ABSTRACT

Title of Dissertation: DECISION-MAKING FOR ROADWAY LANE DESIGNATION AMONG VARIABLE MODES

Emad Hamdi Elshafei, Doctor of Philosophy, 2006

Dissertation directed by: Associate Professor David J. Lovell, Department of Civil and Environmental Engineering

Increasing traffic congestion and a shortage of funds available to build new roads are forcing the transportation infrastructure to function at its maximum capacity. The limited road space available on congested urban street networks in major cities in the United States as well as other parts of the world, notably in Eastern Asian countries, represents a challenge to transportation planners and traffic engineers. The available road space is typically partitioned according to a variety of modes: exclusive lanes for bicycles, buses, parking lanes, etc. The current road space allocation for most urban road networks has been modified throughout the years through a process of incremental changes, each tailored to meet a specific demand or to respond to a specific change at the time.

The questions in this research are: Is there a way to provide a solution to reduce congestion with minimum resources such as pavement markings and traffic signs? Should different modes of transportation be included in roadway lane designation? What are the best possible scenarios that would provide the best measures of effectiveness? And how can transportation professionals provide a comprehensive analysis to stakeholders to allow them to make an informed decision for lane-use allocation in urban transportation networks?

The approach in this study consists of investigating what relationships exist between the lane-use allocation on one hand and the traffic flow, traffic speed, environmental impact, safety impact, mobility, and accessibility on the other. Since not all of the objectives can be transformed into a single monetary dimension, a multi-objective decision-making framework is used to compare different road-allocation scenarios. This method is employed to incorporate multiple and conflicting objectives into a process where all of them are given credence regardless of how well they can be estimated in monetary terms. Further, the suggested decision-making method includes charts as visual tools to help decision-makers understand the results of each objective when corresponding to a specific scenario. The research provides a unique application for a multimodal analysis and a decision-making method not influenced by decision-makers' input, and contributes to the transportation community efforts to improve corridor and network efficiency.

DECISION-MAKING FOR ROADWAY LANE DESIGNATION AMONG VARIABLE MODES

By

Emad Hamdi Elshafei

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2006

Advisory Committee:

Professor, David Lovell, Chair
Professor, Kelly Clifton
Professor, Ali Haghani
Professor, Paul Schonfeld
Professor, Qing Shen

Dedication

I would like to dedicate this dissertation to my father, Dr. Hamdi Elshafei.

Acknowledgments

I would like to take this opportunity to acknowledge many caring people who contributed to my work and had important roles in this achievement. I would like to start with my dissertation committee for accepting to serve on this panel. My advisor, David Lovell, believed in me from the beginning and provided continuous advice and guidance throughout this program. Paul Schonfeld planted the seeds for the idea of this dissertation, and whenever I needed assistance, he expediently provided direction. Ali Haghani provided thoughtful comments that enhanced this dissertation. Kelly Clifton provided good ideas, especially in the bicycle-related area. Last but not least, I want to thank Qing Shen for serving as Dean's Representative, and for his timely responses to my inquiries. My sincere thanks to each one of you for your support and for making this degree possible.

I also would like to thank Rajan Paradkar for his assistance with the VISSIM simulation model, Pat Stroud for providing vehicles' operational costs, and my traffic engineer colleagues from the different jurisdictions in the state on Maryland who participated in the survey. Their input was helpful in determining how transportation professionals look at the traffic congestion problem, and how they evaluate the various performance levels of different lane-use alternatives.

I have the good fortune of working with many caring individuals in the City of Rockville, Maryland. I am grateful to the city officials who supported me while pursuing this study, especially those who responded to the survey.

I have been blessed with a wonderful loving family. My parents, Hamdi Elshafei and Salwa Elgendi, have always inspired me and instilled in me their strong work ethics. Without their love, prayers, and support, I would have never pursued a doctoral program. I also would like to thank my dearest brother Hossam for his love and support, his wife Samar, and my in-laws, Robert and Laraine Hardy, for their help, especially with watching my children.

Lastly, and most importantly, I would like to thank my beloved wife Donna. She encouraged me to pursue this degree and supported me from the beginning. Her continuous love and support helped me complete this dissertation. I want to thank my precious children, Sabrina and Adam, not only for being a source of inspiration for me, but also for being patient with me and for giving up much of our precious time together. I hope I can inspire and assist them in pursuing their dreams.

