In this scenario, mainlane volume, entrance ramp demand and exit ramp demand are 7500, 500 and 1000 vph, respectively. The R-R demand changes from 200 to 500 vph.

Figure 3.25 shows the relation between the R-R demand and the R-R flow for this scenario. Also, Figure 3.26 shows the relation between the R-R demand and the total flow for this scenario.

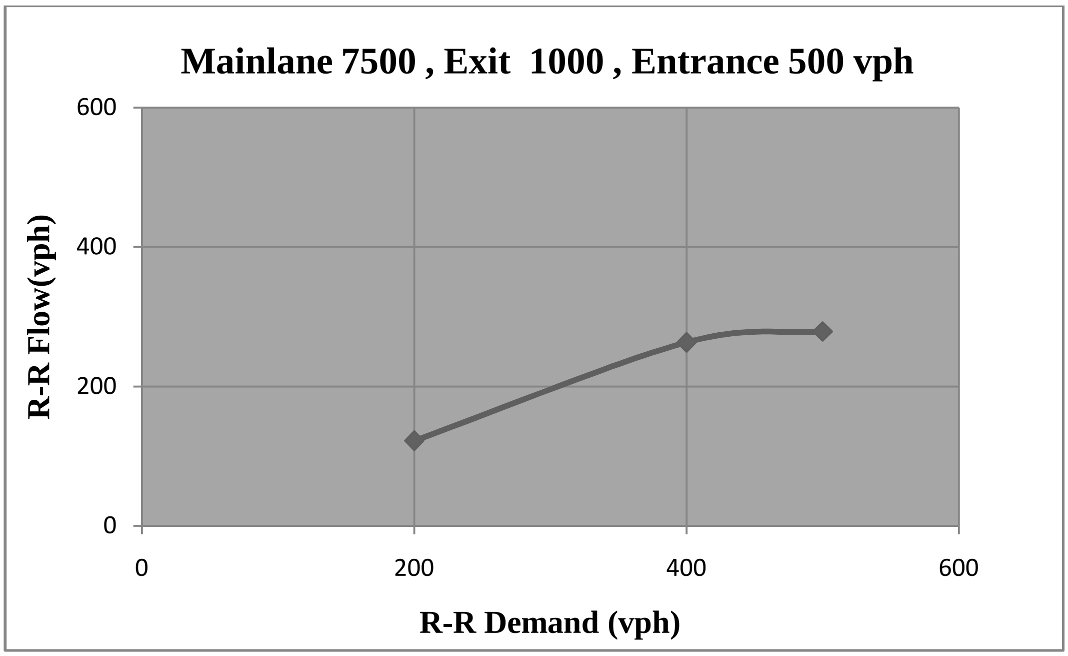



Figure 3.25 R-R Demand vs. R-R Flow for scenario 13 Model 4

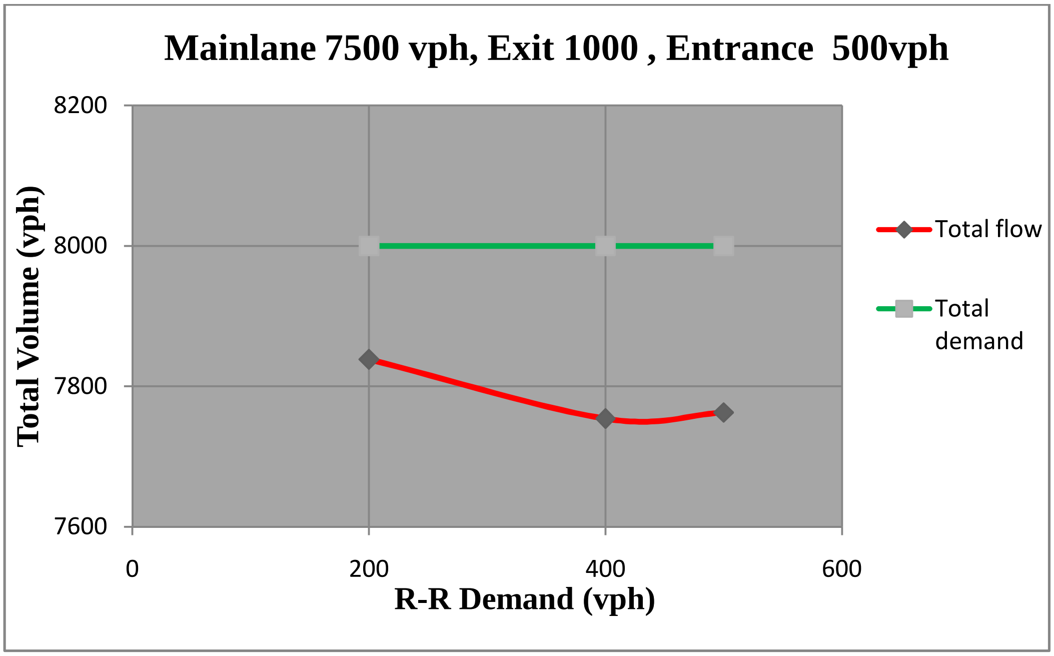



Figure 3.26 R-R Demand vs. Total Volume for scenario 13 Model 4

All scenarios for Model 4 are summarized in Table 3.6.After this stage, the following conclusion can be made.

1- The system reaches capacity when the mainlane demand is somewhere below 7,200 vph.

2- At capacity, as the R-R demand increases, the total volume decreases.

Table 3.6 Summary of all scenarios for Model 4

| Scenario | Demand (vph) | | | | Flow(vph) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mainlane | Exit | Entrance | R-R | Exit | Entrance | R-R | V |
| 1 | 6000 | 1000 | 600 | 200 | 975 | 561 | 183 | 6538 |
| | 6000 | 1000 | 600 | 400 | 956 | 563 | 359 | 6532 |
| | 6000 | 1000 | 600 | 600 | 947 | 566 | 551 | 6523 |
| 2 | 6000 | 1500 | 600 | 200 | 1444 | 523 | 170 | 6493 |
| | 6000 | 1500 | 600 | 400 | 1438 | 561 | 358 | 6531 |
| | 6000 | 1500 | 600 | 600 | 1410 | 541 | 514 | 6510 |
| 3 | 6000 | 2000 | 600 | 200 | 1950 | 560 | 170 | 6535 |
| | 6000 | 2000 | 600 | 400 | 1950 | 583 | 358 | 6557 |
| | 6000 | 2000 | 600 | 600 | 1967 | 595 | 514 | 6579 |
| 4 | 6800 | 1000 | 500 | 200 | 959 | 448 | 171 | 7207 |
| | 6800 | 1000 | 500 | 400 | 940 | 467 | 347 | 7225 |
| | 6800 | 1000 | 500 | 500 | 930 | 469 | 436 | 7232 |
| 5 | 6800 | 1500 | 500 | 200 | 1431 | 348 | 183 | 7121 |
| | 6800 | 1500 | 500 | 400 | 1431 | 447 | 347 | 7207 |
| | 6800 | 1500 | 500 | 500 | 1430 | 468 | 436 | 7237 |
| 6 | 6800 | 2000 | 500 | 200 | 1934 | 448 | 174 | 7202 |
| | 6800 | 2000 | 500 | 400 | 1932 | 474 | 362 | 7245 |
| | 6800 | 2000 | 500 | 500 | 1430 | 468 | 450 | 7236 |
| 7 | 7000 | 1000 | 500 | 200 | 967 | 499 | 175 | 7462 |
| | 7000 | 1000 | 500 | 400 | 941 | 453 | 350 | 7421 |
| | 7000 | 1000 | 500 | 500 | 893 | 424 | 399 | 7390 |
| 8 | 7000 | 1500 | 500 | 200 | 1436 | 499 | 153 | 7463 |
| | 7000 | 1500 | 500 | 400 | 1420 | 450 | 342 | 7417 |
| | 7000 | 1500 | 500 | 500 | 1401 | 442 | 413 | 7406 |
| 9 | 7000 | 1700 | 500 | 200 | 1647 | 481 | 188 | 7430 |
| | 7000 | 1700 | 500 | 400 | 1420 | 450 | 342 | 7417 |
| | 7000 | 1700 | 500 | 500 | 1573 | 431 | 403 | 7393 |
| 10 | 7000 | 1900 | 500 | 200 | 1828 | 431 | 176 | 7412 |
| | 7000 | 1900 | 500 | 400 | 1771 | 427 | 305 | 7357 |
| | 7000 | 1900 | 500 | 500 | 1825 | 488 | 462 | 7411 |
| 11 | 7000 | 2000 | 500 | 200 | 1939 | 452 | 201 | 7403 |
| | 7000 | 2000 | 500 | 400 | 1937 | 433 | 383 | 7425 |
| | 7000 | 2000 | 500 | 500 | 1861 | 421 | 436 | 7350 |

Table 3.6 - continued

| Scenario | Demand (vph) | | | | Flow (vph) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mainlane | Exit | Entrance | R-R | Exit | Entrance | R-R | V |
| 12 | 6000 | 1000 | 600 | 200 | 975 | 561 | 183 | 6538 |
| | 6000 | 1000 | 600 | 400 | 956 | 563 | 359 | 6532 |
| | 6000 | 1000 | 600 | 600 | 947 | 566 | 551 | 6523 |
| 13 | 6000 | 1500 | 600 | 200 | 1444 | 523 | 170 | 6493 |
| | 6000 | 1500 | 600 | 400 | 1438 | 561 | 358 | 6531 |
| | 6000 | 1500 | 600 | 600 | 1410 | 541 | 514 | 6510 |
| 14 | 6000 | 2000 | 600 | 200 | 1950 | 560 | 170 | 6535 |
| | 6000 | 2000 | 600 | 400 | 1950 | 583 | 358 | 6557 |
| | 6000 | 2000 | 600 | 600 | 1967 | 595 | 514 | 6579 |
| 15 | 6800 | 1000 | 500 | 200 | 959 | 448 | 171 | 7207 |
| | 6800 | 1000 | 500 | 400 | 940 | 467 | 347 | 7225 |
| | 6800 | 1000 | 500 | 500 | 930 | 469 | 436 | 7232 |
| 16 | 6800 | 1500 | 500 | 200 | 1431 | 348 | 183 | 7121 |
| | 6800 | 1500 | 500 | 400 | 1431 | 447 | 347 | 7207 |
| | 6800 | 1500 | 500 | 500 | 1430 | 468 | 436 | 7237 |
| 17 | 6800 | 2000 | 500 | 200 | 1934 | 448 | 174 | 7202 |
| | 6800 | 2000 | 500 | 400 | 1932 | 474 | 362 | 7245 |
| | 6800 | 2000 | 500 | 500 | 1430 | 468 | 450 | 7236 |
| 18 | 7000 | 1000 | 500 | 200 | 967 | 499 | 175 | 7462 |
| | 7000 | 1000 | 500 | 400 | 941 | 453 | 350 | 7421 |
| | 7000 | 1000 | 500 | 500 | 893 | 424 | 399 | 7390 |

# CHAPTER 4

# CONCLUSION AND RECOMMENDATIONS

Weaving segments are categorized based on weaving length, configuration, number of lanes, free flow speed and weaving ratio. All mentioned parameters affect weaving capacity. The existing method uses speed to obtain weaving capacity in HCM 2000, while in this research; micro simulation has been used in order to analyze different capacity scenarios. The parameter which has been taken into consideration is the weaving ratio (smaller weaving flow/ total weaving flow). The objective of this research was to extend Vo's work and study the relation between weaving capacity and any potential variables (entrance ramp demand, exit ramp demand, weaving ratio and mainlane demand) on freeways with four lanes.

Vo's calibrated model has been used in order to build the VISSIM model. All the calibration parameters were kept constant. There are some parameters which should to be revised in order for VISSIM to better estimate capacities. They are as follows.

- The acceleration lane was too short. TXDOT usually uses a 400-500 ft acceleration lane which, if used in collaboration withVISSIM would allow a lot more vehicles to enter the freeway.

- Vo’s data [Ref.3] shows that the exit ramp was running at capacity in most of the time, thus causing left lane to have high volumes. In order to give vehicles enough time to change time, Vo had to define a fairly long distance (2500 ft) as lane change distance for vehicles to start merging.
- Time before diffusion specified in Vo’s calibrated model (60 seconds) was too long for vehicles to merge from entrance ramp into the freeway.

The VISSIM model was calibrated under low volume inputs. Therefore, low entrance ramp capacity values have been obtained by this model. Different calibration parameters are the basis of this issue. These calibration parameters are as follows.

- CC0
- CC1
- CC4/CC5
- Time before diffusion
- Minimum headway
- Lane change distance

There are other car-following parameters available in VISSIM. They have not been used in the model calibration process due to the fact that the necessary information was not available. Also, the other car-following parameter has less effect on capacity compared to CC0, CC1 and CC4/CC5.

Four different models have been described to examine the relation between capacity and any potential variables. The results are as follows:

1- When mainlane volume is at 5000-8000 vph, entrance ramp capacity values are 900-400 vph accordingly.

2- Eliminating the exit ramp from VISSIM model did not affect the entrance ramp capacity values, since the entrance ramp capacity values remain the same in Models 1 and Model 2. It also shows that weaving activity is limited under this model.

3- When mainlane volume is at 5000-8000 vph, entrance ramp at capacity and exit ramp demand is at 800-1200 vph, the maximum R-R ratio that this model can process is 20-25%,

4- At capacity, as the R-R demand increases, the total volume ( mainlane + entrance ramp) decreases.

5- When mainlane volume is at 5000-8000 vph, entrance ramp at capacity and exit ramp demand is at 1000-2000 vph, system reaches capacity when mainlane demand is somewhere below 7200 vph.

With regards to results mentioned above, we can recommend the following proposals:

1- It is worthwhile to calibrate the VISSIM model under high volume inputs. Therefore, the micro- simulation analysis will probably result in more logical data sets.

2- In this research the weaving length was 0.52 miles. Another interesting topic is to study the weaving capacity of the two sided type C under varying weaving length.

3- To estimate the weaving capacity of the two-sided type C under varying number of lanes.

4- To use other Microscopic traffic simulation software such as CORSIM, AVENUE, or METSIM and compare their results to the results achieved by VISSIM.

# APPENDIX A

# SIMULATION RESULTS FOR MODEL 1

Appendix A includes simulation results of 4 scenarios for Model 1. The inputs of each scenario are summarized in the following table:

| Demand (vph) | | |
|---|---|---|
| Scenario | Mainlane | Entrance Ramp |
| 1 | 5000 | 200-2000 |
| 2 | 6000 | 200-2000 |
| 3 | 7000 | 200-2000 |
| 4 | 8000 | 200-2000 |

