A TRAFFIC OPERATIONS METHOD FOR EVALUATING AUTOMOBILE AND BICYCLE SHARED ROADWAYS

A Thesis

by

JAMES ALLAN ROBERTSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	H. Gene Hawkins
Committee Members,	Timothy Lomax
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ABSTRACT

A Traffic Operations Method for Evaluating Automobile and Bicycle Shared Roadways.
(May 2011)
James Allan Robertson, B.S. Michigan State University;
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Chair of Advisory Committee: Dr. Gene Hawkins

Shared roadways are a cost effective method for providing bicycle facilities in areas with limited right-of-way; shared roadways have automobiles and bicycles operating in the same traveled way. However, shared roadways may negatively affect traffic operations and there is limited guidance on appropriate shared roadways implementation. This thesis has three objectives: evaluate the impact of shared roadways on automobile quality of service, compare automobile quality of service to bicycle quality of service on shared roadways, and provide guidance on the implementation of shared roadways. The author hypothesizes that shared roadways should only be implemented when automobile Level of Service (LOS), bicycle LOS, and facility safety are "acceptable."

The author accomplishes the objectives by generating data using microsimulation models. The author uses microsimulation model data to evaluate automobile quality of service on shared roadways. In the evaluation of automobile quality of service, the measures of effectiveness are automobile LOS threshold (the maximum automobile flow-rate before a change in automobile LOS) and automobile average travel speed (the average travel time divided by the segment length, a space mean speed). To compare automobile and bicycle quality of service, the author uses the bicycle LOS model in NCHRP Report 616 to generate bicycle LOS thresholds (the maximum automobile flow-rate before a change in bicycle LOS). After generating bicycle LOS thresholds, the author compares the bicycle LOS thresholds to the automobile LOS thresholds. Finally, the author uses the findings of the investigations to provide guidance on the implementation of shared roadways.

In this thesis, the author finds automobile quality of service on shared roadways decreases as automobile free-flow speed, automobile volume, and bicycle volume increase. For most conditions, the author finds bicycle quality of service is better than automobile quality of service on shared roadways. Bicycle quality of service is lower than automobile quality of service with increases in unsignalized access points per mile, signalized intersection crossing distance, and heavy vehicle percent. The author provides guidance on the implementation of shared roadways based upon automobile quality of service.

DEDICATION

To my Family

ACKNOWLEDGEMENTS

I would like to thank my committee chair Dr. Gene Hawkins for his direction and guidance. I am thankful to my committee members Dr. Zhang and Dr. Lomax. Additionally, I would like to thank Shawn Turner and Jim Dale for their assistance in completion of this thesis.

I would like to thank Kay Fitzpatrick and Sue Chrysler for the opportunity to work with gifted and knowledgeable colleagues at the Texas Transportation Institute. I would especially like to thank Marcus Brewer, Vichika Iragavarapu, Jeff Miles, Dan Walker, and Jesse Stanly. It has been a pleasure and privilege to work with them.

I would like to thank my friends from the Institute of Transportation Engineers. I appreciate their support and guidance. I would especially like to thank Jim Gough, Pat Noyes, Robert Wunderlich, Rock Miller, and Dustin Qualls. They remind me why transportation engineering is such a wonderful profession.

I am grateful to all of my friends that I have made while studying at Texas A&M University. Thank you for the memories and the experiences. I wish the best for all of you as we continue on our journey through life.

Finally, I thank my family for their love and support. I would especially like to thank my Aunt Amanda and Uncle Bill. Thank you for sharing your family with me during my time in College Station.

NOMENCLATURE

AASHTO	American Association of State Highway and Transportation Officials
FFS	Free-Flow Speed
HCM	Highway Capacity Manual
LOS	Level of Service
MOE	Measure of Effectiveness
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PTV	Planung Transport Verkehr
VISSIM	A microsimulation program made by PTV

TABLE OF CONTENTS

Page

CHAPTER

LIST OF FIGURES

FIGURE Page

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

The transportation system strives to balance the needs of many users through a variety of modes. One means of providing greater balance is to increase bicycle accommodation through the development of bicycle facilities. Some jurisdictions have embraced the idea of increasing bicycle accommodation by pursuing the goal of providing a system of paths, bicycle lanes, and shared roadways for bicycle users. Among these types of bicycle facilities, paths are separate, exclusive facilities for bicycles and pedestrians, bicycle lanes provide a separate traveled way alongside automobile facilities, and shared roadways have automobiles and bicycles operating in the same traveled way (AASHTO 1999).

Shared roadways are a cost-effective method for providing bicycle facilities in areas with limited right-of-way; they do not require additional right-of-way or separate facilities. However, shared roadways may negatively affect automobile operations and there is limited guidance on appropriate implementation. One example of implementation guidance, developed by the Oregon Department of Transportation (ODOT), uses automobile volume and automobile speed to provide recommendations on shared roadway use; it suggests shared roadways are less acceptable at higher automobile speeds and automobile volumes (ODOT 2009). Engineering judgment seems to be the basis for the draft guidance. Although developed, ODOT has not adopted the draft guidance for use in practice. One weaknesses of the draft guidance is that it ignores bicycle demand in the evaluation of bicycle facilities (ODOT 2009). Furthermore, the draft guidance does not directly take into account the operational performance of shared roadways (ODOT 2009). There is need for a better method for

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This thesis follows the style of the *Journal of Transportation Engineering*.

evaluating shared roadways that considers the operational performance of the facility. This thesis attempts to develop such a method.

Operational performance and quality of service are typically described by Level-of-Service (LOS); the primary reference for determining LOS is the Highway Capacity Manual (HCM). While the HCM 2000 is the current edition, the 2010 edition of the HCM will be released in 2011. The expected procedures for determining automobile LOS and bicycle LOS, on urban streets, were developed in projects sponsored by the National Cooperative Highway Research Program (NCHRP). NCHRP Report 616 documents a model for determining bicycle LOS on urban street segments and it applies to shared roadways; based on user perception data, the model indicates bicycle LOS is a function of unsignalized access points per mile, automobile volume, heavy vehicle percent, pavement condition, outside lane width, and signalized intersection crossing distance (Dowling et. el. 2008). NCHRP Project 3-79 updates the HCM methodology for evaluating automobile LOS on urban street segments, indicating automobile LOS on urban street segments is a function of percent free-flow speed (Bonneson et. el. 2008). Free-flow speed is approximately the speed limit on urban street segments. Percent free-flow speed is the average travel speed divided by the free-flow speed, as a percentage.

The automobile LOS methodology does not include delay associated with bicycles in the traveled way. This means, for inclusion in automobile LOS estimation, automobile delay associated with shared roadways (delay due to bicycle and automobiles sharing the same lane) must come from other sources. Possible sources of delay estimations on shared roadways include field observations and microsimulation. Utilizing the microsimulation approach, this thesis relies on VISSIM 5.10 (a microsimulation program) to model bicycles in the traveled way (PTV 2008).

Problem Statement

This thesis uses microsimulation to evaluate changes in automobile LOS due to the presence of bicycles on shared roadways. The work in this thesis focuses on four-lane, divided, minor arterials and four-lane, divided collectors. The author hypothesizes that shared roadways should only be implemented when automobile LOS, bicycle LOS, and facility safety are "acceptable;" however, an investigation of facility safety is outside the scope of this thesis. This thesis documents the author's efforts to demonstrate a need to consider automobile operations in the evaluation of shared roadway facilities. Additionally, the author provides guidance on the use of shared roadways. If shared roadway design is going to continue, decision makers should understand the impact of shared roadways on automobile LOS.

Research Objectives

As an unfunded effort, this thesis was limited in the scope of data collection that could be undertaken. Therefore, this thesis analyzes microsimulation data using procedures for evaluating automobile LOS expected to be in the HCM 2010. This thesis has three research objectives. The first research objective is to determine the impact of shared roadways on automobile quality of service. The second objective is to compare automobile and bicycle quality of service on shared roadways. The third objective is to provide guidelines on the implementation of shared roadways.

To accomplish the research objectives, the author conducts a sensitivity analysis of independent variables associated with shared roadways. The sensitivity analysis investigates changes in quality of service associated with changes in roadway design and traffic flow independent variables. To evaluate automobile quality of service, the author uses microsimulation to generate data. To evaluate bicycle quality of service, the author uses the bicycle quality of service model documented in NCHRP Report 616 (Dowling et. el 2008). Roadway design and traffic flow independent variables are included in this thesis if:

1. The independent variable is changeable in VISSIM 5.10, or
2. The independent variable is part of the bicycle LOS model found in NCHRP Report 616.

Independent variable values are representative of minor arterials and collectors.

If an independent variable is changeable in VISSIM 5.10, the author uses microsimulation to generate data for identified independent variable values; other variables are not included in microsimulation. The microsimulation outputs are automobile volume, bicycle volume, automobile average travel time, and bicycle average travel time. The author converts automobile average travel time to automobile average travel speed. Using automobile average travel speed, percent free-flow speed is calculated. VISSIM 5.10 uses desired speed distributions to determine vehicle travel speed; this thesis assumes free-flow speed is the median desired speed of the speed distribution. This means, in VISSIM terminology, percent free-flow speed is percent median desired speed.

To accomplish the first research objective, the author uses outputs from VISSIM 5.10 to document relationships between identified independent variables, automobile volume, automobile free-flow speed, and automobile LOS thresholds. Automobile LOS thresholds are the maximum automobile flow rate for a given automobile LOS. The author does not use VISSIM 5.10 outputs to evaluate bicycle LOS; according to the bicycle LOS model, bicycle LOS is independent of bicycle volume and bicycle average travel time (Dowling et. el. 2008).

To accomplish the second research objective, the author obtains bicycle LOS thresholds using the bicycle LOS model in NCHRP Report 616. To obtain bicycle LOS thresholds (the maximum automobile flow rate for a given bicycle LOS), the author manipulates the bicycle LOS model such that it outputs bicycle LOS thresholds. After obtaining comparison bicycle LOS thresholds, the author determines which LOS D threshold is lower (automobile or bicycle). The mode with a lower LOS D threshold governs facility selection for a given set of independent variable values. If each mode has one set of independent variables values in which it governs facility selection, the author's hypothesis is correct. Otherwise, decision makers should only consider the mode that always governs.

To accomplish the third research objective, the author uses the results of the first two research objectives to develop guidance on the implementation of shared roadways. The shared roadway implementation guidance is a function of automobile and bicycle quality of service. The guidance gives three recommendations; shared roadways acceptable, shared roadways unacceptable, and further analysis is necessary. To assist practitioners in conducting further analysis, the author provides a methodology for estimating automobile percent free-flow speed on shared roadways; additionally, the author provides bicycle quality of service considerations. *Note: the values used to develop the guidance and delay estimation methodology are from a microsimulation model not calibrated to observed data.*

Key activities in this thesis are:

- A review of current knowledge (Chapter II),
- The selection of independent variables and variable values (Chapter III),
- The creation and partial calibration of microsimulation models (Chapter III),
- An evaluation of automobile quality of service on shared roadways (Chapter IV),
- A comparison of automobile quality of service to bicycle quality of service on shared roadways (Chapter V), and
- The development of guidance on the implementation of shared roadways (Chapter VI).

The author summarizes the findings and provides recommendations for future efforts in Chapter VII.

It is outside the scope of this thesis to conduct a safety analysis of shared roadways. This thesis assumes current shared roadway design standards produce nominally safe facilities. When analysis methods become available, the author recommends incorporating substantive safety in to the evaluation of shared roadways.

CHAPTER II

BACKGROUND

Shared roadways are a cost-effective method for providing bicycle facilities with limited right-of-way; however, they may negatively affect automobile operations and there is limited guidance in their use. This thesis has three research objectives: to determine the impact of shared roadways on automobile quality of service, to compare the impact on automobile quality of service to the impact on bicycle quality of service, and to use the finding to provide guidance on shared roadway implementation. To accomplish the three research objectives, the author documents background information pertaining to bicycle facility design, roadway functional classification, bicycle LOS, automobile LOS, and VISSIM 5.10. The information in this chapter provides the basis for decisions made in this thesis.

Bicycle Facility Design

When selecting bicycle facility type, decision makers should consider bicycle user characteristics (AASHTO 1999). There are three types of bicycle facilities. Shared use paths have bicycles and pedestrians operating in the same traveled way; automobiles have a separate facility. Bicycle lanes are adjacent to the automobile traveled way. Shared roadways have automobiles and bicycles operating in the same traveled way. Bicycle riding practices on shared roadways may affect automobile quality of service.

User Characteristics

AASHTO (1999) recognizes three types of bicycle users. Experienced cyclists operate bicycles in a manner similar to how they would operate an automobile. Most experienced cyclists are comfortable riding with automobile traffic. Amateur cyclists are less comfortable riding with automobile traffic. Children are the third type of bicycle user; children should not ride with automobile traffic (AASHTO 1999). Experienced cyclists and amateur cyclists are capable of utilizing shared roadways. Amateur cyclists prefer bicycle lane facilities to shared roadways. For children, designers should provide shared use paths or sidewalks clear of obstacles (AASHTO 1999).

This thesis focuses on experienced and amateur cyclists. Most experienced and amateur cyclists operate bicycles within a width of 40 inches (3.3 ft) (AASTHO 1999). The design width of bicycles, with rider, is 30 inches (2.5 ft). Bicycle free-flow speed ranges from 6.2 mph to 17.4 mph (AASHTO 1999). Most bicycles ride at a speed between 7.5 and 12.4 mph (Allen et. el. 1998).

Shared Use Paths

Shared use paths are facilities for bicycles and pedestrians that are separate from automobile facilities (AASHTO 1999). AASHTO (1999) recommends locating shared use paths away from automobile traveled way; this reduces conflicting movements. Shared use paths have bicycles and pedestrians traveling in both directions. The recommended width of shared use facilities is 10 ft; providing 5 ft for each direction (AASHTO 1999). When designing shared use paths, engineers should consider horizontal alignment and sight distance. Shared use paths are ideal for children. Shared use paths require more right-of-way than bicycle lanes and shared roadways.

Bicycle Lanes

Bicycle lanes are adjacent to the automobile traveled way. Pavement markings, and signs, delineate bicycle lanes from automobile traveled way. The minimum design width for bicycle lanes is 4 ft, if there is no gutter pan (AASTHO 1999). The recommended design width is 5 ft (AASTHO 1999). Assuming an automobile lane width of 12 ft, a four lane minor arterial would require a total pavement width of 58 ft. Bicycle lanes require more right-of-way than shared roadways; less than shared use paths.

Shared Roadways

Shared roadways require the least right-of-way and pavement width; they also increase automobile and bicycle interaction. This interaction may negatively affect quality of service. There are two types of shared roadways, those without additional outside lane width and those with additional outside lane width.

When providing additional outside lane width, AASHTO (1999) recommends 14 ft. An outside lane width of 15 ft is preferred, if possible. Travel lanes should not have a width greater than 15 ft. Automobile users may get confused when outside lane widths are greater than 15 ft; they mistakenly believe the one outside lane is in fact two lanes. This means shared roadways have a range of widths; they are 10 ft to 12 ft and 14 ft to 15 ft.

Based upon outside lane width, bicycle-riding style may change. A change in bicycle-riding style may affect automobile quality of service. The League of American Bicyclists (2010) recommendations the following riding practices,

- Bicycles should ride in the same direction as vehicles,
- Bicycles should obey all signs, signals, and markings,
- Bicycles should ride in the proper lanes (e.g. left turn lane when turning left), and
- Bicycles should stay to the right unless passing.

When there is insufficient lane width, bicycles are encouraged to ride towards the center of the travel lane (League of American Bicyclists 2010). Additionally, bicycles are encouraged to ride towards the center of the lane to avoid car doors on facilities with on street parking. This type of riding may cause additional delay to motor vehicles in the traveled way. This thesis seeks to quantify the delay to automobiles in shared roadways.

Roadway Functional Classification

Decision makers should consider roadway functional classification when deciding on type of bicycle facility. Engineers use roadway functional classification to balance mobility and access. Mobility is the need to move vehicles in an efficient manner.

Access is the need for vehicles to be able to enter the roadway network. Higher functionally classified roadways focus on mobility. Lower functionally classified roadways focus on access.

Seven functional classifications are shown in Table 2.1. Decision makers should avoid shared roadway design on roadways that emphasize mobility. This means major arterials, principle arterials, and freeways. Shared roadways are a good solution on most local streets. There is limited guidance for the use of shared roadways on minor arterials, major collectors, and minor collectors. This thesis investigates shared roadways on minor arterials and collectors.

Table 2.1 Functional Class and Characteristics from Least to Most Access, Top to Bottom (Stover and Koepke 2006)

Functional Class	Lanes	Roadway Division	Free-Flow Speed
Freeway	4 to 6	Divided	55 +
Principle Arterial	6	Divided	45 to 55
Major Arterial	4 to 6	Divided	45 to 50
Minor Arterial	4 to 5	Either	40 to 45
Major Collector	2 to 5	Either	35 to 40
Minor Collector	2	Undivided	25 to 35
Local	1 to 2	Undivided	< 25

Level of Service

Level of Service (LOS) is “a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience” (HCM 2000, pg. 2-2). This means LOS describes how drivers perceive operating conditions (HCM

2000). This thesis investigates bicycle LOS and automobile LOS as methods for evaluating shared roadway facilities.

Bicycle LOS

In NCHRP Report 616, researchers developed a new bicycle LOS model (Dowling et. el. 2008). The purpose of the new model is to replace the HCM 2000 method (Dowling et. el. 2002). The bicycle LOS model incorporates user perception data; researchers obtained user response to video clips (Dowling et. el. 2008). The model includes the following independent variables (Dowling et. el. 2008):

- Number of directional through lanes,
- Outside lane width,
- Roadway division,
- Unsignalized access points per mile,
- Signalized intersection crossing distance,
- Percentage of roadway segment with occupied on street parking,
- FHWA's five-point pavement condition rating,
- Automobile speed,
- Automobile volume,
- Heavy vehicle percent, and
- Peak hour factor.

Of these variables, those with the greatest impact are unsignalized access points per mile, automobile volume, heavy vehicle percent, FHWA's five-point pavement condition rating, pavement condition, outside lane width, and signalized intersection crossing distance. The model provides a quality of service rating which is associated with a letter level of service.

Unsignalized access points per mile are an interesting inclusion in the bicycle LOS model. Historically, decision makers have not considered access in the design and planning of roadways (TRB 2003). This has resulted in roadways with high access rates; according to the new model, these roadways have lower bicycle LOS.

The TRB (2003) Access Management Manual discuses four methods for determining access spacing. Stopping sight distance is the distance traveled by a vehicle while the driver perceives a need to stop and successfully performs the maneuver. Stopping sight distance varies by vehicle travel speed. Intersection sight distance, the spacing between vehicles needed by a driver to enter the cross street. Intersection functional area, queue length plus stopping sight distance. Influence distance, the distance from an access point where trailing vehicles begin to brake; trailing vehicles are following a vehicle turning at the access point.

These four access spacing methods are idealized conditions; traditionally, access spacing is less than the recommended minimums. There is support for using stopping sight distance (TRB 2003 & Stover and Koepke 2006). For new constructions, this is not a problem; however, retrofitting this requirement is difficult (TRB 2003). This thesis assumes stopping sight distance as the minimum spacing; the author understands it is an idealized condition.

Automobile LOS

NCHRP Project 3-79 updates the HCM methodology for evaluating automobile LOS on urban street segments (Bonneson et. el. 2008). NCHRP Project 3-79 indicates automobile LOS on urban street segments is a function of percent free-flow speed (Bonneson et. el. 2008). Percent free-flow speed is average travel speed divided by free-flow speed, as a percentage. The current method uses average travel speed, urban street classification, free-flow speed, and typical free-flow speed (HCM 2000).

HCM 2000 criteria and NCHRP Project 3-79 criteria are shown in table 2.2. According to NCHRP Project 3-79, the new ranges more accurately represent automobile user perception. The new methodology does not include delay associated with bicycles in the traveled way. This means, for inclusion in LOS estimation, automobile delay associated with shared roadways must come from other sources. Field observations and microsimulation are possible delay estimation sources.

Table 2.2 HCM 2000 and NCHRP 3-79 Urban Street LOS Criteria

LOS	* HCM 2000*	* HCM 2000 (Percent FFS)	* NCHRP 3-79 (Percent FFS)
	Roadway with FFS of 30 mph		All speeds
LOS A	> 30 mph	> 100	> 85
LOS B	> 24 to 30 mph	> 80 to 100	> 67 to 85
LOS C	> 18 to 24 mph	> 60 to 80	> 50 to 67
LOS D	> 14 to 18 mph	> 47 to 60	> 40 to 50
LOS E	> 10 to 14 mph	> 33 to 47	> 30 to 40
LOS F	< 10 mph	< 33	< 30

*Includes reductions in speed that are the result of control delay

Design Decisions Using LOS

In addition to describing how facilities are operating, transportation engineers use LOS to make decisions concerning the design and operation of roadways. For example, the criterion for adding climbing lanes includes a consideration of automobile LOS. AASHTO (2004) recommends adding a climbing lane if the LOS on the facility is less than D or LOS drops by two or more levels when moving from the approach segment to the grade (from A to C or B to D). This thesis suggests shared roadways are acceptable if the facility is operating at LOS D or better.

VISSIM 5.10

VISSIM 5.10 is a microsimulation program capable of simulating bicycles in the traveled way (PTV 2008). VISSIM 5.10 is also capable of simulating automobiles passing bicycles in the same travel lane (PTV 2008). Proper microsimulation analysis requires calibration of the model to observed data (Dowling et. el. 2002). VISSIM 5.10 is a data intensive program (Dowling et. el. 2002). The author was unable to identify efforts using VISSIM 5.10 to evaluate operational impacts of bicycles.

CHAPTER III
STUDY DESIGN & MICROSIMULATION MODELS

This thesis has three research objectives; they are to evaluate the impact of shared roadways on automobile quality of service, to compare automobile quality of service to bicycle quality of service on shared roadways, and provide guidance on the implementation of shared roadways using automobile and bicycle quality of service. In this chapter, the author documents the study design and microsimulation models used to accomplish the research objectives. The information in this chapter forms the basis for the results and findings in this thesis. This chapter documents the study approach, variable selection, microsimulation model development, microsimulation model coding, microsimulation model output, partial microsimulation model calibration, and summary.

Study Approach

This thesis uses microsimulation to generate data used in a sensitivity analysis of automobile quality of service on shared roadways. The sensitivity analysis investigates changes in automobile quality of service associated with changes in identified independent variables. The measures of effectiveness (MOEs) for automobile quality of service are automobile average travel speed (space mean speed) and automobile LOS threshold. An automobile LOS threshold is the maximum automobile flow rate for a given LOS. For example, the automobile LOS D threshold is the maximum automobile flow rate on a facility before the automobile LOS becomes E.

After an investigation of automobile quality of service, the author compares automobile LOS D thresholds to bicycle LOS D thresholds. The purpose of this comparison is to determine which mode governs shared roadway implementation. A mode governs shared roadway implementation if the associated LOS D threshold is less than the LOS D threshold for the other mode. For example, if the automobile LOS D threshold is less than the bicycle LOS D threshold, automobile LOS governs shared roadway implementation. To obtain bicycle LOS D thresholds (the maximum automobile flow rate for a given bicycle LOS), the author manipulates equations in the bicycle LOS model from NCHRP Report 616; the author changes LOS from an output to an input.

Based upon the results of the automobile quality of service investigation and comparison of automobile and bicycle quality of service, the author provides guidance on the implementation of shared roadways. The guidance recommends not implementing shared roadways on facilities where the automobile LOS would be D or lower. The author provides guidance for shared roadways facilities with an outside lane width less than 14 ft and facilities with an outside lane width greater than 14 ft (wide outside lanes).

Variable Selection

To perform automobile quality of service sensitivity analysis and to compare automobile and bicycle quality of service, the author identifies independent variables that influence automobile and bicycle quality of service on shared roadways. This thesis includes independent variables the author can adjust in VISSIM 5.10 and independent variables included in the bicycle LOS model from NCHRP Report 616 (PTV 2008 & Dowling et. el. 2009). The author identifies eight independent roadway characteristic variables and nine independent traffic flow variables. After identifying independent variables, the author determines independent variable values associated with minor arterials and collectors. This section documents the independent variables, criteria met for inclusion, and values for each independent variable.

Independent Roadway Characteristic Variables

The eight independent roadway characteristic variables, criteria met, and values are shown in Table 3.1. Under criteria met, “simulation” means the variable is changeable in VISSIM 5.10. If the criteria met is “NCHRP,” the variable is part of the bicycle LOS model in NCHRP Report 616 (Dowling et. el. 2009). If the criteria met is “Both,” the variable is changeable in VISSIM 5.10 and included in the bicycle LOS model. This thesis focuses on four-lane divided minor arterials and collectors; therefore, “number of directional through lanes” and “roadway division” (median presence) have one value.

Table 3.1 Independent Roadway Characteristic Variables

Independent Variable	Criteria Met	Value(s)
Number of directional through lanes	Both	2
Outside lane width	Both	12 ft & 15 ft
Segment length	Simulation	1320 ft & 2640 ft
Roadway division	NCHRP	Divided
Unsignalized access points per mile	NCHRP	Table 3.2
Signalized intersection crossing distance	NCHRP	38 ft, 62 ft, & 86 ft
Percentage of roadway segment with occupied on street parking	NCHRP	0 %, 50 % & 100 %
FHWA’s five-point pavement surface condition rating	NCHRP	2, 3, & 4

Unsignalized access points per mile is a rate; it is the total number of unsignalized access points on one side of the roadway segment divided by the length of roadway segment, the value is converted to a per mile equivalent. A recommended spacing of access points along a roadway segment is Stopping Sight Distance (SSD), which varies by Free-Flow Speed (FFS) (Stover and Koepke 2006, TRB 2003). The maximum number of recommended access points along a roadway segment varies with FFS.

Access point rates are shown in Table 3.2. “Half Access” is half the maximum number of access points on a 1320 ft roadway segment using SSD as the minimum spacing; “Maximum Access” is the maximum number of access points on a 1320 ft roadway segment assuming SSD is the minimum spacing. The author assumes access spacing is from center of driveway to center of driveway. Cross streets at signalized intersections are not included in the access point rate; however, the author assumes access points have minimum spacing from the center of the cross street. To calculate the 25 mph FFS "Maximum Access" rate, divide 1320 ft by 155 ft; then subtract one from the obtained value (this accounts for one of the access points being a signalized intersection). Next round the obtained value down to the nearest whole number, this gives you the number of allowable access points on a 1320 ft roadway segment; the per mile equivalent is four times the number of access points on a 1320 ft roadway segment. The author uses the same procedure to calculate the "Maximum Access" rate for the other FFS conditions.

Table 3.2 Unsignalized Access Points Comparison Rates by FFS

FFS (mph)	Minimum Spacing (ft)	No Access (Points per mile)	Half Access (points per mile)	Maximum Access (points per mile)
25	155	0	14	28
30	200	0	10	20
35	250	0	8	16
40	305	0	6	12
45	360	0	4	8

The signalized intersection crossing distances in Table 3.1 are based on cross streets with cross-sections containing a 14 ft median. In addition to a 14 ft median, the author assumes the cross street lanes are 12 ft wide. For bicycle LOS, the author evaluates cross street cross-sections of two, four, and six lanes. For automobile LOS, the author uses a cross street cross-section of four lanes, 62 ft.

Traffic Flow Independent Variables

The nine independent traffic flow variables, criteria met, and values are shown in Table 3.3. Independent traffic flow variables use the same criteria as the roadway design independent variables. This thesis does not evaluate comparison values for peak hour factor; instead, the author evaluates different automobile flow-rates. Additionally, the author only evaluates one distribution of Bicycle FFS; alternative distributions were unavailable.