TABLE OF CONTENTS

List of Tables viii

List of Figures ix

Chapter I: Introduction 1
- 1.1. Background 1
- 1.2. Research Objectives 6
- 1.3. Organization 8

Chapter II: Literature Review 9
- 2.1. Overview 9
- 2.2. Exclusive Bus Lanes 9
  - 2.2.1. Bus Lanes Studies 10
  - 2.2.2. Bus Performance Measures 12
- 2.3. Exclusive Bicycle Lanes 13
  - 2.3.1. Bicycle Performance Measures 15
  - a. Bicycle Level of Service 15
  - b. Bicycle Compatibility Index 18
  - 2.3.2. Bicycle Master Plans 22
  - 2.3.3. Bicycle Facilities and Operational Analysis Research 25
- 2.4. Mobility and Accessibility 29
- 2.5. Environmental and Safety Impacts 32
  - 2.5.1. Environmental Impact 33
  - 2.5.2. Safety Impact 34
  - a. Traffic Safety 35
  - b. Bicycle Safety 43
- 2.6. Lane-use-related Research 44
- 2.7. Combining Modal Split and Equilibrium Assignment Model 47
- 2.8. Multimodal Simulation Software 50
- 2.9. Decision Making 54
  - 2.9.1. Pareto Frontier Concept 54
  - 2.9.2. Multi-objective Decision-making 56
- 2.10. Summary of Literature Review 59

Chapter III: Research Methodology and Tasks 60
- 3.1. The Purpose of the Study 60
- 3.2. Performance Measures 60
- 3.3. Design of the Study/Research Methodology 63
- 3.4. Tasks 66
  - 3.4.1. Identifying Different Alternatives 66
  - 3.4.2. Collecting Traffic Data 67
  - 3.4.3. Applying a Traffic Simulation Model 68

3.4.4. Applying the BCI for Bicycles 68
3.4.5. Computing Travel Speeds, Cost of Delays, and Operating Costs.. 69
3.4.6. Measuring Mobility and Accessibility................................. 70
a. Mobility.. 70
b. Accessibility... 71
3.4.7. Evaluating Environmental and Safety Impacts...................... 71
a. Measuring Environmental Impact.................................. 71
b. Measuring Safety Impact 72
3.4.8. Making a Decision 73
3.4.9. Conducting Final (Sensitivity) Analysis............................... 74
3.5. Summary of Research Methodology 75

Chapter IV: Numerical Example and Results... 78
4.1. Identifying Different Alternatives... 78
4.2. Traffic Data 82
4.3. Applying a Traffic Simulation Model... 82
4.4. Applying the BCI for Bicycles 89
4.5. Computing Travel Speeds, Cost of Delays, and Operating Costs 90
4.6. Measuring Mobility 97
4.7. Measuring Accessibility 100
4.8. Evaluating Environmental Impact 102
4.9. Evaluating Safety Impact.. 104
4.10. Making a Decision 107
4.11. Variability of the Results 110
4.12. Growth in Demand.. 111
4.13. Conducting a Sensitivity Analysis 118
4.14. Experimental Survey... 130
4.14.1. Transportation Professionals Survey Results....................... 131
4.14.2. Officials' Survey Results 132
4.15. Summary of Numerical Example.. 134

Chapter V: Assumptions and Limitations... 136
5.1. Study Assumptions 136
5.2. Study Limitations.. 139

Chapter VI: Conclusion and Recommendations 143

6.1. Conclusion 143
6.2. Recommendations... 149
6.3. Recommendations for Future Research 152

Appendices

Appendix A – Output of the Model for Original Scenarios: 1, 2, 2b, and 3................. 156
Appendix B – Operational Costs Details for Different Types of Vehicles................... 164
Appendix C – Sample of Mobile6 Run for a 31-mph Average Speed 176
Appendix D – Three Cases With Different Lane Widths For Scenario 2b: 10-foot Mixed-Traffic Lane and 16-foot Bus Lane, 11-foot Mixed-Traffic Lane and 15-foot Bus Lane, and 13-foot Mixed-Traffic Lane and 13-foot Bus Lane.. 181
Appendix E – Sensitivity Analysis For Three New Cases For Scenario # 1: 36 Buses and 16 Bicycles, 60 Buses and 16 Bicycles, and 12 buses and 60 Bicycles... 185
Appendix F – Decision-Makers' Survey 192