**Scenario 1**:

- Total mainlane volume is 5000 vph
- Entrance ramp is from 200 to 2000 vph

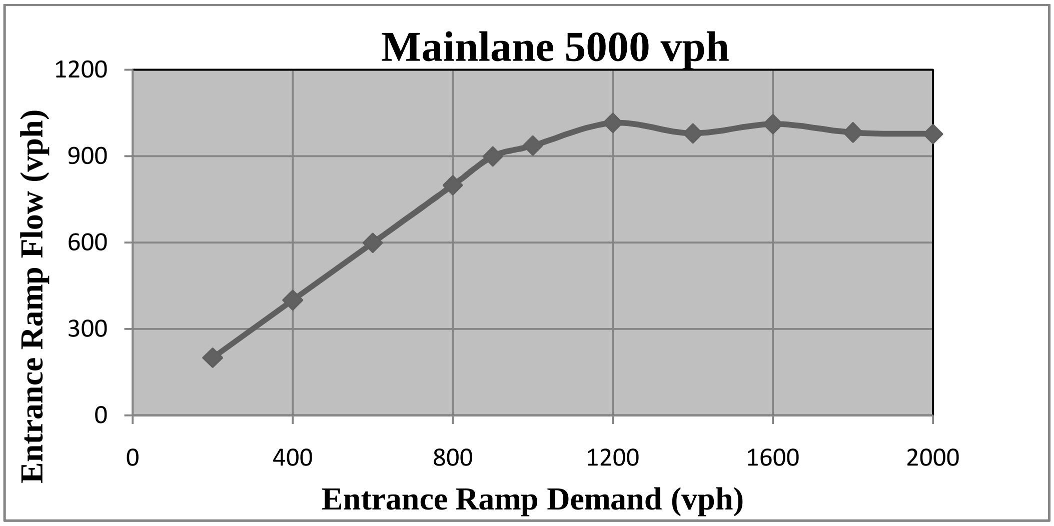



Figure A.1 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 1 Model 1

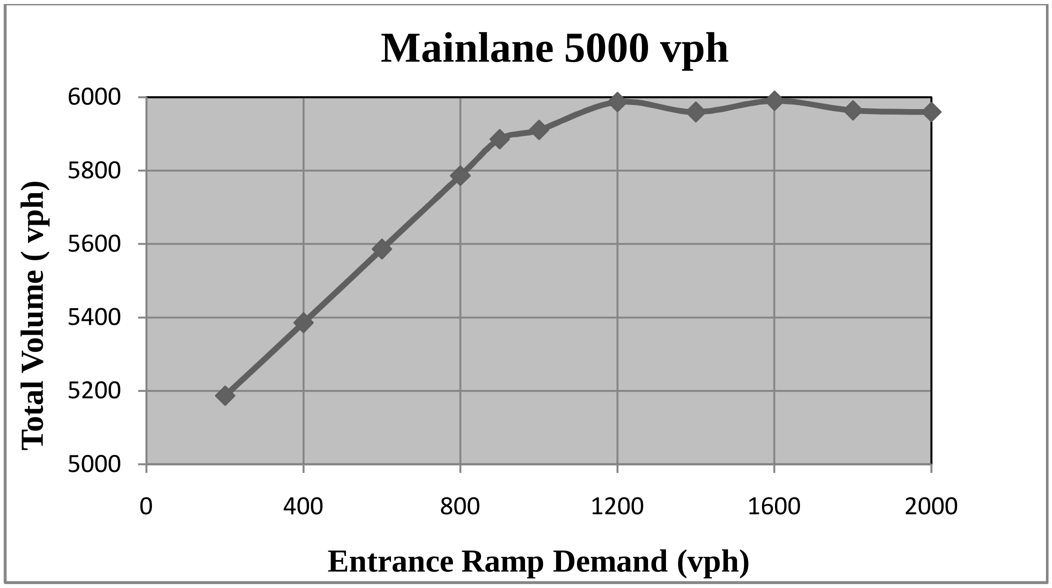



Figure A.2 Entrance Ramp Demand vs. Total Volume for scenario 1 Model 1

**Scenario 2**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 200 to 2000 vph

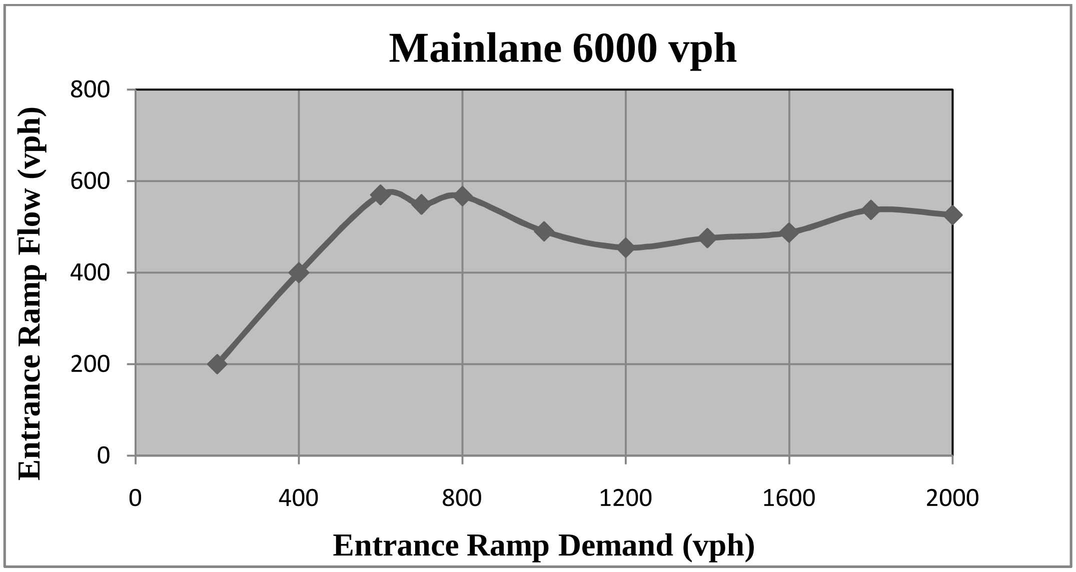



Figure A.3 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 2 Model 1

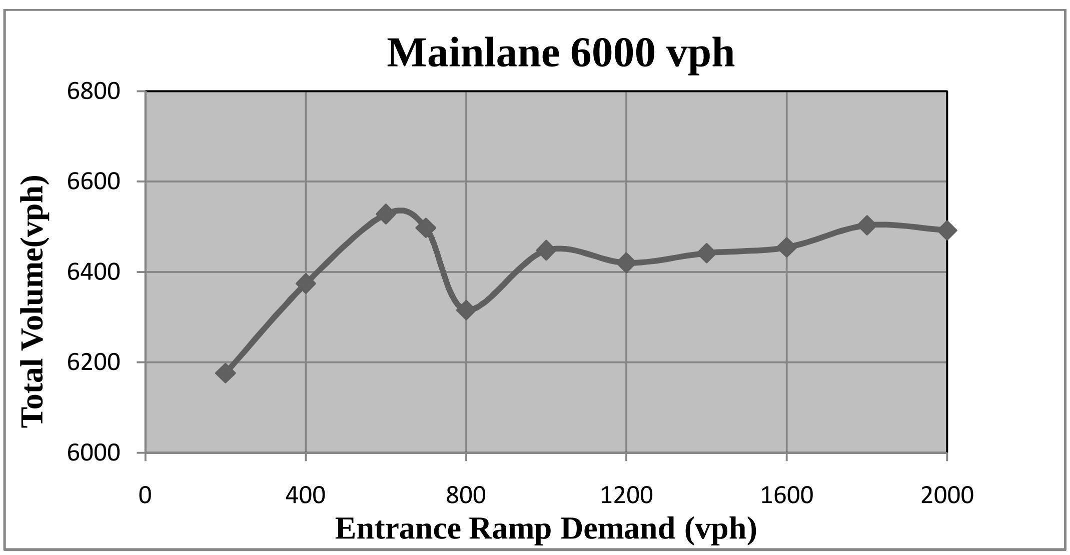



Figure A.4 Entrance Ramp Demand vs. Total Volume for scenario 2 Model 1

**Scenario 3**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 200 to 2000 vph

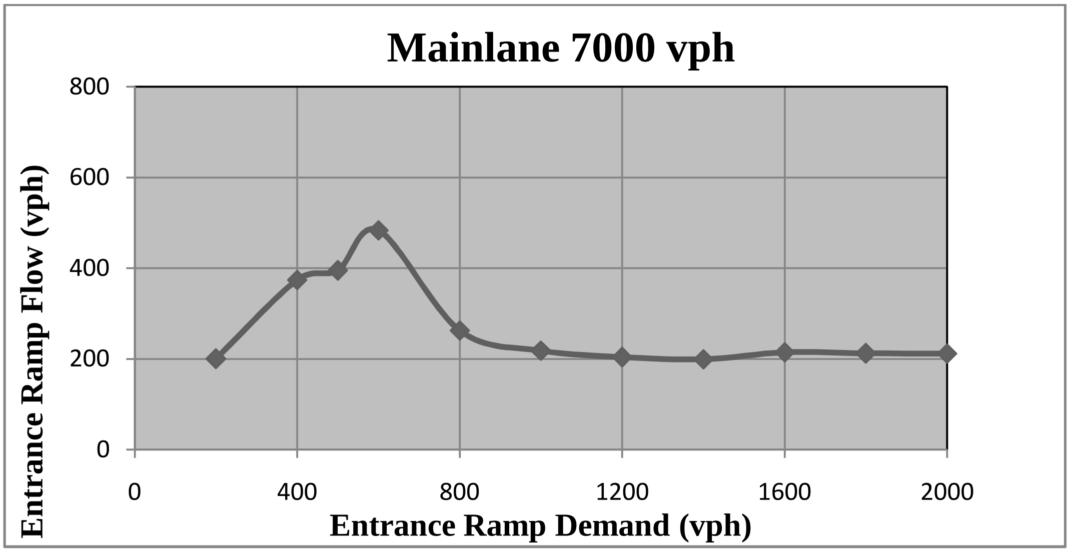



Figure A.5 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 3 Model 1

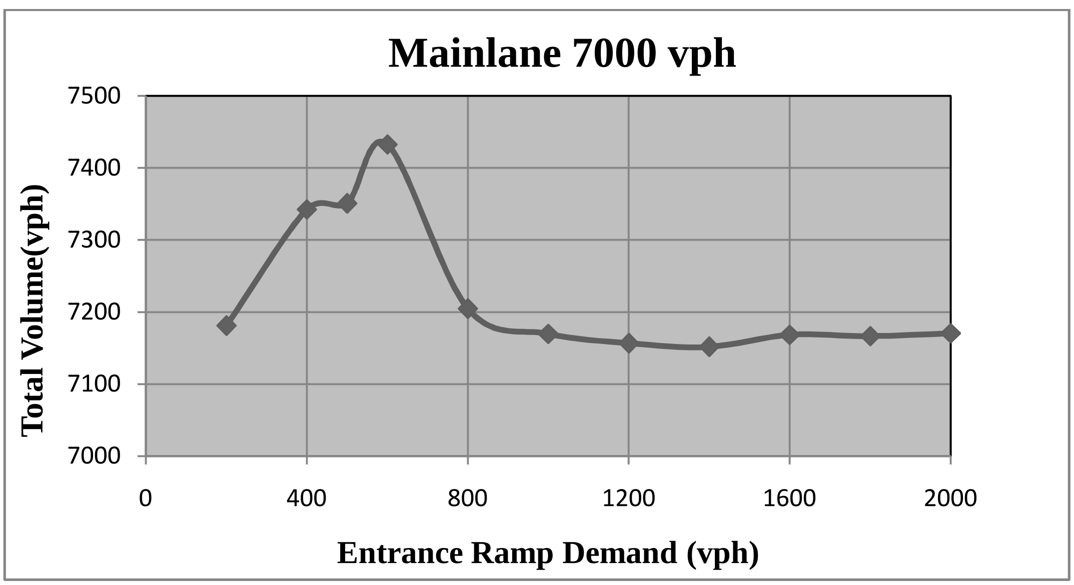



Figure A.6 Entrance Ramp Demand vs. Total Volume for scenario 3 Model 1

**Scenario 4**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 200 to 2000 vph

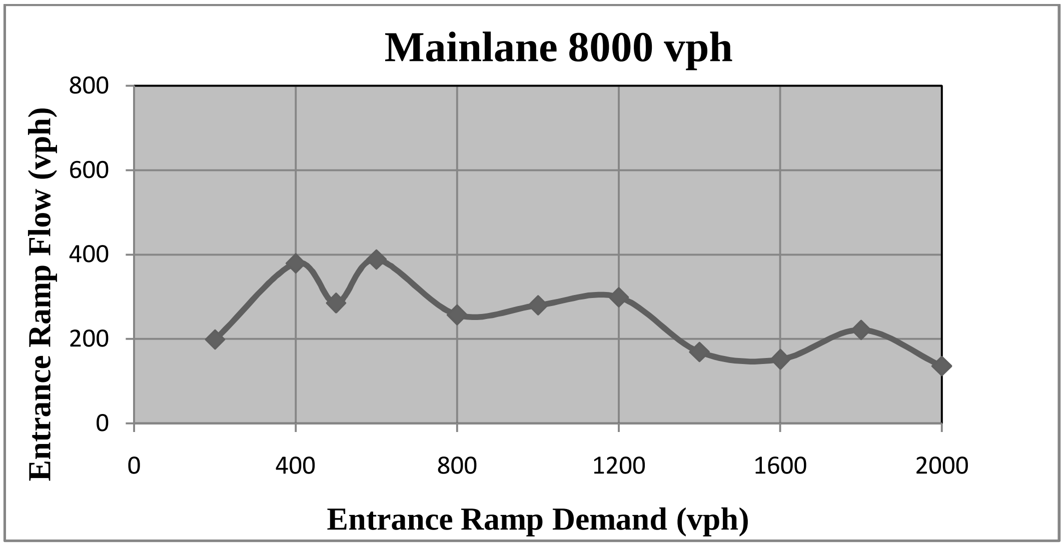



Figure A.7 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 4 Model 1

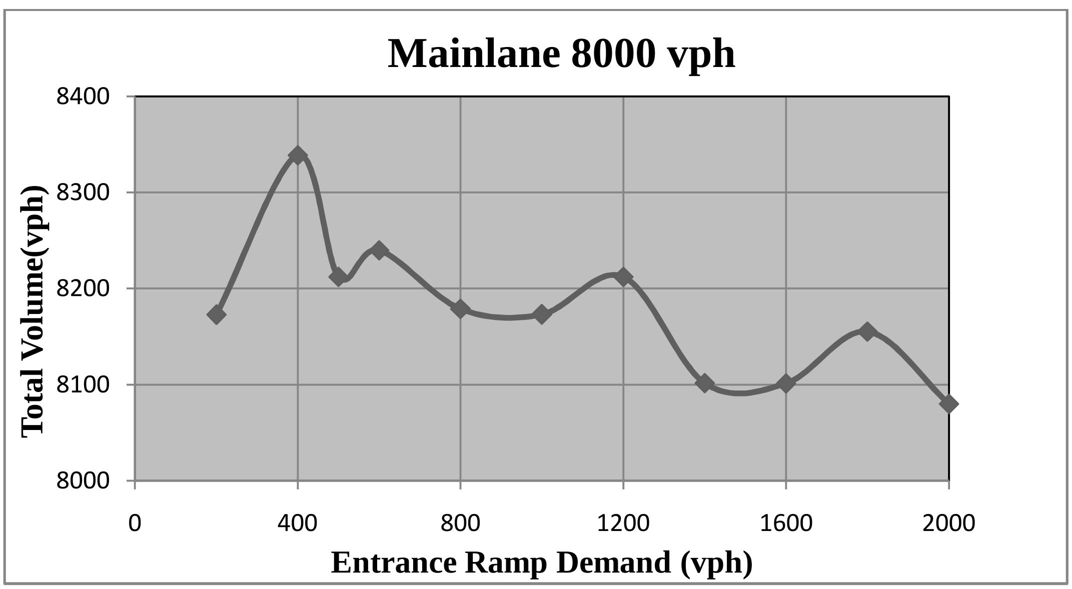



Figure A.8 Entrance Ramp Demand vs. Total Volume for scenario 4 Model 1

# APPENDIX B

# SIMULATION RESULTS FOR MODEL 2

Appendix B includes simulation results of 6 scenarios for Model 2. The inputs of each scenario are summarized in the following table:

| Demand (vph) | | | | |
|---|---|---|---|---|
| Scenario | Mainlane | Exit Ramp | Entrance Ramp | R-R |
| 1 | 4500 | 800 | 100-2000 | 10% |
| 2 | 6000 | 800 | 100-2000 | 25% |
| 3 | 7000 | 1200 | 100-2000 | 25% |
| 4 | 8000 | 1200 | 100-2000 | 25% |
| 5 | 8000 | 800 | 100-2000 | 25% |

**Scenario 1**:

- Total mainlane volume is 4500 vph
- Entrance ramp is from 100 to 2000 vph
- Exit Ramp is 800 vph
- R-R demand is 10%

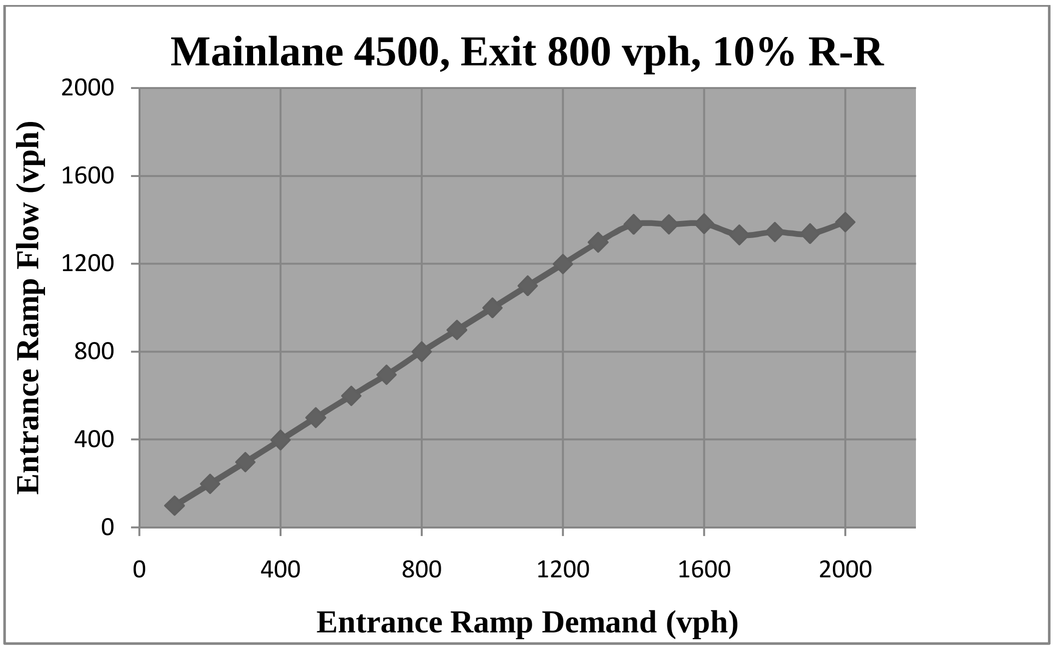



Figure B.1 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 1 Model 2

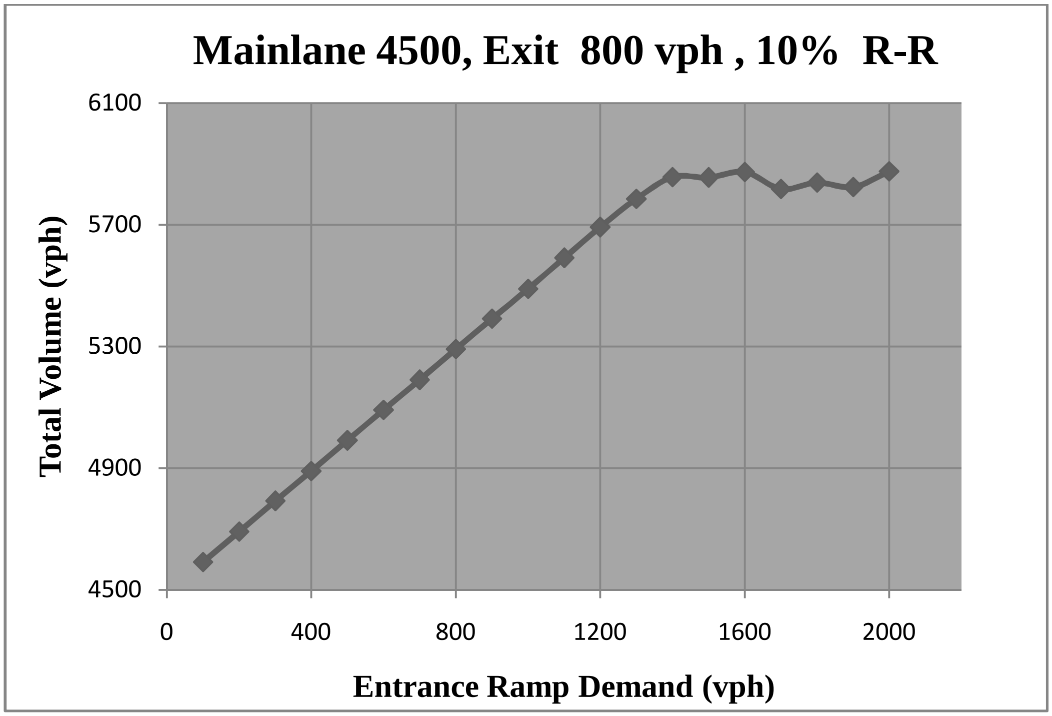



Figure B.2 Entrance Ramp Demand vs. Total Volume for scenario 1 Model 2

**Scenario 2**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 100 to 2000 vph
- Exit Ramp is 800 vph
- R-R demand is 25%

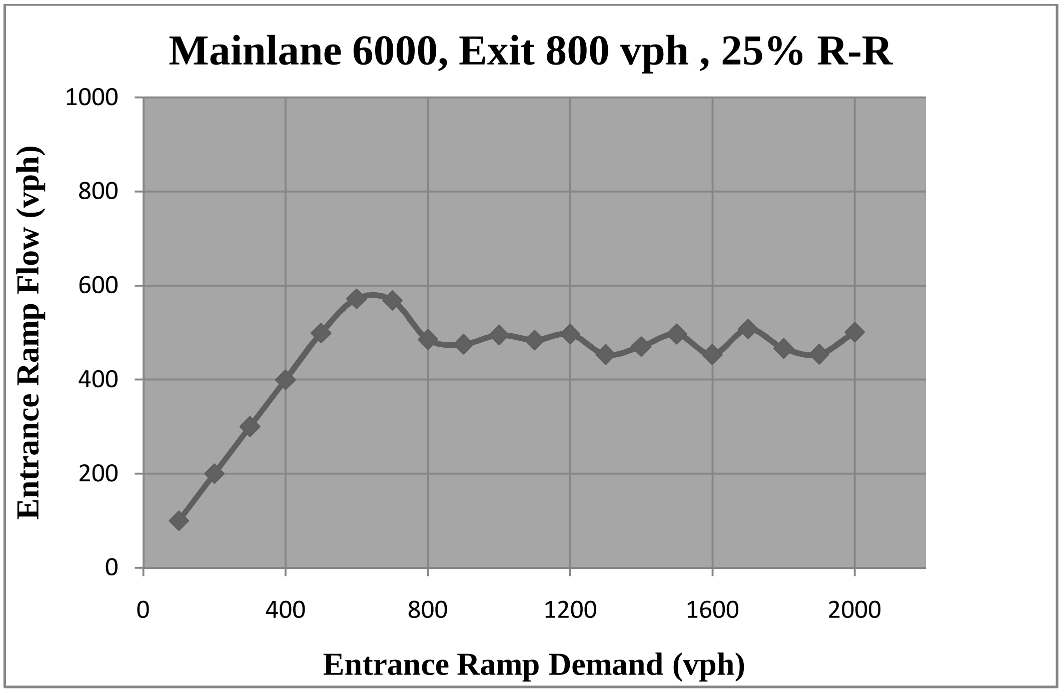



Figure B.3 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 2 Model 2

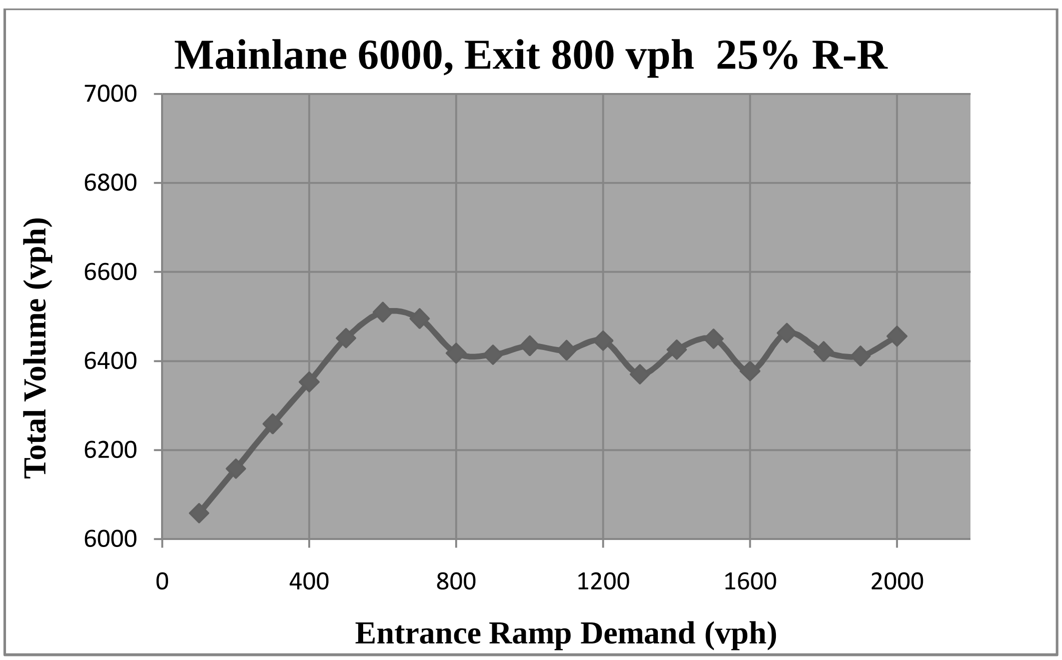



Figure B.4 Entrance Ramp Demand vs. Total Volume for scenario 2 Model 2

**Scenario 3**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 100 to 2000 vph
- Exit Ramp is 1200 vph
- R-R demand is 25%

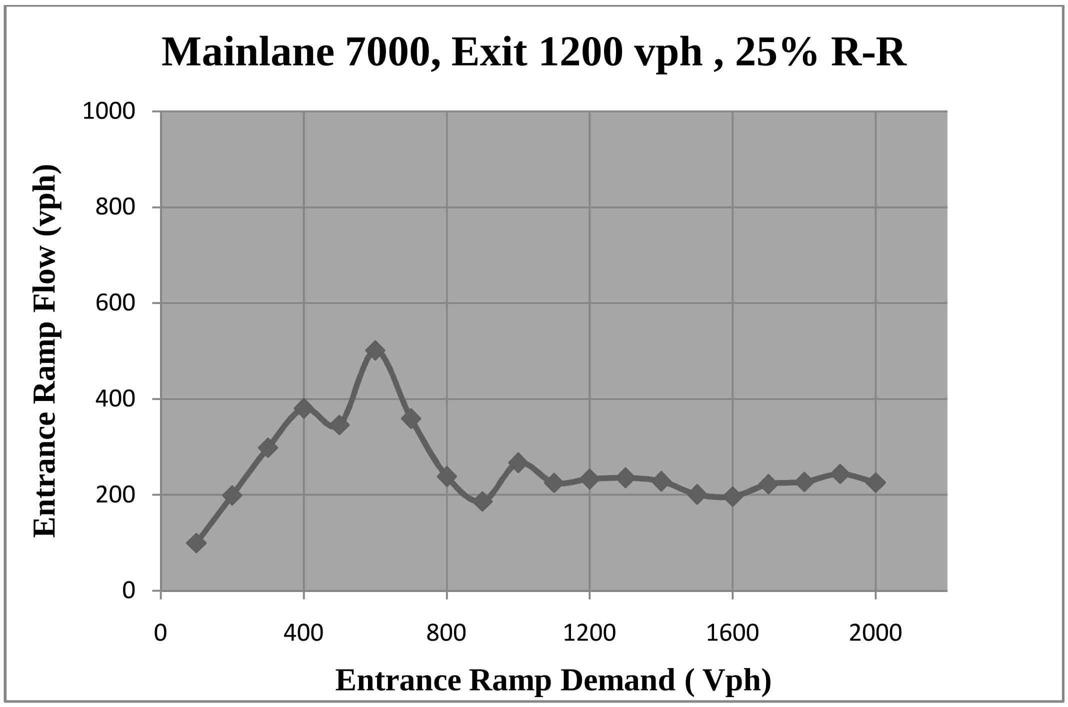



Figure B.5 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 3 Model 2

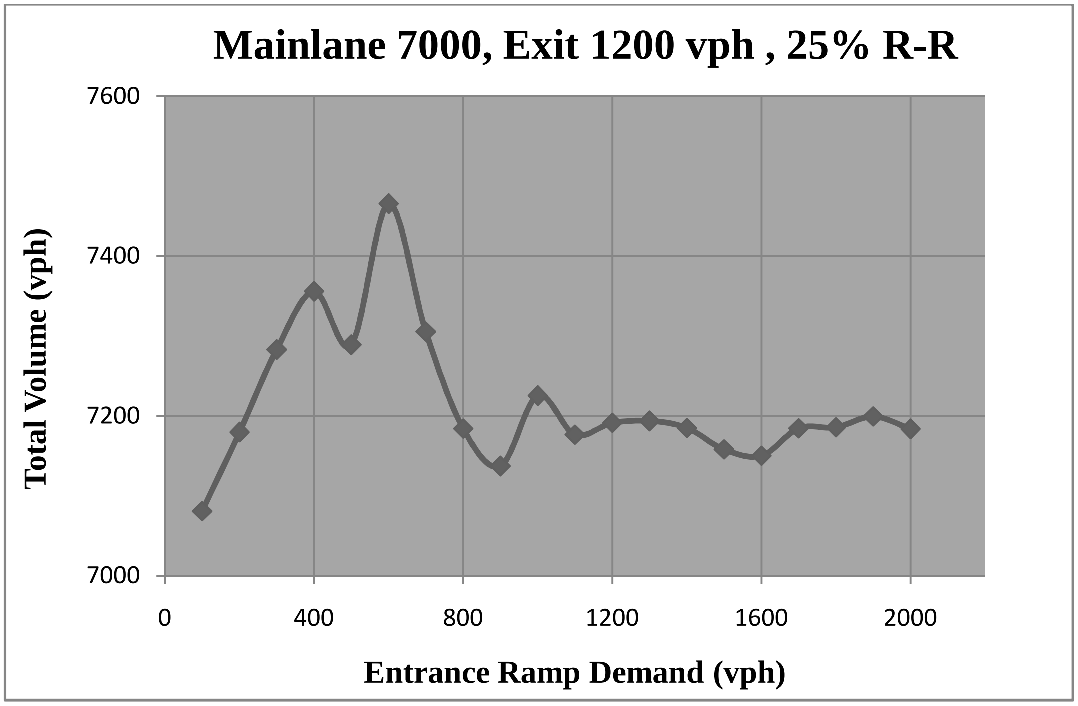



Figure B.6 Entrance Ramp Demand vs. Total Volume for scenario 3 Model 2

**Scenario 4**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 100 to 2000 vph
- Exit Ramp is 800 vph
- R-R demand is 25%