Table 3.3 Independent Traffic Flow Variables

Independent Variable	Criteria Met	Value(s)
Automobile FFS	Both	Table 3.4
Automobile flow-rate	Both	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h
Bicycle FFS	Simulation	7.4 to 12.5 mph-
Bicycle flow-rate	Simulation	0 bikes/h, 25 bikes/h, 50 bikes/h, & 100 bikes/h
Cycle length	Simulation	90 s &120 s
Green time ratio	Simulation	0.20 & 0.4
Signal offset	Simulation	Table 3.5
Heavy vehicle percent	NCHRP	0 %, 5 %, & 10 %
Peak hour factor	NCHRP	1.0

* Also in NCHRP Report 616

VISSIM 5.10 uses desired speed distributions to assign speeds to simulated vehicles. Automobile median speed is the median speed of the desired speed distribution. This thesis simulates five desired speed distributions; the median, minimum, and maximum values of each speed distribution are shown in Table 3.4. This thesis assumes the median speed of the speed distribution is the FFS; FFS is approximately the speed limit on urban street segments. This thesis uses linear speed distributions; this means VISSIM

5.10 assigns speeds with an equal probability between the minimum and maximum speed in each speed distribution.

Table 3.4 Desired Speed Distributions by FFS

FFS (mph)	Median (mph)	Minimum (mph)	Maximum (mph)
25	25	***20***	***30***
30	30	***25***	***35***
35	35	***30***	***40***
40	40	***35***	***45***
45	45	***40***	***50***

For each simulation model, the author simulates five automobile flow-rates. The flow rates used in each model are shown in Table 3.5. The volumes in model 4 are lower because of a lower capacity caused by a lower green time ratio. Capacity for each model is the average number of vehicles traversing the roadway segment in 60 minutes under a demand volume of 3000 veh/h.

For each FFS, this thesis uses a different signal offset; they are shown in Table 3.6. The author uses signal offsets equal to the segment length divided by FFS. Vehicles traveling near the FFS should clear the downstream intersection under low volumes; this is an idealized condition.

Table 3.5 Automobile Flow-Rates by Model

Model	Flow-Rates
Model 1	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h
Model 2	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h
Model 3	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h
Model 4	300 veh/h, 450 veh/h, 600 veh/h, 750 veh/h, & 900 veh/h
Model 5	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h
Model 6	300 veh/h, 600 veh/h, 900 veh/h, 1200 veh/h, & 1500 veh/h

Table 3.6 Signal Offsets by FFS and Segment Length

FFS (mph)	Signal Offset (s)	
	1320 ft Segment	2640 ft Segment
25	36	72
30	30	60
35	26	51
40	23	45
45	20	40

Microsimulation Model Development

There are 96 ways to combine microsimulation variables; this does not include automobile FFS and automobile volume combinations. Including automobile FFS and automobile volume there are 2,400 combinations. As an unfunded effort, this thesis reduces the number of combinations. Variables values not identified in Table 3.1 or Table 3.3 are not simulated.

Also, this thesis does not evaluate the combined effect of independent variables; this reduces the number of microsimulation scenarios and models. For example, only segment length changes in the investigation of segment length; all other variables remain the base value. This approach results in six models; with each model having one to three simulation scenarios (these scenarios do not include the 25 automobile FFS and volume combinations); the connections between models, scenarios, FFSs, and volumes are shown in Figure 3.1. The independent variable values corresponding to each model and scenario are shown in Table 3.7.

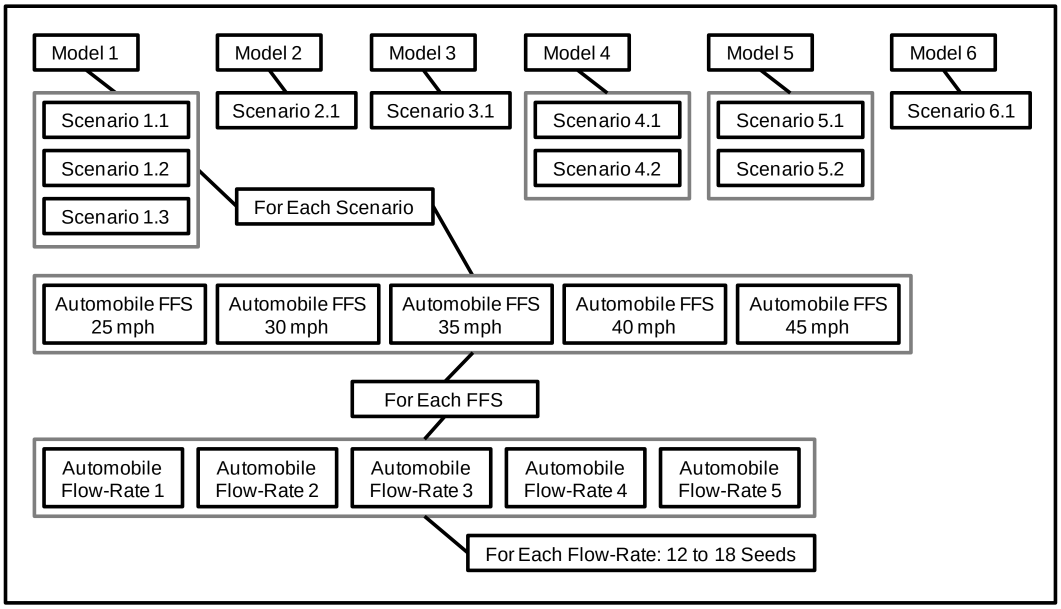


Figure 3.1 Connections between Models, Scenarios, FFSs, and Flow-Rate

Table 3.7 Microsimulation Models and Scenarios

Model	Scenario	Bicycle Flow-Rate	Outside Lane Width	Green Time Ratio	Cycle Length	Segment Length
Model 1	Scenario 1.1	0 bikes/h	12 ft	0.4	90 s	1320 ft
	Scenario 1.2	50 bikes/h	12 ft	0.4	90 s	1320 ft
	Scenario 1.3	50 bikes/h	15 ft	0.4	90 s	1320 ft
Model 2	Scenario 2.1	25 bikes/h	12 ft	0.4	90 s	1320 ft
Model 3	Scenario 3.1	100 bikes/h	12 ft	0.4	90 s	1320 ft
Model 4	Scenario 4.1	0 bikes/h	12 ft	0.2	90 s	1320 ft
	Scenario 4.2	50 bikes/h	12 ft	0.2	90 s	1320 ft
Model 5	Scenario 5.1	0 bikes/h	12 ft	0.4	120 s	1320 ft
	Scenario 5.2	50 bikes/h	12 ft	0.4	120 s	1320 ft
Model 6	Scenario 6.1	50 bikes/h	12 ft	0.4	90 s	2640 ft

For each model, the author runs all the scenarios and speed conditions simultaneously. This means each model has five roadway segments for each scenario (one for each speed condition). The author does this by creating roadway segment sets; there is one roadway segment set for each speed condition. An example of a roadway segment set is shown in Figure 3.2. The number of roadway segments in each roadway segment set is dependent on the number of scenarios. For example, model one has three scenarios and would have three roadway segments in each set; model four has two scenarios and would only have two roadway segments in each set. Each model has five roadway segment sets, one roadway segment set for each FFS. Additionally, the author runs 12 to 18 seeds for each volume; lower volumes use 12 seeds and higher volumes use 18 seeds. A limitation of this approach is having different scenarios and automobile FFS combinations being ran on different roadway segments in the model. This may result in minor differences; running 12 to 18 seeds should account for these differences.

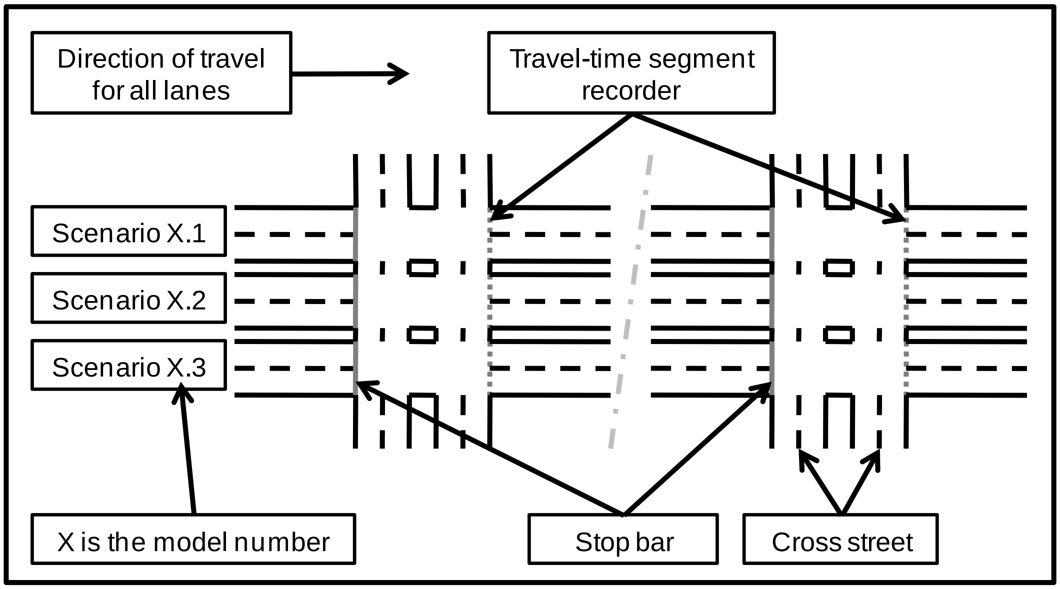


Figure 3.2 Example of a Roadway Segment Set (There are Five Sets in Each Model, One for Each FFS)

Microsimulation Model Coding

The author codes the six microsimulation models in VISSIM 5.10 (PTV 2008). This section covers the coding of these models. The microsimulation parameters are calibrated using model one. After model calibration, the author makes no changes to the calibrated variables. The following variables are coded in VISSIM 5.10:

- Simulation parameters,
- Vehicle speed profiles,
- Vehicle characteristics,
- Driving behavior,
- Roadway segments,
- Signal control, and
- Travel time segments.

This thesis uses the VISSIM 5.10 default values unless otherwise indicated.

Simulation Parameters

Simulation parameters control the simulation period, simulation resolution, simulation seed, and number of cores. This thesis uses a simulation period of 3,900 simulation seconds. This provided 300 seconds for network loading and 3,600 seconds for data collection. Simulation resolution was set at five time steps per simulation second. This means the simulation reevaluates vehicle position, and trajectory, every 0.2 simulation seconds. All simulations began on random seed 40 using one core.

Vehicle Speed Profiles

VISSIM 5.10 assigns vehicle speed using desired speed distributions. Each automobile speed distribution ranged from 5 mph less than the median desired speed to 5 mph greater than the median desired speed. Five miles per hour is the recommended standard deviation used to calculate number of observations needed in a spot speed study (Box and Oppenlander 1976). The five automobile speed distributions are provided in Table 3.4. This thesis assumes median desired speed equals free-flow speed.

Bicycles do not have the same travel speed characteristics as automobiles. Most bicycle free-flow speed observations are between 7.5 mph and 12.4 mph (Allen et. el. 1998). For bicycles, the author assumes a minimum desired speed of 7.5 mph and a maximum desired speed of 12.4 mph. This makes the median desired speed 9.95 mph.

Vehicle Characteristics

Vehicle characteristics are an input in VISSIM 5.10. For the models in this thesis, the author makes changes to vehicle width. The VISSIM 5.10 base vehicle width for automobiles is 4.9 ft; the AASHTO (2004) design vehicle width is 6.9 ft. The VISSIM 5.10 base vehicle width for bicycles is 1.6 ft; the AASHTO (1999) design vehicle width is 2.5 ft. This thesis assumes automobile and bicycle widths of 6.9 ft and 2.5 ft, respectively. The author does not simulate other vehicle types in the traffic stream.

Driving Behavior

As an unfunded effort, it is outside the scope of this thesis to calibrate driver lane-change behavior, driver following behavior, and driver signal-control behavior. Observed data is not available for calibration. This thesis assumes default values for these behaviors. The author worked with a transportation engineer with bicycle experience, using engineering judgment, to calibrate driver lateral behavior. Driver lateral behavior affects how bicycles and automobiles interact when operating in the same traveled way. The author defines three driver lateral behaviors, they are:

- Automobiles in all situations,
- Bicycles in lanes with a width of 15 ft, and
- Bicycle in lanes width a width of 12ft.

Automobile driver lateral behavior is set to allow them to pass bicycles without changing lanes; they must maintain a lateral separation of 3 ft. This means automobiles may pass bicycles without changing lanes if the lateral distance from their vehicle to the bicycle is more than 3 ft. Three feet is the legal minimum in many states (Bisbee 2010). The desired lateral position for all automobiles is middle of the lane. Automobiles may change their lateral position when necessary. For example, they can move over to pass a bicycle without changing lanes. The author does not calibrate this parameter further.

The bicycle desired lateral position is middle when they are in an outside lane whose width is 12 ft. The League of American Bicyclists (2010) recommends this type of riding in lanes with a width less than 14 ft. Bicycles may pass bicycles in the same lane if they can do so without changing lanes. The author determines the lateral distance at which bicycles can pass other bicycles in model calibration.

The bicycle desired lateral position is right when they are in an outside lane whose width is 15 ft. Bicycles may pass other bicycles if they can do so without changing lanes. Bicycles may pull to the right of automobiles stopped at signalized intersections when they are in an outside lane with a width of 15 ft. The author determines the lateral distances at which bicycles can pull to the right of automobiles in model calibration.

Roadway Segments

Roadway segments are drawn using drafting software; the author imported the images into VISSIM 5.10 and then scaled them. After scaling the images, the author creates roadway segments and cross streets in VISSIM 5.10. Cross streets are for visual reference and carry zero traffic volume during simulation. All roadway segments are one-way two-lane roads. The left lane always has a width of 12 ft; the right lane has a width of 12 ft or 15 ft (depending on the scenario). In all scenarios, bicycles are restricted to the right lane. In each model, a grouping of three roadway segments represents each speed condition; the author calls these groupings roadway segment sets. An example of a roadway segment set is shown in Figure 3.2.

Signal Control

This thesis uses fixed time signal control. The base model has a cycle length of 90 s and a green time ratio of 0.40. The stop bar for the downstream intersection is located 1320 ft or 2640 ft from the stop bar of the upstream intersection; the location of stop bars is shown in Figure 3.2. The author calculates signal offset by dividing the roadway segment length by the median desired speed; the author rounds these values to the nearest whole second. The values entered are shown in Table 3.5.

Travel-Time Segments

This thesis collects travel-time data to evaluate automobile speed and automobile LOS. The first travel-time segment recorder is 62 ft past the upstream intersection stop bar and the second travel-time segment recorder is 62 ft past the downstream intersection stop bar. Sixty-two (62) feet is the simulated intersection crossing distance; 38 ft and 86 ft are not simulated in the microsimulation models (signalized intersection crossing distance has minimal effect on automobile quality of service). The location of travel-time segment records matches the definition of a roadway segment found in the HCM; travel time recorders on roadway segments are shown in Figure 3.2. Travel-time segments record the time required for each vehicle to traverse the roadway segment. Using the average travel time, the author calculates automobile average travel speed (space mean speed).

Microsimulation Model Output

Automobile travel time, automobile volume, bicycle travel time, and bicycle volume are output from VISSIM 5.10. This thesis runs 12 to 18 seeds beginning with seed 40, in increments of 3, for each simulation scenario. The automobile volume simulated determines the number of seeds used. If the automobile volume is near capacity for the roadway segment 18 seeds are used, otherwise 12 seeds are used. The author uses 18 seeds to determine capacity for each model. Average travel time and average volume for each model are provided in Appendix A. The author uses the microsimulation outputs to estimate automobile LOS, automobile speed, and automobile delay. The author uses the bicycle volume and travel time to error check the models; this thesis does not analyze bicycle outputs.

Microsimulation Model Partial Calibration

This thesis follows the California Department of Transportation (Caltrans) guidelines for applying microsimulation-modeling software. The Caltrans guidelines suggest a calibration strategy consisting of (Dowling et. el. 2002):

1. Error checking the coded data,
2. Calibrating capacity related factors,
3. Calibrating demand related parameters, and
4. Minor adjustment of factors for realism of model.

As an unfunded effort, it was outside the scope of this thesis to collect data and calibrate models for capacity or demand. The author focuses on error checking and making minor adjustments to account for realism. The author conducts six error checks prior to model calibration, they are:

1. Review vehicle parameters,
2. Review link attributes,
3. Review intersection attributes,
4. Review demand inputs,
5. Run model at low volumes to identify errors,
6. Trace vehicles through the network.

After error checking the coded data, the author calibrates interactions between automobiles and bicycles. A practicing transportation engineer assists in this effort by observing simulation runs with the author. The practicing transportation engineer has bicycle experience. With the practicing engineer's guidance, the author adjusts the following driver lateral behaviors:

- Automobiles passing bicycles in 12 ft lanes,
- Automobiles passing bicycles in 15 ft lanes, and
- Bicycles pulling to the right of automobiles at intersections.

The desired lateral position is middle when bicycles are in an outside lane having a width of 12 ft. Bicycles may queue next to, and pass, other bicycles in this scenario. In doing so, they must maintain the lateral separation for bicycles in outside lanes having a width of 15 ft. Automobiles must change lanes to pass bicycles in this scenario. With bicycles located in the center of the lane, it is not possible for automobiles to maintain a lateral separation of 3 ft without changing lanes.

The desired lateral position is right when bicycles are in an outside lane having a width of 15 ft. Bicycles may queue next to, and pass, other bicycles in this scenario. In doing so, they must maintain the calibrated separation. Automobiles in this scenario may pass bicycles in the same lane if they can maintain the minimum separation, 3 ft. Using a minimum separation of 3 ft, the author and professional engineer observe that most automobiles are willing to pass bicycles in the same lane. This meets with the professional engineers expectations.

The professional engineer expects most bicycles to pull next to automobiles at intersections in lanes with a width of 15 ft. When bicycles have a minimum separation of 3 ft, few bicycles pull to the right of automobiles at intersections. The author lowers the bicycle minimum lateral separation value until most bicycles queue next to automobiles. In VISSIM 5.10, most bicycles are willing to queue next to automobiles when the minimum lateral separation is 1 ft at a travel speed of 0 mph and 2 ft at a travel speed of 31 mph. Zero (0) mph and 31 mph are the inputs for driver lateral behavior in VISSIM 5.10; this does not indicate bicycles are traveling at 31 mph. The professional engineer feels bicyclists are willing to accept a 1 ft separation at 0 mph. The legal minimum 3 ft applies to automobiles, values less than 3 ft are reasonable for bicycles.

Summary

To achieve the research objectives, the author conducts a sensitivity analysis of automobile quality of service on shared roadways. The author then compares automobile quality of service and bicycle quality of service. The author uses the findings of the sensitivity analysis and comparison to provide guidance on shared roadway implementation. This chapter documents the study design and microsimulation models used to generate data for the automobile quality of service analysis. The information in this chapter forms the basis for the results and findings of this thesis.

The author defines eight roadway design independent variables, base values, and comparison values (Table 3.1); additionally, the author defines nine traffic flow independent variables, base values, and comparison values (Table 3.2). Independent variable values correspond to values typical of minor arterials and collectors. Using the indentified variable values, the author creates six microsimulation models. Each model has one to three scenarios. The author runs each scenario with all 25 FFS and automobile volume combinations and either 12 or 18 seeds.

The author codes the models in VISSIM 5.10. The author documents changes made to base VISSIM values and identifies the four VISSIM outputs; the outputs are automobile travel time, automobile volume, bicycle travel time, and bicycle volume. The author is only able to partial calibrate the microsimulation models. The author is unable to calibrate the models to capacity and demand related factors. The author focuses on error checking and making minor adjustments to create realism. The author makes changes to vehicle lateral behavior with the assistance of a professional engineer with bicycle experience.

CHAPTER IV
AUTOMOBILE QUALITY OF SERVICE ANALYSIS

The first research objective is to determine the impact of shared roadways on automobile quality of service. If shared roadways influence automobile operations in a negative manner, decision makers should consider automobile quality of service when evaluating the implementation of shared roadways. In this chapter, the author documents the procedures used to analyze automobile quality of service on shared roadways. This chapter contains automobile LOS threshold analysis procedures, the automobile LOS threshold analysis, the automobile average travel speed analysis, and summary.

Automobile LOS Threshold Analysis Procedures

To conduct the automobile quality of service analysis, the author uses VISSIM 5.10 outputs to evaluate two MOEs. The first MOE is automobile average travel speed; in this thesis, automobile average travel speed is a space mean speed. This means this thesis includes signalized intersection delay in the calculation of average travel speed; therefore, average travel speed will be less than FFS at low automobile volumes. The second MOE is automobile LOS threshold. The author recognizes the correlation between automobile average travel speed and automobile LOS threshold; however, to develop shared roadway implementation guidance, the author needs to investigate both.

The first step in the analysis is to convert each automobile average travel time to automobile average travel speed (the segment length divided by the average travel time in miles per hour); then the author converts each automobile average travel speed to automobile percent FFS (the average travel speed divided by the FFS). Additionally, the author converts each automobile volume output to automobile volume to capacity ratio (automobile volume divided by automobile capacity); automobile capacity for each model by automobile FFS are shown in Table 4.1.

Table 4.1 Capacity for Models shown in Table 3.7 by FFS

FFS (mph)	Model 1, 2, & 3		Model 4 (green time ratio = 0.2)	
	Capacity (veh/h)	Standard Deviation (veh/h)	Capacity (veh/h)	Standard Deviation (veh/h)
25	1617	5.3	890	7.3
30	1712	6.6	937	5.9
35	1758	6.0	961	5.6
40	1788	3.5	965	5.6
45	1800	3.4	965	5.4
FFS (mph)	Model 5 (cycle length = 120 s)		Model 6 (segment length = 2640 ft)	
	Capacity (veh/h)	Standard Deviation (veh/h)	Capacity (veh/h)	Standard Deviation (veh/h)
25	1406	5.1	1615	7.7
30	1490	6.8	1703	8.1
35	1537	5.1	1755	7.0
40	1566	4.4	1786	4.7
45	1581	4.6	1800	4.1

After converting VISSIM 5.10 outputs to automobile percent FFS and automobile volume to capacity ratio, the author plots percent FFS (y-axis) versus automobile volume to capacity ratio (x-axis). After plotting the data, the author fits regression equations to the plotted data; the regression equations estimate automobile percent FFS as a function of automobile volume to capacity ratio. The author produces regression equations for each scenario and combination of automobile flow-rate (Table 3.5) and automobile FFS (Table 3.4). An example plot, with fitted regression equations, is shown in Figure 4.1; the data plotted in Figure 4.1 are outputs from model one (35 mph). All data plots and regression equations are documented in Appendix B.

Readers will notice that percent FFS does not near 100 percent at low automobile volume to capacity ratios; this is the result of using space mean speed to determine automobile travel speed. Space mean speed includes delay caused by the downstream intersection. Therefore, vehicles not clearing the downstream intersection under green have a much lower average travel speed than those that do clear the intersection. This methodology is consistent with HCM procedures; the HCM measures automobile travel speed on urban street segments as the average travel time over the length of the segment. The length of the segment is from the end of the upstream intersection through the downstream intersection (the travel-time segment recorder locations in Figure 3.2).

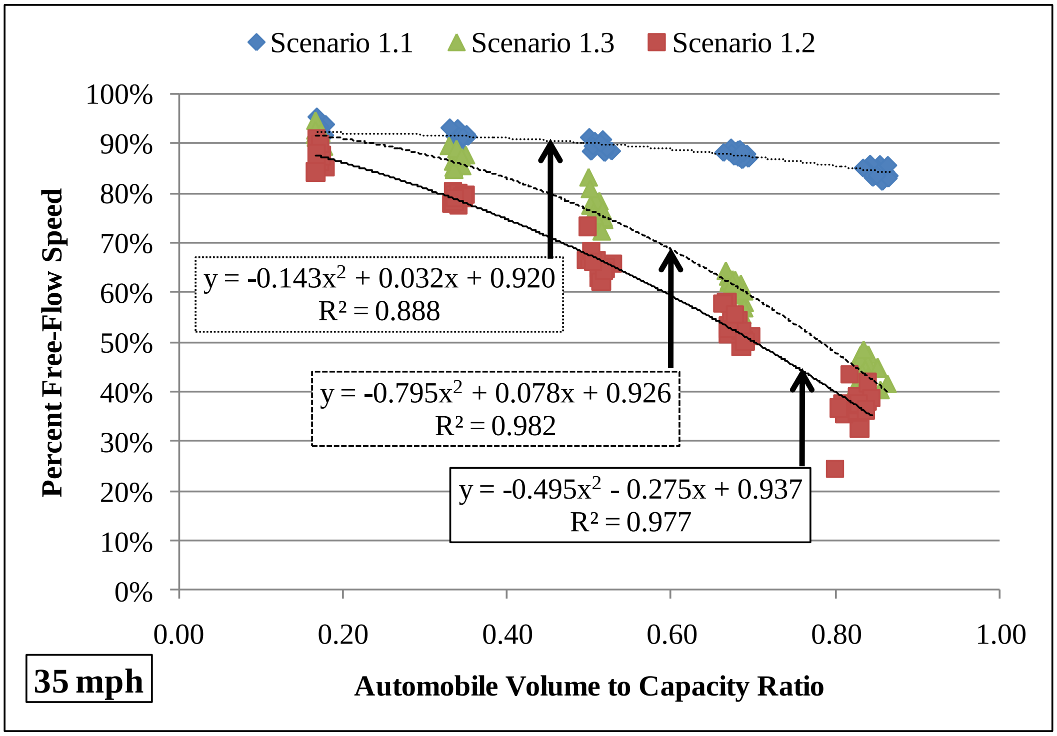


Figure 4.1 Example of Plotted Data and Fitted Regression Equations

After developing regression equations, the author uses the regression equations to determine automobile LOS thresholds. This thesis defines automobile LOS thresholds as the maximum automobile flow rate for a given automobile LOS; however, the regression equation units are automobile volume to capacity ratio. To obtain the maximum automobile flow rate for a given LOS, the author solves the regression equations for the maximum automobile volume to capacity ratio for a given LOS. To convert the maximum automobile volume to capacity ratio to maximum automobile flow rate, the author multiplies the maximum automobile volume to capacity ratio by the applicable capacity. For example, the capacity value that applies to the automobile volume to capacity ratios shown in Figure 4.1 is 1758 vehicles per hour, as shown in Table 4.1.

To determine automobile LOS threshold from percent FFS, the author uses the relationship between percent FFS and automobile LOS documented in NCHRP project 3-79. Each LOS has a lower and upper percent FFS boundary condition. The lower percent FFS boundary corresponds to the automobile LOS threshold; therefore, the author finds automobile LOS thresholds by solving the regression equations for the lower percent FFS boundary. A graphical representation of solving for the LOS D threshold is shown in Figure 4.2. The shaded region represents LOS C or D. The LOS D minimum percent free flow speed is the bottom line of the shaded region. The “12 ft Lane” equation in Figure 4.1 is the equation that corresponds to the regression line shown in Figure 4.2. Using the equation in Figure 4.1, the calculated automobile volume to capacity ratio is 0.801; this is approximately the value shown in Figure 4.2. The automobile LOS threshold is 1408 vehicles per hour (0.801 times 1758 vehicles per hour).