References 199

LIST OF TABLES

Table Page

1. Bicycle Level of Service and LOS scores 18
2. Bicycle Compatibility Index Adjustment Factors 20
3. Bicycle Compatibility Index Ranges Associated With LOS and Compatibility Levels 21
4. Summary of the VISSIM Output for Scenario #1; Two 13-foot Mixed Lanes 84
5. Summary of the VISSIM Output for Scenario #2; One 12-foot Mixed Lane, and One 14-foot Exclusive Bus Lane 85
6. Summary of the VISSIM Output for Scenario #2b; Similar to Scenario #2 Without Bicycles 86
7. Summary of the VISSIM Output for Scenario #3; Two 10.5-foot Mixed Traffic Lanes and One 5-foot Exclusive Bicycle Lane 87
8. Vehicles’ Operational Costs per Mile 95
9. Average Idle Time per Mode of Transportation (in seconds) 96
10. Emission Rates for Different Speeds (10 mph to 32 mph) 103
11. Environmental Impact Comparison 104
12. Average Number of Stops for Each Mode of Transportation 106
13. Summary of Objectives’ Results 109
14. Summary of Objectives’ Results (in percentage) 109
15. Means and Standard Deviations for Study Objectives 111
16. Measures of Effectiveness for the 10-year and 20-year Projections 113
17. Mode Choice Sensitivity Analysis 120

18a. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.0 passenger/auto) 122

18b. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.1 passenger/auto) 123

18c. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.2 passenger/auto) 124

18d. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.5 passenger/auto) 125

18e. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.75 passenger/auto) 126

LIST OF FIGURES

Figure Page

1. Tasks Required for the Decision-making Method 77
2. Travel Section 79
3. Lane Configuration for Scenario # 1 80
4. Lane Configuration for Scenario # 2 81
5. Lane Configuration for Scenario # 3 81
6. Data Collection Points for Speeds 83
7. Average Speed Comparison 88
8. Average Travel Time Comparison 88
9. Average Delay Time Comparison 89
10. Bicycle Compatibility Index Comparison 91
11. Users' Travel Cost Comparison 92
12. Users' Delay Cost Comparison 94
13. Total Operating Cost Comparison 98
14. Mobility Comparison 99
15. Accessibility Comparison 101
16. Environmental Impact Comparison 104
17. Safety Impact Comparison 107
18. Summary of Performances for the Three Scenarios 109
19. Variability for Travel Time for Autos and Bicycles 112
20. Variability for BCI and Predicted Number of Accidents 112
21. Average Travel Time Comparison for the 10-Year Projection 114
22. Safety Impact Comparison for the 10-Year Projection 115
23. Average Travel Time Comparison for the 20-Year Projection 116
24. Safety Impact Comparison for the 20-Year Projection 117
25. Average Travel Time Comparison for the 0, 10, and 20-Year Projections ... 117
26. Sensitivity Analysis for Mode Choice 119
27. Travel Time Comparison for Different Lane-Width Cases - Scenario 2b 127
28. Travel Time for Four Different Cases - Scenario # 1 129
29. Emission Rates for Four Different Cases - Scenario # 1 129

Chapter I: INTRODUCTION

1.1. Background

The transportation infrastructures in some major cities all over the world are functioning at their maximum capacity (at certain times of the day), or at a level that roads cannot sustain (Thomson, 2002). The problem is getting worse due to the continuous increase in travel demand and the shortage of funds available (among other constraints) to build new roads. The limited road space available on congested urban street networks represents a challenge to transportation planners and traffic engineers. Although constructing new capital facilities remains part of the solution to congestion and mobility problems, efficient operation of these facilities plays an equally important role (Gayle, 2003). There is also the inability to build enough lanes to address congestion because of high costs of construction and right-of-way, environmental concerns, and community concerns.

Road space allocation among different users might play a major role in improving the efficiency of roadways in terms of moving vehicles and people, encouraging fuel conservation, and thus improving air quality, and increasing overall accessibility and mobility. Shifting user modes from autos to alternative modes of transportation such as bicycles and buses, among other modes, can provide some help in relieving traffic congestion and improving the environment. This is a common goal for major cities around the world (Primitivo, 2002).