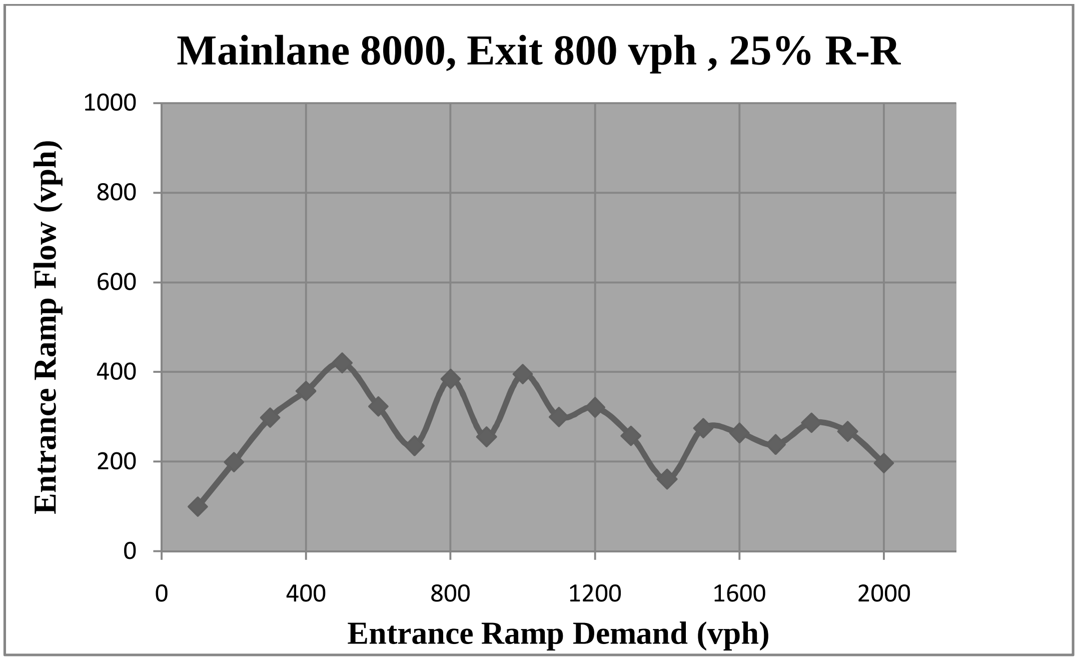



Figure B.7 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 4 Model 2

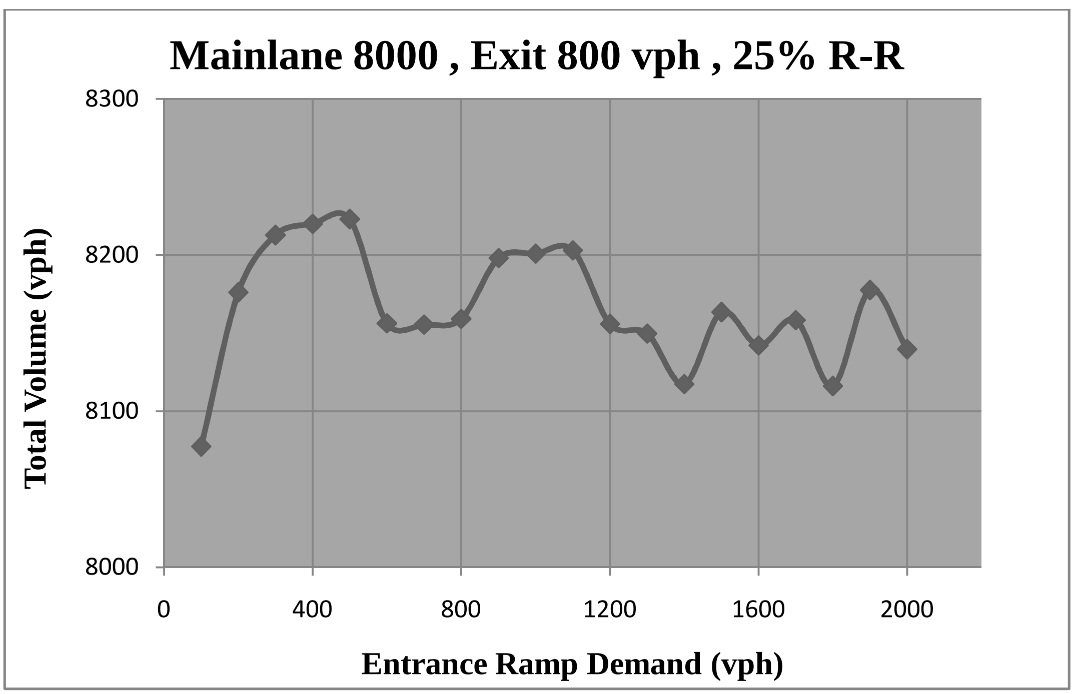



Figure B.8 Entrance Ramp Demand vs. Total Volume for scenario 4 Model 2

**Scenario 5**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 100 to 2000 vph
- Exit Ramp is 1200 vph
- R-R demand is 25%

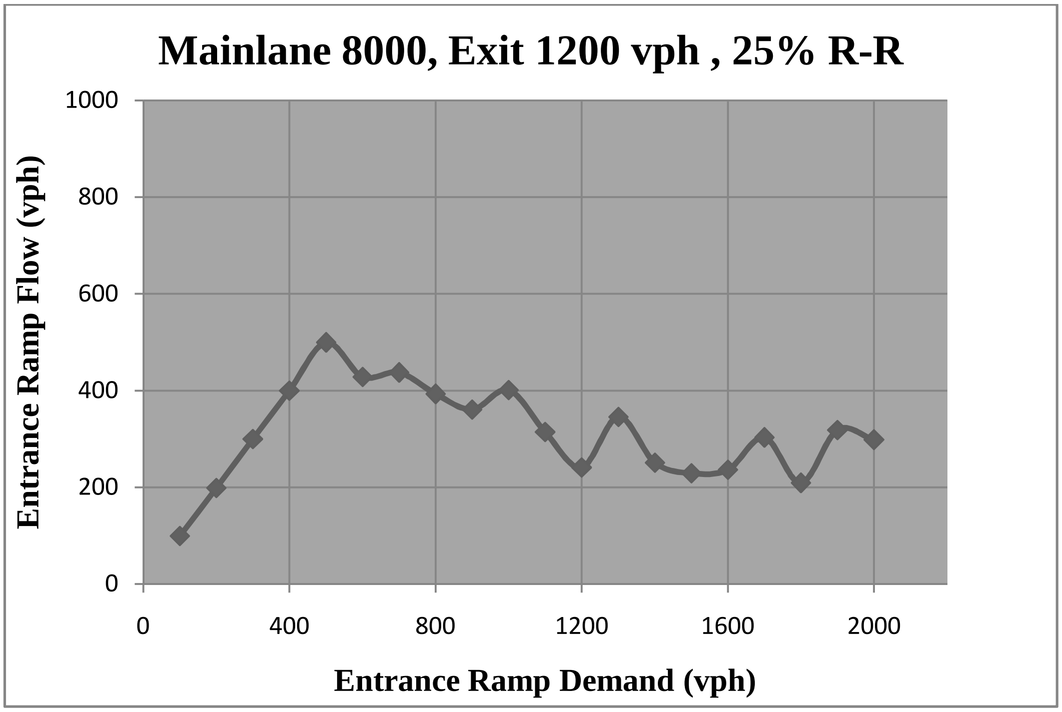



Figure B.9 Entrance Ramp Demand vs. Entrance Ramp Flow for scenario 5 Model 2

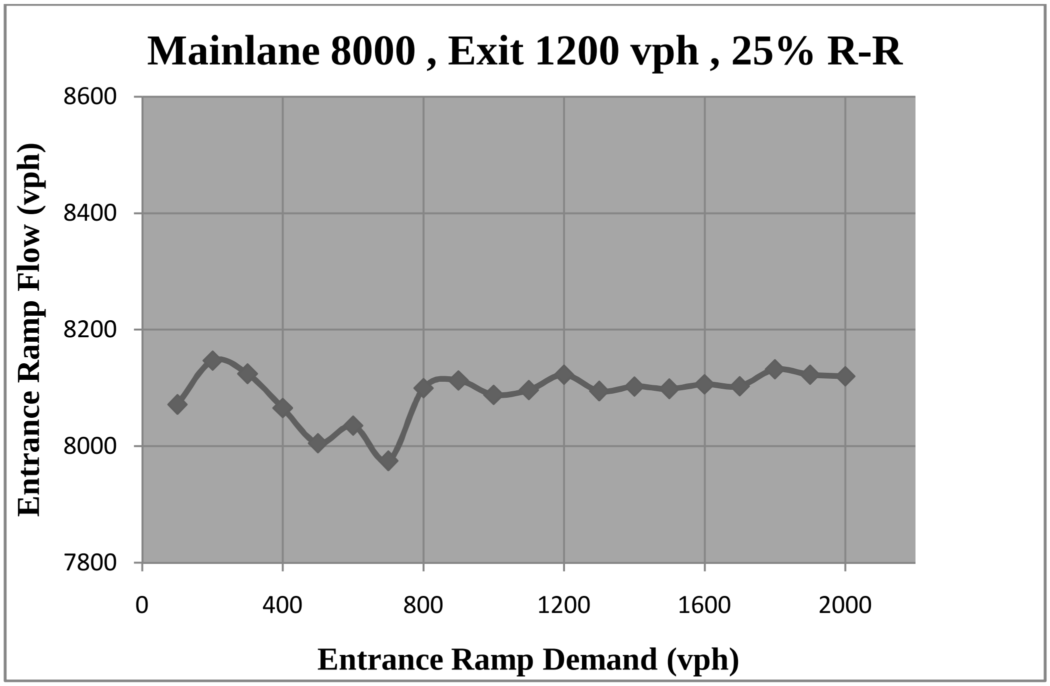



Figure B.10 Entrance Ramp Demand vs. Total Volume for scenario 5 Model 2

# APPENDIX C

# SIMULATION RESULTS FOR MODEL 3

Appendix C includes simulation results of 5 scenarios for Model 3. The inputs of each scenario are summarized in the following table:

| Demand (vph) | | | | |
|---|---|---|---|---|
| Scenario | Mainlane | Exit Ramp | Entrance Ramp | R-R |
| 1 | 5000 | 900 | 900 | 100-900 |
| 2 | 6000 | 500 | 600 | 100-500 |
| 3 | 6000 | 600 | 600 | 100-600 |
| 4 | 7000 | 400 | 400 | 80-400 |
| 5 | 8000 | 400 | 400 | 80-400 |

**Scenario 1**:

- Total mainlane volume is 5000 vph
- Entrance ramp is from 900 vph
- Exit Ramp is 900 vph
- R-R demand is from 100-900 vph

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 5000 | 900 | 900 | 200 | 4986 | 895 | 899 | 197 | 5881 | 4458 | 0.76 |
| 5000 | 900 | 900 | 400 | 4983 | 895 | 896 | 390 | 5879 | 4844 | 0.82 |
| 5000 | 900 | 900 | 600 | 4977 | 879 | 878 | 573 | 5856 | 5224 | 0.89 |
| 5000 | 900 | 900 | 800 | 4987 | 887 | 894 | 784 | 5874 | 5638 | 0.96 |
| 5000 | 900 | 900 | 900 | 4988 | 892 | 898 | 884 | 5880 | 5832 | 0.99 |

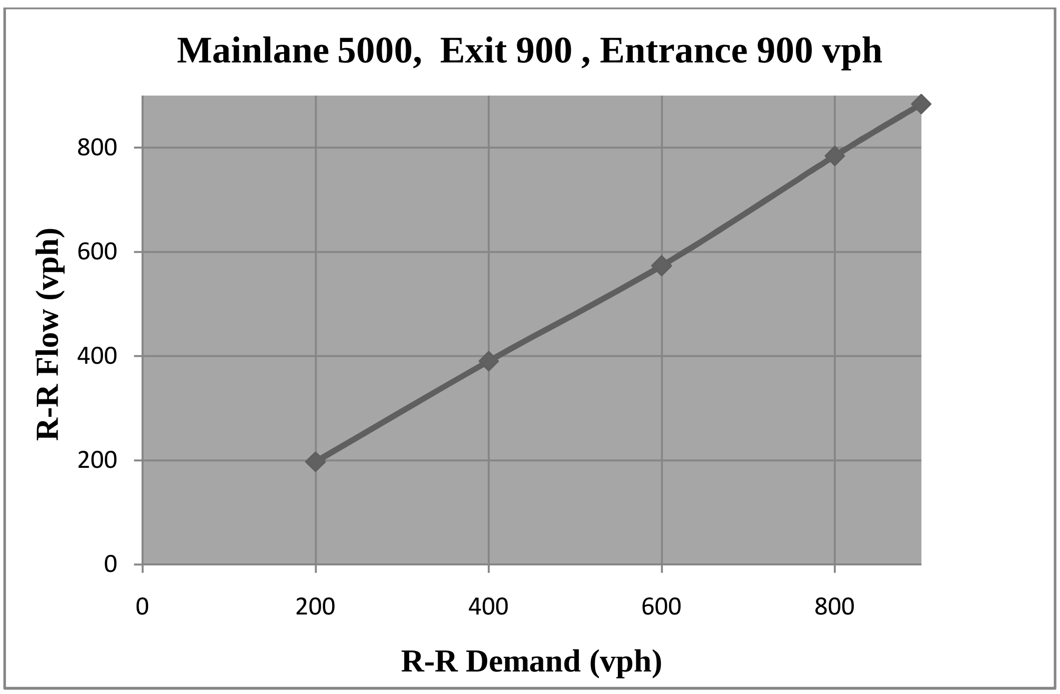



Figure C.1 R-R Demand vs. R-R Flow for scenario 1 Model 3

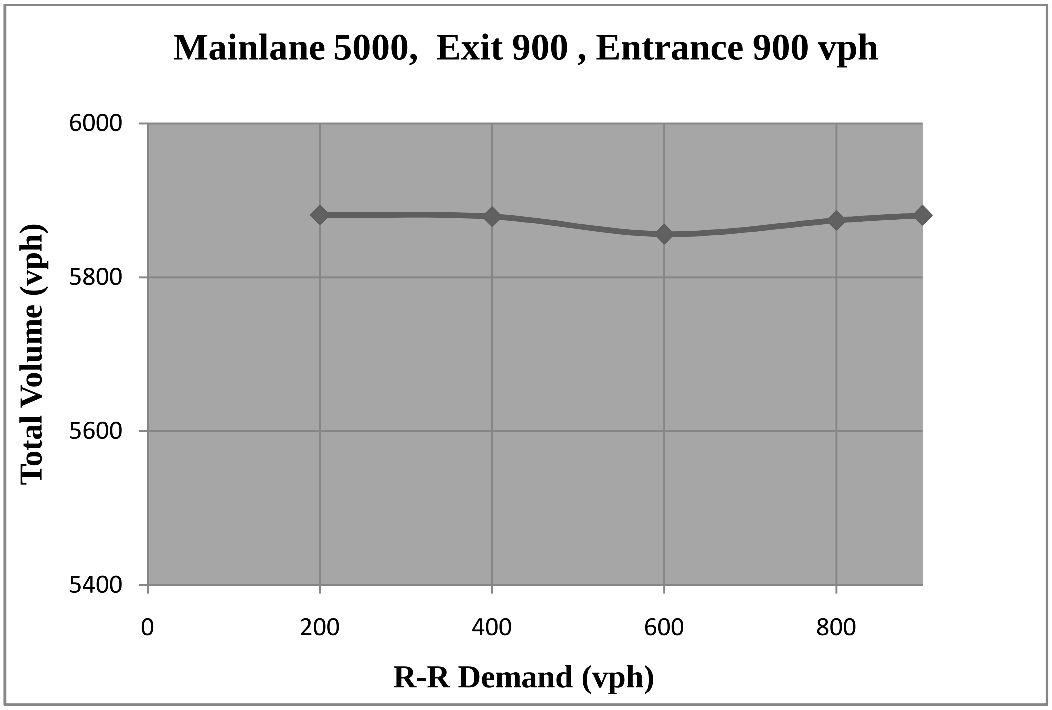



Figure C.2 R-R Demand vs. Total Volume for scenario 1 Model 3

**Scenario 2**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 600 vph
- Exit Ramp is 500 vph
- R-R demand is from 100-500 vph

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6000 | 500 | 600 | 100 | 6050 | 486 | 571 | 94 | 6537 | 5641 | 0.86 |
| 6000 | 500 | 600 | 120 | 6020 | 481 | 557 | 106 | 6501 | 5815 | 0.89 |
| 6000 | 500 | 600 | 200 | 6042 | 476 | 554 | 178 | 6518 | 5990 | 0.92 |
| 6000 | 500 | 600 | 300 | 6051 | 450 | 531 | 249 | 6501 | 6169 | 0.95 |
| 6000 | 500 | 600 | 400 | 6061 | 426 | 521 | 328 | 6487 | 6359 | 0.98 |
| 6000 | 500 | 600 | 500 | 6079 | 428 | 535 | 422 | 6507 | 5671 | 0.87 |

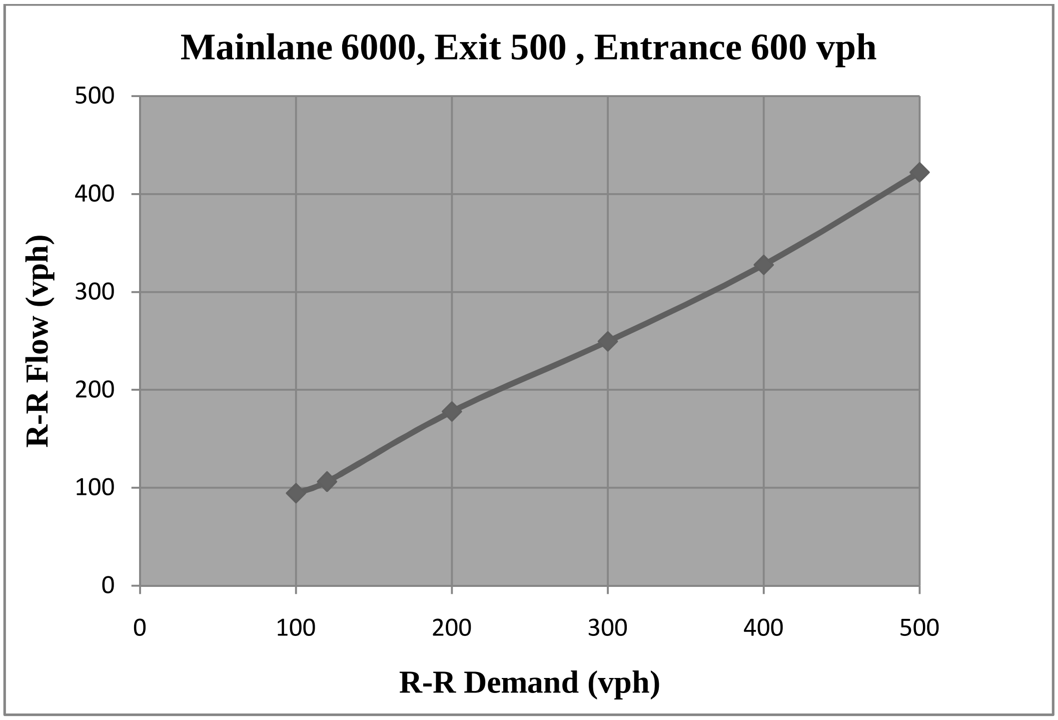



Figure C.3 R-R Demand vs. R-R Flow for scenario 2 Model 3

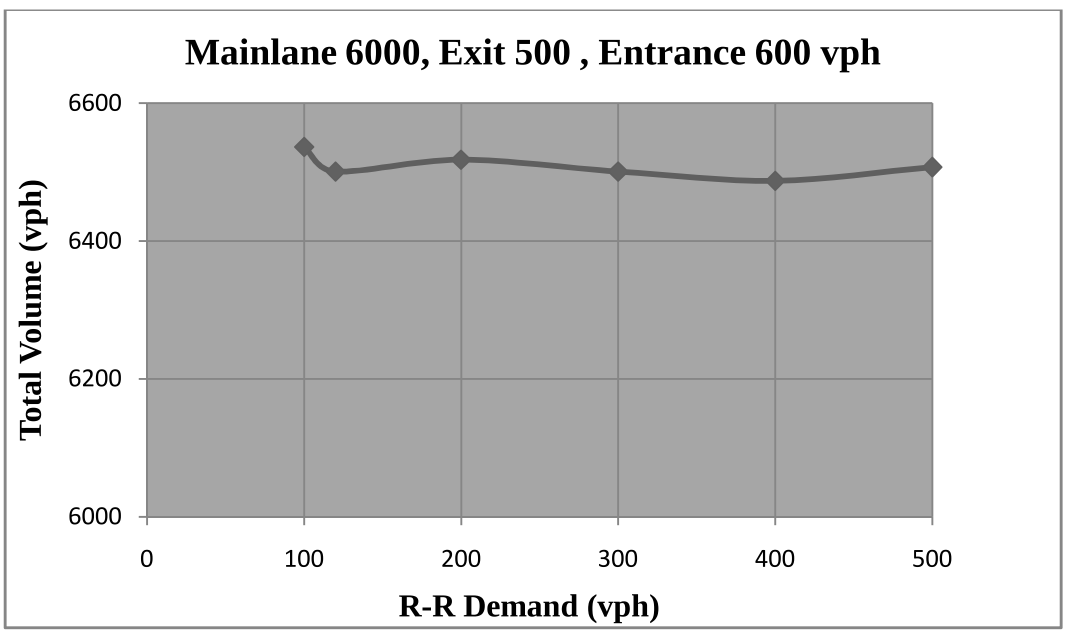



Figure C.4 R-R Demand vs. Total Volume for scenario 2 Model 3

**Scenario 3**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 600 vph
- Exit Ramp is 600 vph
- R-R demand is from 100-600 vph