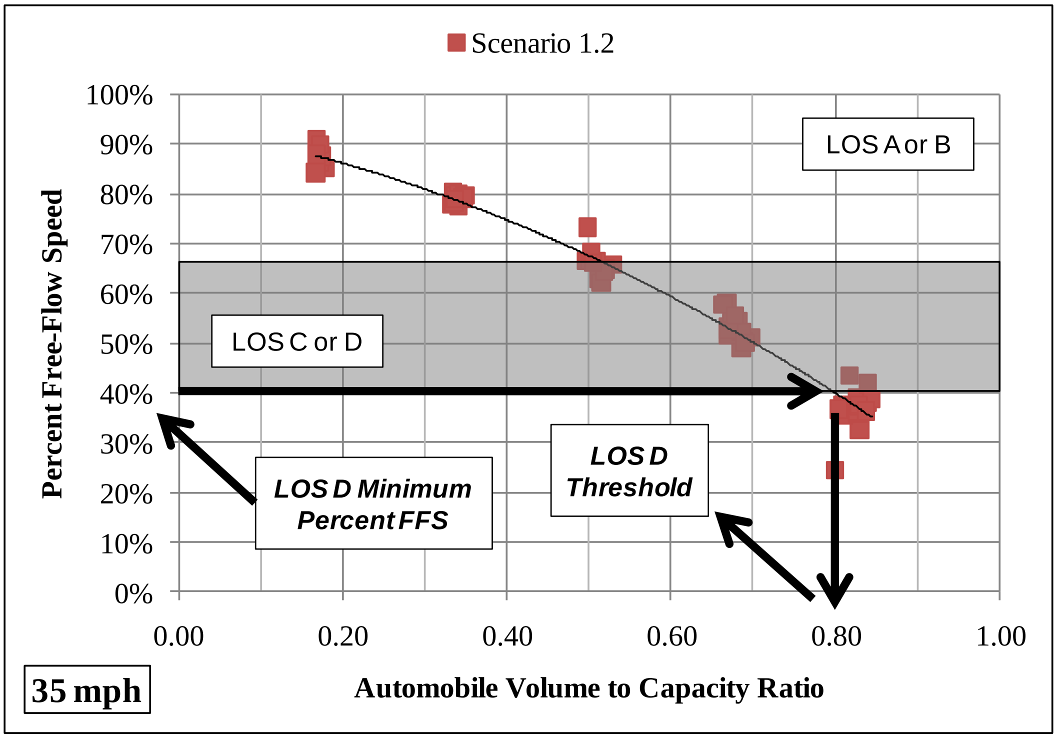


Figure 4.2 Example of Solving for LOS D Threshold Value

Automobile LOS Threshold Analysis

This section documents a sensitivity analysis of the first MOE, automobile LOS threshold. The sensitivity analysis looks at change in automobile LOS threshold associated with change in independent variable values. The author documents automobile LOS threshold changes in five independent variables; the variables investigated are outside lane width, segment length, bicycle volume, cycle length, and green time ratio. The results of this section serve two purposes. One, they help answer the question asked by the first objective (what is the impact of shared roadways on automobiles). Two, the author compares the results to bicycle LOS thresholds in Chapter V.

To compare each variable, the author compares the scenarios in Table 3.7. For each variable, the author provides a graphical representation of the automobile LOS threshold. Additionally, the author determines if the difference is the result of differences in capacity. This means the author determines if changing the variable also changes the capacity; and therefore, the difference in threshold value is not the result of bicycle presence. For example, changing the green time ratio from 0.4 to 0.2 reduces the capacity of the roadway segment. In these cases, the author adds the capacity difference to the appropriate condition. For example, in the case of a change in green time ratio, the author adds the capacity difference to the 0.2 automobile LOS thresholds. The results indicate if there is a difference in the relationship between automobile and bicycles or if the difference in automobile LOS threshold is the result of a change in capacity independent of bicycle presence.

Outside Lane Width

The author first investigates differences associated with outside lane width. The outside lane widths investigated are 12 ft (Scenario 1.2) and 15 ft (Scenario 1.3). Automobiles must change lanes to pass bicycles in 12 ft outside lanes; in 15 ft lanes, automobiles may not have to change lanes to pass bicycles. The results reflect the difference in automobile ability to pass. As shown in Figure 4.3, the automobile LOS D threshold for 15 ft lanes is greater than the automobile LOS D threshold for 12 ft lanes. This means 15 ft outside lanes have less of an impact on automobile operations than 12 ft lanes.

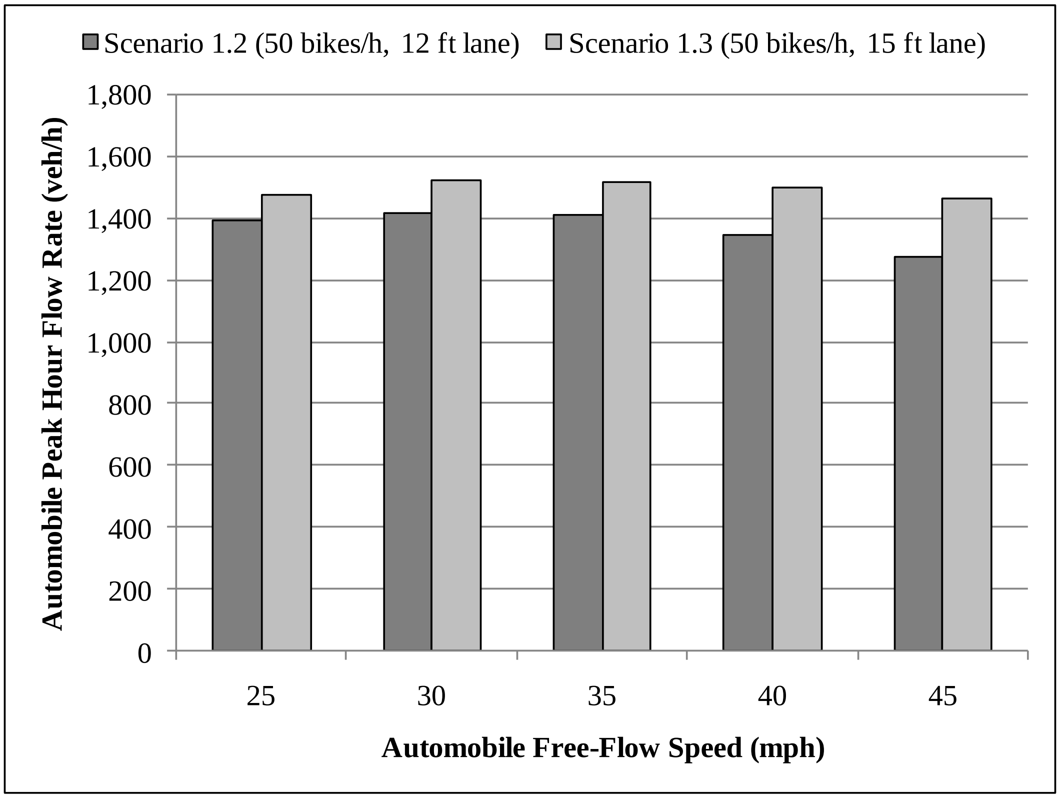


Figure 4.3 Outside Lane Width, Automobile LOS D Thresholds

Segment Length

Segment length is the next independent variable investigated; the segment lengths investigated are 1320 ft (Scenario 1.2) and 2640 ft (Scenario 6.1). The results indicate the automobile LOS D threshold is greater for a longer roadway segment, shown in Figure 4.4. The concept of startup loss time helps explain the differences. Startup loss time is the time it takes vehicles to accelerate to their desired travel speed from the stopped condition. When the segment length is shorter, startup loss time would constitute a greater portion of the average travel time; therefore, average travel speeds are lower on shorter roadway segments. The author concludes that that segment length does not change the interaction between bicycles and automobiles because average travel speeds are naturally lower on roadway segments with shorter lengths. Therefore, level of service thresholds are lower on shorter roadway segments and the difference in Figure 4.4 are likely differences in average travel speed associated with different segment lengths.

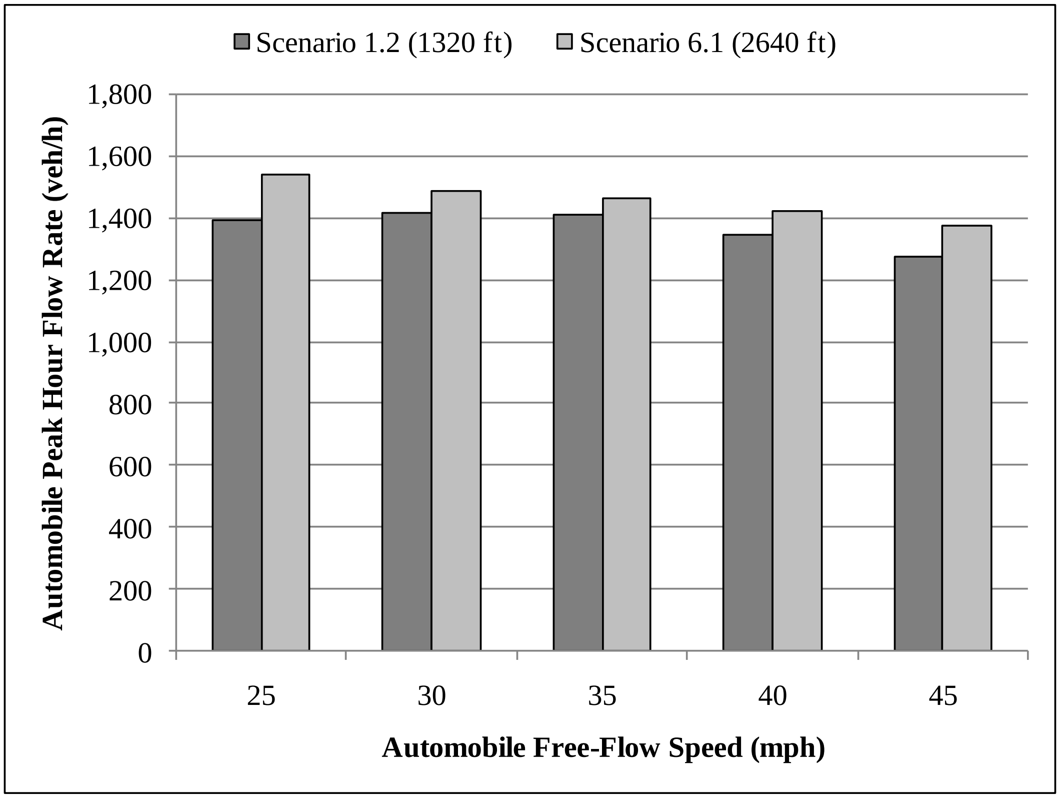


Figure 4.4 Segment Length, Automobile LOS D Thresholds

Bicycle Flow-Rate

The impact of three bicycle flow-rates are investigated; they are 25 bikes/h (Scenario 2.1), 50 bikes/h (Scenario 1.2), and 100 bikes/h (Scenario 3.1). The resulting automobile LOS D Thresholds are shown in Figure 4.5. The results show that bicycle flow-rate does affect automobile operations; the automobile LOS D threshold decreases as bicycle volume increases. These results suggest bicycle flow-rate affects automobile operations, on shared roadways.

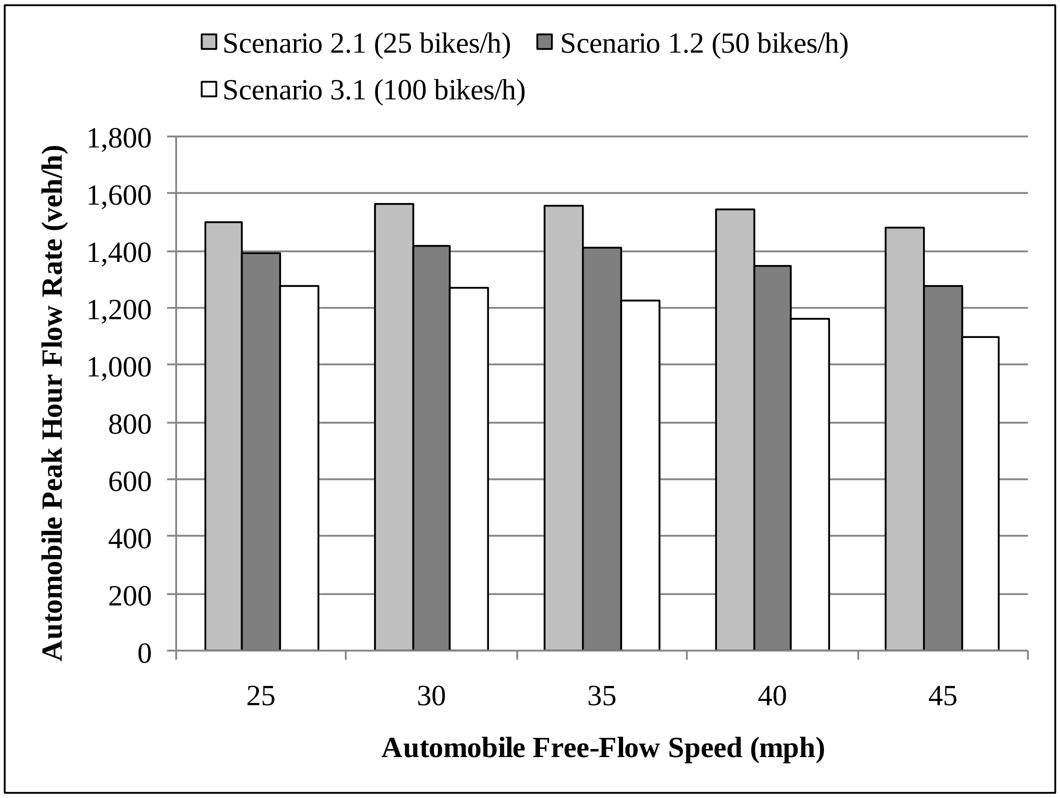


Figure 4.5 Bicycle Flow-Rate, Automobile LOS D Thresholds

Cycle Length

The author compares the impact of two cycle lengths; they are 90 s (Scenario 1.2) and 120 s (Scenario 5.2). The resulting automobile LOS D thresholds are shown in Figure 4.6. The results show a 120 s cycle has a lower level of service D threshold than a 90 s cycle; however, a 120 s cycle has a lower capacity than a 90 s cycle. The difference in capacity between a 120 s cycle and a 90 s cycle is approximately the difference in the automobile LOS D thresholds; capacities for each model are shown in Table 4.1. Therefore, the author concludes bicycle presence is not causing the difference in thresholds between Scenario 1.2 and Scenario 5.2.

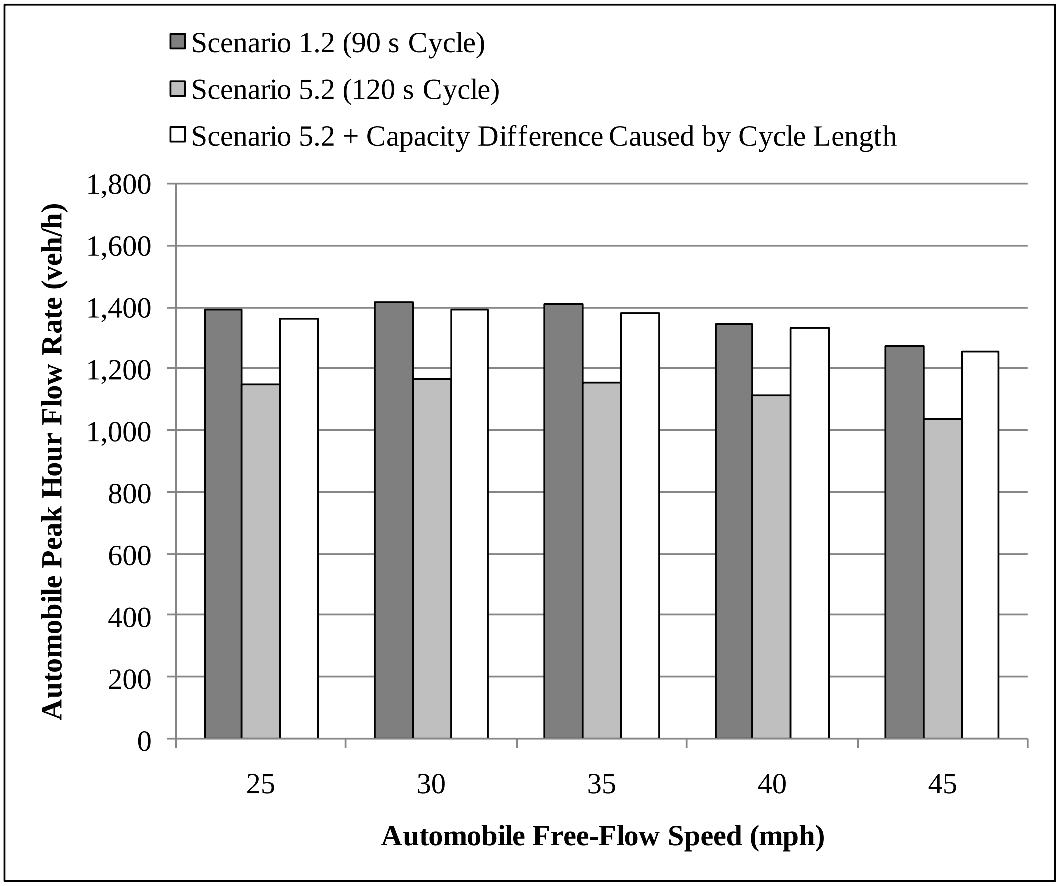


Figure 4.6 Cycle Length, Automobile LOS D Thresholds

Green Time Ratio

The author compares the impacts of two green time ratios; they are 0.4 (Scenario 1.2) and 0.2 (Scenario 4.2). The resulting automobile LOS D thresholds are shown in Figure 4.7. The results show a 0.2 green time ratio has a lower automobile LOS D threshold than a 0.4 green time ratio; however, a 0.2 green time ratio has a lower capacity than a 0.4 green time ratio. The difference between Scenario 1.2 and Scenario 4.2 approximately the capacity difference; capacities for each model are shown in Table 4.1. Therefore, the author concludes bicycle presence is not causing the difference in thresholds between Scenario 1.2 and Scenario 4.2.

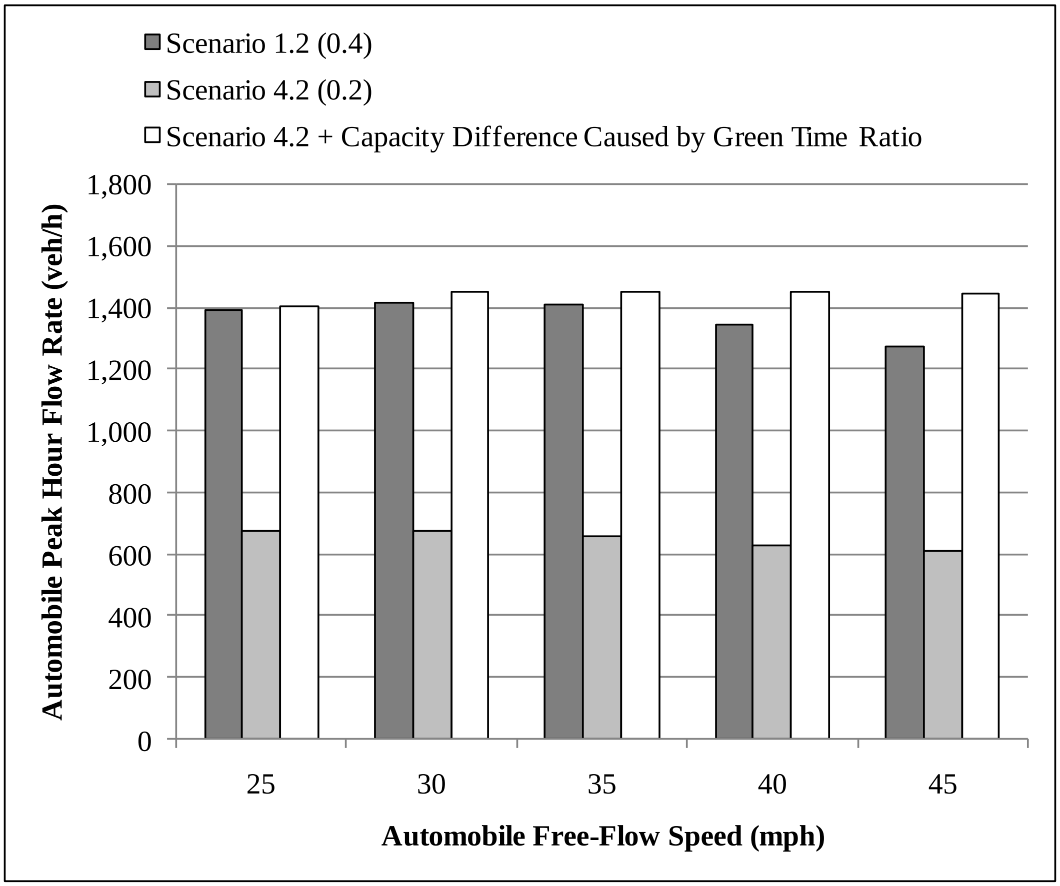


Figure 4.7 Green Time Ratio, Automobile LOS D Thresholds

Automobile Average Travel Speed Analysis

This section documents a sensitivity analysis of the second MOE, automobile average travel speed. The sensitivity analysis looks at the change in automobile average travel speed associated with a change in the independent variable. The results of the automobile LOS threshold analysis (in the previous section) indicate three independent variables do not affect the bicycle influence automobile operations, on shared roadways (segment length, cycle length, and green time ratio). The other two variables analyzed (outside lane width and bicycle flow-rate) do affect bicycle influence on automobile operations.

For outside lane width and bicycle volume, the author quantifies variable influence on automobile average travel speed. To accomplish this, the author uses the regression equations developed from microsimulation data. Using the regression equations, the author calculates percent FFS for five volume to capacity ratios (0.5, 0.6, 0.7, 0.8, and 0.9); the author then converts FFS to average travel speed (FFS times percent FFS). The models corresponding to the two variables investigated are model one, model two, and model three; the author calculates average travel speeds for all five scenarios using the regression equations in Appendix B. The calculated values are shown in Table 4.2. For visual comparison, the author graphs the bolded values for each scenario.

Table 4.2 Automobile Average Speeds, Values Given in Miles per Hour

Scenario 1.1	FFS	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
0 bikes/h 12 ft lane	25 mph	21.7	20.8	**19.7**	18.3	16.6
	30 mph	26.6	26.1	**25.3**	24.5	23.4
	35 mph	**31.5**	**31.1**	**30.5**	**29.9**	**29.2**
	40 mph	36.3	36.0	**35.7**	35.4	35.2
	45 mph	41.4	41.2	**41.0**	40.8	40.7
Scenario 1.2	FFS	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
50 bikes/h, 12 ft lane	25 mph	19.1	17.4	**15.4**	13.1	10.4
	30 mph	23.2	21.0	**18.3**	15.2	11.6
	35 mph	**26.8**	**24.0**	**20.7**	**16.8**	**12.3**
	40 mph	29.7	26.4	**22.4**	17.9	12.7
	45 mph	32.6	28.7	**24.1**	18.8	12.8
Scenario 1.3	FFS	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
50 bikes/h, 15 ft lane	25 mph	18.3	16.4	**14.3**	11.7	8.9
	30 mph	21.4	19.0	**16.1**	12.9	9.2
	35 mph	**23.7**	**20.8**	**17.6**	**14.0**	**10.1**
	40 mph	25.7	22.1	**18.2**	13.8	9.1
	45 mph	27.3	23.0	**18.4**	13.4	8.1
Scenario 2.1	FFS	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
25 bikes/h, 12 ft lane	25 mph	19.5	17.9	**16.0**	13.6	10.8
	30 mph	23.5	21.4	**18.9**	16.0	12.5
	35 mph	**26.5**	**24.0**	**20.9**	**17.4**	**13.4**
	40 mph	29.1	26.1	**22.6**	18.7	14.3
	45 mph	31.2	27.6	**23.6**	19.1	14.2
Scenario 3.1	FFS	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
100 bikes/h, 12 ft lane	25 mph	16.8	14.8	**12.4**	9.7	6.6
	30 mph	19.8	16.9	**13.5**	9.7	5.3
	35 mph	**21.4**	**17.9**	**13.9**	**9.4**	**4.4**
	40 mph	22.7	18.3	**13.5**	8.2	2.4
	45 mph	23.2	18.4	**13.3**	7.9	2.2

Bold values are shown in Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11

Outside Lane Width

Figure 4.8 and Figure 4.9 provide a visual comparison of outside lane width by automobile FFS. A trend is shown in the bar charts; as volume to capacity ratio and automobile FFS increase, automobile average travel speed decreases. These results agree with the ODOT implementation guidance (shared roadways become less acceptable as automobile speed and automobile volume increase) (ODOT 2009). Additionally, automobile average travel speed is lower for 12 ft lanes than it is for 15 ft lanes. These results indicate outside lane width influences automobile operations on shared roadways.