For example, urban areas nationwide in the United Sates, such as the Washington, D.C. metropolitan area, experience severe congestion. The data collected for 2000 by the

Texas Transportation Institute revealed that the Washington region remained among the worst three places to drive, in a country where congestion periods generally are getting longer (Thomson, 2002). The institute continued to say that all across the nation the penalty for making rush hour trips is greater, traffic congestion periods are longer, and the number of streets and highways that are congested is higher. An article in the “Better Roads” publication (Consdorf, 2003) revealed that the Texas Transportation Institute, in its 2002 Urban Mobility Study, estimated that the overall costs of congestion are $68 billion a year, and that 61 percent of urban principal arterials are congested during peak travel times. Transit officials continue to debate what combination of programs would improve things.

Other than the United States, countries in Asia, and notably Vietnam, Thailand, India, Indonesia, China, The Philippines, Singapore, Bangladesh, Cambodia, Taiwan, Japan, and Hong Kong suffer from major congestion (Primitivo, 2002). The gap between supply and demand is widening, and is aggravated by the poor quality of existing infrastructure. The problem is more serious in big cities where the negative externalities of transportation, such as traffic congestion, air pollution and traffic accidents, are significant. Lack of institutional capability and capacity is often cited as among the causes for the worsening situation. It is in this area that this research can make a significant contribution.

If we assume that infrastructure improvement will always follow an incremental expansion path (limited availability of construction resources alone assures this), then lessons about how that path does or does not lead to an efficient final solution are very valuable. In fact, simply having a process defined by which to make these assessments is an important contribution.

The current road space allocation for most urban road networks has been modified throughout the years through a process of incremental changes, each to meet a specific developmental demand requirement, to mitigate the effect of a change in land use, or to improve a specific demand for a specific time. Several questions are addressed in this study and include: did these incremental changes lead to the most efficient road allocation for the various transportation modes vying for it? Is there a way to provide a solution to reduce congestion with minimum resources such as pavement markings and traffic signs? Should different modes of transportation be included in roadway lane designation? What are the best possible scenarios that would provide the best measures of effectiveness? And how can transportation professionals provide a comprehensive analysis to stakeholders to allow them to make an informed decision for lane-use allocation in urban transportation networks? Further, the study investigates what are the relations between the lane-use allocation on one hand and traffic flow, traffic speed, environmental and safety impacts, mobility, and accessibility on the other hand. The lane-use allocation can be described as the distribution of the public right-of-way available between the two curbs on each side of the road among mixed-traffic lanes, exclusive bus lanes, bicycle lanes, and on-street parking lanes.

Specifically, this study describes an effort to develop a decision method that can be used to justify and design different lane-use allocations in an urban street network. It is an effort to bring together the disciplines of transportation planning and traffic engineering and to reduce congestion with benign resources where possible, such as pavement markings and traffic signs. The core of the suggested method to achieve this goal consists of comprehensive evaluation and comparison of different alternatives of lane usage among variable modes of transportation.

An approach taken to solve similar problems in the past consisted of focusing on one objective: to minimize total “cost,” where all relevant outcomes were monetized. This study suggests that part of this evaluation can be performed by computing some of the cost associated with each alternative, but the other part should depend on evaluating non-monetary factors such as mobility, accessibility, environmental impact, and safety impact associated with each alternative.

The total monetary cost includes the operating cost for each mode of transportation and the costs incurred by users, which in each case depends largely on the average travel speed of the selected transportation mode. A traffic simulation model is applied to generate traffic data for different alternatives and to estimate the average travel speed for each lane-use alternative. The traffic flow and speed data are compared and the total travel time is calculated. Once the total travel time and delays for each mode of transportation are determined for each alternative, they are used to determine the cost of delays.

The traffic simulation model applied in this study is VISSIM (2004) - a microscopic, time step and behavior-based simulation model developed to model urban traffic and public transit operations. This software, designed for multimodal analysis, allows the integration of all relevant modes of transportation into one consistent network model. Other than the average travel speed for each mode, the output of this software includes travel time, delays, and other measures of effectiveness. The measures of effectiveness (MOEs) are used to compare alternatives.