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6000 | 600 | 600 | 100 | 5991 | 590 | 590 | 99 | 6581 | 5548 | 0.84 |
| 6000 | 600 | 600 | 200 | 5944 | 569 | 569 | 176 | 6512 | 5724 | 0.88 |
| 6000 | 600 | 600 | 300 | 5965 | 569 | 569 | 269 | 6535 | 5909 | 0.90 |
| 6000 | 600 | 600 | 400 | 5976 | 557 | 557 | 357 | 6532 | 6097 | 0.93 |
| 6000 | 600 | 600 | 500 | 5984 | 527 | 527 | 426 | 6510 | 6268 | 0.96 |
| 6000 | 600 | 600 | 600 | 5988 | 583 | 583 | 551 | 6571 | 6520 | 0.99 |

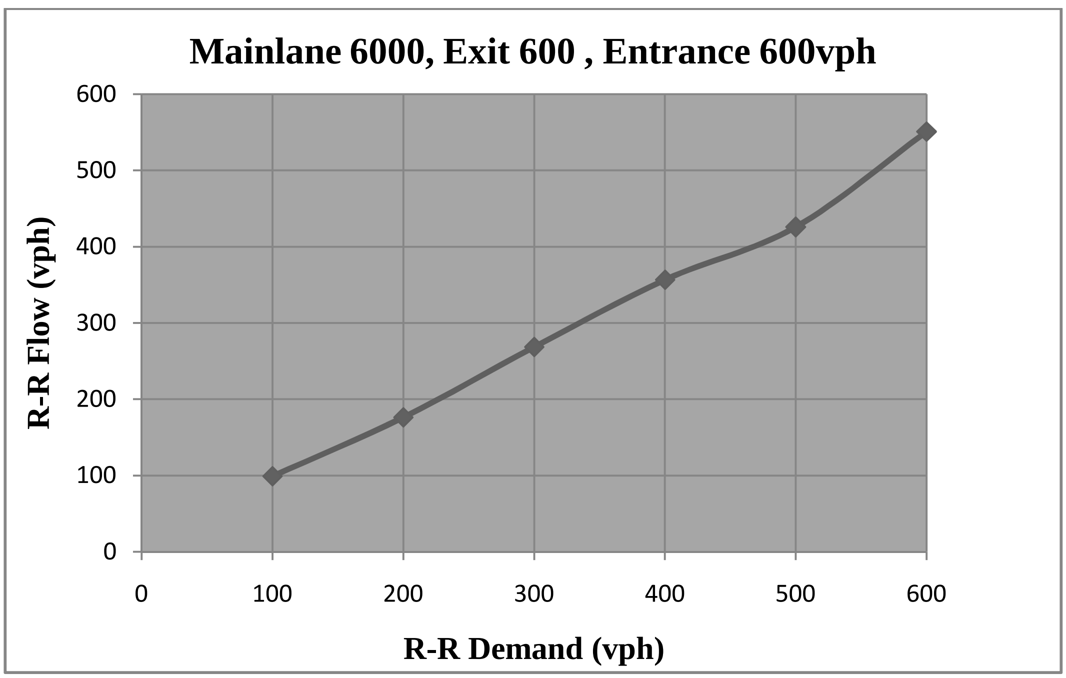



Figure C.5 R-R Demand vs. R-R Flow for scenario 3 Model 3

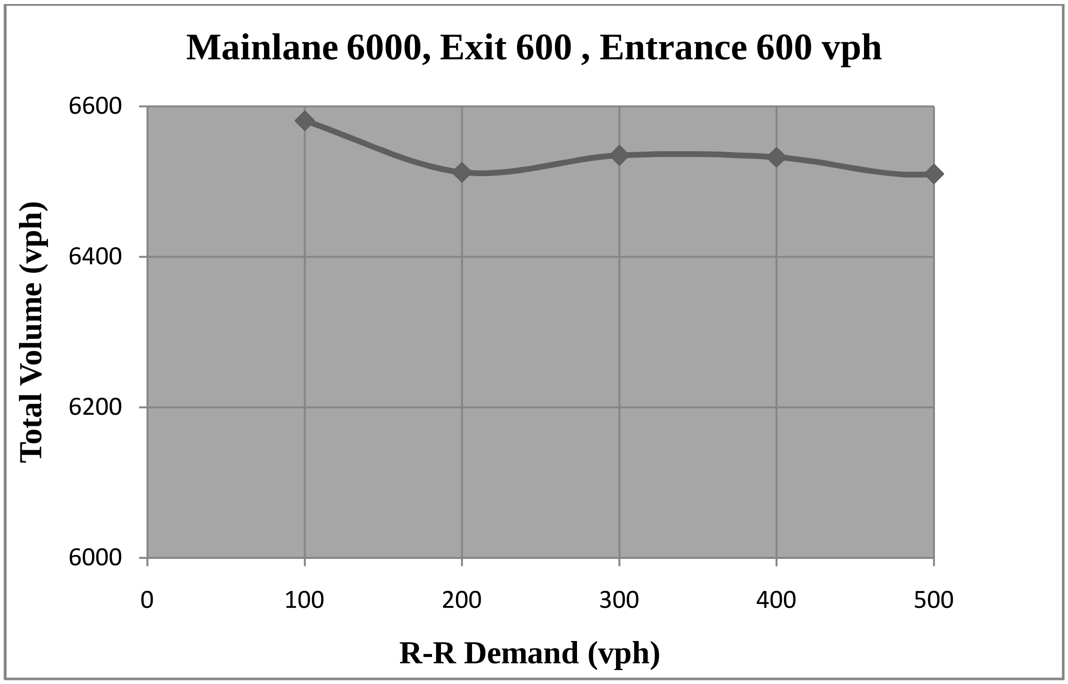



Figure C.6 R-R Demand vs. Total Volume for scenario 3 Model 3

**Scenario 4**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 400 vph
- Exit Ramp is 400 vph
- R-R demand is from 80-400 vph

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 400 | 400 | 80 | 6970 | 391 | 391 | 78 | 7361 | 6724 | 0.913 |
| 7000 | 400 | 400 | 100 | 6955 | 386 | 373 | 92 | 7341 | 6906 | 0.941 |
| 7000 | 400 | 400 | 200 | 6967 | 374 | 373 | 177 | 7341 | 7096 | 0.967 |
| 7000 | 400 | 400 | 300 | 6976 | 371 | 377 | 270 | 7347 | 7282 | 0.991 |
| 7000 | 400 | 400 | 400 | 6984 | 362 | 383 | 358 | 7346 | 6689 | 0.911 |

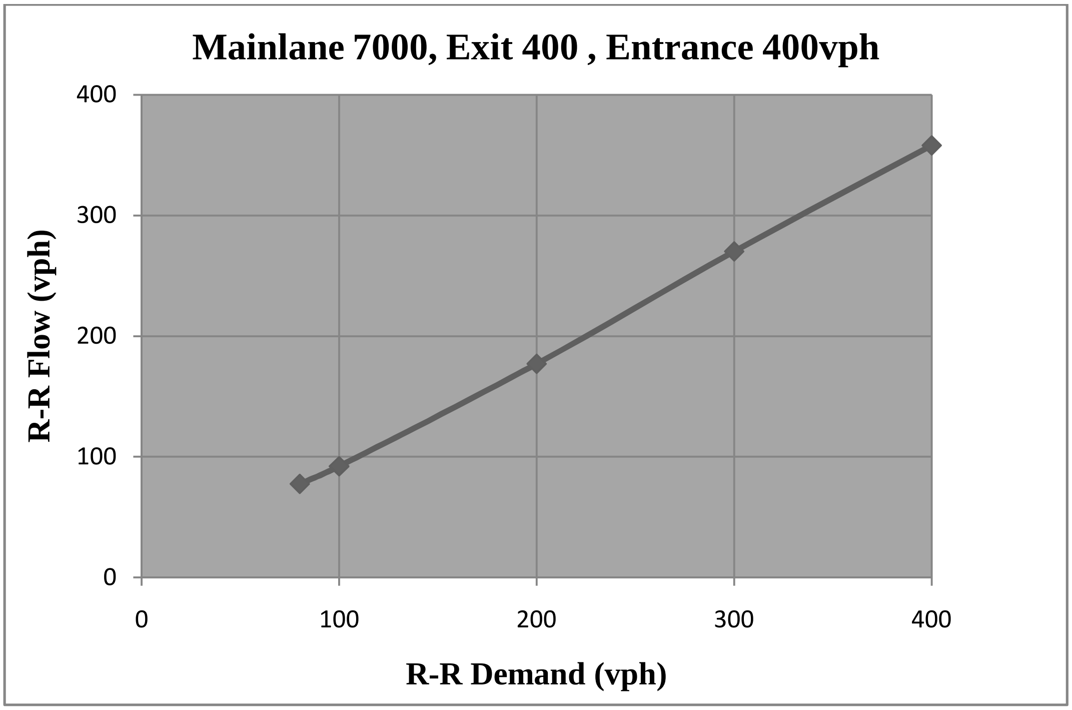



Figure C.7 R-R Demand vs. R-R Flow for scenario 4 Model 3

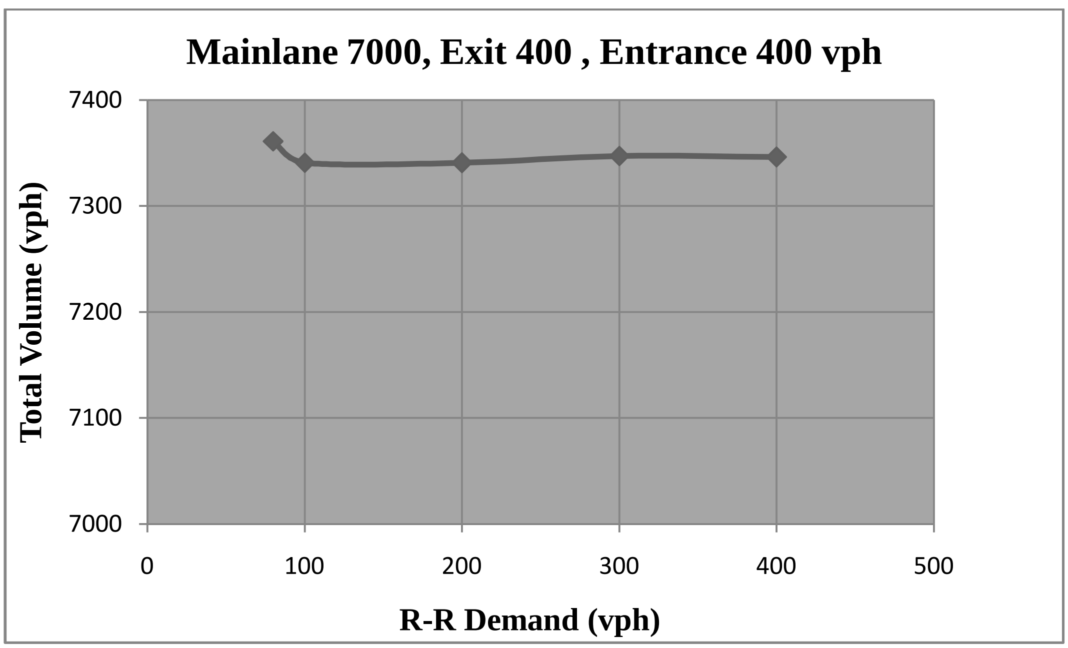



Figure C.8 R-R Demand vs. Total Volume for scenario 4 Model 3

**Scenario 5**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 400 vph
- Exit Ramp is 400 vph
- R-R demand is from 80-400 vph

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 8000 | 400 | 400 | 80 | 7955 | 398 | 400 | 80 | 8353 | 7688 | 0.920 |
| 8000 | 400 | 400 | 100 | 7931 | 386 | 379 | 94 | 8316 | 7857 | 0.945 |
| 8000 | 400 | 400 | 200 | 7928 | 382 | 385 | 186 | 8310 | 7990 | 0.961 |
| 8000 | 400 | 400 | 300 | 7965 | 336 | 344 | 238 | 8301 | 7922 | 0.954 |
| 8000 | 400 | 400 | 400 | 7928 | 388 | 344 | 371 | 8317 | 7652 | 0.920 |

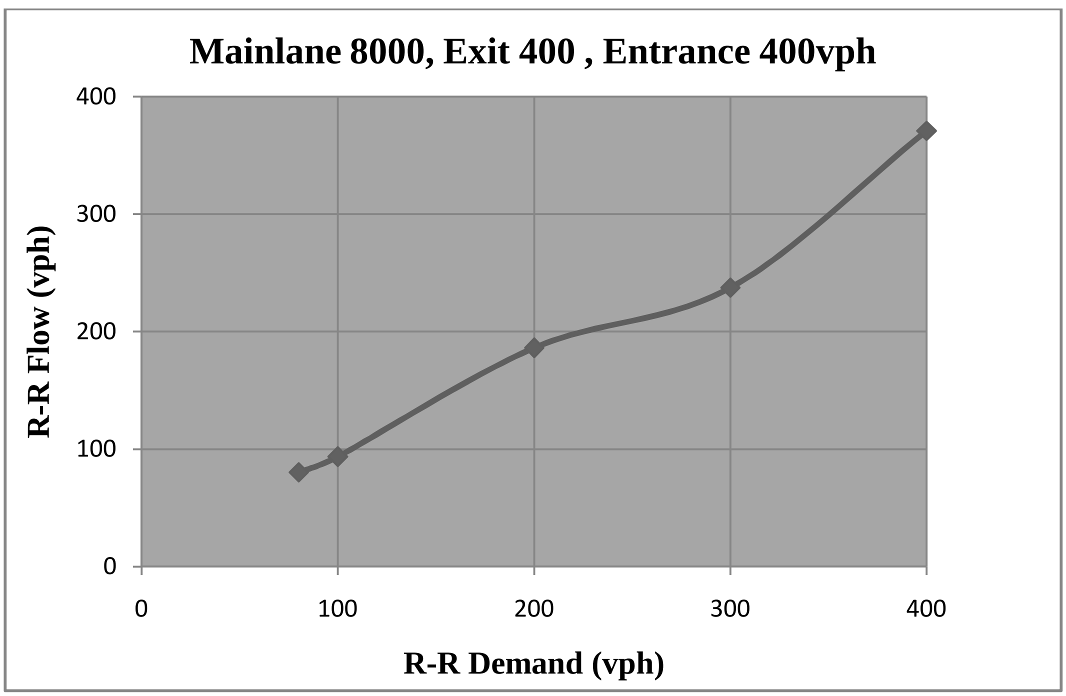



Figure C.9 R-R Demand vs. R-R Flow for scenario 5 Model 3

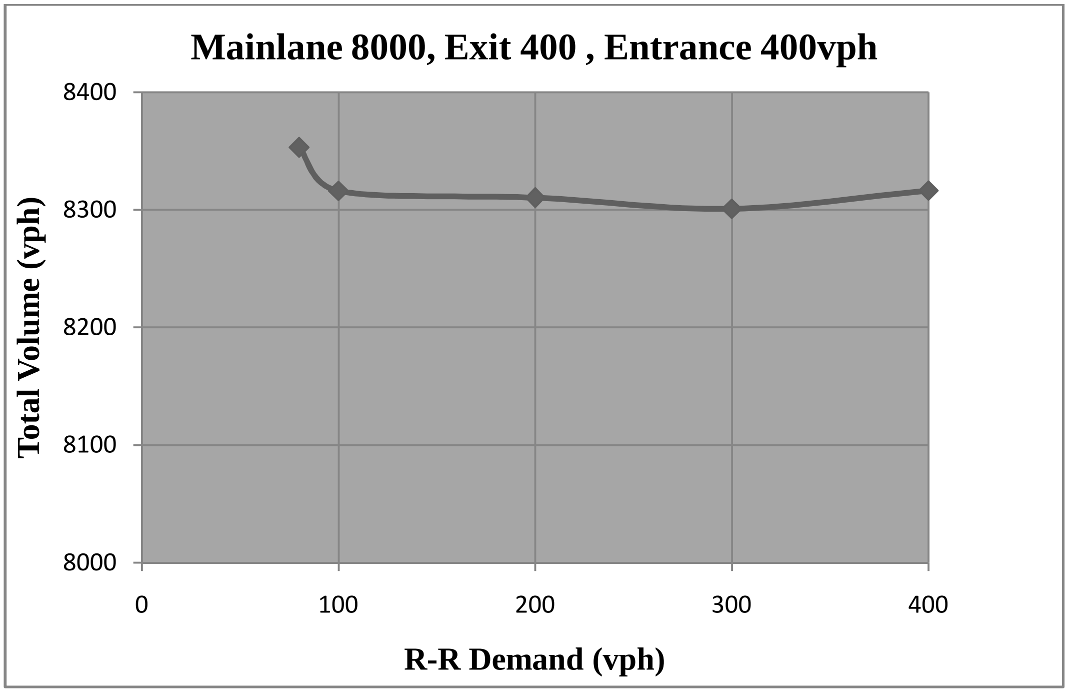



Figure C.10 R-R Demand vs. Total Volume for scenario 5 Model 3

# APPENDIX D

# SIMULATION RESULTS FOR MODEL 4

Appendix C includes simulation results of 18 scenarios for Model 4. The inputs of each scenario are summarized in the following table:

| scenario | entrance ramp | Mainlanes | Exit Ramp | R-R |
|---|---|---|---|---|
| 1 | 600 | 6000 | 1000 | 200-600 |
| 2 | 600 | 6000 | 1500 | 200-600 |
| 3 | 600 | 6000 | 2000 | 200-600 |
| 4 | 500 | 6800 | 1000 | 200-500 |
| 5 | 500 | 6800 | 1500 | 200-500 |
| 6 | 500 | 6800 | 2000 | 200-500 |
| 7 | 500 | 7000 | 1000 | 200-500 |
| 8 | 500 | 7000 | 1500 | 200-500 |
| 9 | 500 | 7000 | 1700 | 200-500 |
| 10 | 500 | 7000 | 1900 | 200-500 |
| 11 | 500 | 7000 | 2000 | 200-500 |
| 12 | 500 | 7200 | 1000 | 200-500 |
| 13 | 500 | 7500 | 1000 | 200-500 |
| 14 | 500 | 7500 | 1500 | 200-500 |
| 15 | 500 | 7500 | 2000 | 200-500 |
| 16 | 500 | 8000 | 1000 | 200-500 |
| 17 | 500 | 8000 | 1500 | 200-500 |
| 18 | 500 | 8000 | 2000 | 200-500 |

**Scenario 1**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 600 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-600 vph

The system is not at capacity at this scenario.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6000 | 1000 | 600 | 200 | 5562 | 975 | 561 | 183 | 6538 | 5334 | 0.816 |
| 6000 | 1000 | 600 | 400 | 5576 | 956 | 563 | 359 | 6532 | 5703 | 0.873 |
| 6000 | 1000 | 600 | 600 | 5576 | 947 | 566 | 551 | 6523 | 6099 | 0.935 |

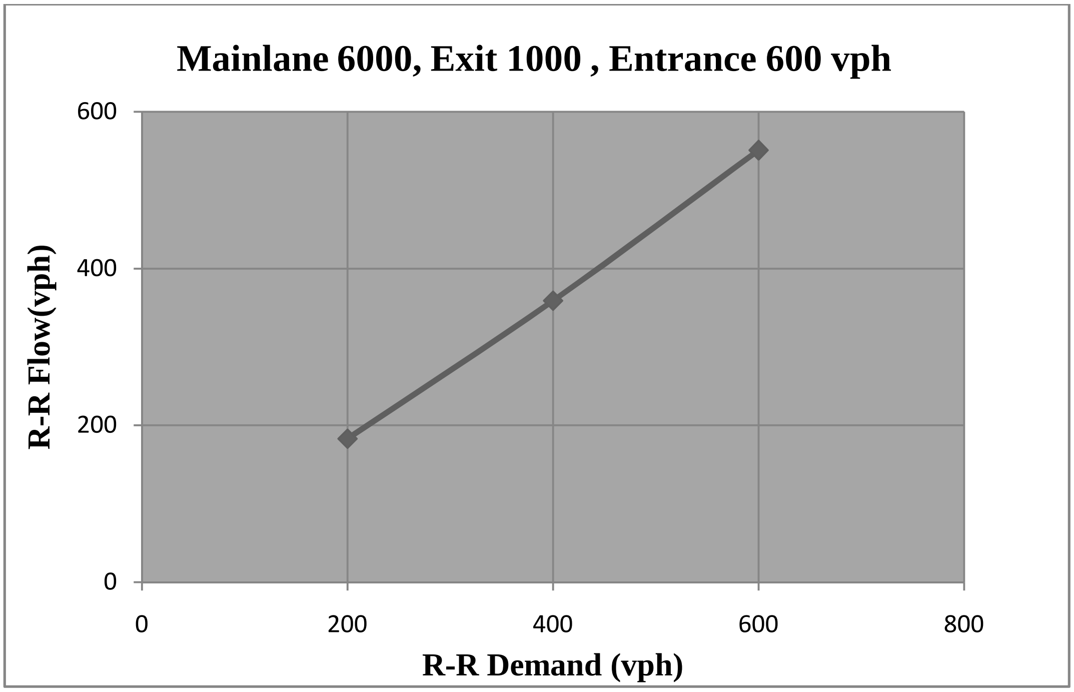



Figure D-1 R-R Demand vs. R-R Flow for scenario 1 Model 4

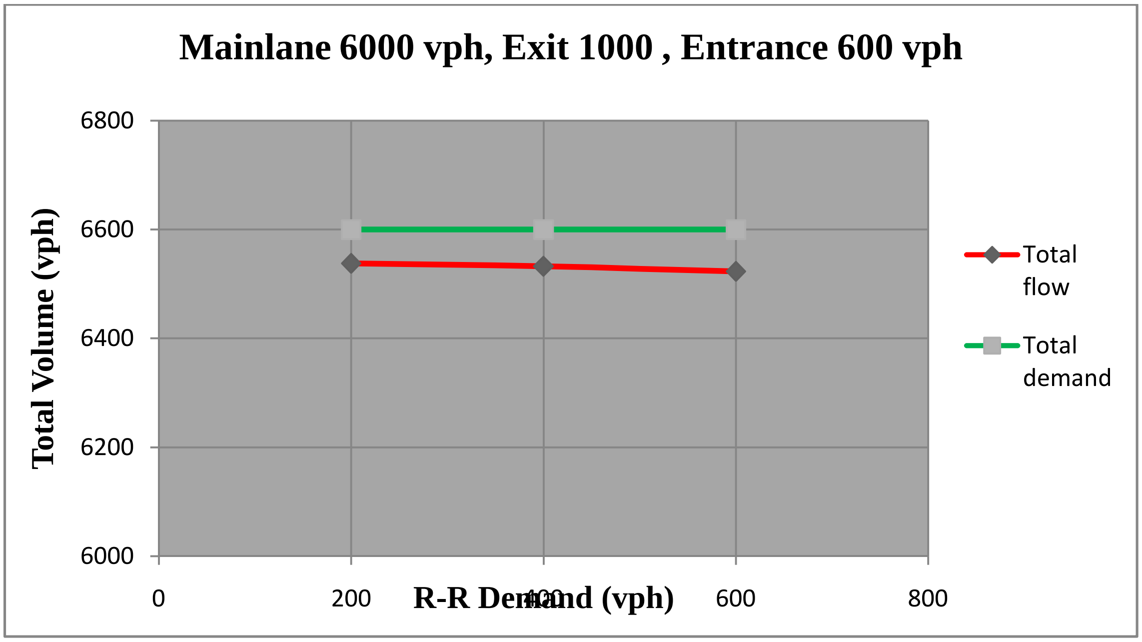



Figure D-2 R-R Demand vs. Total Volume for scenario 1 Model 4

**Scenario 2**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 600 vph
- Exit Ramp is 1500 vph
- R-R demand is from 0-600 vph