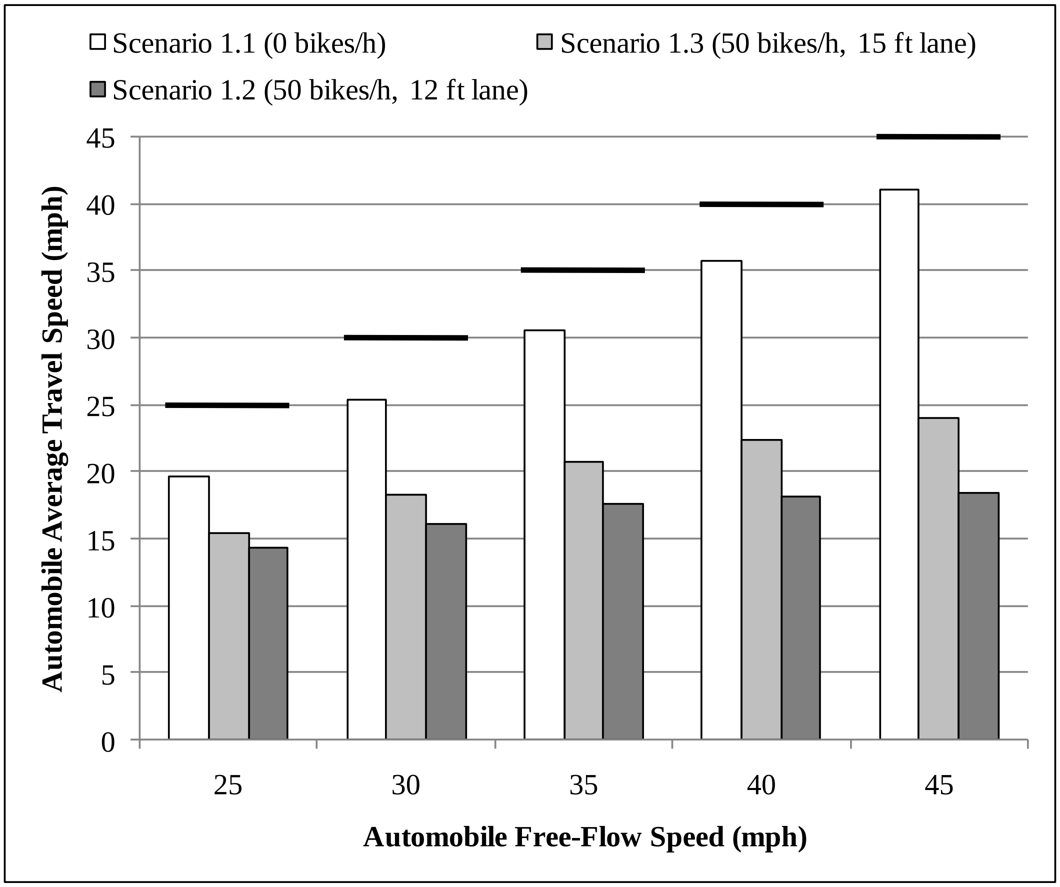


Figure 4.8 Outside Lane Width Affect by Automobile FFS

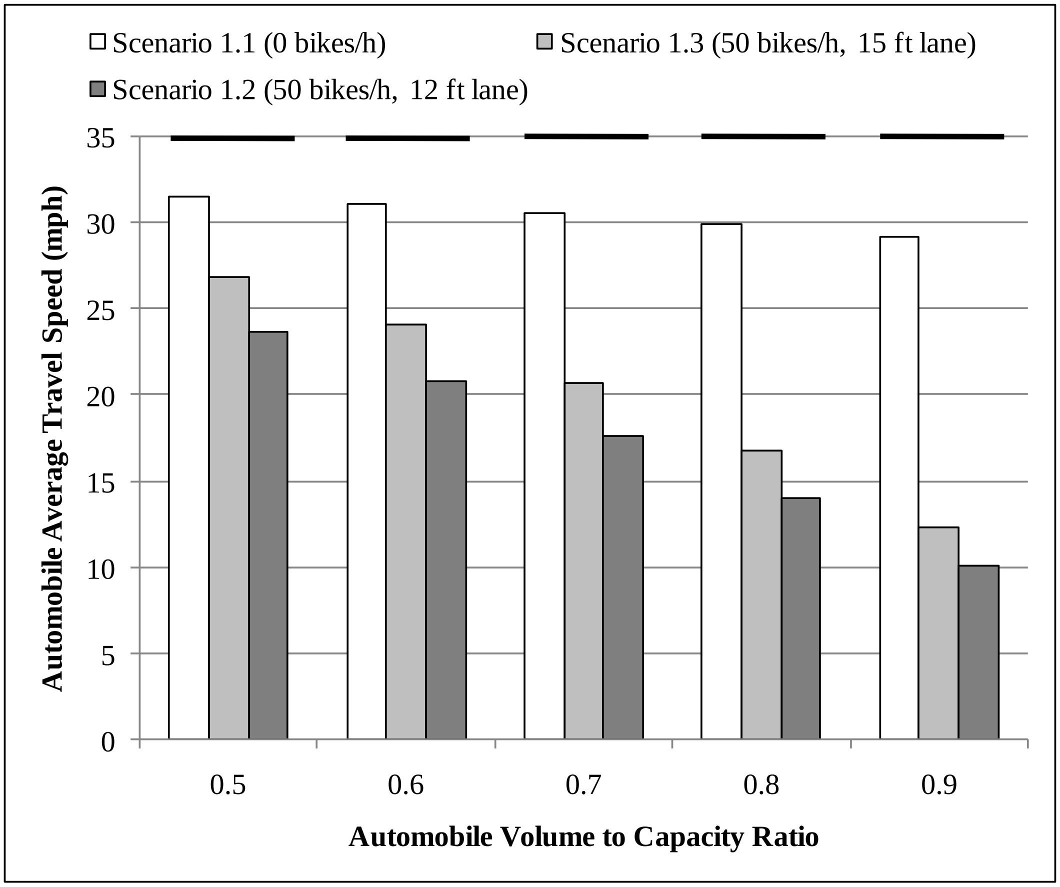


Figure 4.9 Outside Lane Width Affect by Automobile Volume to Capacity Ratio

Bicycle Flow-Rate

Figure 4.10 and Figure 4.11provides a visual comparison how of bicycle flow-rate affects automobile operations. A trend is shown in the bar charts; as volume to capacity ratio and automobile FFS increase, automobile average travel speed decreases. Additionally, automobile average travel speed decreases as bicycle volume increases; the difference become more pronounced at higher automobile FFSs and automobile volume to capacity ratios. These results indicate greater bicycle flow-rates negatively influence automobile operations on shared roadways.

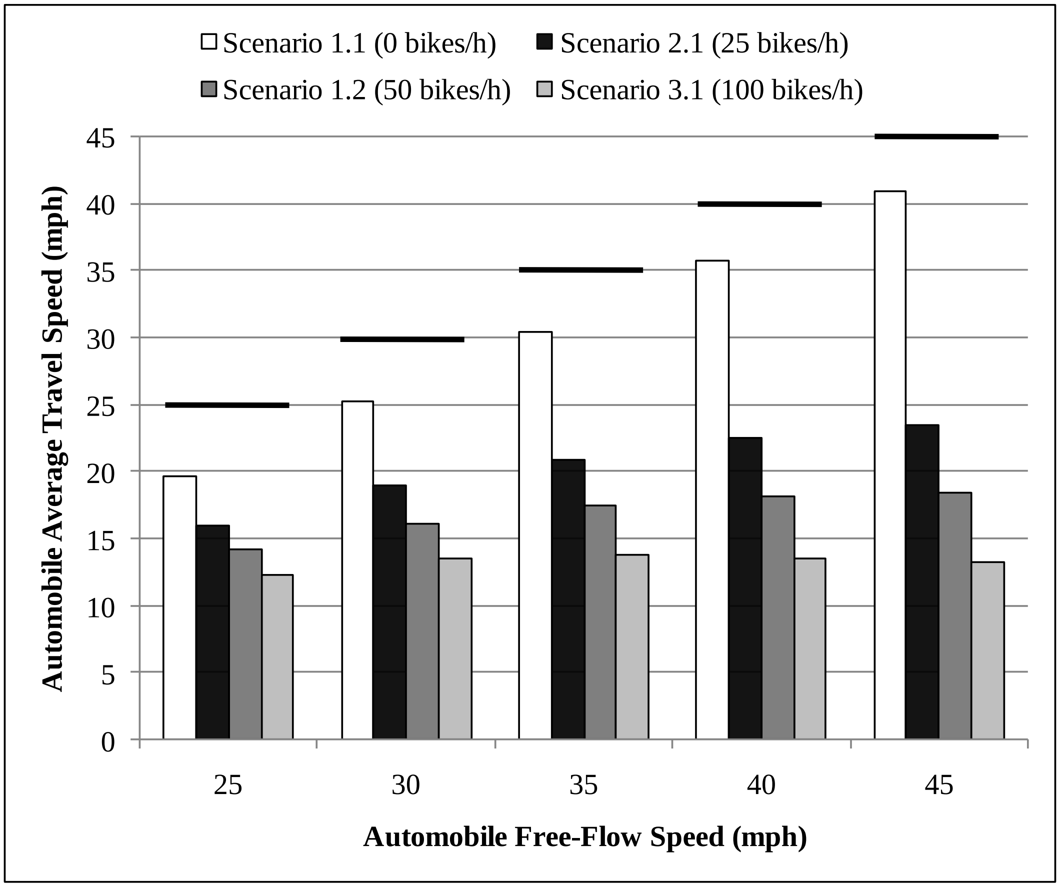


Figure 4.10 Bicycle Flow-Rate Affect by Automobile FFS

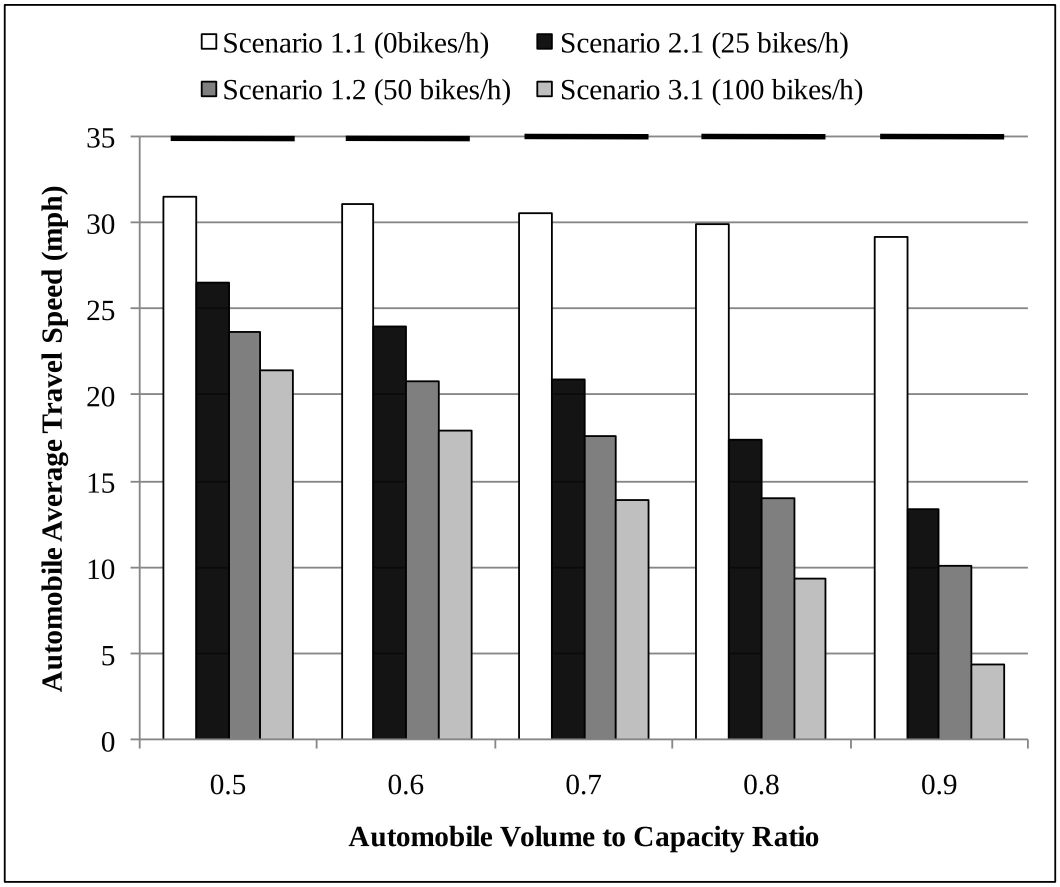


Figure 4.11 Bicycle Flow-Rate Affect by Automobile Volume to Capacity Ratio

Summary

In this chapter, the author answers the question, “Do shared roadways impact automobile operations?” The analysis indicates higher bicycle flow-rates and narrower lanes negatively affect automobile operations on shared roadways. Outside lanes with a width of 12 ft have more of a negative impact than outside lanes with a width of 15 ft. The negative effect of shared roadways increases as bicycle flow-rate increases; this means as bicycle volume increases, automobile quality of service decreases.

The results of the automobile LOS threshold analysis were confirmed and quantified in the automobile average travel time analysis. Additionally, the automobile average travel time analysis shows a decrease in automobile quality of service as automobile volume to capacity ratio and automobile FFS increase. The results agree with the ODOT implementation guidance (shared roadways become less acceptable as automobile volume and automobile speed increases) (ODOT 2009).

The analysis found that cycle length and green time ratio change the capacity of the roadway. The change in capacity is approximately the difference in automobile LOS threshold. This indicates these variables do not increase nor decrease the influence of bicycles on automobile operations. Additionally, the author concludes that differences in automobile LOS D thresholds corresponding to changes in segment length are the result of startup loss time. This means the author does not evaluate segment length further.

CHAPTER V

AUTOMOBILE AND BICYCLE QUALITY OF SERVICE COMPARISON

The second research objective is to compare automobile quality of service to bicycle quality of service on shared roadways. The author does this by comparing automobile LOS thresholds to bicycle LOS thresholds. If automobile LOS thresholds are less than bicycle LOS thresholds, decision makers should consider automobile quality of service when considering shared roadway implementation. This chapter contains analysis procedures, LOS threshold comparison, and summary.

Analysis Procedures

To compare automobile quality of service on shared roadways to bicycle quality of service on shared roadways, uses the findings from the automobile LOS threshold analysis and compares them to bicycle LOS thresholds. Bicycle LOS thresholds are generated using equations in NCHRP 616. The author manipulates equations in NCHRP 616 to generate bicycle LOS thresholds instead of predicting bicycle LOS.

After generating bicycle LOS thresholds, the author compares automobile LOS D thresholds to bicycle LOS D thresholds. The mode with a lower LOS D threshold governs facility selection. If each mode has one set of independent variable values in which it governs facility selection, decision makers should consider both modes when considering shared roadway implementation; otherwise, they should consider the mode that always governs.

Automobile and Bicycle LOS Threshold Comparison

This section documents the comparison of automobile LOS thresholds to bicycle LOS thresholds. For each variable, the author provides a graphical representation of bicycle LOS D thresholds and automobile LOS D thresholds. In this analysis, the author investigates variables included in this thesis because they predict bicycle LOS according to NCHRP Report 616; additionally, the variable must have comparison values shown in Table 3.1 or Table 3.3. The automobile LOS D threshold is model number one, 50 bikes/h, and 12 ft lane scenario; additionally, the author shows automobile LOS D thresholds for variables simulated in VISSIM 5.10.

Outside Lane Width

The author first compares automobile LOS D thresholds and bicycle LOS D thresholds corresponding to different outside lane widths. The author compares LOS D thresholds for outside lane widths of 12 ft and 15 ft. The results are shown in Figure 5.1. The results show that bicycle LOS D thresholds for 15 ft outside lane widths are greater than bicycle LOS D thresholds for 12 ft outside lane widths. Additionally, the results automobile LOS D thresholds are less than bicycle LOS D thresholds. This means decision makers should consider automobile quality of service when evaluating shared roadways.

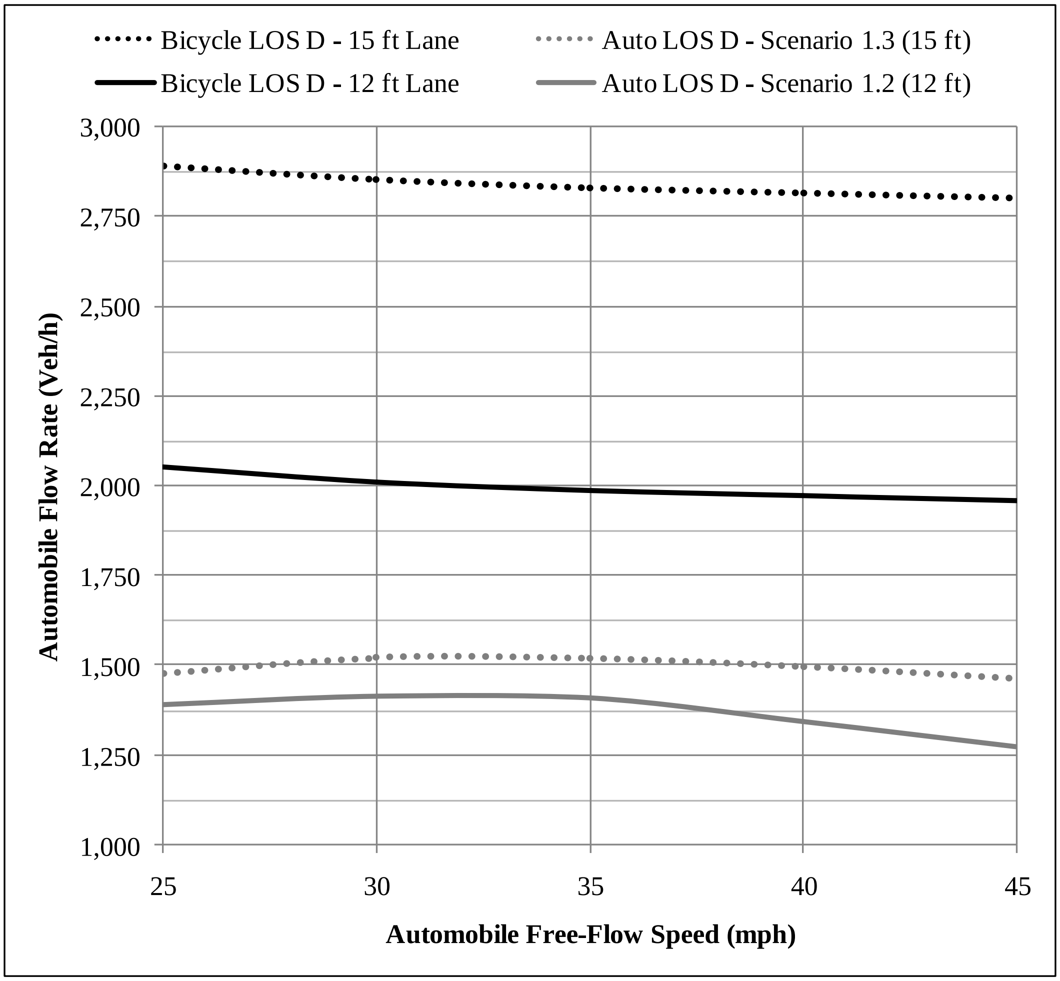


Figure 5.1 Outside Lane Width Threshold Comparison

Unsignalized Access Points per Mile

Unsignalized access points per mile are the next independent variable investigated; the author investigates three unsignalized access rates. The unsignalized access points per mile rates are zero access points per mile, maximum access points per mile, and zero access points per mile; rates by FFS are shown in Table 3.2. The results of the comparison are shown in Figure 5.2. The results show that bicycle LOS D is less than automobile LOS D for lower speeds and higher access rates; this indicates that decision makers should consider bicycle and automobile quality of service when considering shared roadway implementation.

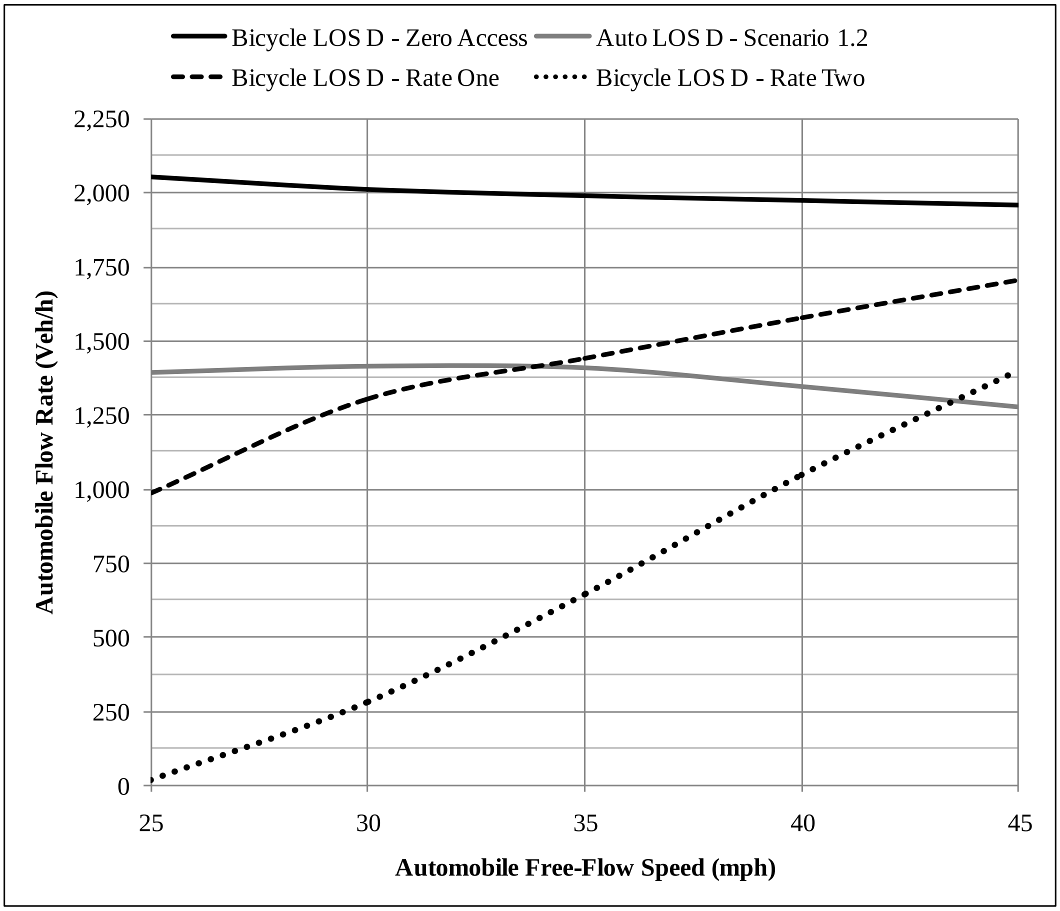


Figure 5.2 Unsignalized Access Points per Mile Threshold Comparison

Signalized Intersection Crossing Distance

The author investigates three signalized intersection crossing distances; they are 38 ft, 62 ft, and 86 ft. The results are shown in Figure 5.3. For the signalized intersection crossing distances considered, the results show automobile LOS D thresholds are less than bicycle LOS D threshold; however, at greater crossing distances, the bicycle LOS D threshold gets closer to the automobile LOS D threshold. This indicates bicycle LOS D thresholds may be lower than automobile LOS D thresholds at higher crossing distances; this indicates decision makers should consider automobile and bicycle quality of service when considering shared roadway implementation.

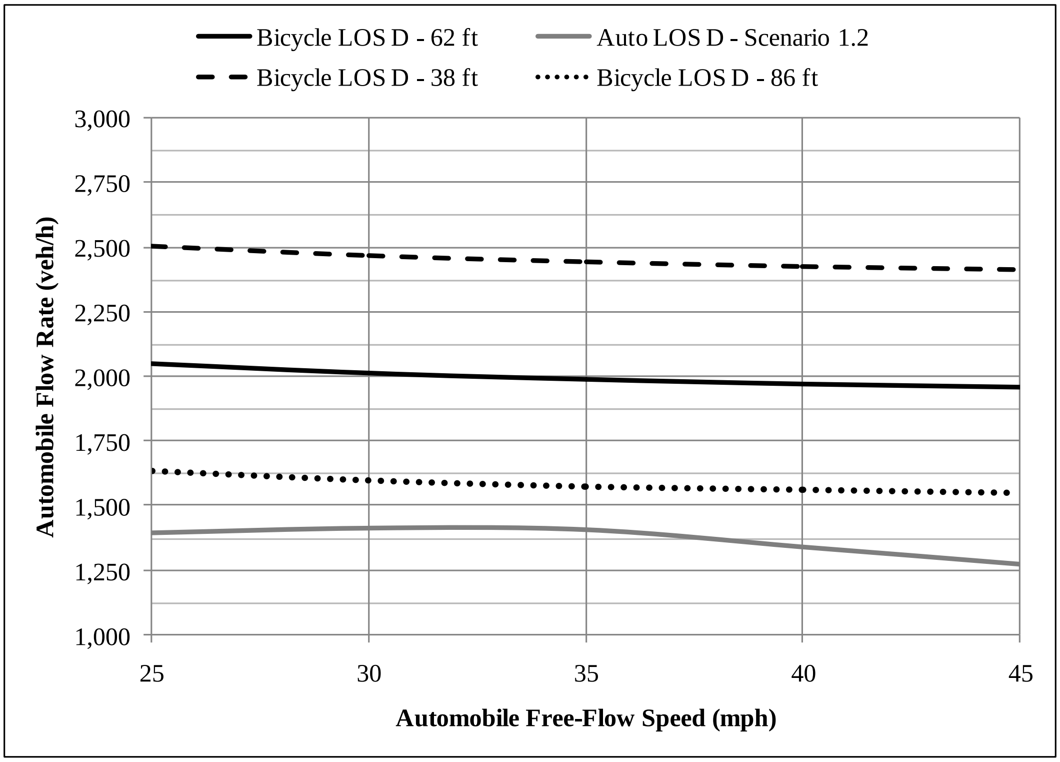


Figure 5.3 Signalized Intersection Crossing Distance Threshold Comparison

Percentage of Roadway Segment with Occupied on Street Parking

Three percentage of roadway segment with occupied on street parking are considered; they are 0 percent, 5 percent, and 10 percent. The results are shown in Figure 5.4. The results show that automobile LOS D thresholds are less than bicycle LOS D thresholds.

This indicates decision makers should consider automobile quality of service when considering shared roadway implementation.

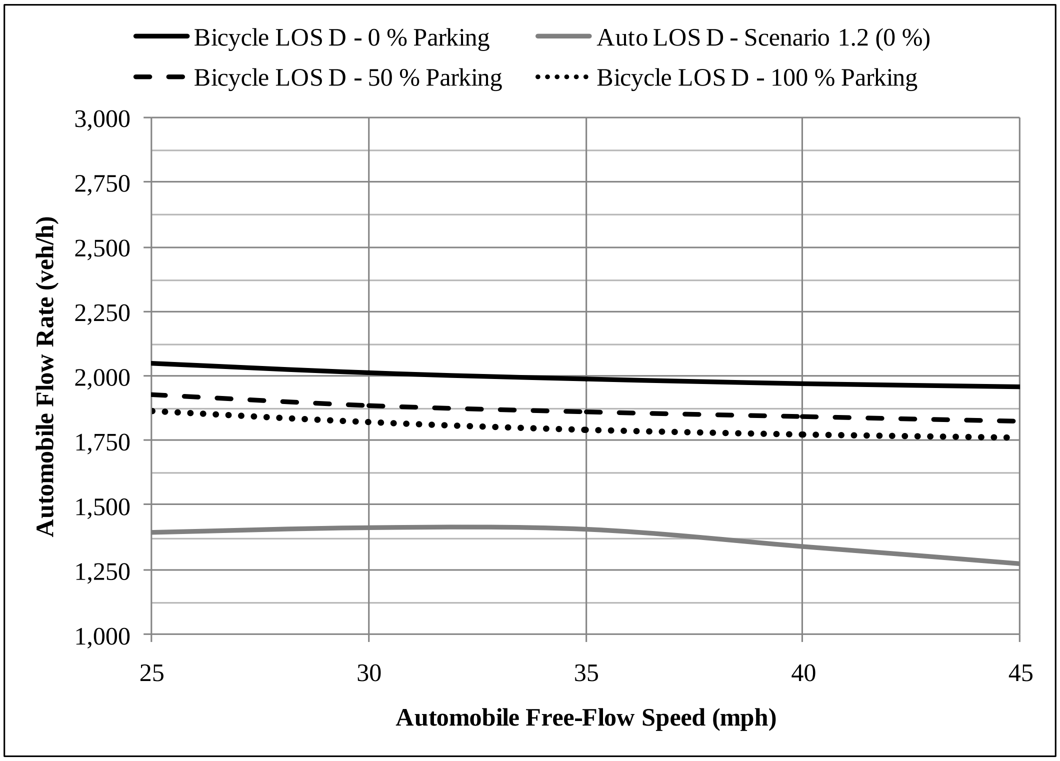


Figure 5.4 Percentage of Roadway Segment with Occupied on Street Parking Threshold Comparison

FHWA Five-Point Pavement Surface Condition Rating

This thesis investigates three FHWA five-point pavement surface condition ratings; they are pavement condition rating two, three, and four. The results are shown in Figure 5.5. For the investigated pavement condition ratings, the results show that automobile LOS D thresholds are less than bicycle LOS D thresholds; however, lower pavement condition ratings may have bicycle LOS D thresholds less than automobile LOS D thresholds.

This indicates decision makers should consider automobile and bicycle quality of service when considering shared roadway implementation.