It should be noted here that since each alternative has a different lane-use allocation, the average speed for each transportation mode will change and thus, the travelers' decision on mode of transportation choice might change as well. This issue affects the number of travelers using each mode of transportation. For example, some travelers might consider biking to work if bicycle lanes are more available and less congested than mixed-traffic lanes or bus lanes. Efforts were made to develop a model combining modal split and equilibrium assignment, as will be noted in chapter two. Because this remains an open field of study, with a number of models vying for acceptance, and perhaps new ones forthcoming, this method refrains from choosing a method to integrate these steps. Instead, the more cautious process of using VISSIM to do the microsimulation-assignment models is suggested, along with the application of a sensitivity analysis to provide information about changes in the performance of the transportation system when the traffic flow of one or more modes of transportation changes.

Other than comparing the operating costs and the cost of delays, to achieve a more comprehensive evaluation of alternatives, bicycle operation, environmental and safety impacts, mobility, and accessibility are also considered in the evaluation. Bicycle operation is evaluated by using the Bicycle Compatibility Index developed by the Federal Highway Administration (FHWA, 1998). Mobility is evaluated by quantifying person-miles or by calculating the travel time needed to reach a specific point of attraction such as a Central Business District (CBD). Accessibility is evaluated by quantifying the number of people who can reach this CBD within a specific period of time. Environmental impact is assessed by comparing emission data generated by different models for each alternative. Emissions are calculated using Mobile6 (2003), a method authorized by the Environmental Protection Agency (EPA), which will be described in chapter four. Safety impact is evaluated by using an accident prediction algorithm described in section 3.4.6.

Since there is no single way to measure transportation performance that is both convenient and comprehensive (Litman, 2003), this study investigates the possibility of using a multi-objective decision-making framework to determine how it can be applied to decide on which alternative is better than another in relation to: reducing costs and delays, improving safety, mobility, accessibility and air quality, and reducing pollutants. One important feature of the multi-objective decision-making approach is its capability of allowing many intangible objectives that are difficult to express on an absolute numerical scale to be considered without the need to convert the units into a monetary scale. The application context is that of real decision-makers assessing real alternatives, so the tools are aimed at a level of practicality appropriate for that setting.

1.2. Research Objectives

The main objective of this study is to develop a decision-making process that allows officials and stakeholders to make an informative choice for a lane-use allocation scenario in an existing urban transportation network. The network includes mixed-traffic lanes, exclusive bus lanes, bicycle lanes, and on-street parking lanes. This issue is connected to developments review, permits, and master plans performed by local government agencies. Although the study can be extended to include sidewalks and pedestrians, this research is limited to the existing paved surface between curbs. The ideal solution is the one that provides less overall cost for users and road system, less travel time and delays, better air quality, better traffic safety conditions, and better overall mobility and accessibility. It is not expected, however, that all objectives would be achieved simultaneously.

Another objective for the study is to provide a bridge between transportation planning and traffic engineering, demonstrating that together, they can present a solution for a common problem: road congestion. Often, some transportation planners do not consider some potential traffic operation problems during the planning phase and traffic engineers frequently blame some of the congestion problems on poor design. This objective is achieved in this study by using a traffic simulation software platform during the planning phase in an effort to improve traffic operations, and the attempt to fully include engineering assessments in the decision support tools offered to decision makers.

The study also suggests and encourages the use of different travel options in a congested network, and looks into increasing safety by separating bicycles from buses and from motor vehicles. The recommended simulation software allows the integration of those different modes of transportation.

Finally, an objective of the study is to develop specific charts demonstrating how different scenarios of lane allocation, i.e. different lane-use and lane-width, for a specific road-width, can affect costs, road capacity, delays, and the environment. The charts are developed by using the results obtained from the outcome of each scenario’s performance and they show the impact of the trade-offs in road-space allocation among different modes of transportation. They are then presented to stakeholders in the form of a survey so they can make a final decision on their preferred alternative. Field-testing a suite of those performance measure charts is a part of this objective.

1.3. Organization

Chapter two of this research describes previous research and related literature. In the third chapter, the methodology, and the tasks that were performed to develop the suggested method are presented. Chapter four provides a numerical example where the proposed process is applied, and chapter five presents the study assumptions and limitations. The research ends with a conclusion and general recommendations, including those for future research.

Chapter II: LITERATURE REVIEW

2.1. Overview

Several topics of interest are connected to this research and this chapter highlights some of the work done previously in the different related fields. For example, since this study deals with exclusive bus lanes and bicycle lanes, research related to exclusive lanes and their effects as well as lane-use research in general is presented. It also includes research performed in measuring mobility and accessibility, a few multimodal network equilibrium models, and multimodal simulation computer programs, one of which is used in this research. Finally, some review is included for measuring environmental and safety impacts, and for applying multi-objective decision-making techniques to solve similar transportation problems. The role of the literature review here is to provide insights of previous research efforts in several areas related to this study while exploring the most promising method to solve the current problem.