The system is not at capacity at this scenario.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6000 | 1500 | 600 | 200 | 5049 | 1444 | 523 | 170 | 6493 | 4843 | 0.746 |
| 6000 | 1500 | 600 | 400 | 5093 | 1438 | 561 | 358 | 6531 | 5228 | 0.8 |
| 6000 | 1500 | 600 | 600 | 5099 | 1410 | 541 | 514 | 6510 | 5569 | 0.856 |

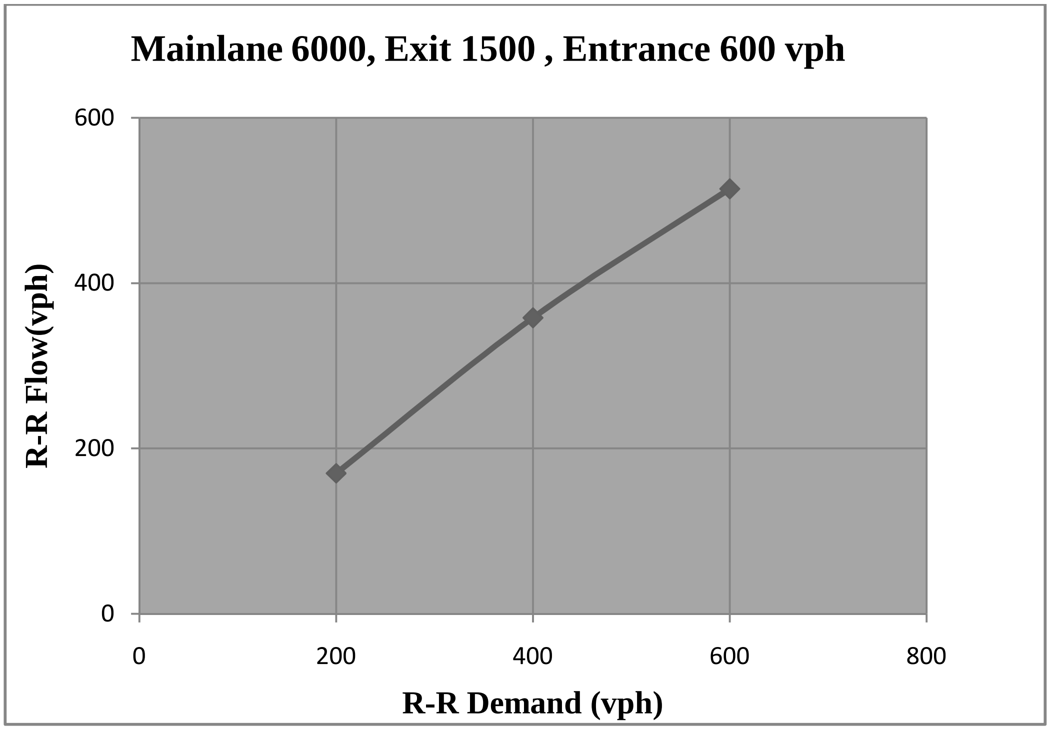



Figure D-3 R-R Demand vs. R-R Flow for scenario 2 Model 4

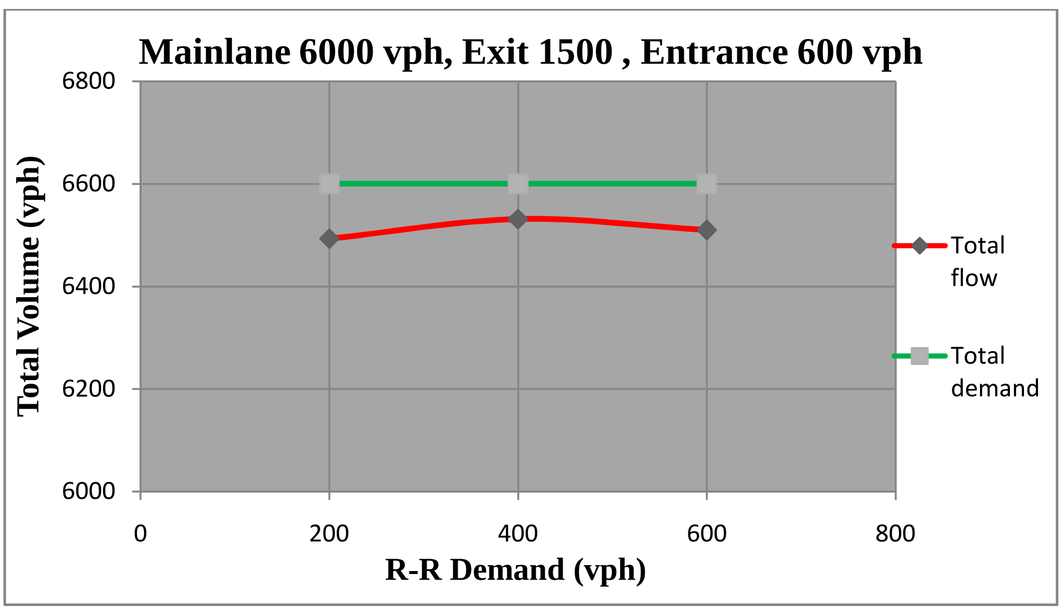



Figure D-4 R-R Demand vs. Total Volume for scenario 2 Model 4

**Scenario 3**:

- Total mainlane volume is 6000 vph
- Entrance ramp is from 600 vph
- Exit Ramp is 2000 vph
- R-R demand is from 0-600 vph

The system is not at capacity at this scenario.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6000 | 2000 | 600 | 200 | 4585 | 1950 | 560 | 170 | 6535 | 4368 | 0.668 |
| 6000 | 2000 | 600 | 400 | 4607 | 1950 | 583 | 358 | 6557 | 4746 | 0.724 |
| 6000 | 2000 | 600 | 600 | 4613 | 1967 | 595 | 514 | 6579 | 5152 | 0.783 |

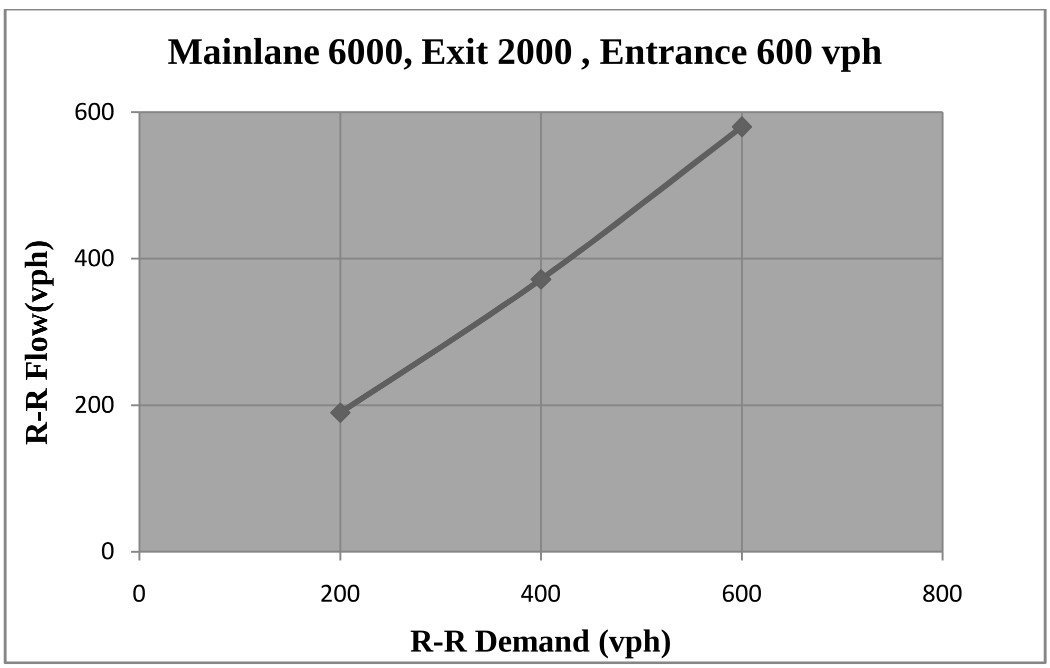



Figure D-5 R-R Demand vs. R-R Flow for scenario 3 Model 4

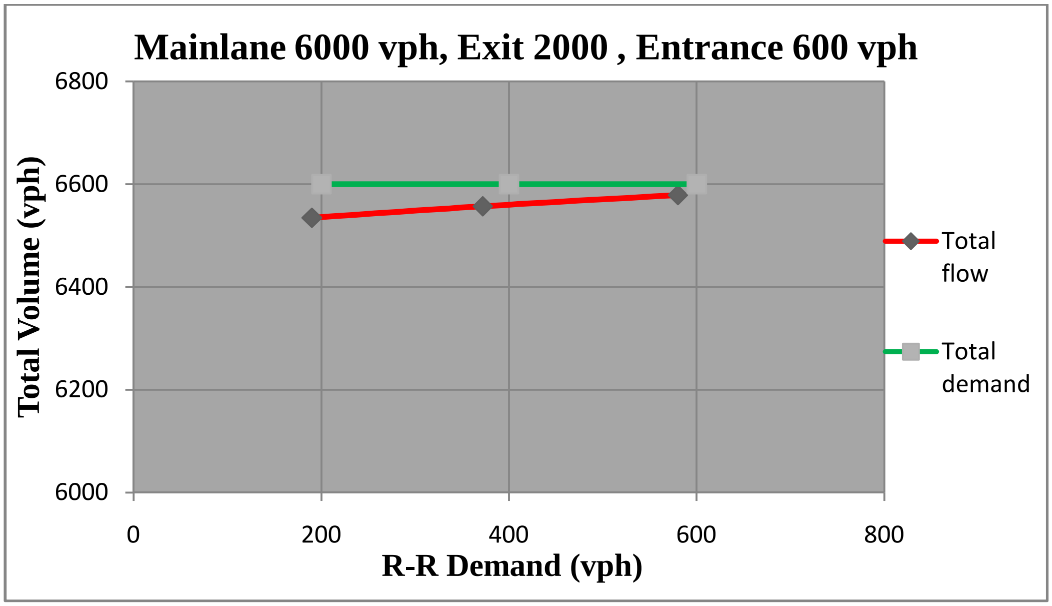



Figure D-6 R-R Demand vs. Total Volume for scenario 3 Model 4

**Scenario 4**:

- Total mainlane volume is 6800 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6800 | 1000 | 500 | 200 | 6248 | 959 | 448 | 171 | 7207 | 6120 | 0.849 |
| 6800 | 1000 | 500 | 400 | 6285 | 940 | 467 | 347 | 7225 | 6486 | 0.898 |
| 6800 | 1000 | 500 | 500 | 6302 | 930 | 469 | 436 | 7232 | 6679 | 0.923 |

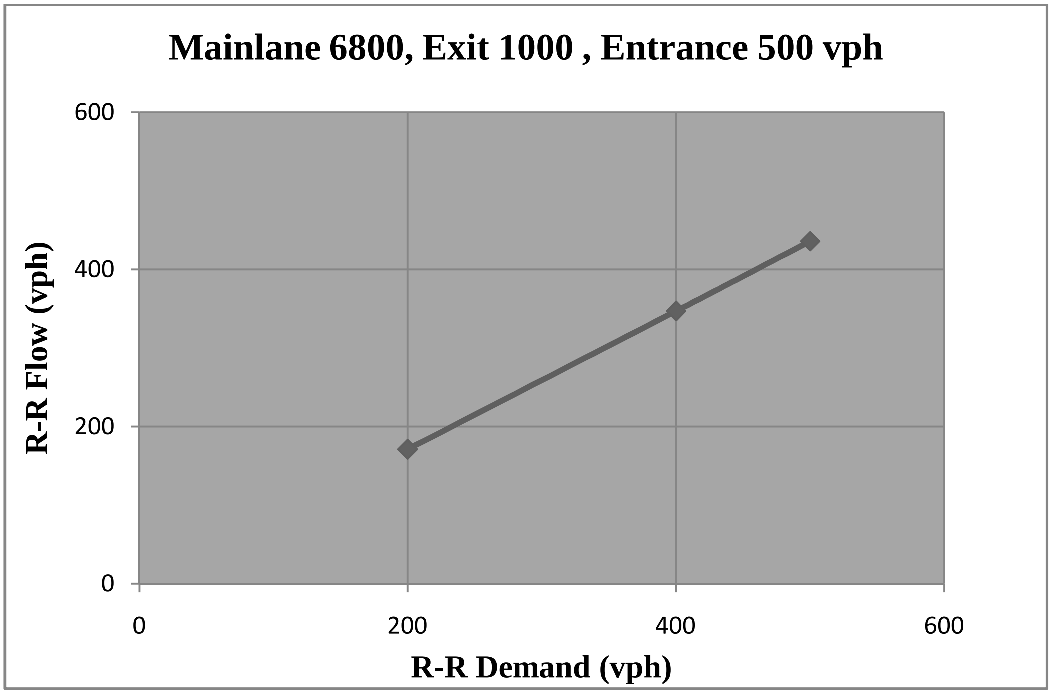



Figure D-7 R-R Demand vs. R-R Flow for scenario 4 Model 4

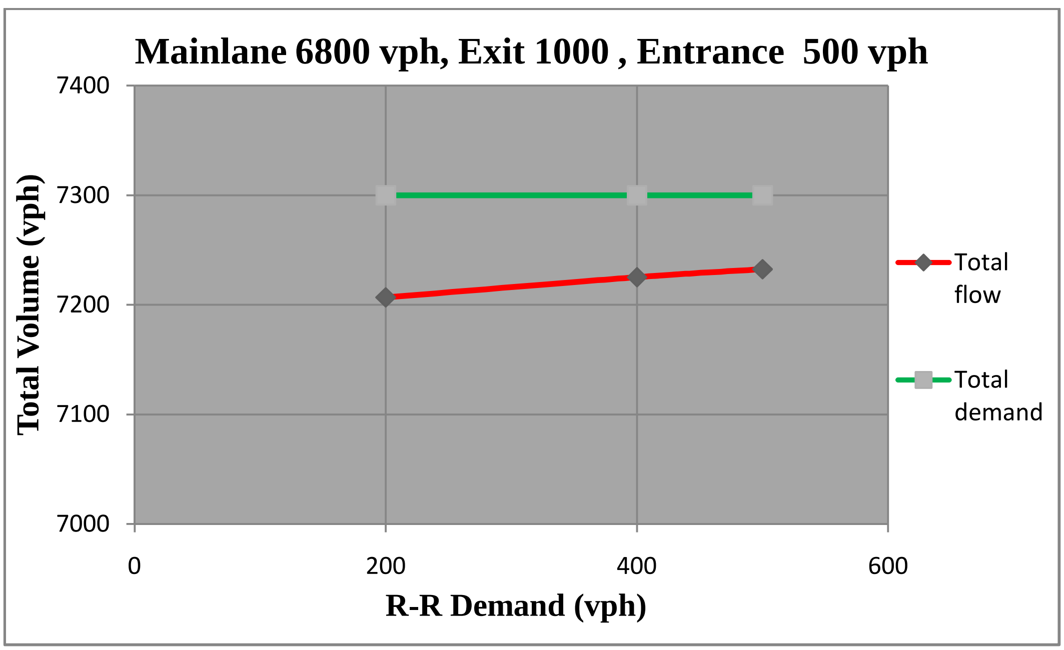



Figure D-8 R-R Demand vs. Total Volume for scenario 4 Model 4

**Scenario 5**:

- Total mainlane volume is 6800 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1500 vph
- R-R demand is from 0-500 vph

The system is not at capacity at this scenario.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6800 | 1500 | 500 | 200 | 5690 | 1431 | 348 | 183 | 7121 | 5650 | 0.793 |
| 6800 | 1500 | 500 | 400 | 5776 | 1431 | 447 | 347 | 7207 | 5967 | 0.828 |
| 6800 | 1500 | 500 | 500 | 5807 | 1430 | 468 | 436 | 7237 | 6198 | 0.856 |

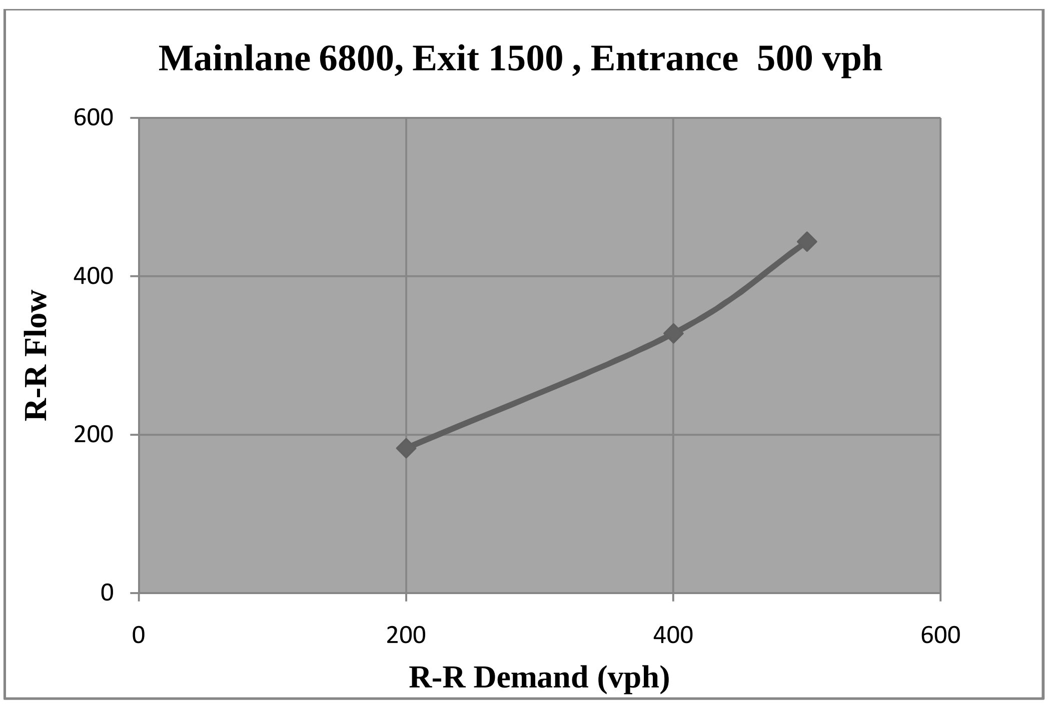



Figure D-9 R-R Demand vs. R-R Flow for scenario 5 Model 4

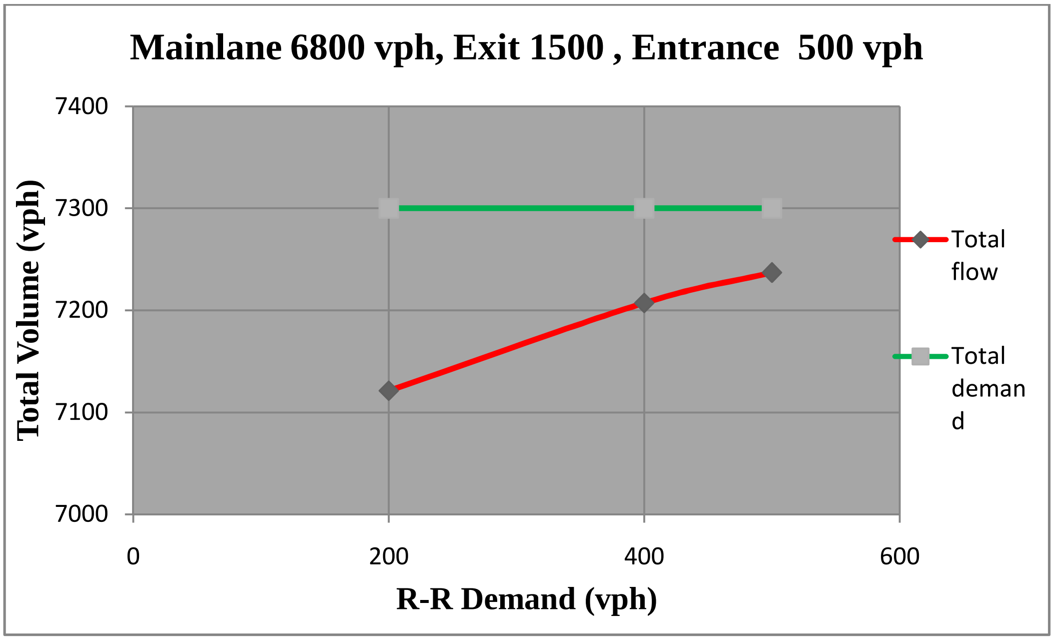



Figure D-10 R-R Demand vs. Total Volume for scenario 5 Model 4

**Scenario 6**:

- Total mainlane volume is 6800 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 2000 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 6800 | 2000 | 500 | 200 | 5268 | 1934 | 448 | 174 | 7202 | 5141 | 0.714 |
| 6800 | 2000 | 500 | 400 | 5313 | 1932 | 474 | 362 | 7245 | 5529 | 0.763 |
| 6800 | 2000 | 500 | 500 | 5806 | 1430 | 468 | 450 | 7236 | 5715 | 0.790 |