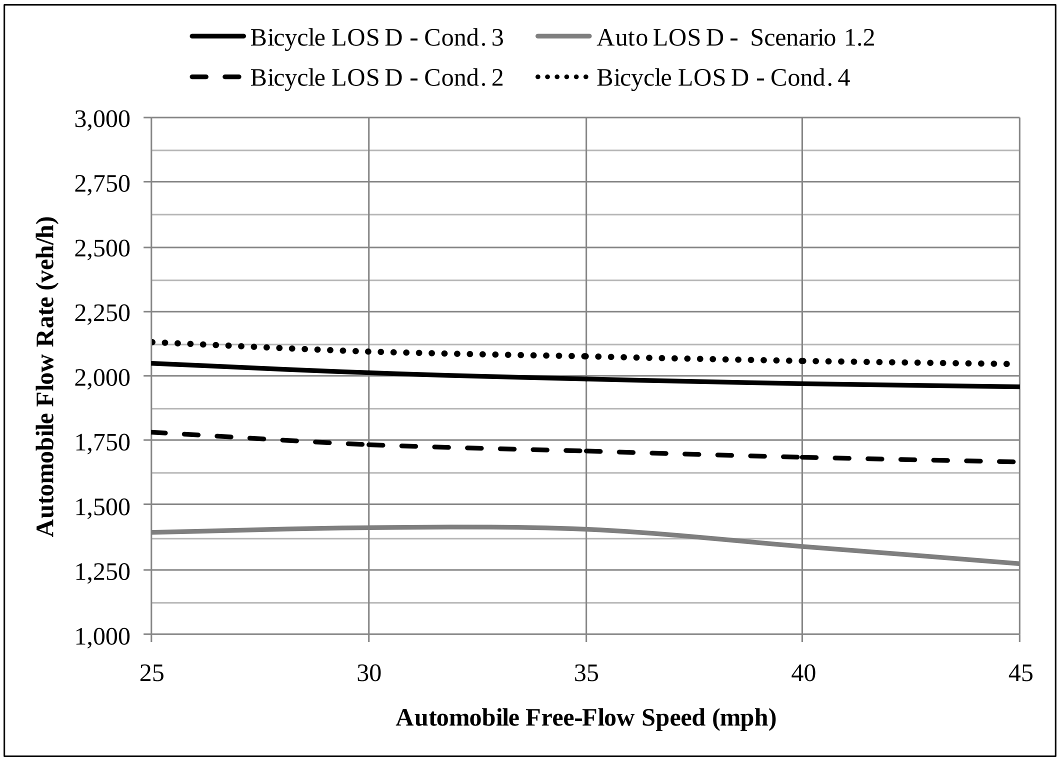


Figure 5.5 FHWA Five-Point Pavement Surface Condition Rating Threshold Comparison

Heavy Vehicle Percent

This thesis investigates three heavy vehicle percents; they are zero percent, five percent, and ten percent. The results are shown in Figure 5.6. The results show that at higher heavy vehicle percents, and automobile FFSs, bicycle LOS D thresholds are less than automobile LOS D thresholds. This indicates decision makers should consider automobile and bicycle quality of service when considering shared roadway implementation.

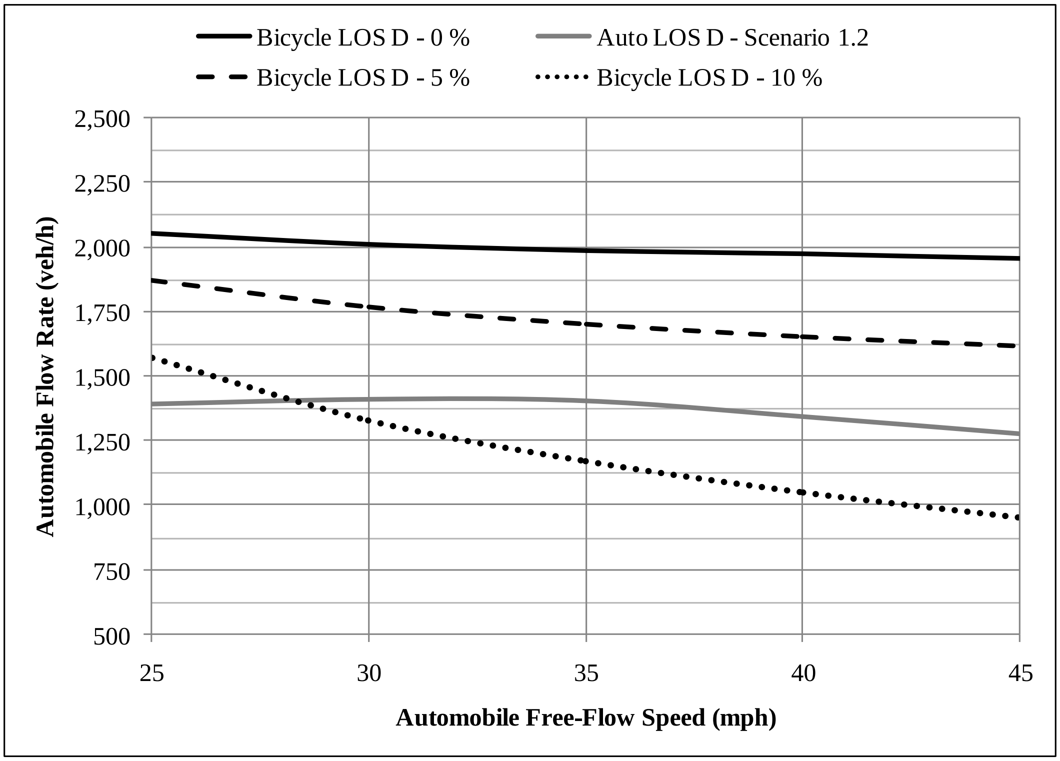


Figure 5.6 Heavy Vehicle Percent Threshold Comparison

Summary

This chapter compared automobile and bicycle quality of service to determine which mode should be included in a consideration of shared roadway implementation. The results show that automobile LOS D thresholds are more frequently less than bicycle LOS D thresholds. This indicates automobile quality of service should be included in a consideration of shared roadways. The results also indicate the importance of bicycle quality of service in a consideration of shared roadway implementation. The three variables that lower bicycle LOS D thresholds below automobile LOS D thresholds are unsignalized access points per mile, signalized intersection crossing distance, and heavy vehicle percent; the author uses these results to provide guidance on shared roadway implementation.

CHAPTER VI

SHARED ROADWAY IMPLEMENTATION GUIDELINES

The third research objective is to provide guidance on the implementation of shared roadways. Using results of the automobile quality of service impact analysis and LOS threshold comparison, the author develops guidance on the implementation of shared roadways. The author provides guidance on the implementation of two shared roadway designs. The first shared roadway design is 12 ft outside lane widths; the second shared roadway design is 15 ft outside lane widths. The basis for the guidance is automobile operations; therefore, this guidance does not consider safety. This chapter contains the methodology for developing shared roadway guidance, shared roadway implementation guidance on 12 ft outside lane width facilities, shared roadway implementation guidance on 15 ft outside lane width facilities, bicycle considerations, and summary.

Note: The author did not calibrate the microsimulation model to observed data; for this reason, use caution in precise application. Better delay estimates are possible through a data collection effort and proper model calibration.

Methodology for Developing Shared Roadway Guidance

To develop guidance on the implementation of shared roadways, the author uses results from the automobile LOS threshold analysis and average travel speed investigation. The author assumes decision makers should not implement shared roadways if the automobile LOS on the facility is less than LOS D (a criteria used by AASHTO for the inclusion of climbing lanes). Given LOS D is the decision point; shared roadways are acceptable on facilities with a volume and speed combination that yield an automobile LOS A, LOS B, or LOS C (determined by the LOS C threshold). Additionally, shared roadways are not acceptable on facilities with a volume and speed combination that yields an automobile LOS F (determined by the LOS E threshold). If the volume and speed combination is between LOS C and LOS F (between the automobile LOS C and

LOS E threshold), the author recommends conducting further analysis to confirm the facility will operate at LOS D or better. Therefore, the first step in the development of guidance on shared roadway implementation is to determine automobile LOS C and LOS E thresholds. The author provides automobile LOS thresholds for shared roadways having 12 ft (Scenario 1.2) and 15 ft (Scenario 1.3) outside lane widths. The author bases the guidance on a bicycle flow-rate of 50 bicycles per hour; this flow rate may be high in some jurisdictions. After determining automobile LOS thresholds, the author converts the threshold to volume to capacity ratio. The author then graphs the LOS thresholds, as volume to capacity ratio, on the x-axis and speed limit on the y-axis; this thesis assumes FFS is equal to the speed limit.

Further analysis uses the automobile average travel speed analysis to estimate percent FFS on the facility. Given the results of the average travel speed analysis, the author only uses bicycle volume to adjust percent FFS. If the percent FFS is less than 40 percent (the lower bounds of LOS D), the author recommends not implementing shared roadways. If the value is close to 40 percent, the author provides bicycle quality of service considerations. The bicycle considerations provide engineers with a basis for making engineering judgment decisions.

Shared Roadway Implementation Guidance, 12 ft Outside Lane Widths

General guidance on the implementation of shared roadways with outside lane widths of 12 ft (scenario 1.2) is shown in Figure 6.1. The guidance provides three recommendations; they are shared roadways are acceptable, do not use shared roadways, and conduct further analysis. The guidance shows that at higher volume to capacity ratios, and greater speed limits, shared roadways are less acceptable. Volume to capacity ratio is the observed hourly automobile volume divided by the roadway segment capacity. Capacity for the roadway segment is the saturation flow rate (shown in Table 6.1) times the upstream-signalized intersection green time; then divided by the upstream cycle length. For example, if the FFS is 40 mph, the green time ratio is 0.4, the capacity is 1788 veh/h, and the volume is 1252; the calculated volume to capacity ratio is 0.7 and the guidance is to conduct further analysis.

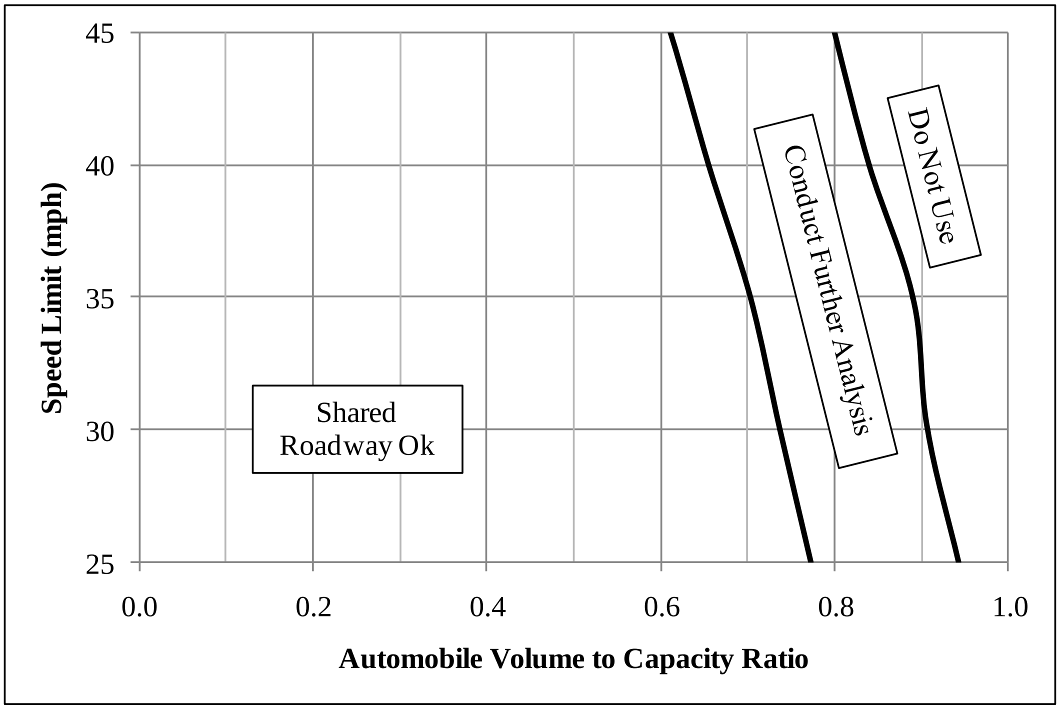


Figure 6.1 Shared Roadway Implementation Guidance on Roadways with 12 ft Outside Lane Width

Table 6.1 Saturation Flow Rates

FFS	Saturation Flow Rate
25 mph	4043 veh/h
30 mph	4280 veh/h
35 mph	4395 veh/h
40 mph	4470 veh/h
45 mph	4500 veh/h

To conduct further analysis, the author recommends estimating the percent FFS for the facility. The author recommends not using shared roadways if automobile LOS is less than LOS D (40 percent FFS or less). The first step in the process is to round the calculated automobile volume to capacity ratio to the nearest tenth. Using Table 6.2, determine the base percent FFS; the percent FFS is 0.45 for a 40 mph speed limit and 0.7 volume to capacity ratio. After determining the base percent FFS, adjust the average travel speed by the factors in Table 6.3. The factors account for differences in average travel speed caused by differences in bicycle volume. For example, if the bicycle volume is not 50 bikes/h but 100 bikes per hour; the adjustment factor is 0.74. If we multiply 0.45 by 0.74, we get a percent FFS of 0.33; because LOS D is a percent FFS greater than 0.40, a shared roadway facility is unacceptable under an automobile volume of 1252 veh/h and speed limit of 40 mph. However, if the estimated FFS is close to 0.40, the author recommends considering bicycle quality of service before implementing shared roadways.

Table 6.2 Shared Roadways Percent Free-Flow Speed, 12 ft Outside Lane Width

Scenario	Speed Limit	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
50 bikes/h, 12 ft lane	25 mph	0.73	0.66	0.57	0.47	0.35
	30 mph	0.71	0.63	0.54	0.43	0.31
	35 mph	0.68	0.59	0.50	0.40	0.29
	40 mph	0.64	0.55	0.45	0.35	0.23
	45 mph	0.61	0.51	0.41	0.30	0.18

Table 6.3 Bicycle Volume Adjustment Factors

Scenario	Speed Limit	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
25 bikes/h, 12 ft lane	25 mph	1.07	1.09	1.12	1.16	1.23
	30 mph	1.10	1.13	1.17	1.24	1.36
	35 mph	1.12	1.15	1.19	1.24	1.32
	40 mph	1.13	1.18	1.24	1.35	1.57
	45 mph	1.14	1.20	1.28	1.42	1.75
Scenario	Speed Limit	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
100 bikes/h, 12 ft lane	25 mph	0.92	0.90	0.87	0.82	0.75
	30 mph	0.92	0.89	0.84	0.75	0.58
	35 mph	0.91	0.86	0.79	0.67	0.43
	40 mph	0.88	0.83	0.74	0.59	0.26
	45 mph	0.85	0.80	0.72	0.59	0.27

Shared Roadway Implementation Guidance, 15 ft Outside Lane Width

General guidance on the implementation of shared roadways with outside lane widths of 15 ft is shown in Figure 6.2. The guidance provides the same three recommendations as the 12 ft outside lane width guidance. Use the values in Table 6.1 to calculate volume to capacity ratio. If further analysis is necessary, use table 6.4 to select a percent FFS. If bicycle volume adjustment is necessary, use the values in table 6.3. For the example scenario stated in the 12 ft outside lane section, (1252 veh/h. 40 mph FFS, and 0.4 green time divided by cycle length) 15 ft outside lane width shared roadways are ok. If percent FFS is near 40 percent, the author recommends considering bicycle quality of service before implementing shared roadways.

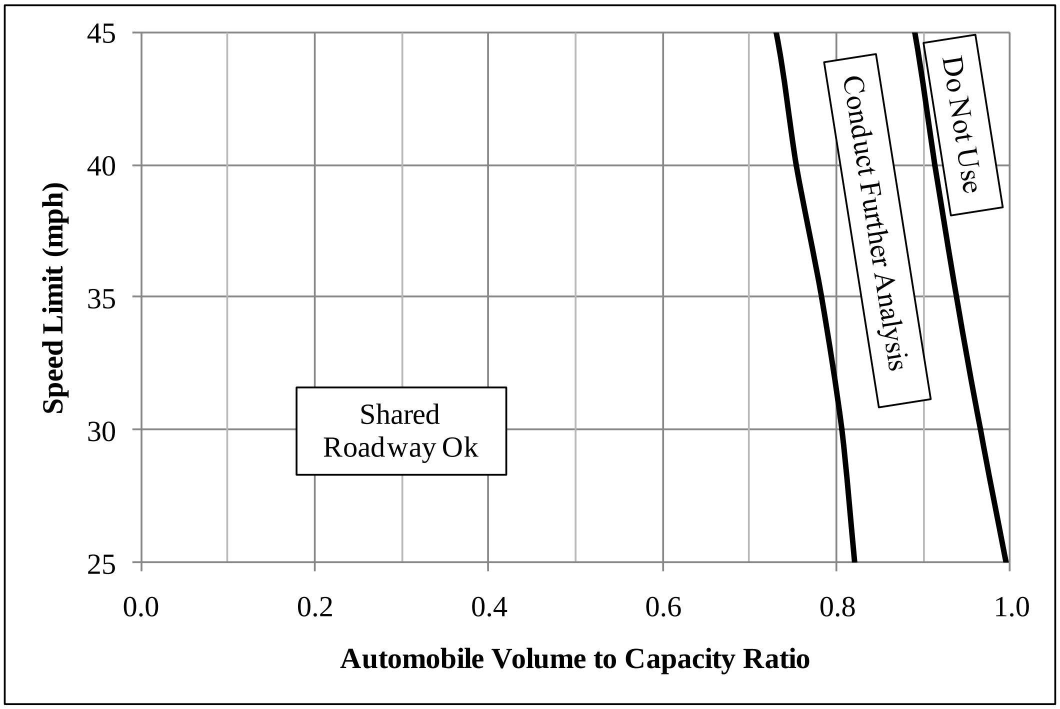


Figure 6.2 Shared Roadway Implementation Guidance on Roadways with 15 ft Outside Lane Width

Table 6.4 Shared Roadways Percent Free-Flow Speed, 15 ft Outside Lane Width

Scenario	Speed Limit	Volume to Capacity Ratio				
		0.5	0.6	0.7	0.8	0.9
50 bikes/h, 15 ft lane	25 mph	0.77	0.70	0.62	0.52	0.41
	30 mph	0.77	0.70	0.61	0.51	0.39
	35 mph	0.77	0.69	0.59	0.48	0.35
	40 mph	0.74	0.66	0.56	0.45	0.32
	45 mph	0.72	0.64	0.53	0.42	0.29

Shared Roadway Implementation Bicycle Considerations

When considering automobile quality of service does not provide a clear recommendation, the author recommends considering bicycle quality of service. One option for considering bicycle quality of service is to calculate bicycle LOS on the facility using the model in NCHRP Report 616; this is a data intensive process. For quicker analysis, the author recommends looking at the consideration in Table 6.5. The three variables in Table 6.5 are those that lowered bicycle LOS D thresholds below Automobile LOS D thresholds.

Table 6.5 Shared Roadway Implementation Bicycle Considerations

Variable	Lower Value	Higher Value
Unsignalized Access Points per Mile	More Acceptable	Less Acceptable
Signalized Intersection Crossing Distance	More Acceptable	Less Acceptable
Heavy Vehicle Percent	More Acceptable	Less Acceptable

Summary

In this chapter, the author provides guidance on the implementation of shared roadways. The author proposes that decision makers should not implement shared roadways when automobile LOS is less than LOS D. When the FFS and volume to capacity ratio combination is close to the LOS D threshold, the author provides an estimation of percent FFS. If the estimated percent FFS is less than 40 percent (LOS D threshold), the author recommends not implementing shared roadways. If the value is close to 40 percent, the author recommends considering bicycle quality of service. For rough estimates using engineering judgment, the author recommends looking at the three variables that cause bicycle LOS D thresholds to go below automobile LOS D thresholds. If data are available, the author recommends using the bicycle LOS model in NCHRP Report 616 to estimate bicycle LOS.

CHAPTER VII

CONCLUSIONS & RECOMMENDATIONS

This thesis has three objectives. The first objective is to evaluate the impact of shared roadways on automobile quality of service. The second objective is to compare automobile quality of service to bicycle quality of service. The third objective is to provide recommendations on the implementation of shared roadways. The author accomplishes the first objective in Chapter IV, the second objective in Chapter V, and third objective in Chapter VI. This chapter documents the author's conclusions and recommendations.

Automobile Quality of Service Analysis

The automobile quality of service analysis finds that bicycle volume and outside lane width are primary factors in the evaluation automobile quality of service on shared roadways. The negative effects of shared roadways increase as bicycle volume increases; additionally, the negative effect of shared roadways is greater on shared roadways with 12 ft outside lane widths than 15 ft outside lane widths. The analysis found that cycle length and green time ratio change the capacity of the roadway; the author found no additional effect because of bicycles in the traveled way.

Automobile and Bicycle Quality of Service Comparison

The automobile and bicycle quality of service comparison finds that unsignalized access points per mile, signalized intersection crossing distance, and heavy vehicle percent are variables that have the greatest impact on bicycle quality of service. These three variables are the ones that drop bicycle LOS D thresholds below automobile LOS D thresholds. In most scenarios, bicycle LOS D thresholds are greater than automobile LOS D thresholds; this means decision makers should consider automobile quality of service when considering shared roadway implementation.

Shared Roadway Implementation Guidance

The author provides guidance on the implementation of shared roadways for facilities with outside lane widths of 12 ft and 15 ft. The 12 ft outside lane facility guidance is shown in Figure 6.1; the 15 ft outside lane facility guidance is shown in Figure 6.2. The guidance shows that as automobile FFS, and volume to capacity ratio increase, shared roadways become less acceptable. When the FFS and volume to capacity ratio combination is between LOS C and LOS E the author recommends further analysis. The author provides an estimation of percent FFS and bicycle quality of service shared roadway considerations.

Limitations

The results and findings of this thesis have the following limitations:

- Guidance are based upon operations and does not consider facility safety,
- Only one bicycle speed distribution was considered,
- The guidance assumes a bicycle flow rate of 50 bicycles per hour which may be higher than some jurisdictions will experience,
- Microsimulation models were not calibrated to observed data,
- Each speed condition was ran on a different roadway segment in VISSIM 5.10 (this may create minor differences between each scenario, 12 and 18 seeds were run to limit the impact),
- The results only apply to four-lane divided shared roadways with free-flow speeds of 25, 30, 35, 40, and 45 mph,
- The bicycle LOS model used may not be the one included in the 2010 edition of the HCM, and
- The automobile LOS method may not be the one included in the 2010 edition of the HCM.

Future Work

Given the limitations of this thesis, the author recommends data collection efforts to quantify the impact of bicycles in the traveled way. If future efforts seek to calibrate microsimulation models to observed data, the author provides the following insights:

- Observe speed distributions for each FFS,
- Observe speed distributions for bicycles taking into consideration roadway geometry (such as grade),
- The driver following and passing models may not properly model automobile driver behavior behind bicycles (the models were developed for automobile behind automobile), and
- Observe lateral interactions between automobiles and bicycles; specifically, obtain speed and lateral clearance values for input in VISSIM.

REFERENCES

Allen, D., Rouphail, N., Hummer, J., and Milazzo, J., (1998) "Opperational Analysis of Uninterrupted Bicycle Facilities." *Transportation Research Record*, 1636, 29 – 36.

American Association of State Highway and Transportation Officials (AASHTO), 1999, *A Guide for the Development of Bicycle Facilities*, American Association of State Highways and Transportation Officials. Washington D.C.

American Association of State Highway and Transportation Officials (AASHTO), 2004, *A Policy on Geometric Design of Highway and Streets*, American Association of State Highways and Transportation Officials, Washington D.C.

Bisbee, G. (2010), "15 States Require 3-foot Clearance for Bicycles; Updated." Biking Bis, <http://www.bikingbis.com/blog/_archives/2008/3/5/3549263.html> (October 29, 2010).

Bonneson, J.A., Pratt, M.P., and Vandehey, M.A. (2008). "Predicting the Performance of Automobile Traffic on Urban Streets." National Cooperative Highway Research Program *Project 3-79 Final Report Part B.*, Washington, D.C. http://tcd.tamu.edu/Documents/N3-79_ObjB_final.pdf

Box, P. and Oppenlander, J. (1976) *Manual of Traffic Engineering Studies* 4th edition. Institute of Transportation Engineers, Washington, D.C.

Dowling, R., Reinke, D., Flannery, A., Ryus, P. Vandehey, M., et. el. (2008). *Multimodal Level of Service Analysis for Urban Streets*. National Cooperative Highway Research Program (NCHRP), *Report 616*, Washington, D.C.

Dowling, R., Holland, J., and Huang, A. (2002). *California Department of Transportation Guidelines for Applying Traffic Microsimulation Modeling Software*. Dowling and Associates, Oakland, California.

Highway Capacity Manual (HCM). (2000). *Highway Capacity Manual*, Transportation Research Board National Research Council, Washington, D.C.

League of American Bicyclists. (2010). "Confident Cycling Commuting." League of American Bicyclists, <http://www.bikeleague.org/programs/education/pdfs/confident_cycling_commuting_driving_your-bike_script.pdf> (April 11, 2010)

Oregon Department of Transportation (ODOT). (2009). When are Bike Lanes Needed in Urban/suburban Settings? Oregon Department of Transportation, <http://www.oregon.gov/ODOT/HWY/BIKEPED/docs/bike_lane_matrix.pdf>, (September 22, 2009)

Planung Transport Verkehr (PTV). (2008). *VISSIM 5.10 User Manual*. Planung Transport Verkehr AG, Karlsruhe, Germany.

Stover, V. and Koepke, F. (2006) *Transportation and Land Development* 2nd edition. Institute of Transportion Engineers, Washington, D.C.

Transportation Research Board (TRB), (2003), *Access Management Manual*, Transportation Research Board, Washington, D.C.