2.2. Exclusive Bus Lanes

One of the options available when designating travel lanes in an urban transportation network is to consider exclusive bus lanes. This section presents literature about exclusive bus lanes and methods to measure their performance.

Several studies and papers have been published about exclusive lanes for special purposes, e.g., for buses, carpools, high-occupancy vehicles (HOV's) and bicycles; however, not much has been written on generalizing that into a road-space allocation problem. The use of bus lanes might be justified under the grounds that bus lanes allow more efficient bus services, and buses represent an important mode of transportation, especially since they can potentially carry more passengers than automobiles. The use of buses as a transportation mode has several other advantages: a) It decreases the need for private vehicles and thus relieves vehicular traffic congestion in the downtown area through efficient use of right-of-way, b) it increases roadway capacity during peak periods and provides a minimum level of accessibility to individuals without access to vehicles, c) it provides an affordable, and for many people necessary, alternative to driving, d) it is less stressful and can be convenient and faster than driving, and e) it is also essential for some students and senior citizens. On the other hand, when bus lanes are justified on the grounds of safety and efficiency, since buses do not interact or conflict with other modes of transportation in this case, the space taken away from mixed traffic can create congestion due to capacity constraints and it can lead to an inefficient use of travel time for the mixed traffic.

This section describes several exclusive bus-lane studies conducted for street networks in the United States, India, and South Korea, where exclusive bus lanes on urban networks were evaluated by comparing collected traffic data before and after implementation. It also highlights studies evaluating transit performance measures.

2.2.1. Bus Lanes Studies

Erdman and Panuska (1976) performed a study to identify and measure the impact of exclusive bus lanes on a two-directional roadway with two lanes in each direction in the Baltimore metropolitan region. Even though automobile total trip time increased and bus total trip time decreased after the implementation of the exclusive lanes, it was determined that the trip from home to work during the morning peak period, for example, would still take the average commuter more than 50 percent longer if he/she used the bus rather than a passenger car. This time did not include either the time necessary to travel from the house to the bus stop or the waiting time at the bus stop. The authors concluded that for the majority of the time the bus lane proved to be detrimental to both automobile and bus movements, insofar as travel time was concerned.

After exclusive bus lanes were introduced for the first time in Delhi, India, in 1976, Sarin et al. (1983) responded to the Delhi Traffic Police request to evaluate the functioning of exclusive bus lanes in Delhi. The study revealed that the system failed and that this was mainly due to the non-compliance of road-users; consequently, it was discontinued in 1981. A similar challenge will likely face most third world countries unless traffic laws are strictly followed and enforced.

Unlike the two previously mentioned studies in which exclusive bus lanes did not help reducing congestion, Choi and Choi (1995) conducted their study in South Korea and concluded that the bus-lane use was successful. The travel time for buses was significantly reduced, a modal shift from car to bus was estimated to be more than 12%, and accident rates were reduced. The success of exclusive bus lanes was partially attributed to public acceptance, which can differ widely from one country to another.

Another bus Rapid Transit study was conducted in Boston, MA, for the Silver Line BRT service (Ivany, 2004). The 60-foot long buses were running on 5-minute headways, and the average daily traffic (ADT) was 10,000 on a one-lane road in each direction. On-street parking was a key element of the community’s acceptance of the project: “From a traffic engineering standpoint, the elimination of the on-street parking would have been ideal in reducing traffic conflicts and allowing even wider sidewalks for pedestrian amenities. However, this was unacceptable for the residences and businesses along the corridor.” The bus lane was also used for bicycles and traffic making right turns. Community acceptance allowed the transit project to move forward. Ridership was higher than expected and traffic operations for transit have been relatively smooth for both the bus service and for general traffic.

The studies in this section show that public acceptance of exclusive bus lanes, road-users’ compliance and enforcement are important factors upon which exclusive bus lanes can be successful. It should also be noted that exclusive running ways and traffic signal pre-emption can help delivering patrons more efficiently (Kimbler, 2005). Bus rapid transit operations can also be optimized by using Global Positioning System (GPS) technology to locate and announce bus arrival times. This would significantly improve the quality, ease of use and reliability of the bus.