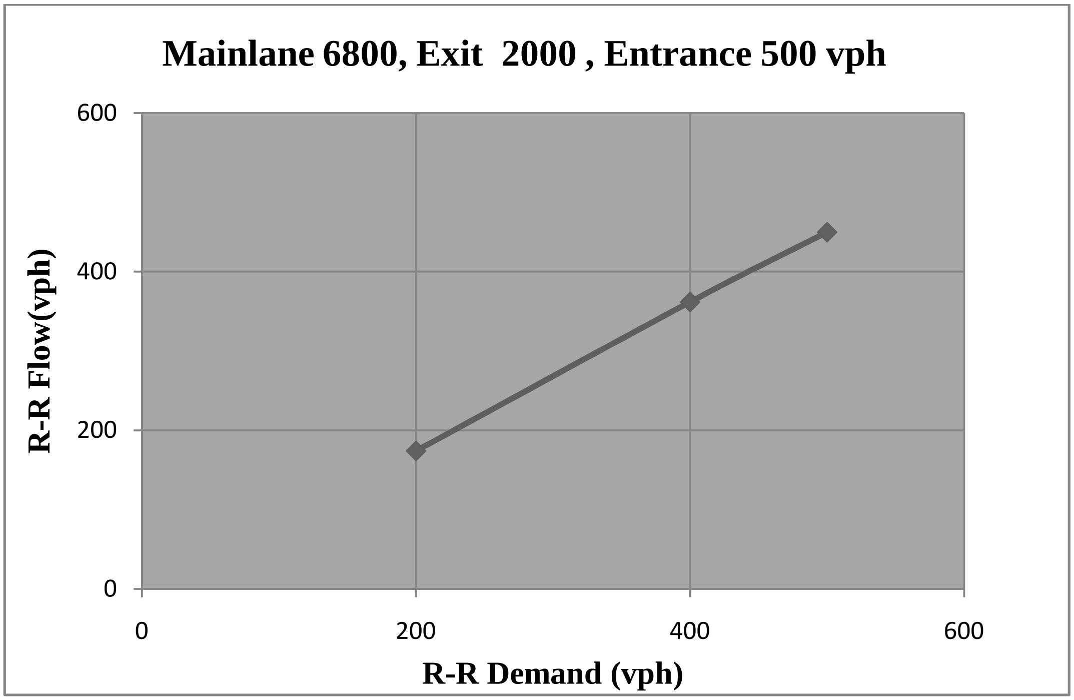



Figure D-11 R-R Demand vs. R-R Flow for scenario 6 Model 4

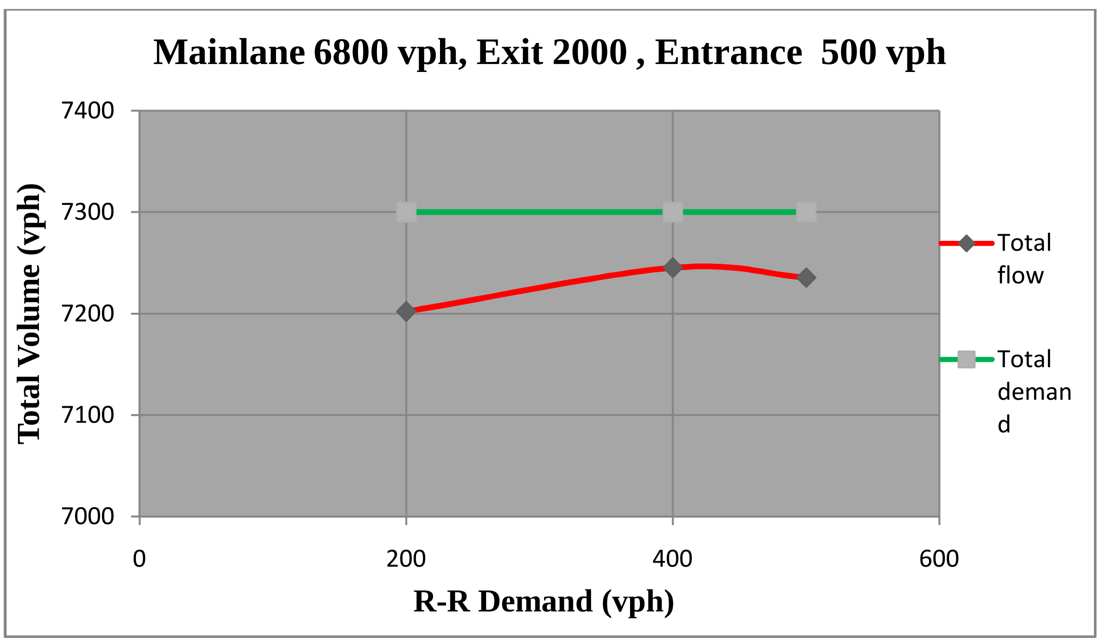



Figure D-12 R-R Demand vs. Total Volume for scenario 6 Model 4

**Scenario 7**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 1000 | 500 | 200 | 6495 | 967 | 499 | 175 | 7462 | 6317 | 0.847 |
| 7000 | 1000 | 500 | 400 | 6480 | 941 | 453 | 350 | 7421 | 6683 | 0.901 |
| 7000 | 1000 | 500 | 500 | 6497 | 893 | 424 | 399 | 7390 | 6837 | 0.925 |

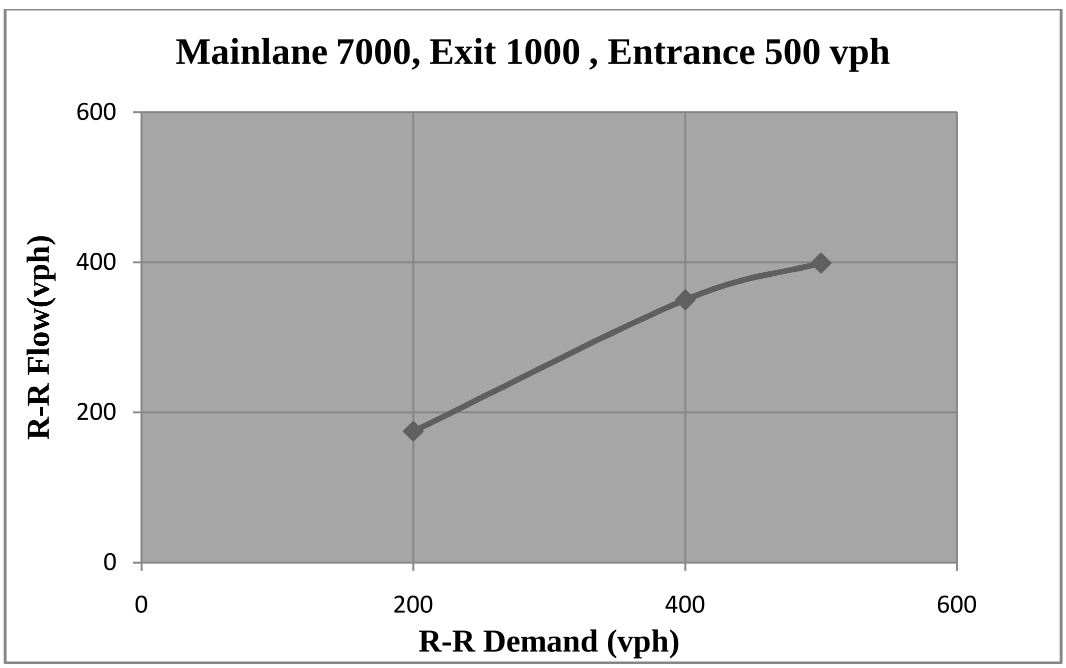



Figure D-13 R-R Demand vs. R-R Flow for scenario 7 Model 4

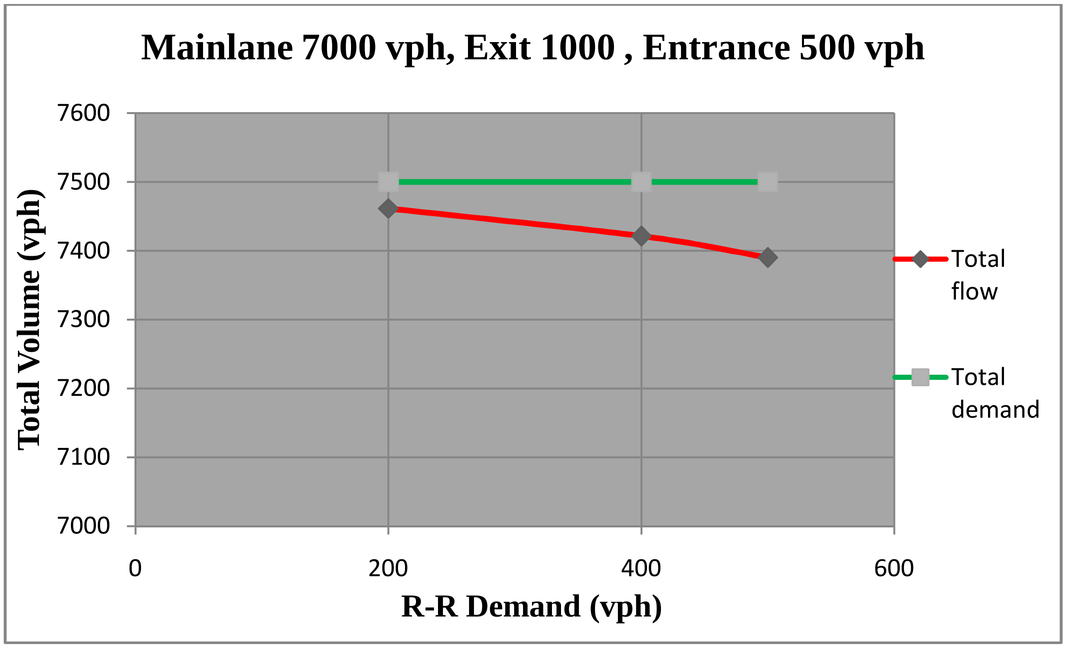



Figure D-14 R-R Demand vs. Total Volume for scenario 7 Model 4

**Scenario 8**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1500 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 1500 | 500 | 200 | 6027 | 1436 | 499 | 153 | 7463 | 5818 | 0.78 |
| 7000 | 1500 | 500 | 400 | 5998 | 1420 | 450 | 342 | 7417 | 6199 | 0.836 |
| 7000 | 1500 | 500 | 500 | 6005 | 1401 | 442 | 413 | 7406 | 6363 | 0.859 |

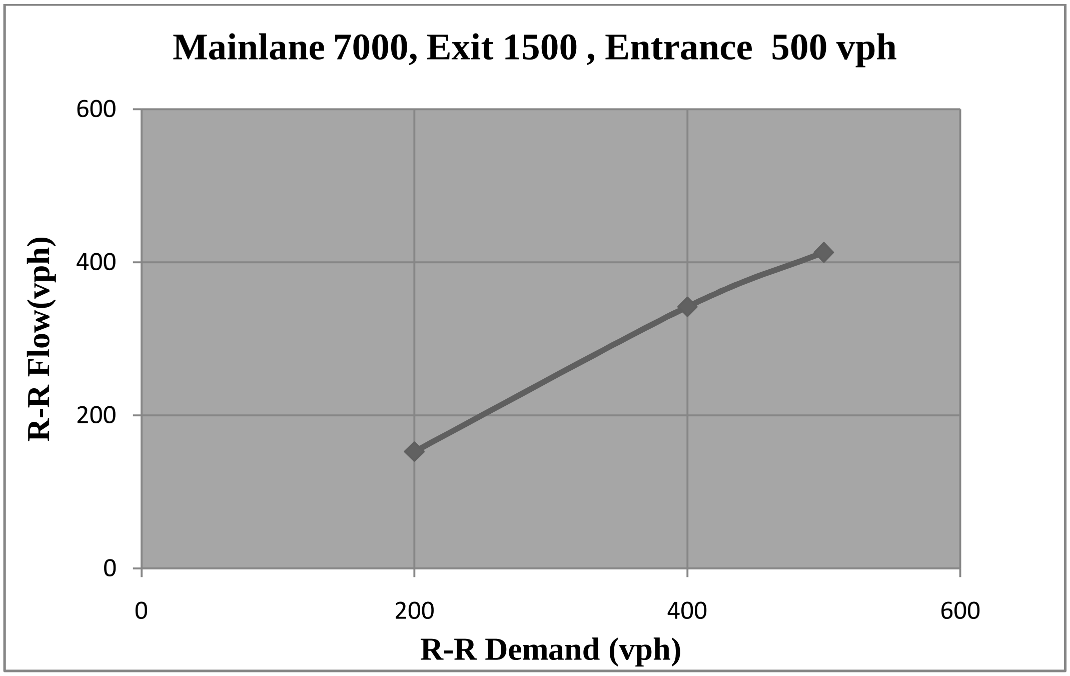



Figure D-15 R-R Demand vs. R-R Flow for scenario 8 Model 4

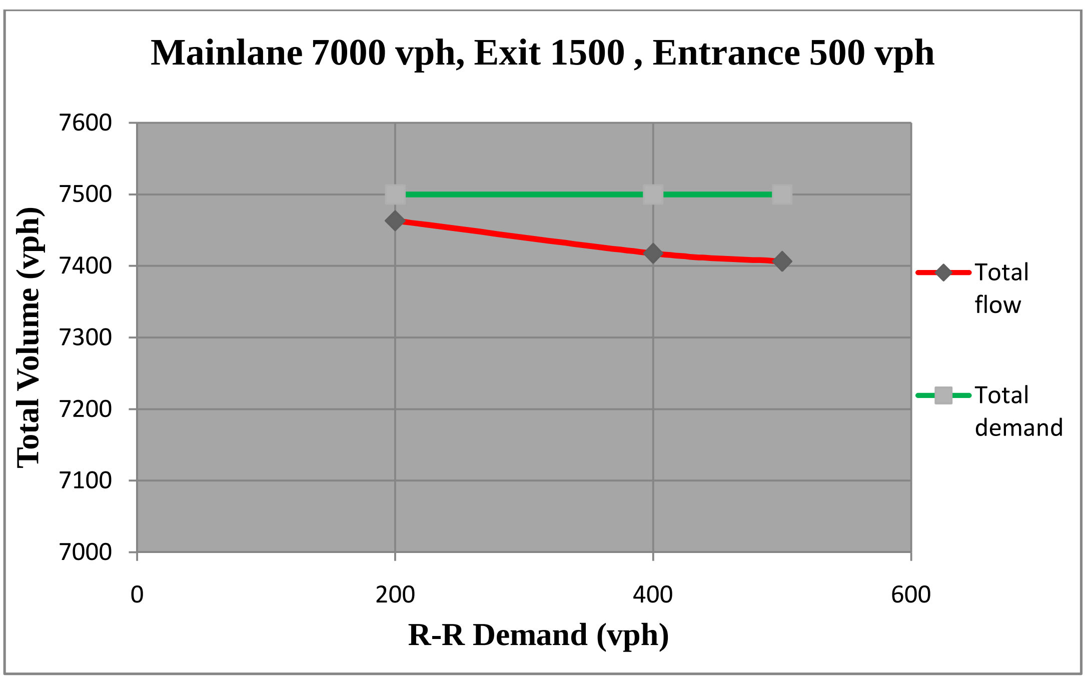



Figure D-16 R-R Demand vs. Total Volume for scenario 8 Model 4

**Scenario 9**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1700 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 1700 | 500 | 200 | 5783 | 1647 | 481 | 188 | 7430 | 5637 | 0.759 |
| 7000 | 1700 | 500 | 400 | 5998 | 1420 | 450 | 342 | 7417 | 6189 | 0.834 |
| 7000 | 1700 | 500 | 500 | 5820 | 1573 | 431 | 403 | 7393 | 6152 | 0.832 |

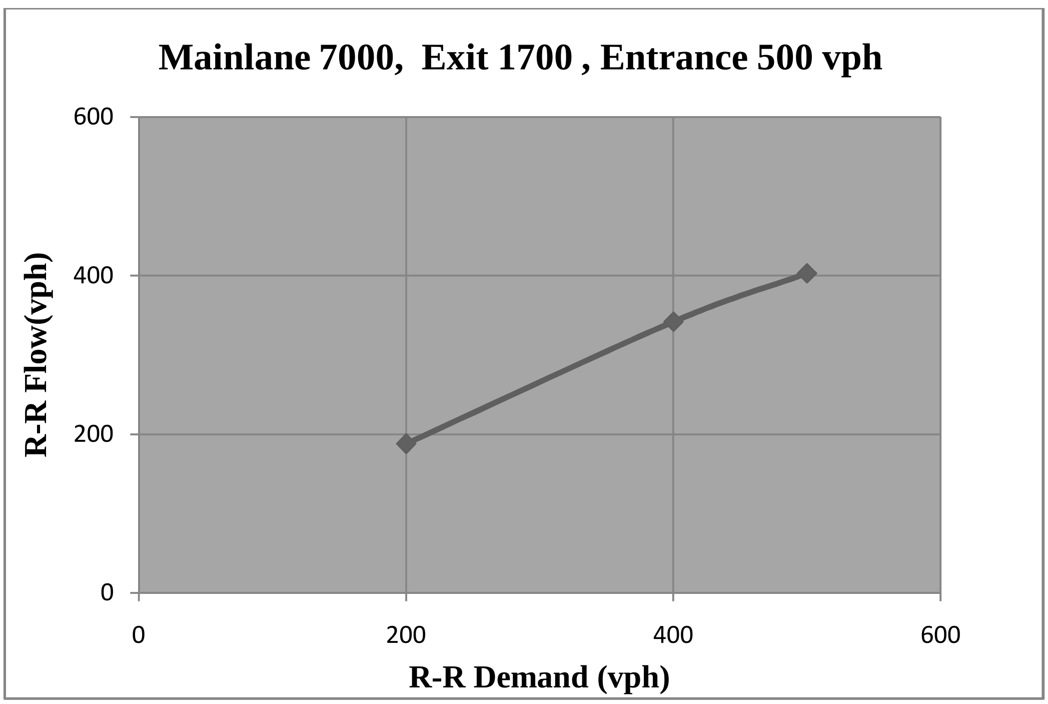



Figure D-17 R-R Demand vs. R-R Flow for scenario 9 Model 4

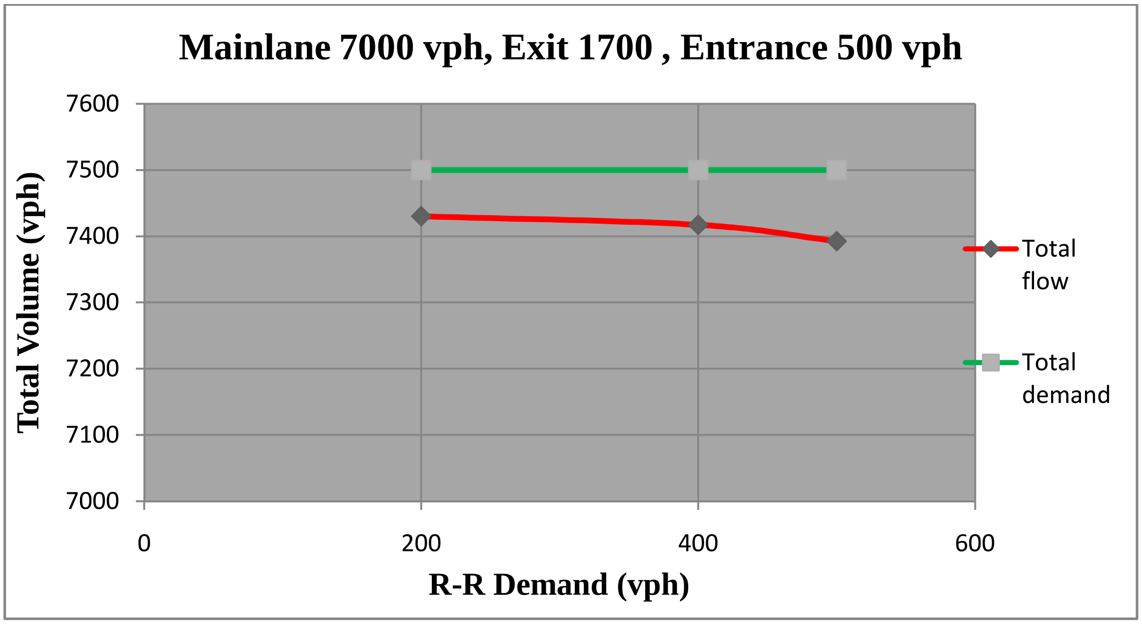



Figure D-18 R-R Demand vs. Total Volume for scenario 9 Model 4

**Scenario 10**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1900 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 1900 | 500 | 200 | 5584 | 1828 | 431 | 176 | 7412 | 5421 | 0.731 |
| 7000 | 1900 | 500 | 400 | 5586 | 1771 | 427 | 305 | 7357 | 5744 | 0.781 |
| 7000 | 1900 | 500 | 500 | 5586 | 1825 | 488 | 462 | 7411 | 5998 | 0.809 |