APPENDIX A

VISSIM 5.10 OUTPUT SUMMARIES

TABLE Page

Table A.1 Summary of VISSIM Output: Model 1, 12 ft Lane

Model 1, 12 ft Lane			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	39.9	0.8	303	4.6	41.5	0.8	304	5.2	118.4	1.7	51	3.7
	600	12	41.1	0.5	601	9.9	45.4	1.6	602	8.8	117.8	1.8	51	3.7
	900	12	42.7	0.4	902	15.1	52.7	1.7	901	13.7	119.0	1.8	51	3.7
	1,200	18	46.2	0.5	1,203	15.8	66.0	2.6	1,199	15.3	121.3	2.2	50	3.4
	1,500	18	56.5	2.0	1,497	16.1	93.7	8.5	1,395	17.6	133.8	9.1	49	3.9
	3,000	18	75.6	7.6	1,617	5.3								
30 mph	300	12	32.6	0.6	304	5.5	34.1	0.8	303	6.5	113.6	1.1	50	3.1
	600	12	33.4	0.4	602	10.4	37.2	0.8	599	10.4	112.8	1.2	50	3.1
	900	12	34.0	0.3	906	15.3	43.6	1.9	902	17.1	113.5	1.7	50	3.1
	1,200	18	35.3	0.3	1,202	15.3	55.2	2.0	1,198	17.0	115.8	2.0	49	3.5
	1,500	18	38.1	0.5	1,499	17.1	79.6	9.9	1,431	21.3	123.9	8.1	48	3.6
	3,000	18	42.6	0.5	1,712	6.6								
35 mph	300	12	27.9	0.5	303	6.0	29.4	0.7	301	5.7	109.7	1.3	49	3.5
	600	12	28.1	0.4	601	11.5	32.6	0.4	597	9.9	109.0	1.4	49	3.5
	900	12	28.7	0.3	902	14.9	39.0	1.6	897	17.0	110.1	1.9	49	3.5
	1,200	18	29.2	0.2	1,198	14.2	48.6	2.2	1,192	16.1	112.1	2.2	49	3.4
	1,500	18	30.5	0.4	1,496	17.2	70.7	9.5	1,451	21.8	117.8	9.1	48	3.7
	3,000	18	33.0	0.3	1,758	6.0								
40 mph	300	12	24.2	0.3	301	6.2	25.9	0.6	302	6.2	107.8	1.4	49	3.8
	600	12	24.5	0.3	597	12.0	29.2	1.1	598	10.8	107.1	1.5	49	3.8
	900	12	24.7	0.2	896	13.5	35.6	1.3	892	14.5	108.1	1.7	49	3.8
	1,200	18	25.0	0.2	1,194	13.2	45.0	2.8	1,193	17.0	109.7	2.4	49	3.2
	1,500	18	25.6	0.3	1,493	17.1	70.6	11.3	1,451	26.5	119.2	9.9	48	3.3
	3,000	18	27.1	0.2	1,788	3.5								
45 mph	300	12	21.5	0.4	301	6.8	23.1	0.5	302	6.4	105.8	1.6	49	2.7
	600	12	21.6	0.2	597	9.6	26.8	0.7	599	9.2	105.2	1.8	49	2.7
	900	12	21.7	0.2	896	15.2	33.8	1.4	899	14.5	106.5	2.2	49	2.7
	1,200	18	21.9	0.2	1,198	16.7	43.5	2.2	1,198	16.5	108.8	1.9	49	2.8
	1,500	18	22.1	0.2	1,495	16.9	74.1	13.1	1,459	22.7	123.6	15.2	48	2.6
	3,000	18	23.1	0.2	1,800	3.4								

Table A.2 Summary of VISSIM Output: Model 1, 15 ft Lane

Model 1, 15 ft Lane			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 15 ft Outside Lane				15 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	39.9	0.8	303	4.6	40.5	1.0	304	4.9	118.8	1.7	49	3.2
	600	12	41.1	0.5	601	9.9	43.3	0.9	602	9.6	118.7	1.4	49	3.2
	900	12	42.7	0.4	902	15.1	49.5	1.0	905	15.0	118.9	1.5	49	3.2
	1,200	18	46.2	0.5	1,203	15.8	62.4	2.1	1,200	16.5	119.4	1.1	49	3.1
	1,500	18	56.5	2.0	1,497	16.1	86.5	4.8	1,451	14.9	119.4	1.4	49	3.1
	3,000	18	75.6	7.6	1,617	5.3								
30 mph	300	12	32.6	0.6	304	5.5	33.1	0.5	302	6.2	114.3	0.9	49	3.4
	600	12	33.4	0.4	602	10.4	35.0	0.7	598	11.3	114.2	1.0	49	3.4
	900	12	34.0	0.3	906	15.3	39.3	0.7	897	17.4	114.4	1.0	49	3.4
	1,200	18	35.3	0.3	1,202	15.3	49.6	2.1	1,195	14.7	114.7	1.6	49	3.5
	1,500	18	38.1	0.5	1,499	17.1	68.8	5.1	1,473	21.6	114.7	1.2	49	3.5
	3,000	18	42.6	0.5	1,712	6.6								
35 mph	300	12	27.9	0.5	303	6.0	28.3	0.5	302	6.2	110.3	1.5	49	3.5
	600	12	28.1	0.4	601	11.5	29.6	0.5	598	9.7	110.3	1.7	49	3.5
	900	12	28.7	0.3	902	14.9	33.6	1.3	896	12.3	110.6	1.5	49	3.5
	1,200	18	29.2	0.2	1,198	14.2	42.8	1.8	1,192	13.7	111.1	1.3	49	3.3
	1,500	18	30.5	0.4	1,496	17.2	59.3	3.7	1,477	18.2	111.2	1.4	49	3.2
	3,000	18	33.0	0.3	1,758	6.0								
40 mph	300	12	24.2	0.3	301	6.2	24.7	0.4	301	7.3	108.5	1.4	50	3.3
	600	12	24.5	0.3	597	12.0	26.2	0.4	599	11.8	108.6	1.5	50	3.3
	900	12	24.7	0.2	896	13.5	30.5	1.2	897	15.1	108.8	1.4	50	3.3
	1,200	18	25.0	0.2	1,194	13.2	38.3	1.6	1,195	14.8	108.5	2.0	49	3.0
	1,500	18	25.6	0.3	1,493	17.1	54.4	3.6	1,480	20.9	109.1	1.8	49	3.0
	3,000	18	27.1	0.2	1,788	3.5								
45 mph	300	12	21.5	0.4	301	6.8	22.1	0.4	300	6.0	106.4	1.8	49	2.6
	600	12	21.6	0.2	597	9.6	23.6	0.5	597	9.9	106.4	1.8	49	2.6
	900	12	21.7	0.2	896	15.2	27.5	0.9	897	15.5	106.9	1.8	49	2.6
	1,200	18	21.9	0.2	1,198	16.7	35.6	2.1	1,200	17.8	107.2	1.4	50	3.3
	1,500	18	22.1	0.2	1,495	16.9	52.4	5.5	1,491	19.0	107.5	1.5	50	3.3
	3,000	18	23.1	0.2	1,800	3.4								

Table A.3 Summary of VISSIM Output: Model 2, 25 bikes/h

Model 2, 25 bikes/h			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	39.9	0.8	303	4.6	40.9	0.85	304	5.29	119.3	1.3	26	1.8
	600	12	41.1	0.5	601	9.9	43.7	0.76	601	10.1	118.4	1.6	26	1.8
	900	12	42.7	0.4	902	15.1	48.5	0.93	899	18.1	119.0	2.1	25	2.4
	1,200	18	46.2	0.5	1,203	15.8	58.2	1.89	1,199	17.9	120.6	2.4	25	2.4
	1,500	18	56.5	2.0	1,497	16.1	85.0	10.53	1,450	21.3	127.5	9.3	25	2.3
	3,000	18	75.6	7.6	1,617	5.3								
30 mph	300	12	32.6	0.6	304	5.5	33.4	0.63	303	6.47	114.1	1.3	25	2.7
	600	12	33.4	0.4	602	10.4	35.5	0.55	598	11.1	112.9	1.5	25	2.7
	900	12	34.0	0.3	906	15.3	39.4	1.04	900	17.4	113.5	1.9	24	2.7
	1,200	18	35.3	0.3	1,202	15.3	47.1	1.75	1,199	18.0	115.2	2.2	24	2.7
	1,500	18	38.1	0.5	1,499	17.1	66.1	6.76	1,474	23.9	118.6	3.4	24	2.7
	3,000	18	42.6	0.5	1,712	6.6								
35 mph	300	12	27.9	0.5	303	6.0	28.7	0.56	301	5.66	109.9	1.3	24	2.7
	600	12	28.1	0.4	601	11.5	30.6	0.68	598	10.4	109.2	1.5	24	2.7
	900	12	28.7	0.3	902	14.9	34.4	0.99	896	17.1	109.6	1.8	23	2.8
	1,200	18	29.2	0.2	1,198	14.2	41.4	1.88	1,193	16.4	111.4	2.1	23	2.8
	1,500	18	30.5	0.4	1,496	17.2	57.5	4.75	1,477	19.8	114.1	3.0	23	2.7
	3,000	18	33.0	0.3	1,758	6.0								
40 mph	300	12	24.2	0.3	301	6.2	25.3	0.55	302	6.05	107.3	1.7	24	2.9
	600	12	24.5	0.3	597	12.0	27.1	0.87	599	10.9	106.7	1.8	24	2.9
	900	12	24.7	0.2	896	13.5	31.3	0.99	897	14.4	107.9	2.1	24	2.5
	1,200	18	25.0	0.2	1,194	13.2	37.8	2.18	1,195	16.2	109.5	2.5	24	2.5
	1,500	18	25.6	0.3	1,493	17.1	52.0	4.41	1,481	22.7	111.9	3.1	24	2.5
	3,000	18	27.1	0.2	1,788	3.5								
45 mph	300	12	21.5	0.4	301	6.8	22.5	0.36	302	6.36	106.0	1.9	24	2.4
	600	12	21.6	0.2	597	9.6	24.7	0.64	599	9.1	105.4	1.9	24	2.4
	900	12	21.7	0.2	896	15.2	29.2	0.96	900	15.5	106.4	2.2	24	2.1
	1,200	18	21.9	0.2	1,198	16.7	35.8	2.23	1,199	16.7	108.3	2.4	24	2.1
	1,500	18	22.1	0.2	1,495	16.9	50.8	4.59	1,486	23.2	111.2	3.6	24	2.1
	3,000	18	23.1	0.2	1,800	3.4								

Table A.4 Summary of VISSIM Output: Model 3, 100 bikes/h

Model 3, 100 bikes/h			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	39.9	0.8	303	4.6	42.4	1.0	305	5.3	119.7	0.74	101	4.32
	600	12	41.1	0.5	601	9.9	47.9	1.1	602	8.7	119.0	0.6	101	4.3
	900	12	42.7	0.4	902	15.1	58.1	1.1	900	16.6	120.3	0.9	100	4.4
	1,200	18	46.2	0.5	1,203	15.8	74.8	3.6	1,195	17.5	124.2	1.9	100	4.3
	1,500	18	56.5	2.0	1,497	16.1	102.8	12.3	1,312	12.9	144.3	15.1	98	5.2
	3,000	18	75.6	7.6	1,617	5.3								
30 mph	300	12	32.6	0.6	304	5.5	35.0	1.2	304	7.0	113.9	0.61	101	4.34
	600	12	33.4	0.4	602	10.4	39.1	0.5	600	11.8	113.2	0.7	101	4.3
	900	12	34.0	0.3	906	15.3	48.1	1.1	900	15.9	114.2	1.1	100	4.2
	1,200	18	35.3	0.3	1,202	15.3	62.8	1.8	1,197	17.9	117.6	1.3	100	4.1
	1,500	18	38.1	0.5	1,499	17.1	94.0	13.9	1,339	17.3	138.0	15.5	98	5.2
	3,000	18	42.6	0.5	1,712	6.6								
35 mph	300	12	27.9	0.5	303	6.0	30.3	0.9	300	6.3	109.8	1.01	100	4.34
	600	12	28.1	0.4	601	11.5	34.8	0.8	597	10.9	109.4	0.9	100	4.3
	900	12	28.7	0.3	902	14.9	43.3	1.0	896	16.6	110.4	1.0	99	4.1
	1,200	18	29.2	0.2	1,198	14.2	57.4	2.3	1,192	17.5	113.8	1.6	100	3.9
	1,500	18	30.5	0.4	1,496	17.2	90.0	17.9	1,349	21.8	136.2	19.1	97	4.7
	3,000	18	33.0	0.3	1,758	6.0								
40 mph	300	12	24.2	0.3	301	6.2	26.8	0.8	301	6.4	107.9	0.88	100	4.03
	600	12	24.5	0.3	597	12.0	31.6	1.3	598	10.5	107.3	0.8	100	4.0
	900	12	24.7	0.2	896	13.5	40.7	1.2	896	14.1	108.6	1.1	99	4.1
	1,200	18	25.0	0.2	1,194	13.2	55.5	2.4	1,191	16.6	112.1	1.5	99	4.1
	1,500	18	25.6	0.3	1,493	17.1	91.9	13.3	1,349	20.1	138.1	13.5	97	4.7
	3,000	18	27.1	0.2	1,788	3.5								
45 mph	300	12	21.5	0.4	301	6.8	24.2	0.5	301	7.1	106.6	0.79	99	4.07
	600	12	21.6	0.2	597	9.6	29.7	1.3	598	9.9	106.2	1.0	99	4.1
	900	12	21.7	0.2	896	15.2	39.5	1.2	897	14.7	107.5	1.1	99	4.0
	1,200	18	21.9	0.2	1,198	16.7	54.5	2.9	1,193	18.6	111.0	1.8	99	4.0
	1,500	18	22.1	0.2	1,495	16.9	94.1	9.0	1,359	15.3	142.2	11.3	97	4.9
	3,000	18	23.1	0.2	1,800	3.4								

Table A.5 Summary of VISSIM Output: Model 4, Green Time Ratio

Model 4, Green Time Ratio			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	41.8	1.0	303	5.5	47.8	1.8	304	4.6	123.3	0.9	50	3.7
	450	12	44.9	1.4	453	6.3	57.3	2.2	453	5.8	124.2	0.7	50	3.7
	600	12	51.7	1.8	601	8.8	74.1	2.4	601	7.8	129.4	4.0	50	3.5
	750	18	64.6	2.4	748	10.5	107.7	12.4	728	9.6	162.9	19.7	47	3.2
	900	18	94.2	11.1	871	13.3	123.4	9.8	755	8.9	186.0	16.7	46	3.7
	3,000	18	105.9	12.7	890	7.3								
30 mph	300	12	33.5	0.7	304	5.5	39.1	1.7	304	6.2	117.4	0.8	50	3.1
	450	12	34.6	0.5	451	7.5	46.3	1.7	450	9.0	117.7	0.8	50	3.1
	600	12	37.3	1.1	601	9.2	60.7	3.8	597	8.6	120.5	2.1	50	2.9
	750	18	43.6	1.4	749	11.3	90.3	12.2	731	12.9	146.8	19.0	48	3.8
	900	18	56.3	3.5	891	14.7	115.4	6.9	778	13.0	184.1	8.3	46	4.2
	3,000	18	74.8	15.8	937	5.9								
35 mph	300	12	28.8	0.7	303	6.0	35.5	1.9	300	6.0	113.1	1.2	49	3.5
	450	12	29.4	0.4	449	8.4	42.8	2.9	445	8.7	113.4	1.1	49	3.5
	600	12	31.1	0.7	601	11.5	54.6	5.5	594	10.7	116.2	1.8	48	3.3
	750	18	34.8	0.8	746	12.1	83.5	13.1	731	12.1	139.1	21.0	47	3.7
	900	18	42.3	1.4	893	13.5	110.4	9.9	785	12.6	178.6	12.4	45	3.9
	3,000	18	48.6	2.9	961	5.6								
40 mph	300	12	24.8	0.4	301	6.2	31.8	1.5	301	6.5	111.0	1.4	49	3.8
	450	12	25.6	0.2	449	9.5	39.4	2.4	448	10.1	111.2	1.5	49	3.8
	600	12	26.3	0.6	597	11.5	51.0	4.7	597	10.9	114.4	3.6	49	3.7
	750	18	28.2	0.7	747	11.3	79.4	13.4	730	10.9	138.9	21.1	48	2.7
	900	18	32.7	0.8	892	13.7	110.9	13.3	782	12.1	181.0	15.0	45	3.8
	3,000	18	35.8	0.7	965	5.6								
45 mph	300	12	21.9	0.4	301	6.8	25.0	1.4	300	5.8	108.9	1.3	49	2.6
	450	12	22.1	0.2	447	10.1	37.2	1.8	449	10.5	110.1	1.9	49	2.5
	600	12	22.7	0.4	597	9.3	47.3	3.6	597	9.2	112.5	2.2	49	2.5
	750	18	24.2	0.6	749	12.2	78.6	11.9	733	10.2	141.5	18.9	48	3.1
	900	18	27.3	0.7	893	15.0	104.5	12.7	778	13.3	173.6	14.2	45	3.0
	3,000	18	29.2	0.7	965	5.4								

Table A.6 Summary of VISSIM Output: Model 5, Cycle Length

Model 5, Cycle Length			Automobile								Bicycle			
			Zero Bicycles				With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	40.4	0.7	303	5.60	42.8	1.2	305	5.11	138.7	3.1	51	3.36
	600	12	41.9	0.4	600	9.7	48.4	1.7	602	10.0	140.0	2.2	51	3.3
	900	12	43.8	0.7	903	15.9	62.6	3.1	902	16.7	142.5	2.7	51	3.2
	1,200	18	51.4	1.3	1,203	15.7	96.0	9.2	1,172	19.6	151.9	6.8	49	3.6
	1,500	18	72.6	5.1	1,398	8.0	104.3	12.7	1,210	13.2	156.2	9.5	49	3.4
	3,000	18	71.7	6.9	1,406	5.1								
30 mph	300	12	33.0	0.4	304	5.82	35.0	0.9	304	6.91	138.7	2.2	50	2.98
	600	12	33.8	0.6	601	10.2	38.9	0.9	600	9.5	137.1	2.5	50	3.0
	900	12	34.5	0.5	905	15.8	51.1	1.7	901	16.5	137.9	1.6	50	3.0
	1,200	18	36.5	0.4	1,202	15.3	75.9	6.8	1,181	22.9	143.2	2.8	49	4.0
	1,500	18	41.9	0.8	1,468	17.6	95.2	12.2	1,251	22.7	151.5	7.9	48	4.0
	3,000	18	43.7	2.5	1,490	6.8								
35 mph	300	12	28.0	0.8	302	6.13	29.9	0.7	300	5.62	135.5	2.0	49	3.85
	600	12	28.5	0.3	600	9.5	34.2	1.3	598	8.6	133.9	1.9	49	3.8
	900	12	28.9	0.4	902	14.4	45.2	2.4	896	15.2	134.5	2.0	49	3.8
	1,200	18	29.8	0.3	1,198	15.0	66.8	4.8	1,181	18.1	138.7	2.4	48	4.0
	1,500	18	32.6	0.5	1,485	19.9	86.1	10.1	1,275	21.0	145.7	5.1	48	4.1
	3,000	18	33.6	0.4	1,537	5.1								
40 mph	300	12	24.5	0.5	301	6.91	26.8	0.5	302	6.83	132.2	1.8	49	4.32
	600	12	24.7	0.2	598	11.4	31.3	1.4	599	10.8	130.7	1.5	49	4.3
	900	12	24.9	0.3	895	14.4	42.0	2.3	892	14.9	132.2	1.7	49	4.3
	1,200	18	25.2	0.4	1,193	14.0	62.3	5.0	1,184	18.1	136.6	2.4	48	3.7
	1,500	18	26.8	0.3	1,488	19.9	91.4	16.1	1,291	23.7	149.0	12.2	47	3.9
	3,000	18	27.6	0.3	1,566	4.4								
45 mph	300	12	21.7	0.3	300	8.14	23.8	0.7	301	7.84	131.3	1.3	49	2.71
	600	12	21.7	0.2	597	9.9	29.7	1.2	598	9.8	130.3	1.2	49	2.7
	900	12	21.8	0.2	895	15.7	40.9	2.1	896	15.3	131.5	1.5	49	2.7
	1,200	18	21.9	0.2	1,196	17.4	61.8	4.4	1,189	19.4	135.4	2.3	48	3.0
	1,500	18	22.8	0.3	1,489	18.9	71.3	5.4	1,364	22.1	150.4	15.4	47	3.3
	3,000	18	23.2	0.2	1,581	4.6								

Table A.7 Summary of VISSIM Output: Model 6, Segment Length

Model 6, Segment Length			Automobile				Bicycle			
			With Bicycles, 12 ft Outside Lane				12 ft Outside Lane			
Speed Conditon	Input Volume (veh/h)	Seeds	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)	Average Travel Time (s)	Standard Deviation (s)	Average Volume (veh/h)	Stanard Deviaton (veh/h)
25 mph	300	12	82.1	1.3	305	5.33	200.6	5.4	50	3.37
	600	12	90.7	1.4	601	7.8	202.3	4.8	50	3.4
	900	12	103.0	1.7	898	14.6	203.7	5.3	50	3.1
	1,200	18	121.5	2.3	1,191	16.2	210.1	5.9	50	3.3
	1,500	18	151.3	6.6	1,387	18.4	233.3	6.2	47	3.1
	3,000	18	133.5	8.1	1,615	7.7				
30 mph	300	12	67.5	1.0	304	8.48	197.7	5.0	50	2.78
	600	12	73.5	1.1	598	10.0	197.9	4.9	50	2.9
	900	12	84.8	1.7	898	15.1	200.7	5.1	49	3.5
	1,200	18	102.0	2.9	1,191	18.3	206.3	6.1	49	3.4
	1,500	18	138.8	8.6	1,416	18.2	228.0	9.8	47	3.6
	3,000	18	97.3	6.3	1,703	8.1				
35 mph	300	12	57.3	0.7	299	6.34	198.3	4.6	49	3.53
	600	12	63.1	1.2	597	9.5	199.2	4.7	49	3.6
	900	12	73.8	1.9	895	16.4	201.3	5.5	49	3.6
	1,200	18	90.2	2.1	1,187	16.2	206.8	6.7	49	3.6
	1,500	18	125.6	8.9	1,435	18.1	223.7	6.7	47	3.7
	3,000	18	71.7	6.6	1,755	7.0				
40 mph	300	12	49.7	0.5	302	6.56	200.1	6.0	49	4.22
	600	12	55.8	1.4	600	11.5	200.8	5.7	49	4.2
	900	12	67.2	1.5	896	14.9	203.5	5.3	48	3.6
	1,200	18	82.9	2.4	1,190	17.6	207.4	5.5	49	3.4
	1,500	18	119.2	12.2	1,442	15.9	223.6	7.4	48	3.6
	3,000	18	54.3	0.4	1,786	4.7				
45 mph	300	12	44.7	0.9	301	7.63	200.4	4.8	48	2.96
	600	12	51.3	1.2	598	10.3	200.9	4.9	48	2.8
	900	12	64.1	1.5	898	15.7	205.0	4.6	48	3.0
	1,200	18	79.8	2.8	1,195	19.4	209.0	4.7	48	3.0
	1,500	18	113.4	10.5	1,450	20.6	224.0	8.7	48	2.9
	3,000	18	46.5	0.2	1,800	4.9				