2.2.2. Bus Performance Measures

Bus performance measures are limited in this study to bus average speed, travel time, delay, and the associated costs. It should be noted, however, that bus performance measures include a wide variety of different measures related to the operator, the passenger, and the vehicle operation. The Highway Capacity Manual (HCM, 2000) identifies several transit performance measures, and they include the travel time (total trip time), hours of service, extent of service (route miles of service), reliability (on-time performance), accessibility (service coverage), pedestrian environment and amenities, transit information, transfers, cost, and appearance and comfort.

Kittelson and Associates (1999) conducted a study to evaluate performance measures for an urban transit network. The following measures were identified: frequency (every 15 minutes for example), span of service (hours of service), reliability (on-time), loading (percentage of loading capacity), and travel speed (including dwell time, stops, and delays).

Also Fu, Saccomanno, and Xing (2005) evaluated transit quality of service by developing a comprehensive quality-of-service index called Transit Service Indicator (TSI). A sensitivity analysis to the proposed TSI was applied to a realistic traffic corridor under a set of hypothetical service design options. Sensitivity analysis to travel time variation showed 14 percent difference in TSI between the constant demand case and high demand variation case. For the sensitivity analysis to traffic congestion, the proposed TSI was higher when the traffic congestion was higher, even if the transit service remained the same. More investigation was recommended to examine this outcome.

2.3. Exclusive Bicycle Lanes

Bicycles represent the primary mode of transportation in congested cities in Europe and Asia. They also have significant use in the United States especially in college towns. In recent years, bicycle lanes have become much more common than a decade ago. Several local jurisdictions have started to include them in their planning process and several bicycle master plans have been established in urban communities.

The Maryland State Highway Administration started incorporating bicycle lanes in new projects, even those related to intersection improvements. As an example, bicycle lanes were considered in the concept design plan recently prepared to upgrade the intersection of MD28/MD586/MD911 in Rockville, Maryland (MSHA, 2006).

The National Bicycling and Walking Study (2004), in its ten-year-status report, showed how bicycling is getting more attention in the last decade. The spending of federal transportation funds on bicycling and walking modes rose from $6 million in 1990 to $238 million in 1997. Under the Transportation Equity Act for the 21st Century (TEA-21) passed by the Congress in 1998, the federal transportation funds on bicycling and walking improvements rose from $204 million in 1998 to $422 million in 2004. The study also showed that the concept of using bicycles as a mode of transportation has become more acceptable and realistic to people. Bicycling trips increased from 1.7 billion in 1990 to 3.3 billion in 2001 (National Household Travel Survey - 2003).

The report concluded by pointing out that the transportation community came a long way from 1990, when the FHWA Administrator referred to bicycling and walking as "the forgotten modes," to 2001 during a speech delivered by the Secretary of Transportation, Norman Mineta, to participants at the National Bike Summit on March 27, 2001: "Bicycle and pedestrian facilities and programs are an integral part of our nation's transportation system for the 21st Century." He also pledged full support of the Department of Transportation.

It should also be noted than in 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) bill was signed. It guaranteed $244.1 billion to fund highways, highway safety, and public transportation totaling. SAFETEA-LU represents the largest surface transportation investment in the United States' history. It establishes $370 million through 2009 to continue a recreational trail program to develop and maintain trails for recreational purposes. Also, $100 million fund was appropriated through 2009 to fund pilot projects to construct a network of non-motorized transportation infrastructure facilities. (SAFETEA-LU, 2005)

This section describes several bicycle-related research projects, which include: 1) bicycle performance measures, 2) bikeway master plan studies in different US cities, and 3) bicycle facilities and operational analysis research.

2.3.1. Bicycle Performance Measures

Two major performance measures for bicycles emerged in the last few years: bicycle level of service (BLOS) and the bicycle compatibility index (BCI).

a. Bicycle Level of Service

The "Level of Service" (LOS) is a widely used framework to describe conditions for a mode of travel in a transportation system. For several decades, the LOS has been used for motor vehicles and it is usually based on average speed and travel time for motorists traveling on a specific road. In the 1990's, methodologies for bicycle level of service were developed and used by several cities in the US. It should be noted that LOS measures for motor vehicles are different than those for bicycles. Bicycle LOS depends more on the level of comfort and safety a bicyclist experiences while riding a bicycle.