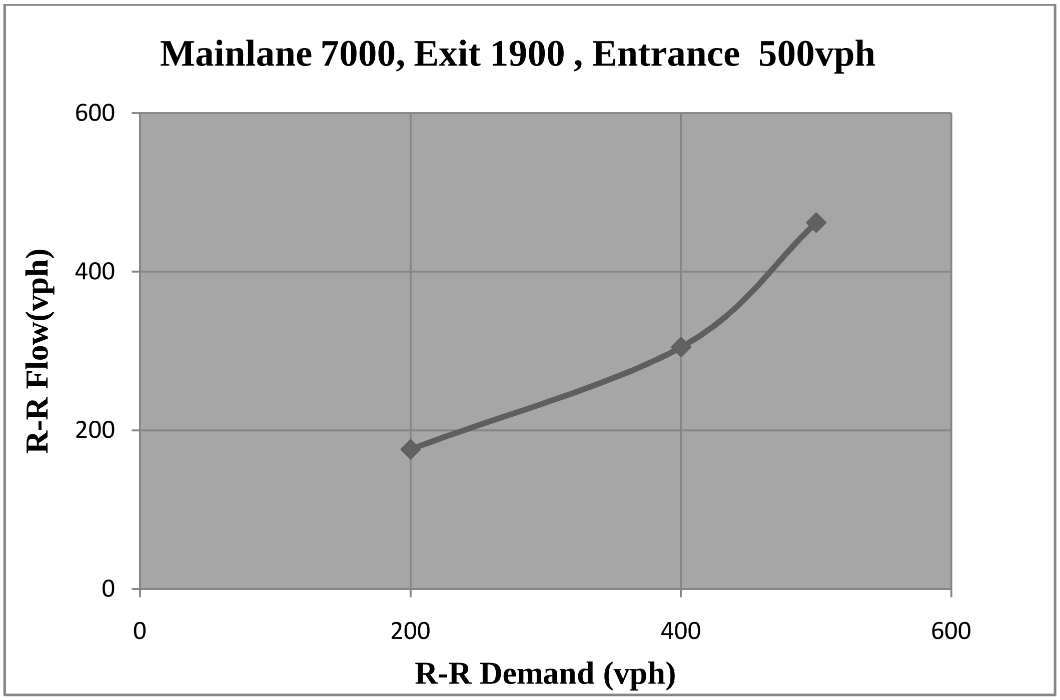



Figure D-19 R-R Demand vs. R-R Flow for scenario 10 Model 4

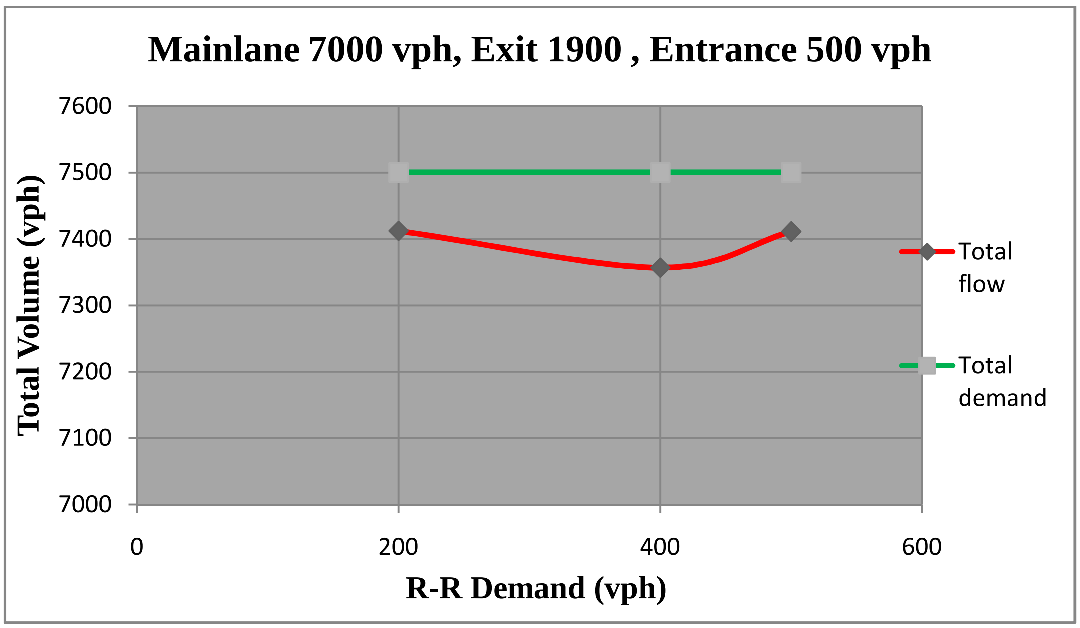



Figure D-20 R-R Demand vs. Total Volume for scenario 10 Model 4

**Scenario 11**:

- Total mainlane volume is 7000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 2000 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7000 | 2000 | 500 | 200 | 5464 | 1939 | 452 | 201 | 7403 | 5354 | 0.723 |
| 7000 | 2000 | 500 | 400 | 5489 | 1937 | 433 | 383 | 7425 | 5788 | 0.779 |
| 7000 | 2000 | 500 | 500 | 5489 | 1861 | 421 | 436 | 7350 | 5940 | 0.808 |

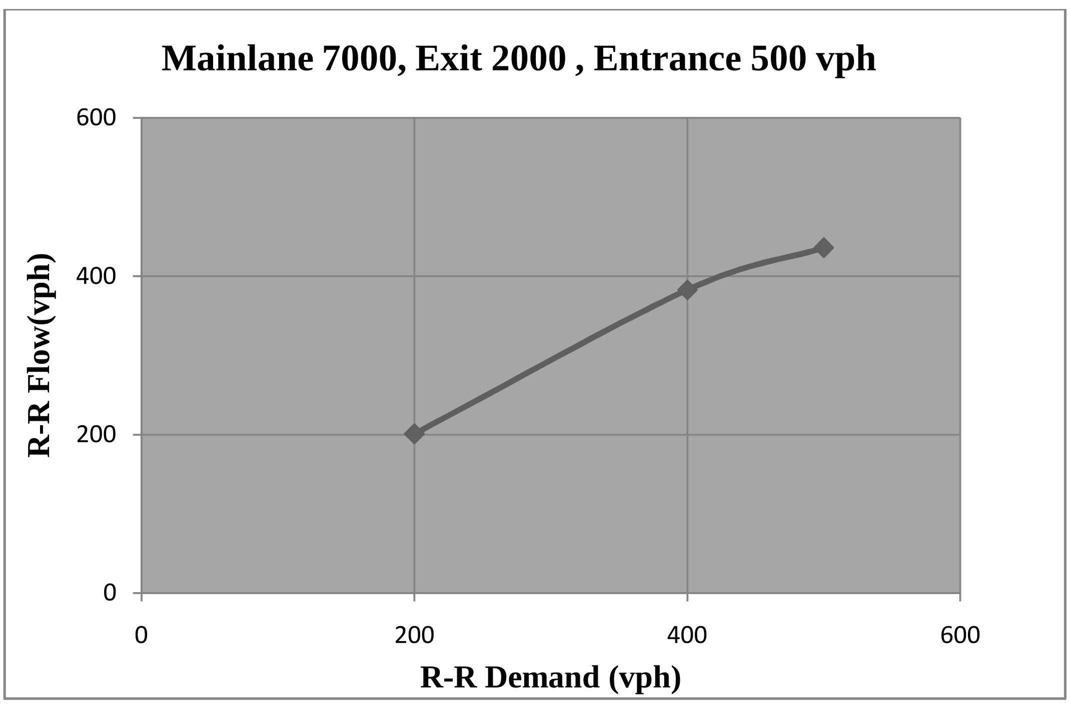



Figure D-21 R-R Demand vs. R-R Flow for scenario 11 Model 4

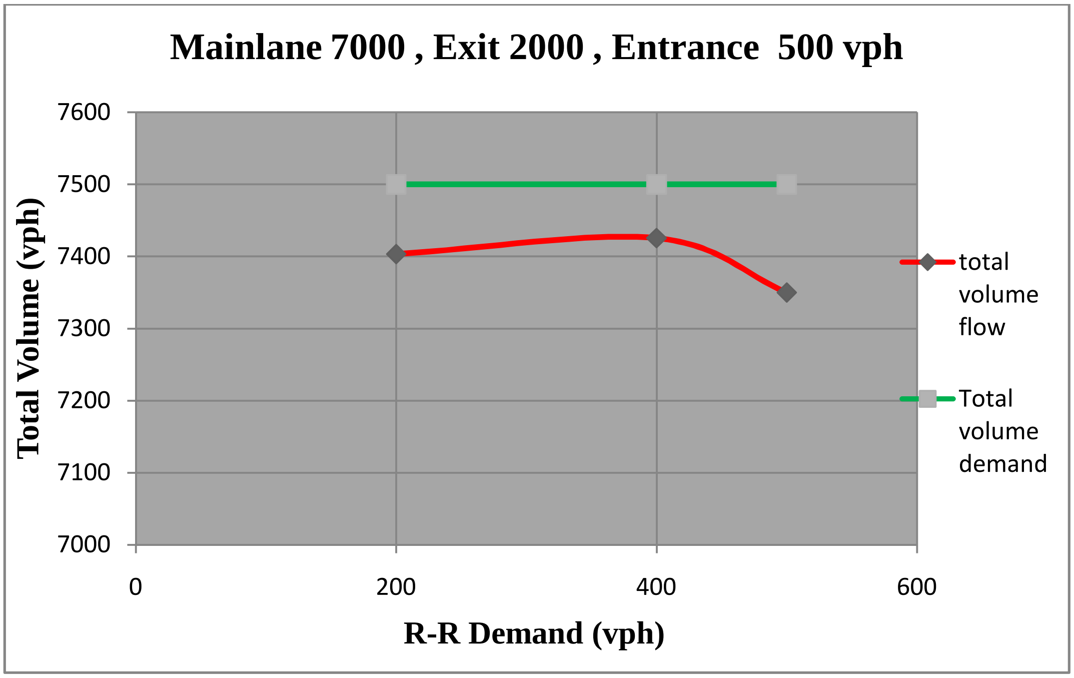



Figure D-22 R-R Demand vs. Total Volume for scenario 11 Model 4

**Scenario 12**:

- Total mainlane volume is 7200 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-500 vph

The system is not at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7200 | 1000 | 500 | 200 | 6596 | 927 | 367 | 133 | 7523 | 6471 | 0.860 |
| 7200 | 1000 | 500 | 400 | 6662 | 840 | 353 | 245 | 7502 | 6773 | 0.903 |
| 7200 | 1000 | 500 | 500 | 6694 | 888 | 427 | 393 | 7582 | 7028 | 0.927 |

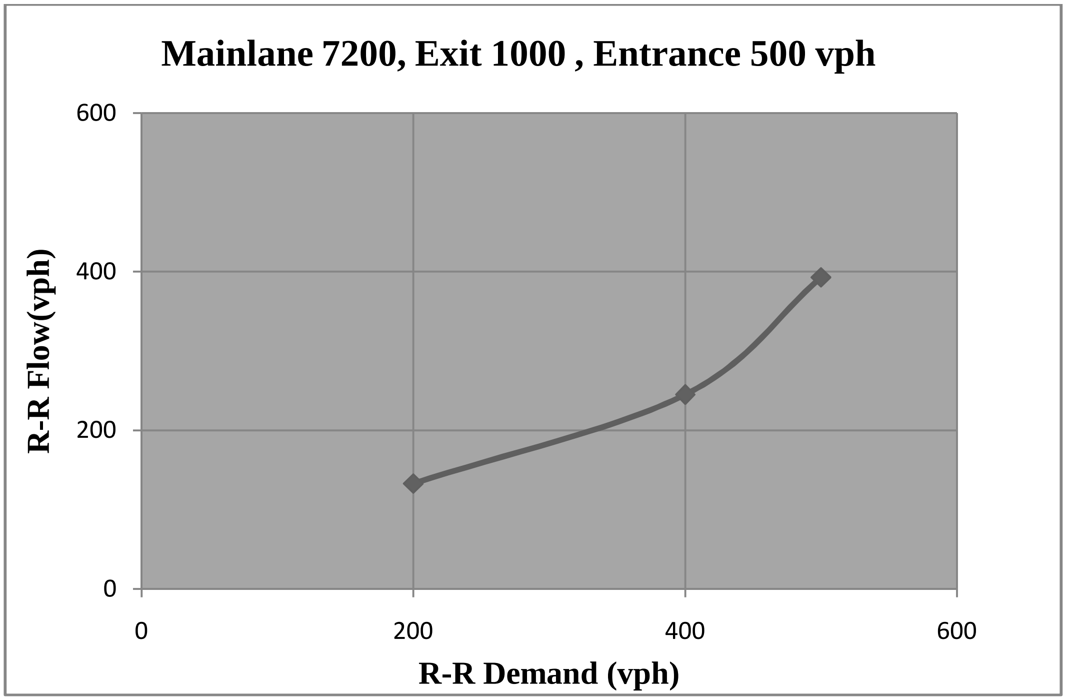



Figure D-23 R-R Demand vs. R-R Flow for scenario 12 Model 4

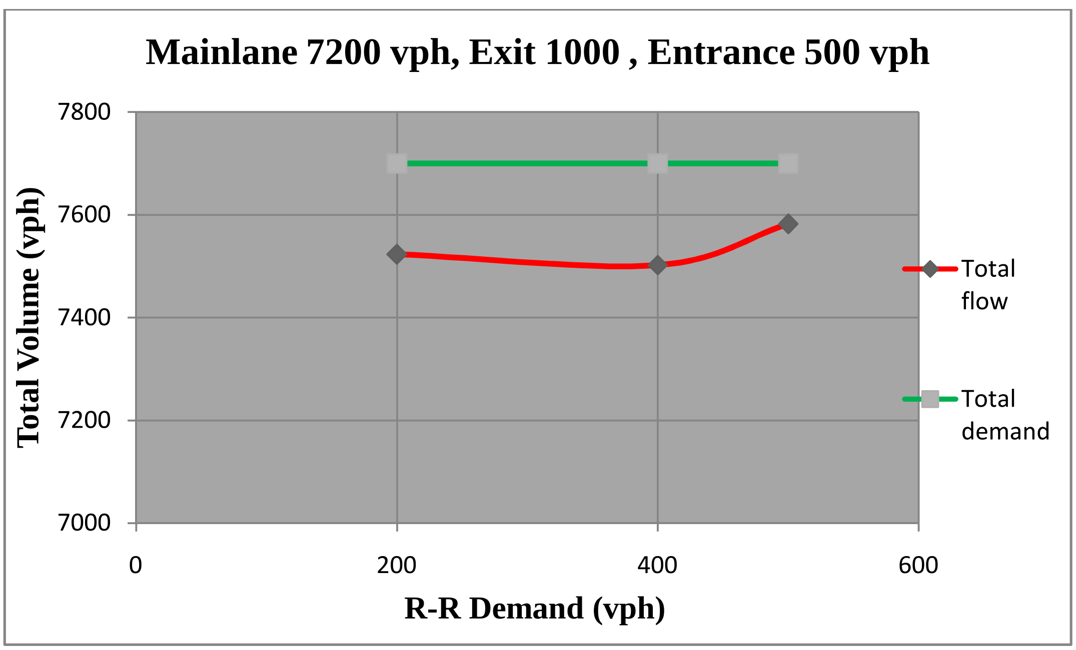



Figure D-24 R-R Demand vs. Total Volume for scenario 12 Model 4

**Scenario 13**:

- Total mainlane volume is 7500 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7500 | 1000 | 500 | 200 | 6864 | 907 | 338 | 122 | 7771 | 6755 | 0.869 |
| 7500 | 1000 | 500 | 400 | 6849 | 918 | 341 | 263 | 7767 | 7085 | 0.912 |
| 7500 | 1000 | 500 | 500 | 6973 | 770 | 332 | 279 | 7743 | 7201 | 0.930 |

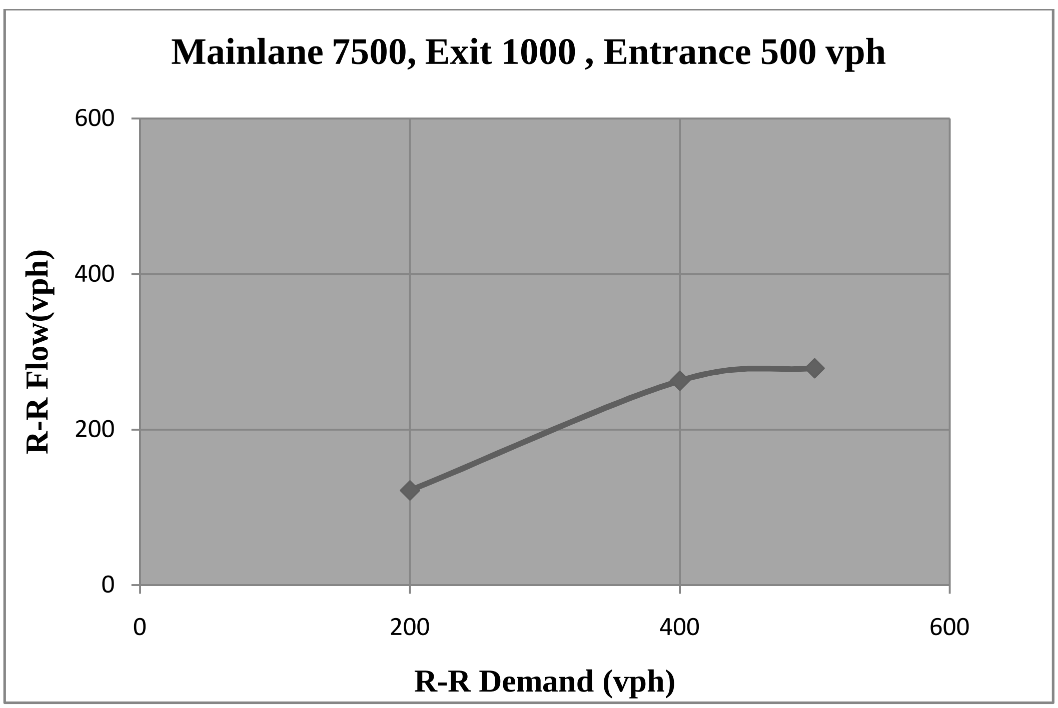



Figure D-25 R-R Demand vs. R-R Flow for scenario 13 Model 4

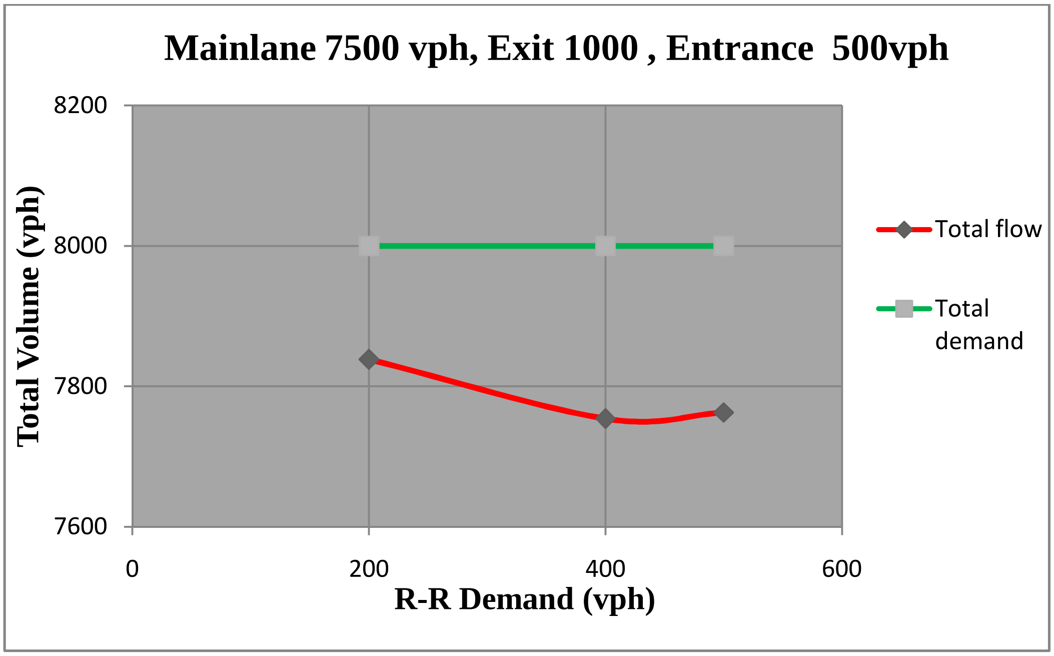



Figure D-26 R-R Demand vs. Total Volume for scenario 13 Model 4

**Scenario 14**:

- Total mainlane volume is 7500 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1500 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7500 | 1500 | 500 | 200 | 6403 | 1436 | 489 | 193 | 7838 | 6248 | 0.797 |
| 7500 | 1500 | 500 | 400 | 6373 | 1381 | 423 | 313 | 7754 | 6526 | 0.842 |
| 7500 | 1500 | 500 | 500 | 6377 | 1386 | 428 | 396 | 7763 | 6715 | 0.865 |

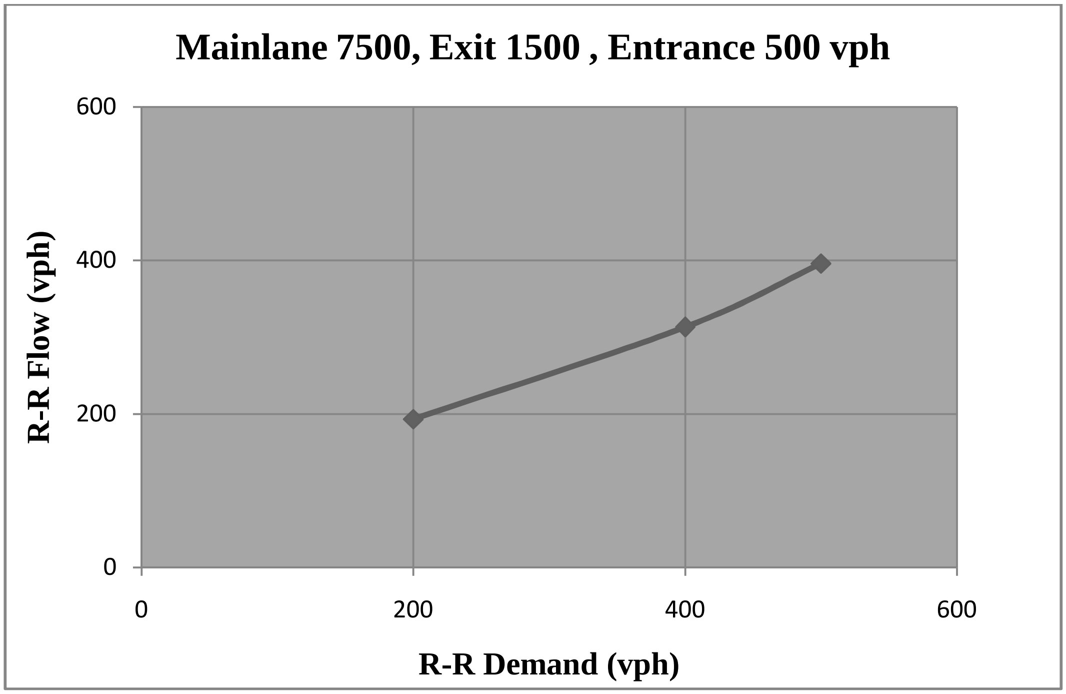



Figure D-27 R-R Demand vs. R-R Flow for scenario 14 Model 4

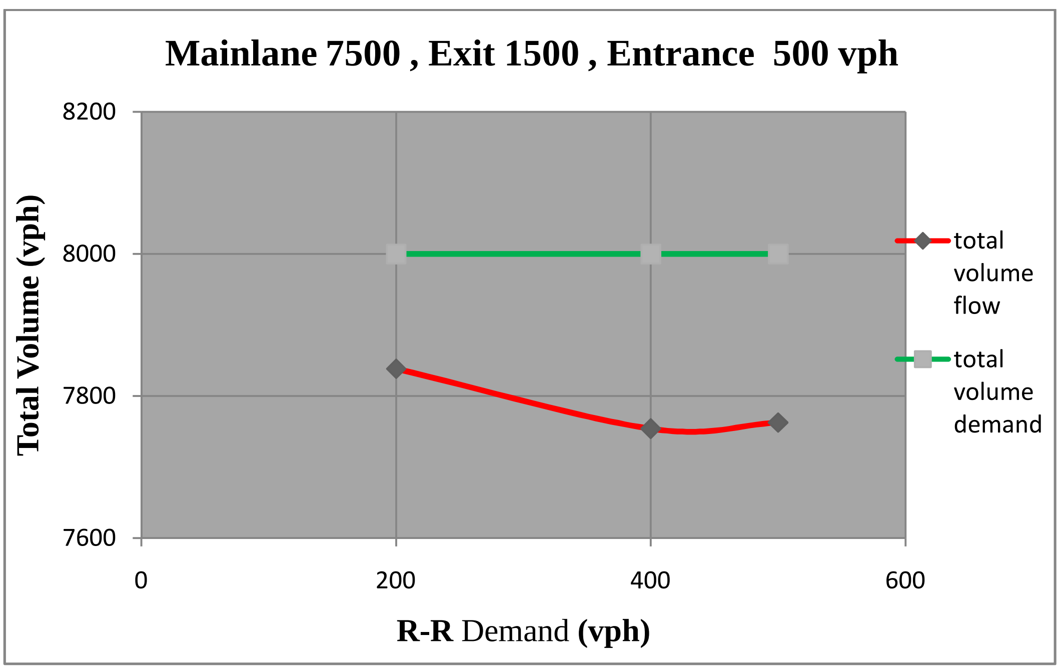



Figure D-28 R-R Demand vs. Total Volume for scenario 14 Model 4

**Scenario 15**:

- Total mainlane volume is 7500 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 2000 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 7500 | 2000 | 500 | 200 | 5720 | 1873 | 499 | 200 | 7593 | 5565 | 0.733 |
| 7500 | 2000 | 500 | 400 | 5702 | 1869 | 493 | 371 | 7571 | 5924 | 0.782 |
| 7500 | 2000 | 500 | 500 | 5695 | 1883 | 499 | 486 | 7578 | 6126 | 0.808 |