APPENDIX B

PLOTTED VISSIM DATA AND REGRESSION EQUATIONS

FIGURE Page

FIGURE Page

Figure B.1 Model 1, 25 mph

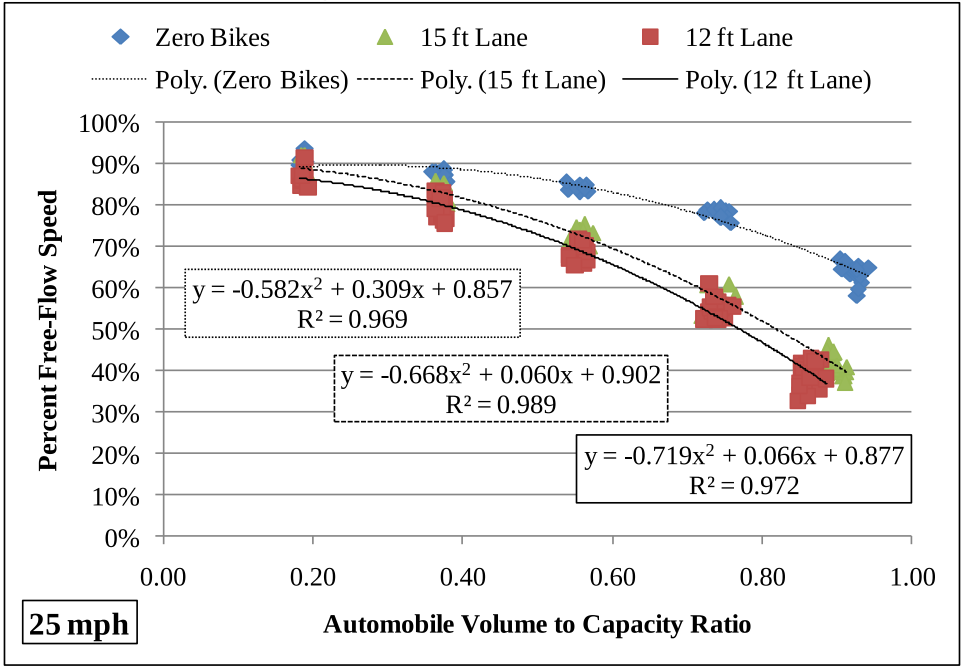


Figure B.2 Model 1, 30 mph

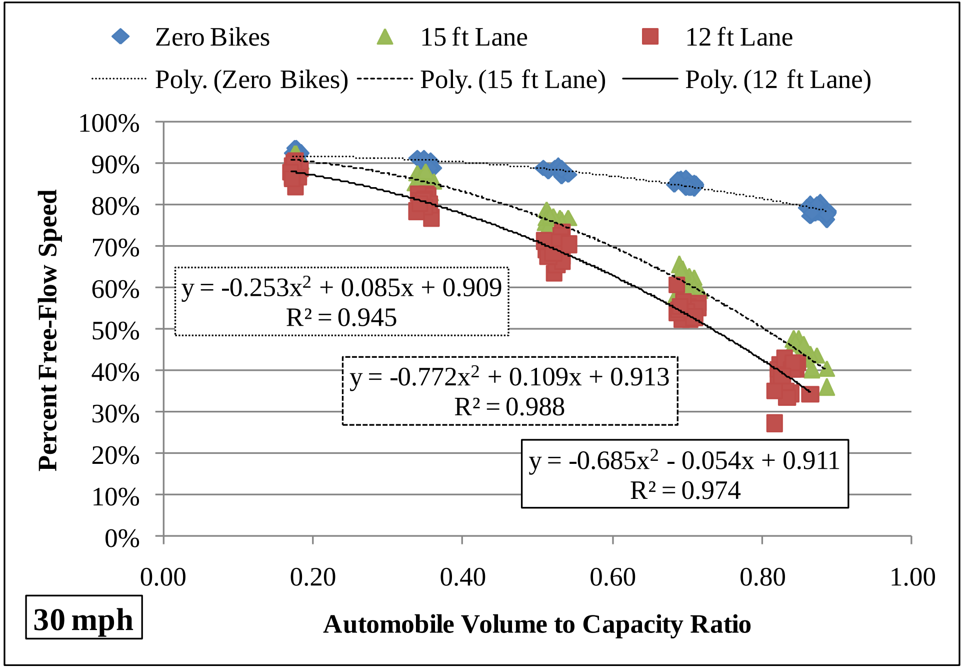


Figure B.3 Model 1, 35 mph

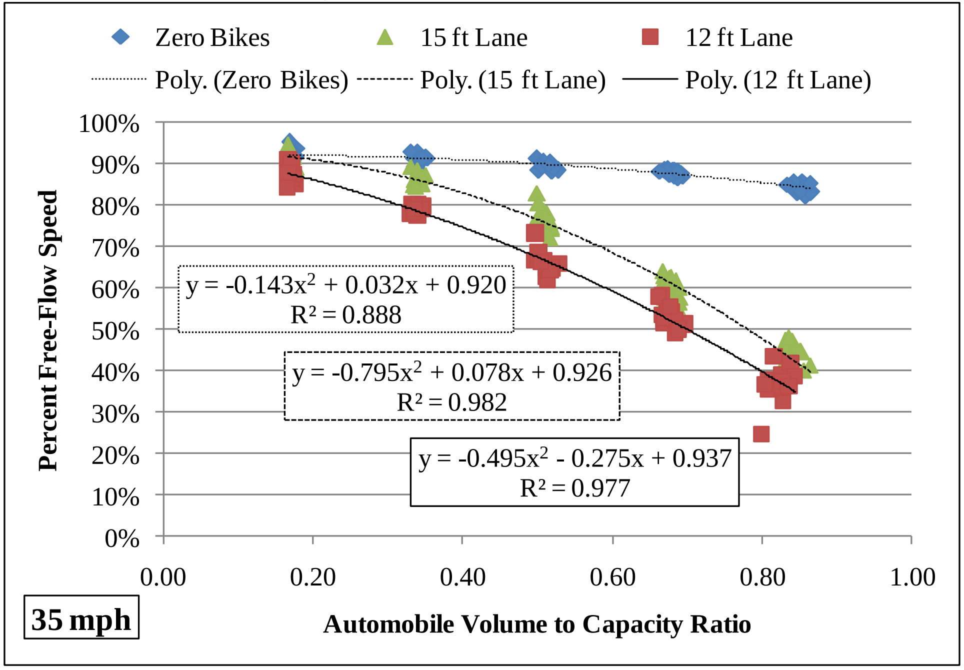


Figure B.4 Model 1, 40 mph

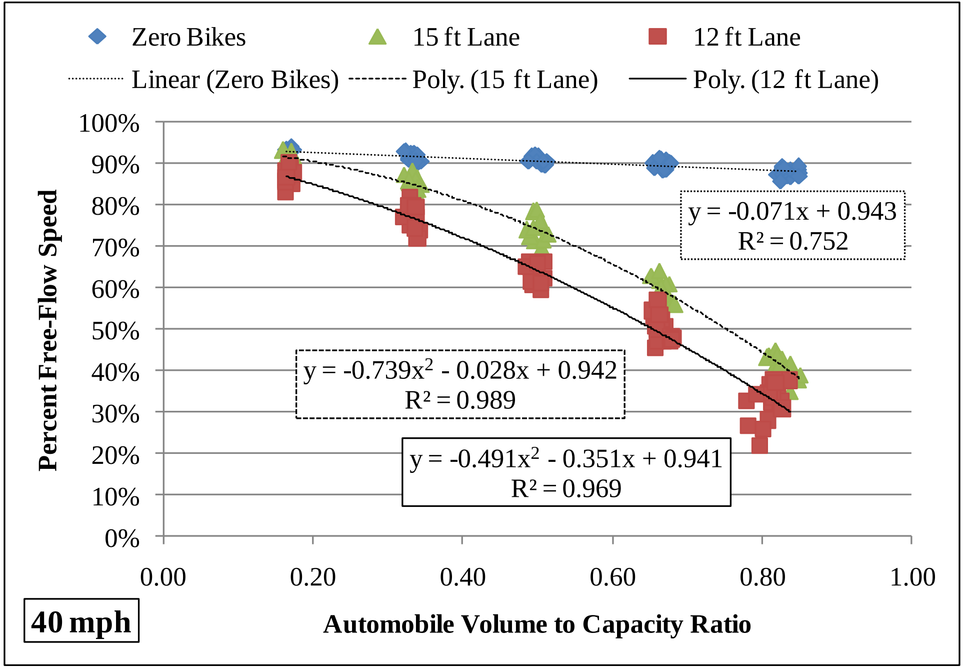


Figure B.5 Model 1, 45 mph

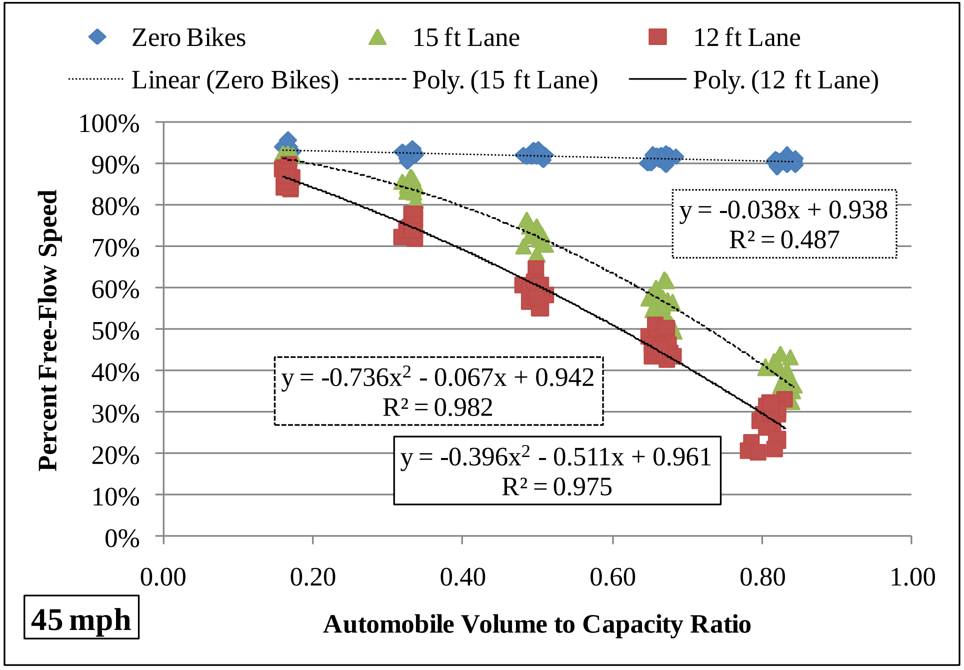


Figure B.6 Model 2, 25 mph

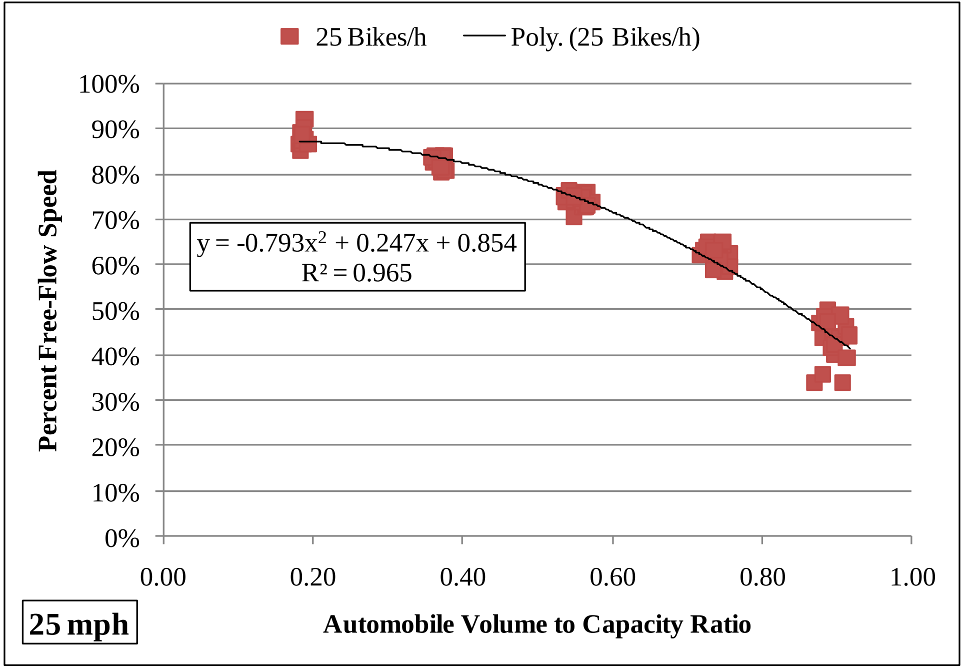


Figure B.7 Model 2, 30 mph

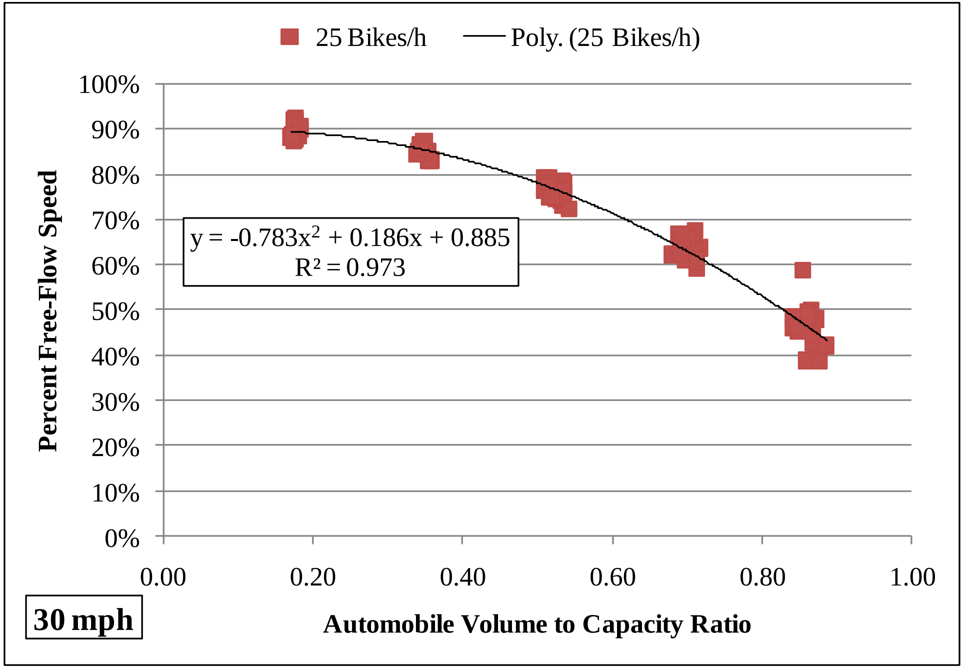


Figure B.8 Model 2, 35 mph

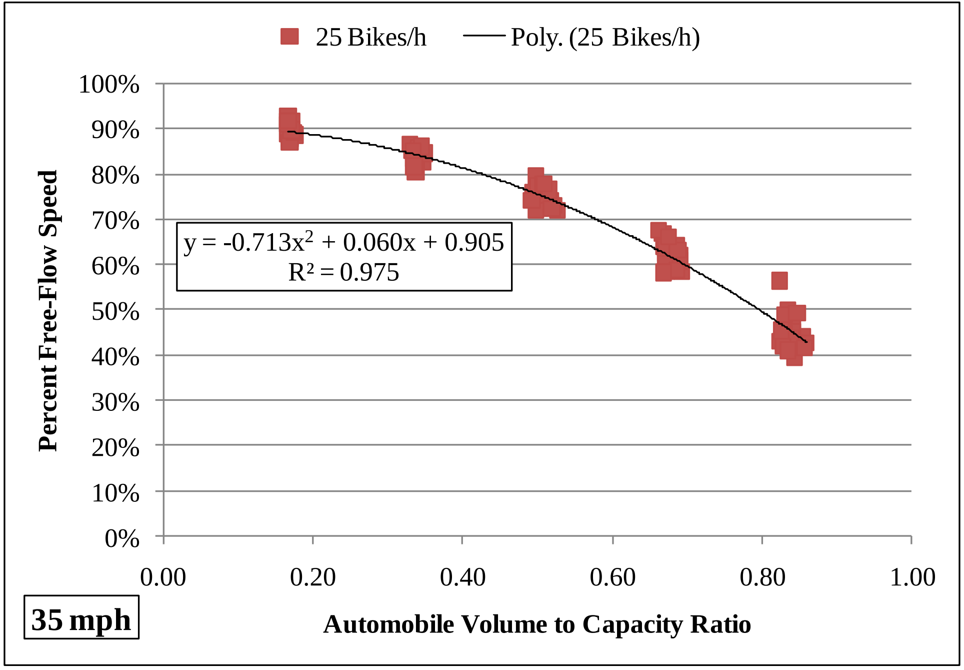


Figure B.9 Model 2, 40 mph

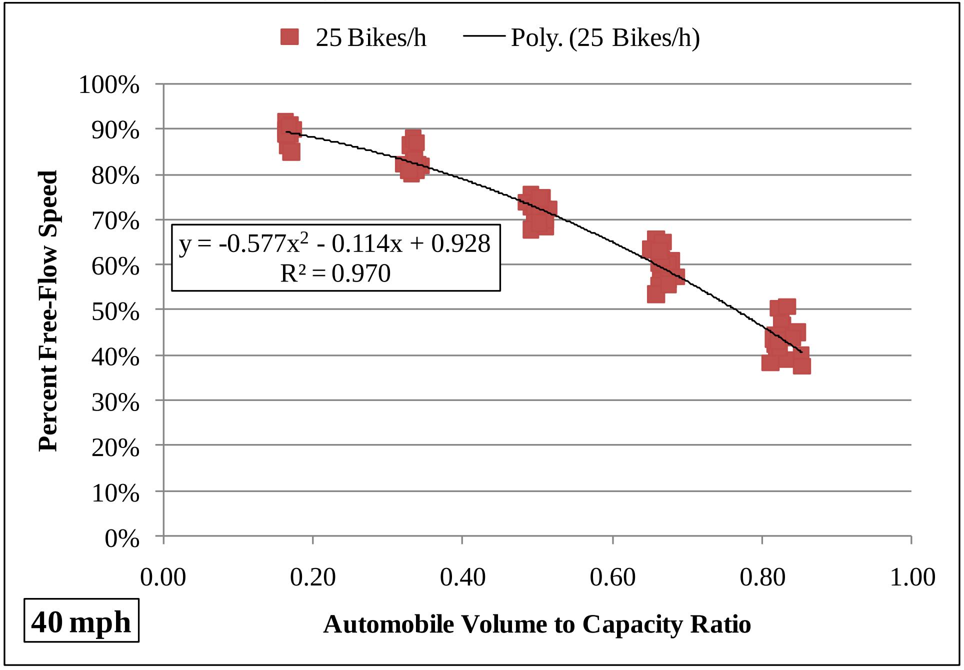


Figure B.10 Model 2, 45 mph

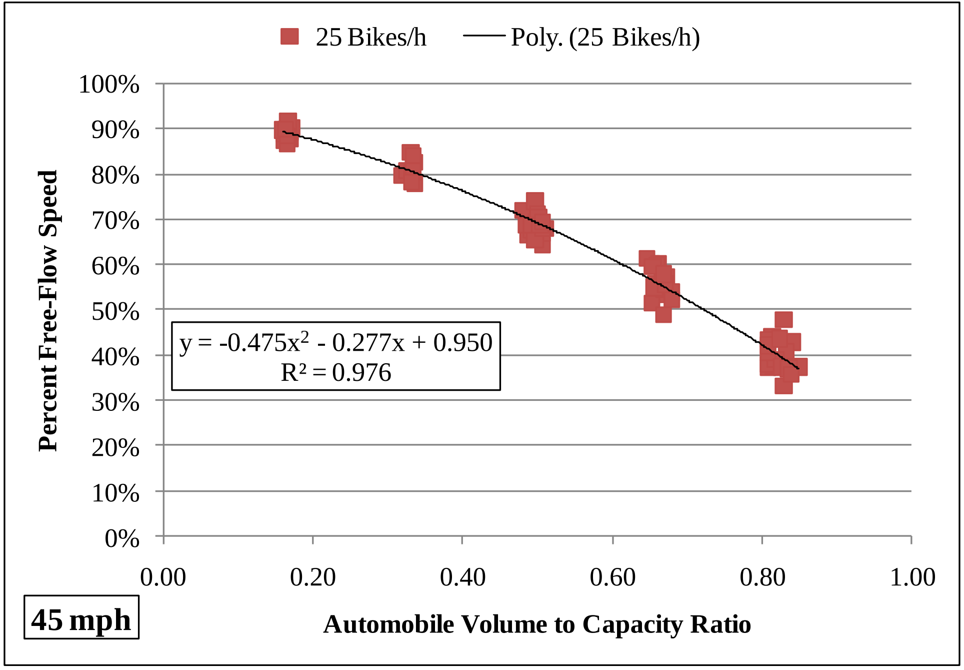


Figure B.11 Model 3, 25 mph

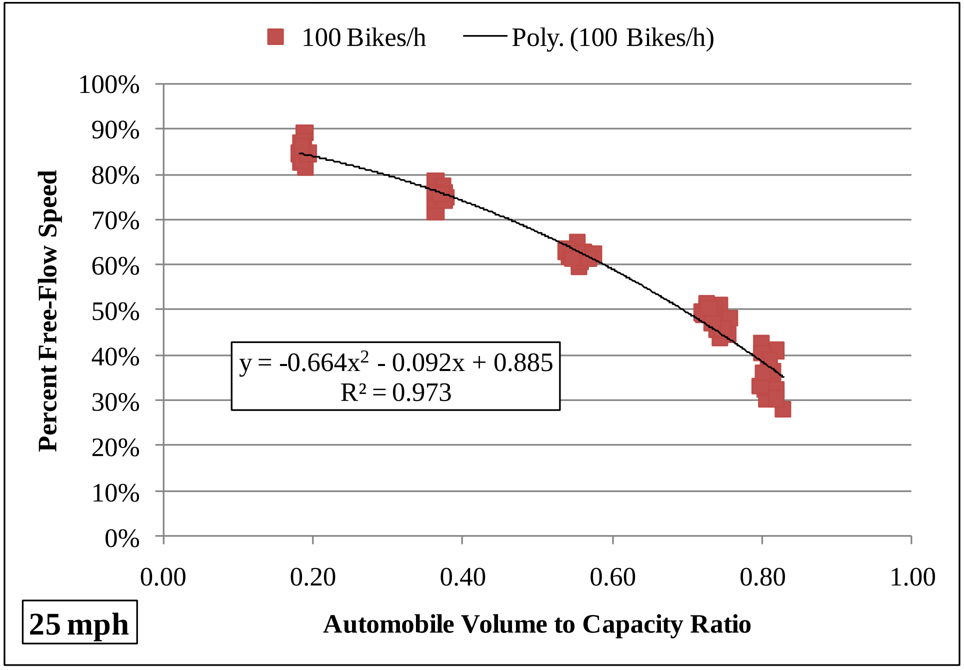


Figure B.12 Model 3, 30 mph

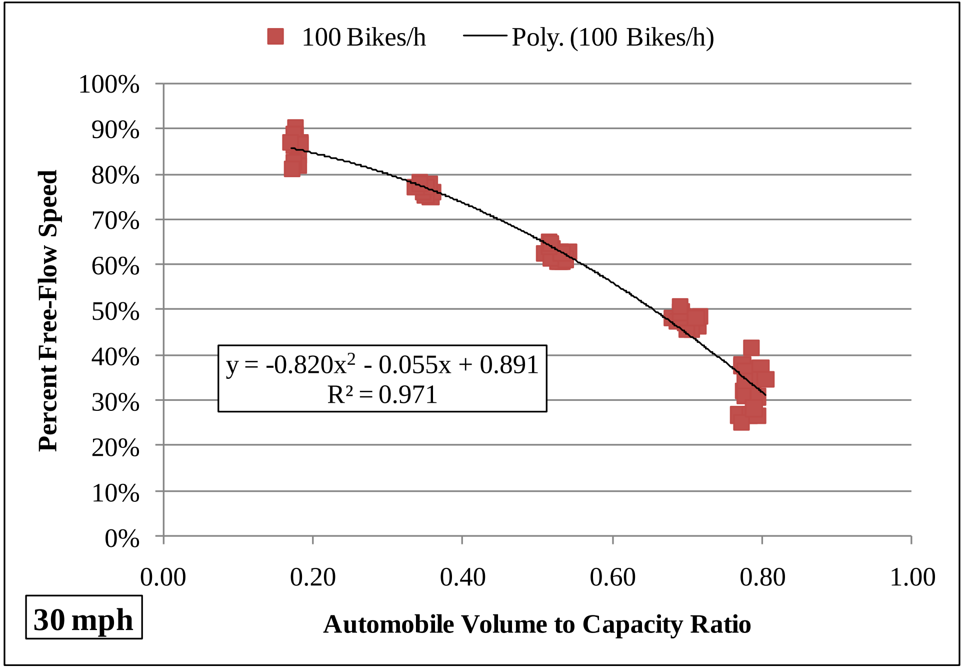


Figure B.13 Model 3, 35 mph

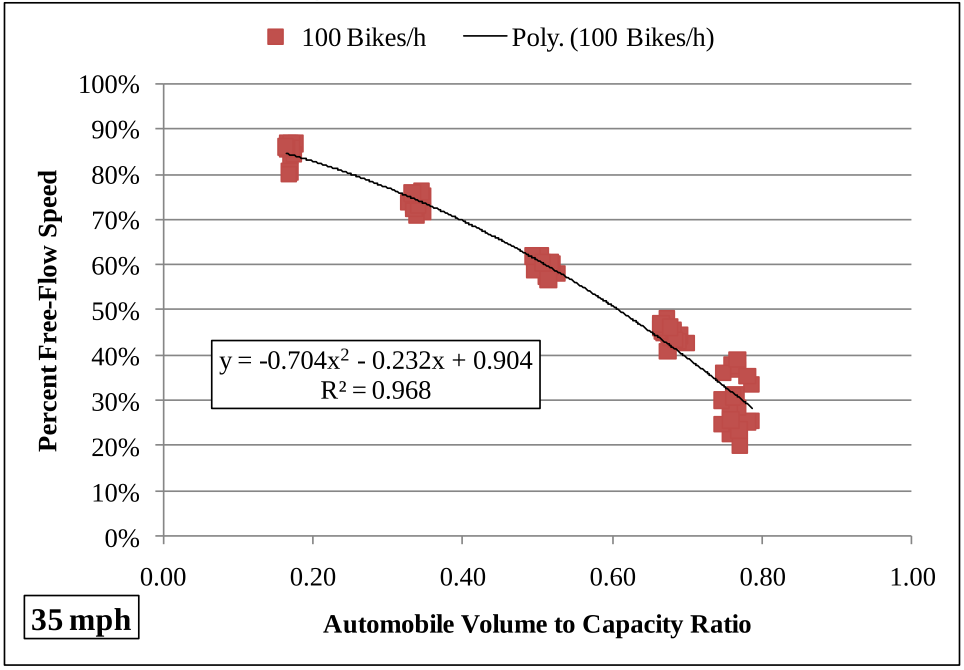


Figure B.14 Model 3, 40 mph

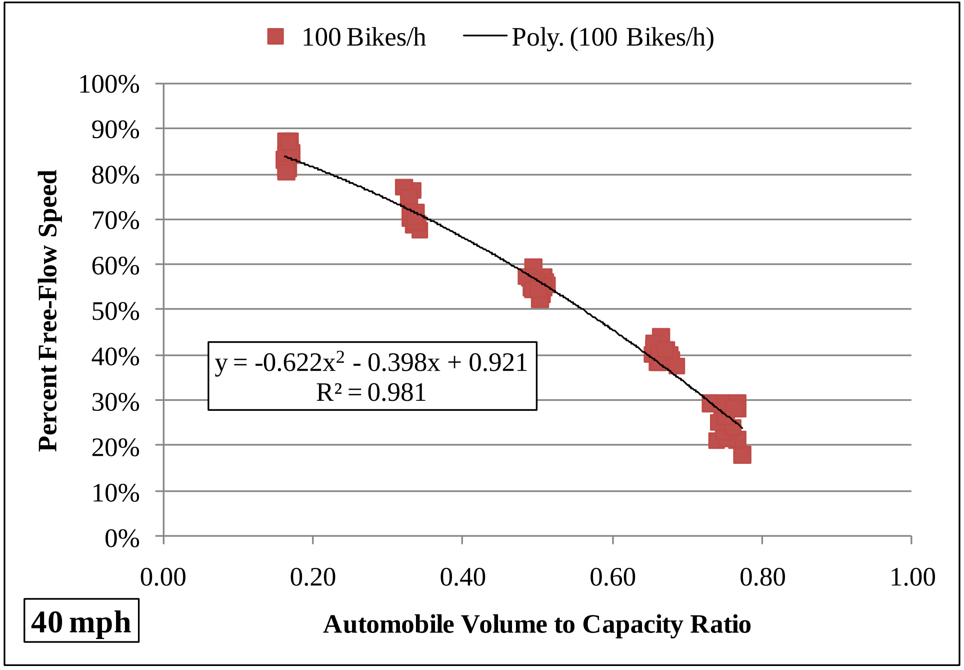


Figure B.15 Model 3, 45 mph

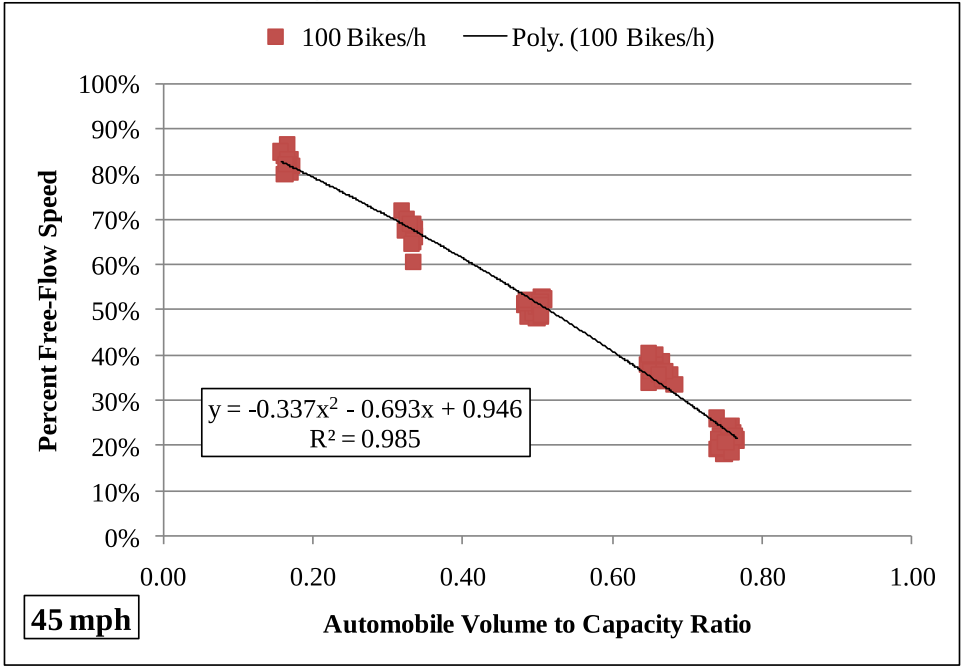