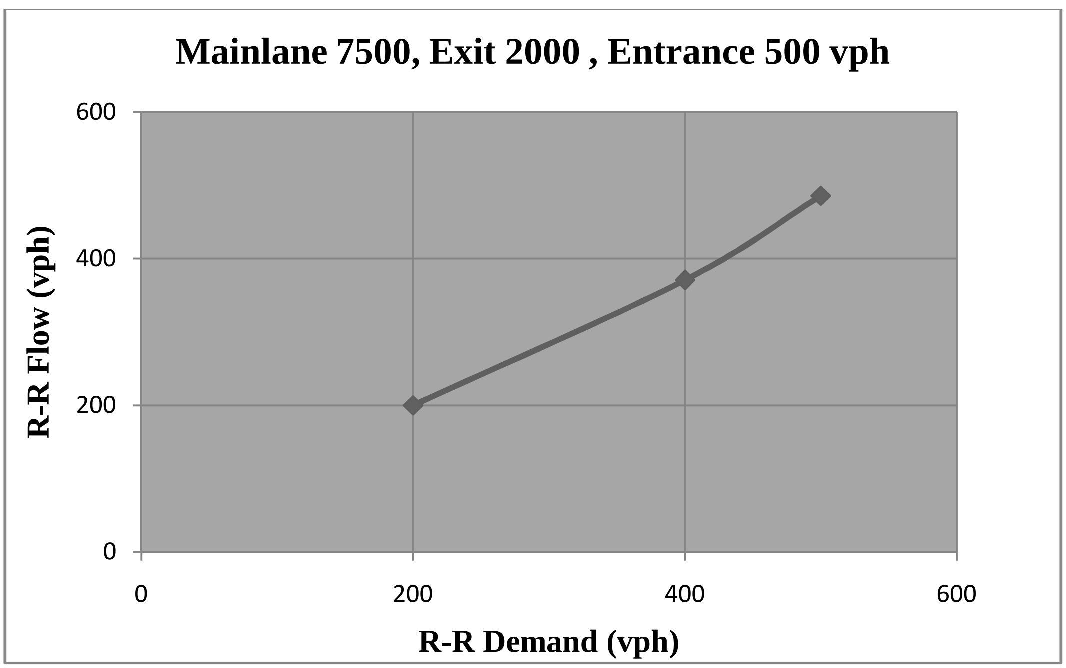



Figure D-29 R-R Demand vs. R-R Flow for scenario 15 Model 4

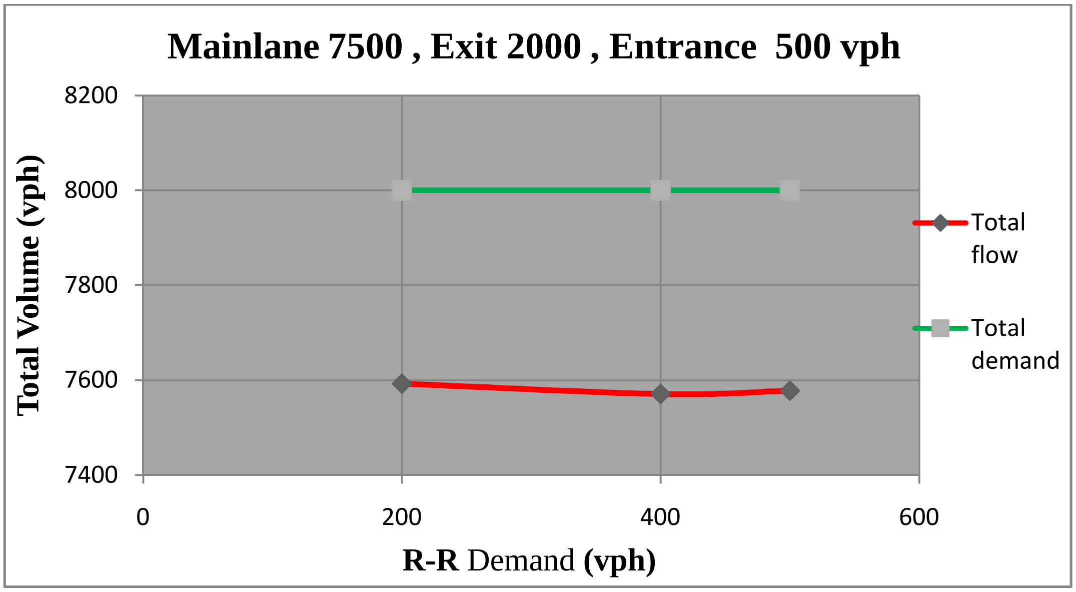



Figure D-30 R-R Demand vs. Total Volume for scenario 15 Model 4

**Scenario 16**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1000 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 8000 | 1000 | 500 | 200 | 7043 | 1054 | 499 | 201 | 8097 | 6816 | 0.842 |
| 8000 | 1000 | 500 | 400 | 7121 | 953 | 499 | 393 | 8073 | 7342 | 0.909 |
| 8000 | 1000 | 500 | 500 | 7141 | 927 | 476 | 452 | 8068 | 7522 | 0.932 |

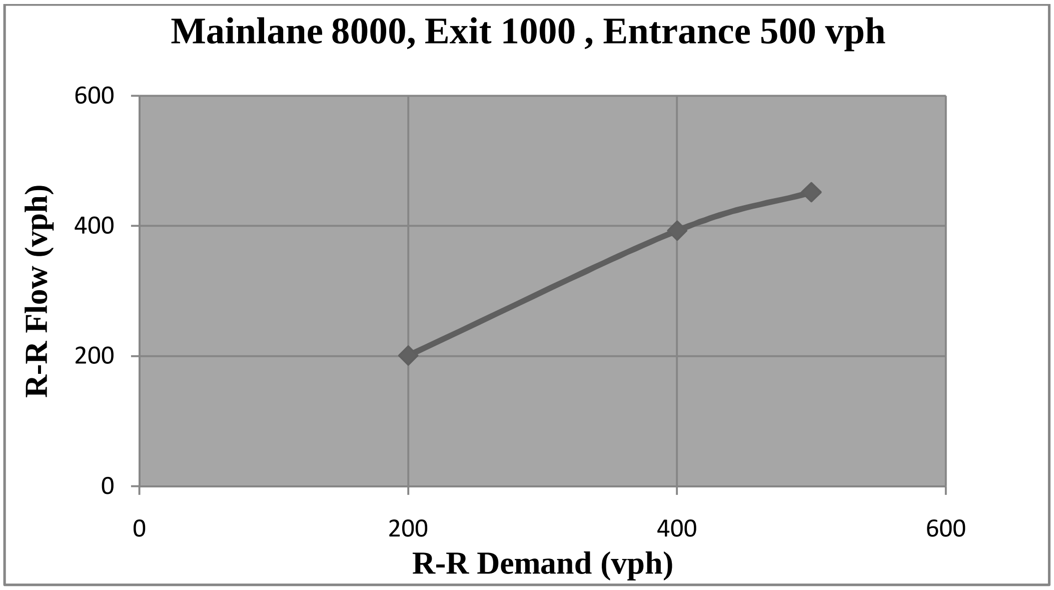



Figure D-31 R-R Demand vs. R-R Flow for scenario 16 Model 4

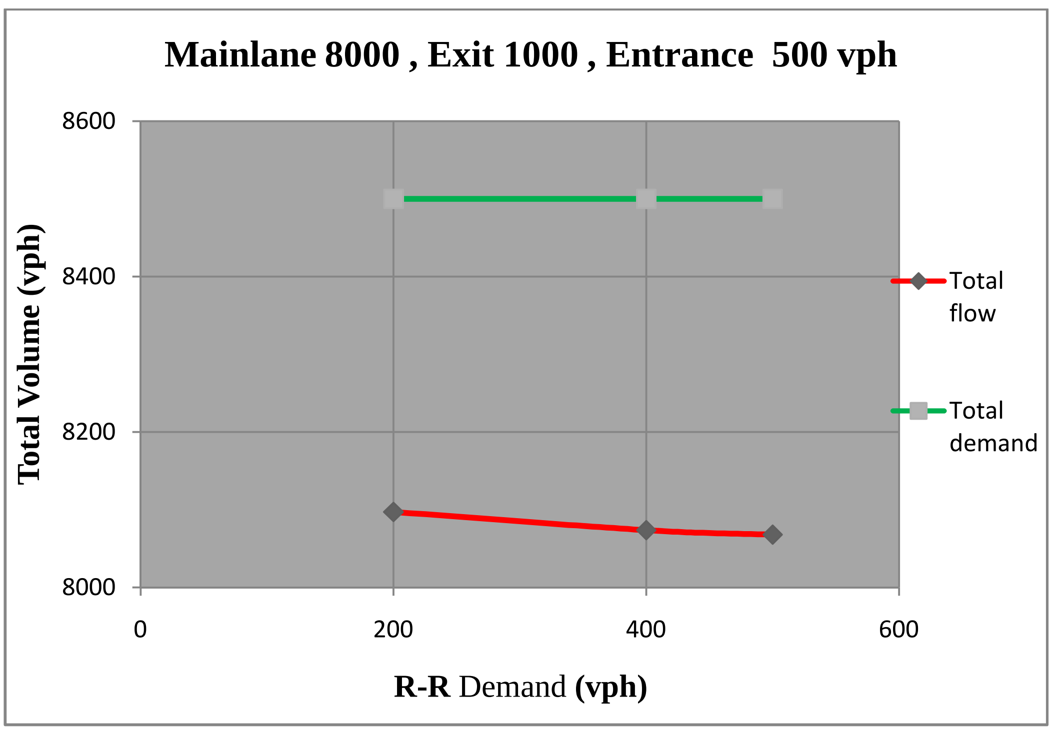



Figure D-32 R-R Demand vs. Total Volume for scenario 16 Model 4

**Scenario 17**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 1500 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 8000 | 1500 | 500 | 200 | 6574 | 1358 | 438 | 167 | 7932 | 6449 | 0.813 |
| 8000 | 1500 | 500 | 400 | 6543 | 1367 | 459 | 351 | 7910 | 6737 | 0.852 |
| 8000 | 1500 | 500 | 500 | 6404 | 1399 | 499 | 494 | 7803 | 6830 | 0.875 |

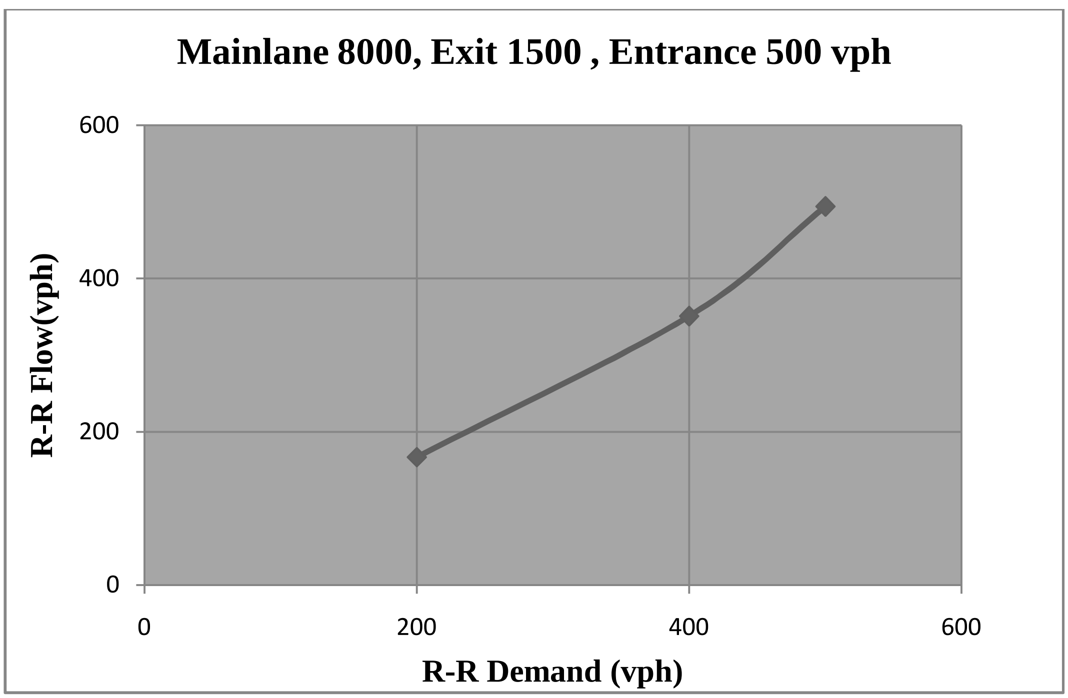



Figure D-33 R-R Demand vs. R-R Flow for scenario 17 Model 4

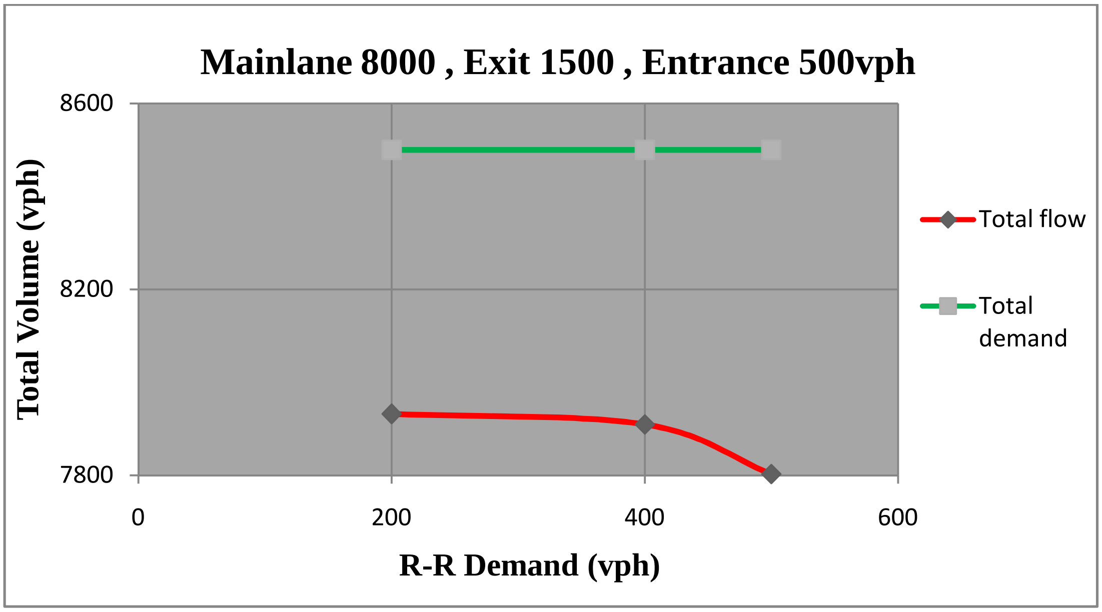



Figure D-34 R-R Demand vs. Total Volume for scenario 17 Model 4

**Scenario 18**:

- Total mainlane volume is 8000 vph
- Entrance ramp is from 500 vph
- Exit Ramp is 2000 vph
- R-R demand is from 0-500 vph

The system is at capacity.

| Demand | | | | Actual Volume (Flow) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mainlane | Exit | Entrance | R-R | Mainlane | Exit | Entrance | R-R | V | Vw | Vr |
| 8000 | 2000 | 500 | 200 | 5868 | 1775 | 499 | 200 | 7644 | 5721 | 0.748 |
| 8000 | 2000 | 500 | 400 | 5841 | 1801 | 499 | 376 | 7642 | 6114 | 0.800 |
| 8000 | 2000 | 500 | 500 | 5816 | 1805 | 500 | 496 | 7621 | 6264 | 0.822 |

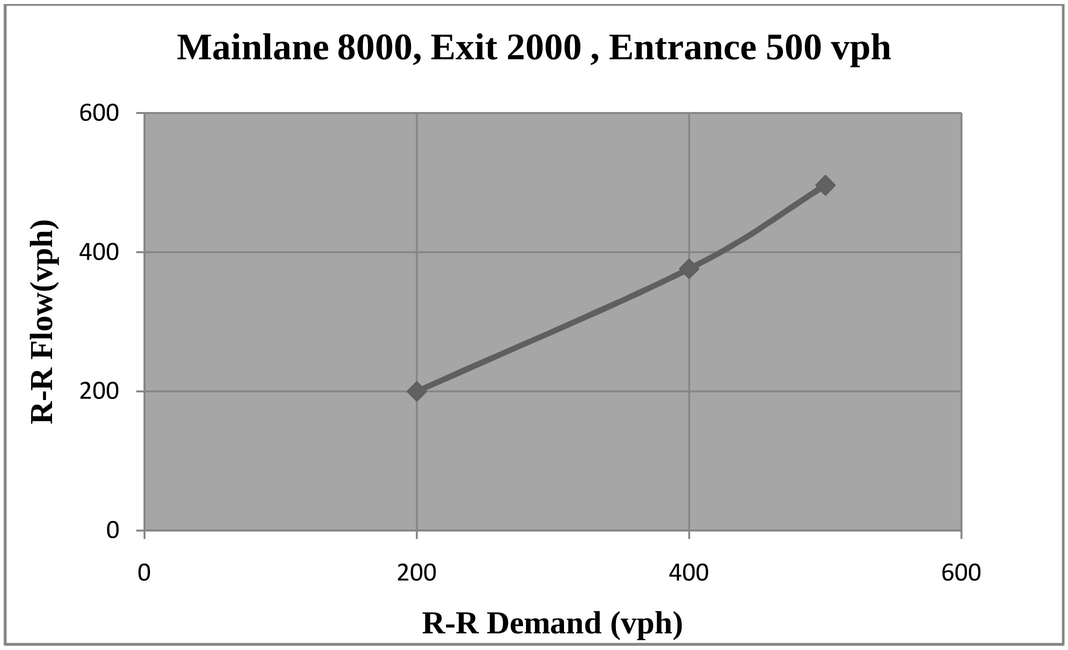



Figure D-35 R-R Demand vs. R-R Flow for scenario 18 Model 4

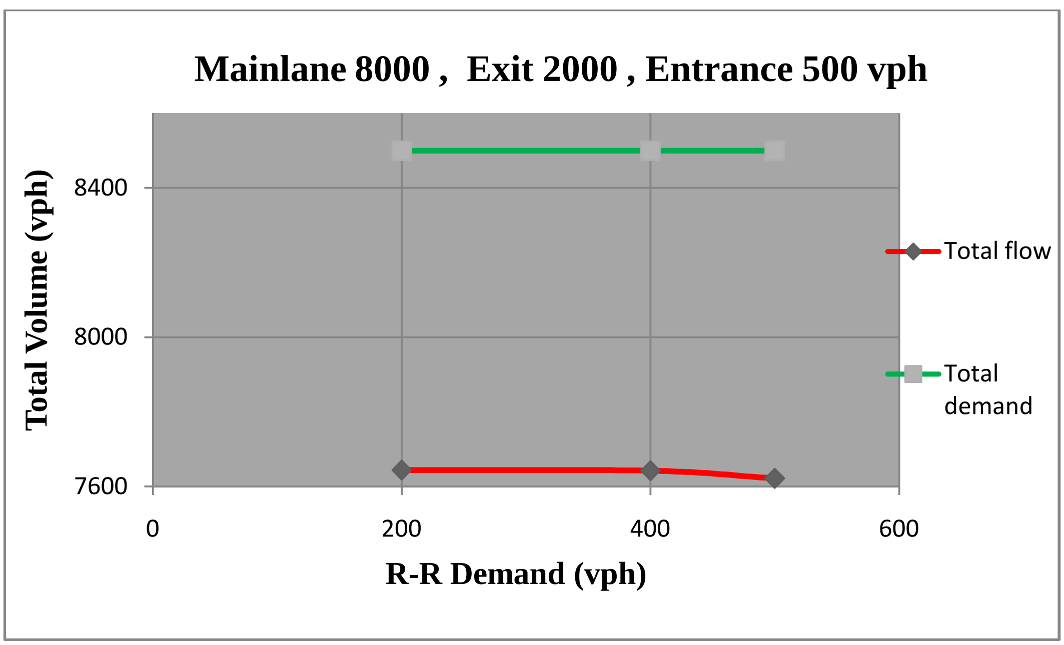



Figure D-36 R-R Demand vs. Total Volume for scenario 18 Model 4

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## BIOGRAPHICAL INFORMATION

Shadi Ghasemi-majd was born on Aug 5, 1978 in Iran. In the year 2000, she received her bachelor's degree in Civil Engineering from Isfahan University of Technology. During that time she became the chief editor of the monthly scientific publication of SARA. After receiving her bachelor's degree, she moved to Vancouver, B.C., Canada, where she resided for 3 years. To pursue her master's degree, she applied to UTA (University of Texas at Arlington), in 2006. She became a master's student at that time and she chose the field of Transportation Engineering within the Civil Engineering Department. She was hired by C & M Associates, as a Transportation System Modeler in 2007, where she is presently employed. She received her master's degree from the Civil Engineering Department of UTA in December of 2008.