Figure B.16 Model 4, 25 mph

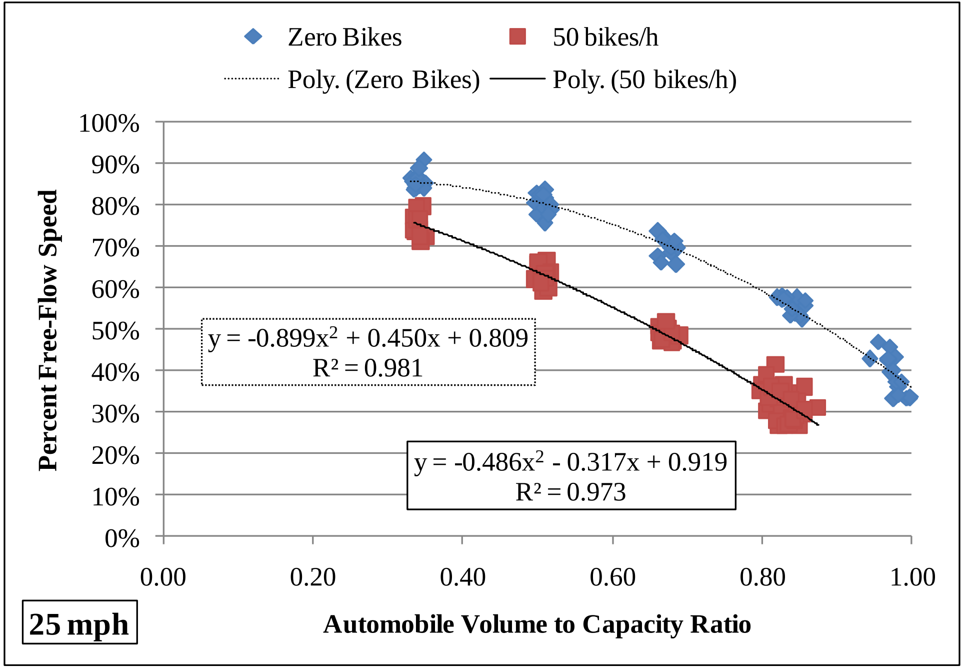


Figure B.17 Model 4, 30 mph

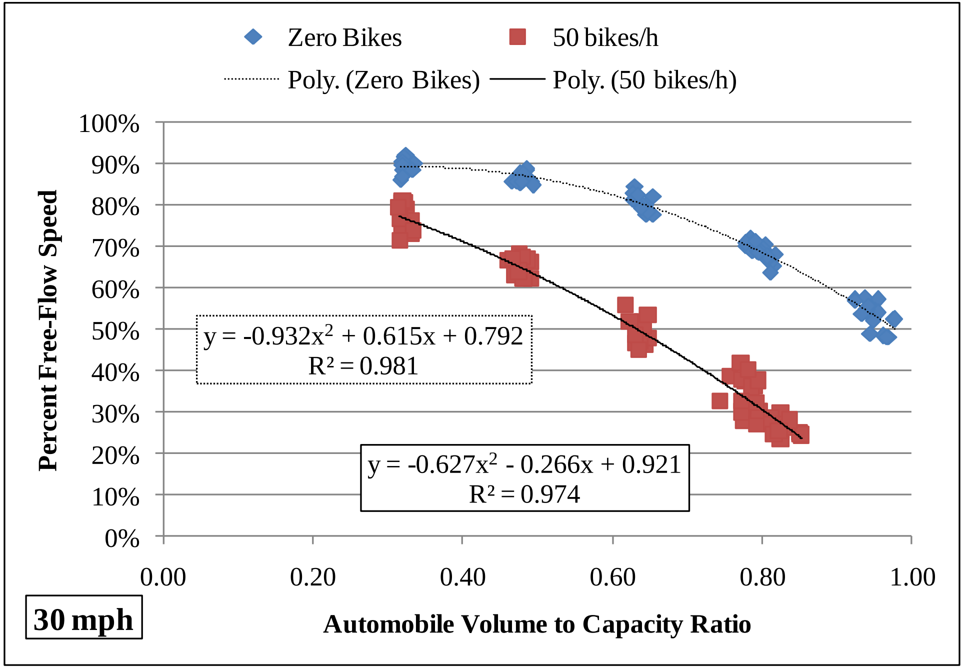


Figure B.18 Model 4, 35 mph

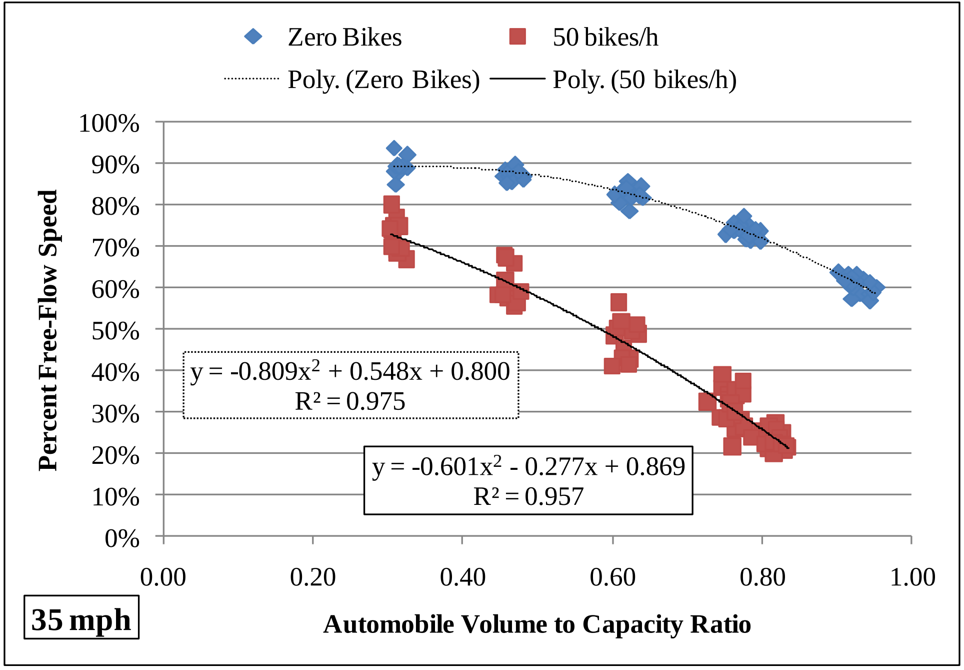


Figure B.19 Model 4, 40 mph

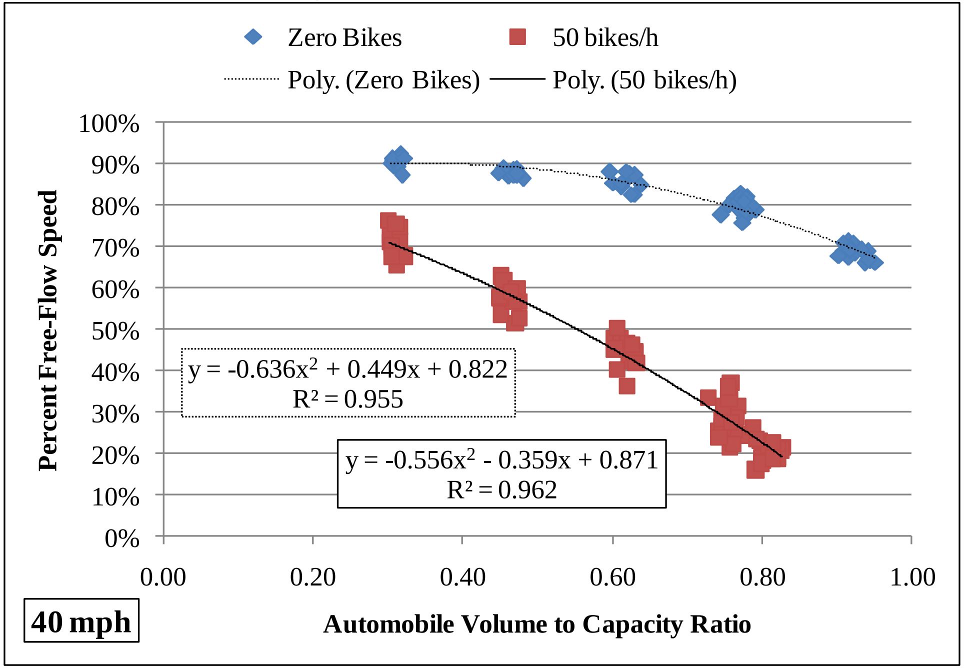


Figure B.20 Model 4, 45 mph

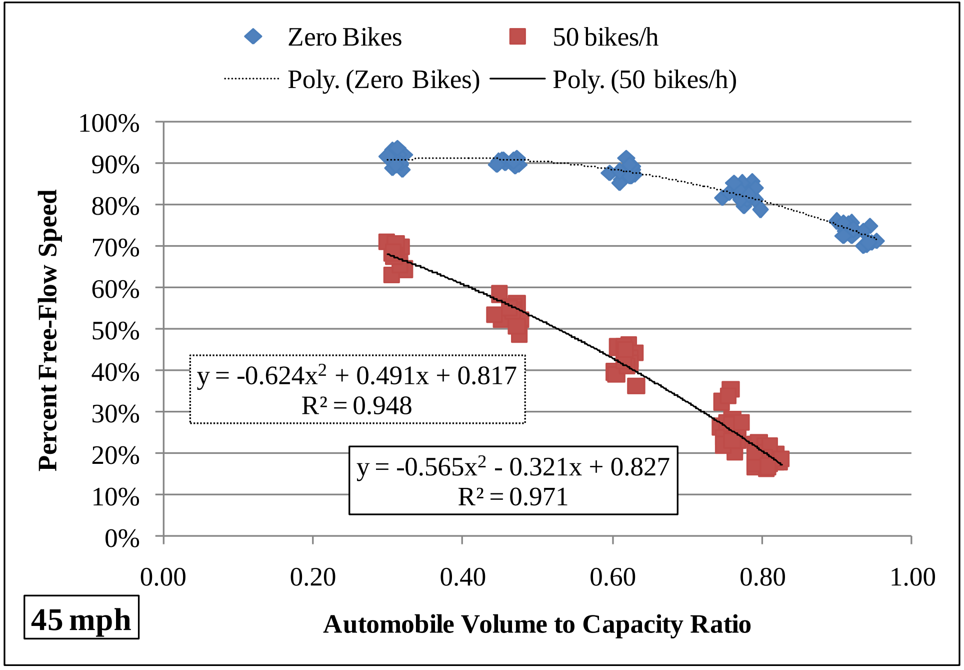


Figure B.21 Model 5, 25 mph

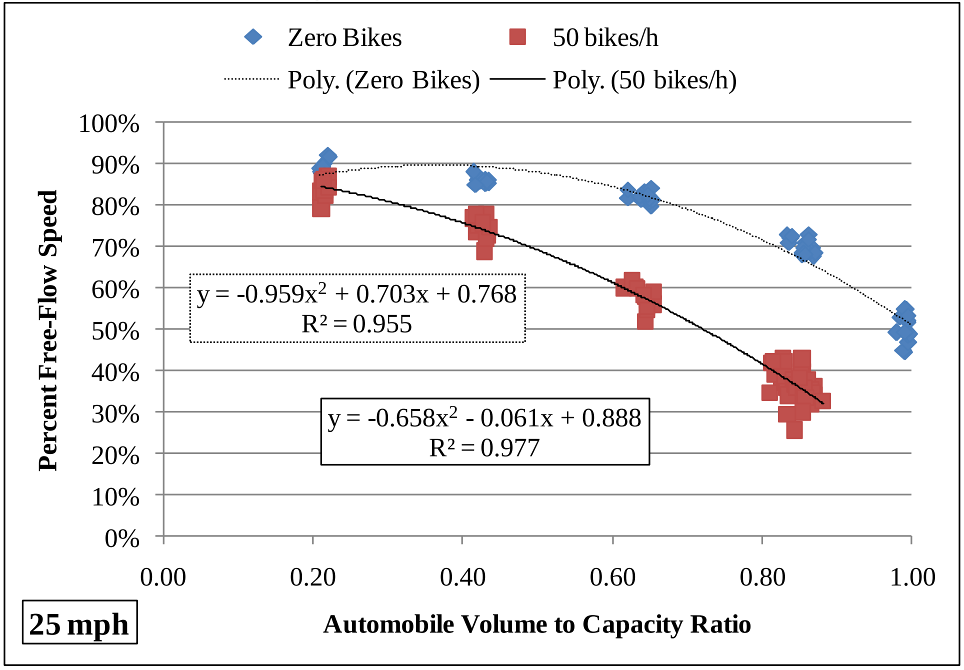


Figure B.22 Model 5, 30 mph

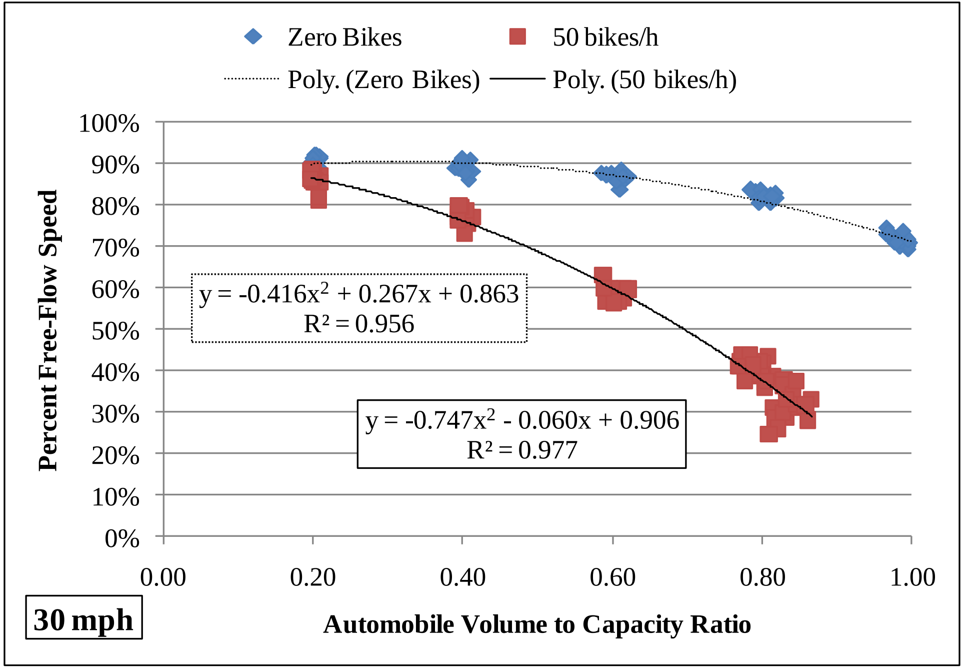


Figure B.23 Model 5, 35 mph

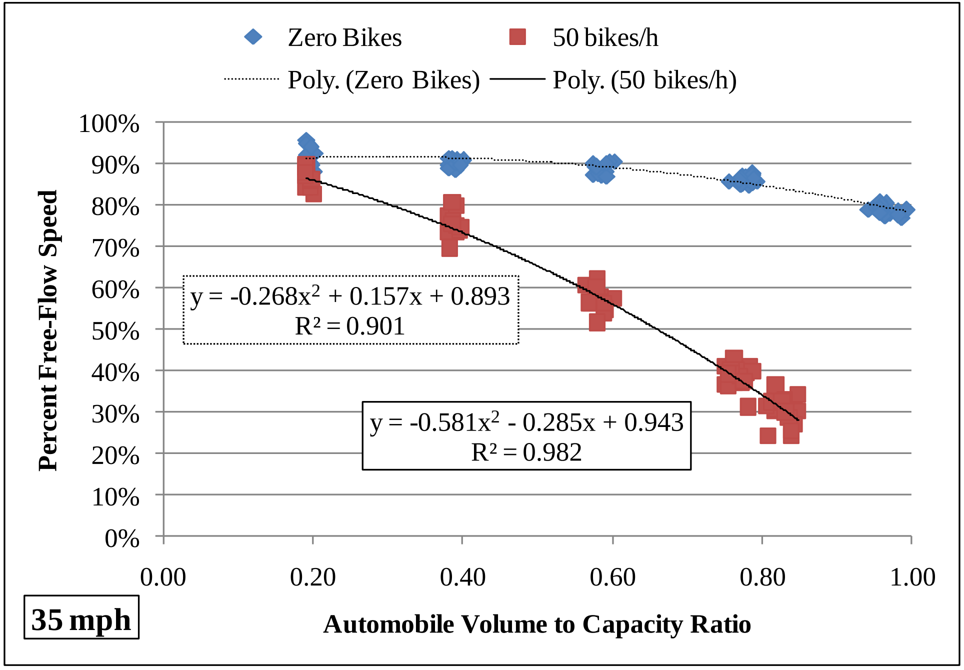


Figure B.24 Model 5, 40 mph

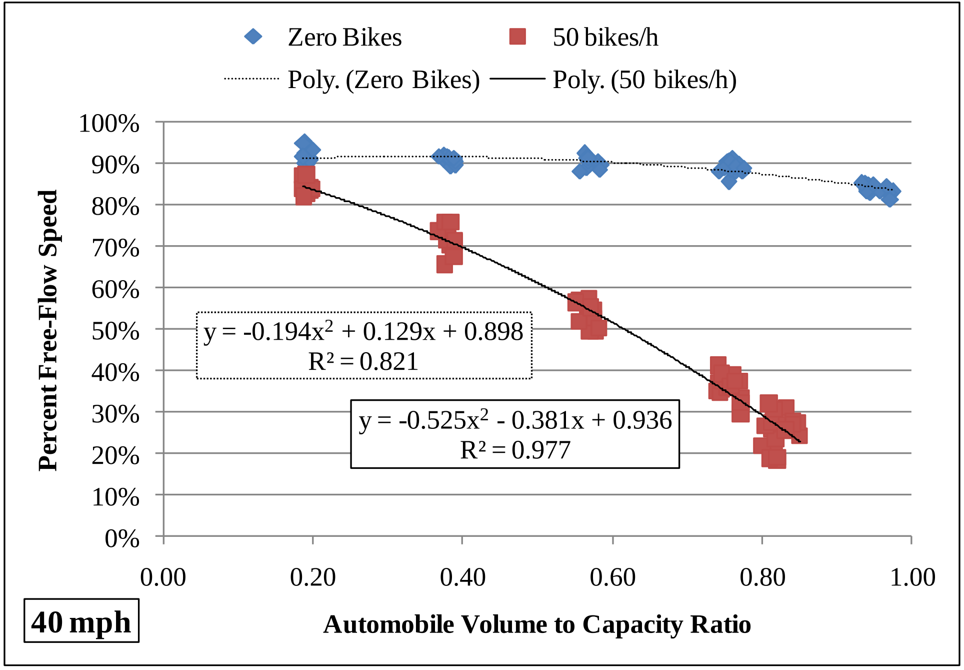


Figure B.25 Model 5, 45 mph

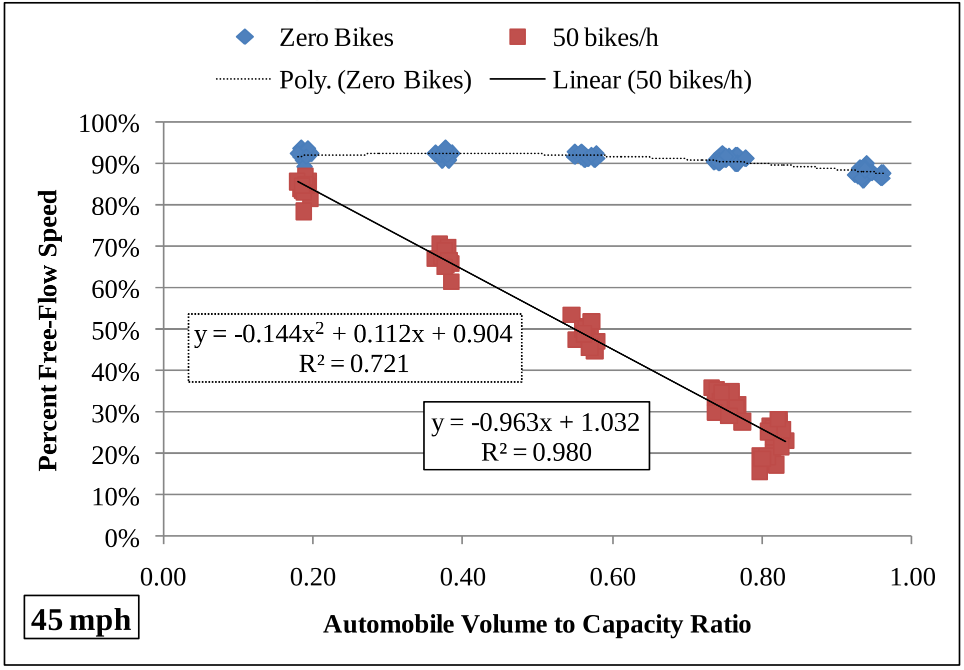


Figure B.26 Model 6, 25 mph

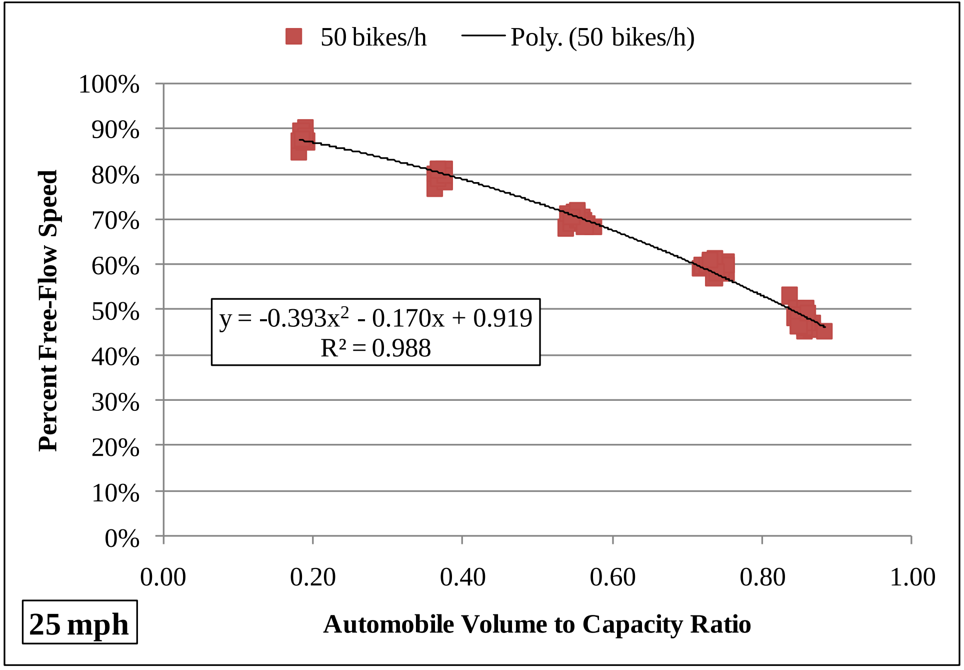


Figure B.27 Model 6, 30 mph

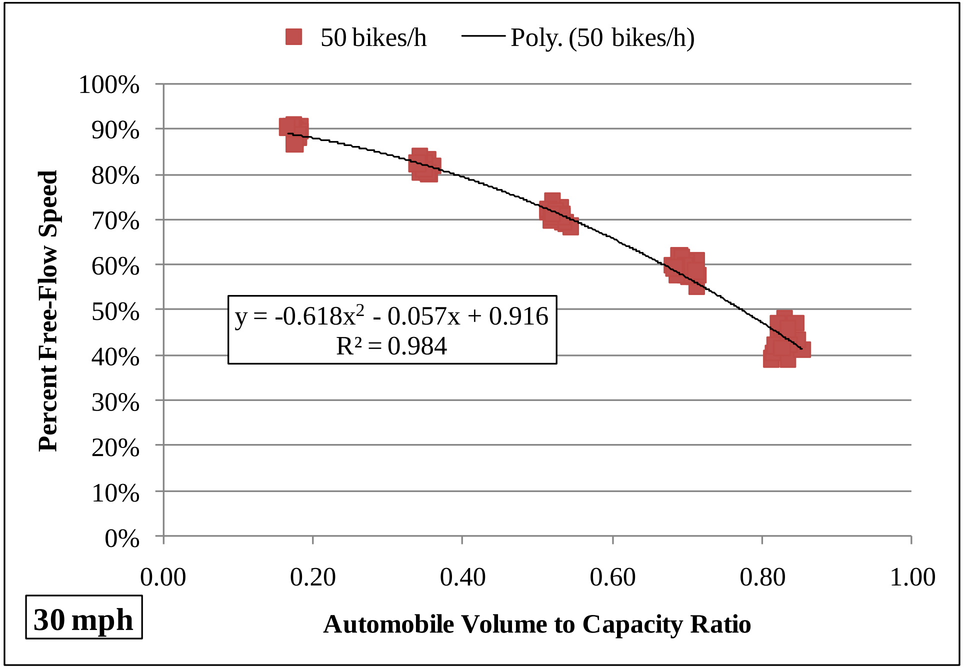


Figure B.28 Model 6, 35 mph

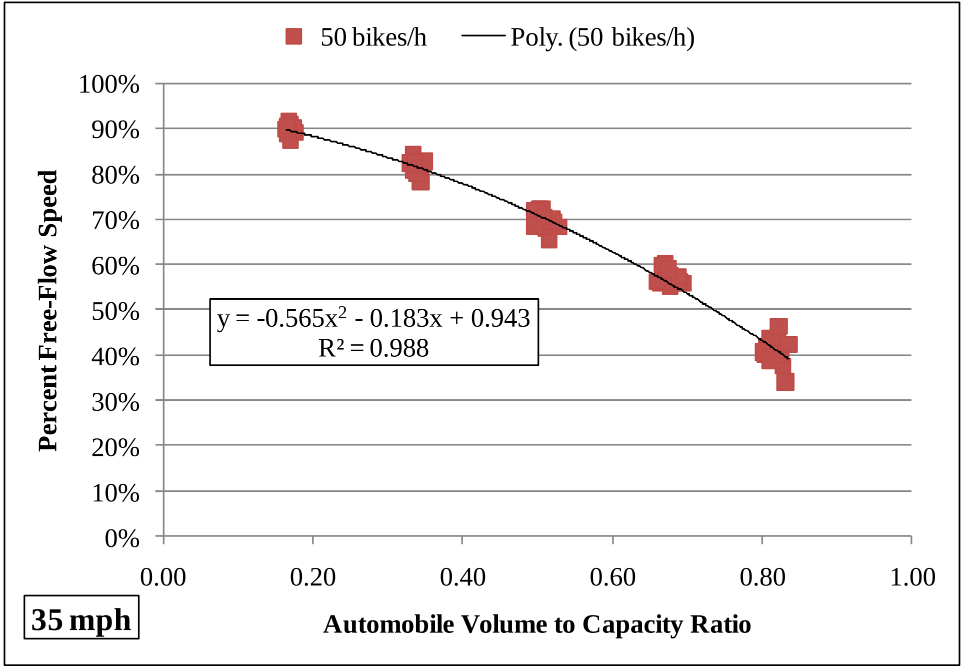


Figure B.29 Model 6, 40 mph

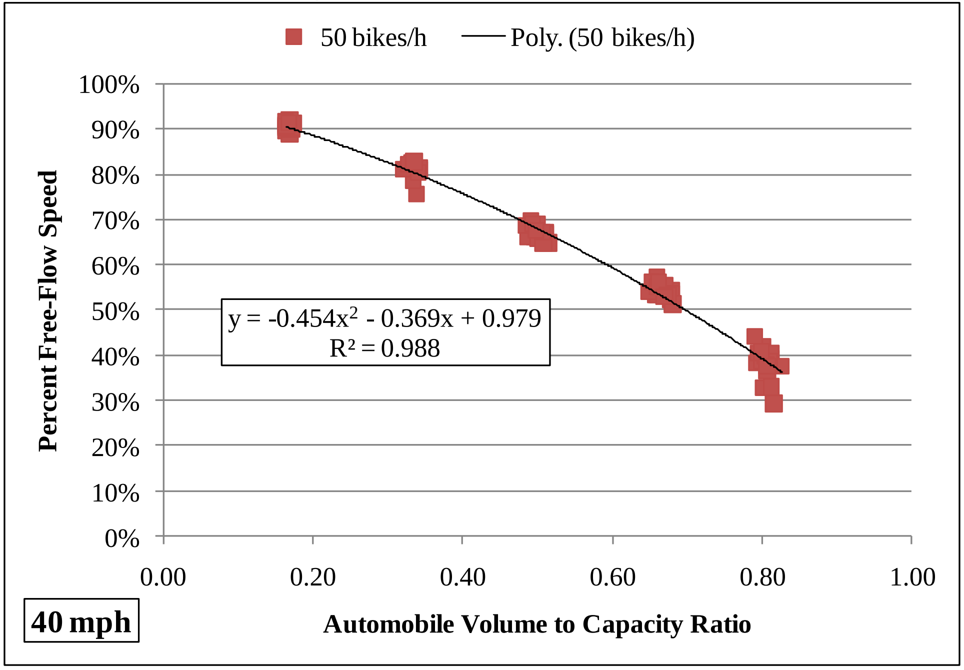
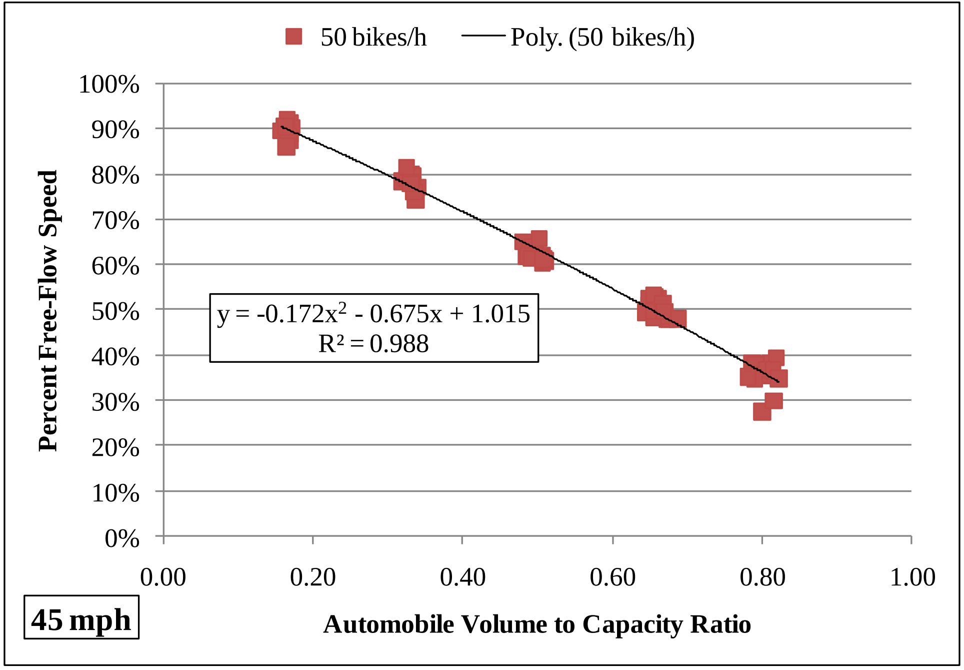


Figure B.30 Model 6, 45 mph



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