Landis et al. (1997) conducted the first study to develop a statistically calibrated bicycle-quality or level of service model based on perceptions from bicyclists traveling in actual urban traffic and roadway conditions in U.S. metropolitan areas. The model was developed after evaluating over 150,000 miles of roads and streets across North America. The bicycle level of service (BLOS) model provides a value that reflects the effect on bicycling suitability or compatibility due to several factors. Those factors include traffic volumes per lane, posted speed limit, percentage of heavy trucks, pavement conditions and lane width available for bicycles. The model has a high multiple correlation coefficient ($R^2 = 0.73$), and reveals that pavement-surface conditions and striping of bicycle lanes are important factors in the quality of service. During a statewide application in Delaware, the model was enhanced and the R^2 increased to 0.77. Below is the equation used to calculate the Bicycle Level of Service (BLOS) model, along with the definitions of factors:

$BLOS = 0.507 \ln (Vol_{15}/L_n) + 0.199\, SP_t (1+10.38\, HV)_2 + 7.066\, (1/PR_5)_2 - 0.005\, (W_e)_2 + 0.760$

where:

Vol_{15} = volume of directional traffic in 15 minutes = $(ADT \text{ x } D \text{ x } K_d) / (4 \text{ x } PHF)$

ADT = Average Daily Traffic on the segment

D = Directional Factor

K_d = Peak to Daily Factor

PHF = Peak Hour Factor

L_n = Total number of directional through lanes

SP_t = effective speed limit = $1.1199 \ln (SP_p - 20) + 0.8103$, where SP_p is the posted speed limit

HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)

PR_5 = FHWA's 5-point pavement surface condition rating

W_e = average effective width of outside through lane:

$W_e = W_v - (10 \text{ ft} \times OSPA)$ if $W_l = 0$,

$= W_v + W_l (1 - 2 \times OSPA)$ if $W_l > 0$ & $W_{ps} = 0$

$= W_v + W_l - 2 (10 \text{ ft} \times OSPA)$ if $W_l > 0$, $W_{ps} > 0$ and a bicycle lane exists.

where:

W_t = total width of outside lane (and shoulder) pavement

$OSPA$ = fraction of segment with occupied on-street parking

W_l = width of paving between outside lane stripe and edge of pavement

W_{ps} = width of pavement striped for on-street parking

W_v = effective width as a function of traffic volume

$W_v = W_t$, if $ADT > 4{,}000$ vehicles/day

$= W_t (2 - 0.00025 \times ADT)$, if $ADT \leq 4{,}000$ vehicles/day, and if the street/road is undivided and un-striped.

Bicycle Level of Service ranges are associated with level of service designations as shown in **Table 1**.

This model has been applied in several bicycle plan studies including the ones recently completed for the City of Rockville in Maryland, and the District of Columbia. For example, on Nelson Street in the City of Rockville, MD, the BLOS improved from C to B after bicycle lanes were installed. The BLOS in this model is a function of the bicycle-lane width.

Table 1. Bicycle Level of Service and LOS Scores

Level of Service	Bicycle LOS Score
A	≤ 1.50
B	1.51 - 2.50
C	2.51 - 3.50
D	3.51 - 4.50
E	4.51 - 5.50
F	> 5.50

b. Bicycle Compatibility Index:

The Bicycle Compatibility Index (BCI) was developed by the Federal Highway Administration (FHWA, 1998) and focuses on evaluating the compatibility or suitability of bicycle travel along existing roads based on roadway conditions and traffic operation factors. It incorporates both geometrics and operational variables important to cyclists while riding on roads in the presence of motor vehicle traffic.

The BCI model was developed by using perspective of more than 200 participants rating 67 sites with respect to how comfortable they feel while riding. It predicts the overall comfort level rating for a bicyclist. It depends on several factors, including the number of through lanes, curb-lane width, presence and width of bicycle lane, posted speed limit, 85th percentile speed, curb lane and other lane(s) volumes per hour, % heavy trucks, % right-turning vehicles, exposure to parking (on-street, occupancy, parking time limit), and type of development area. Currently it does not include intersection LOS for bicycles, but this part is under development by the Florida Department of Transportation.

The BCI method uses a multi-variable regression formula to calculate a value that provides a linkage with traditional LOS designations, A through F, with A being the best conditions and F being the worst. This value ranges between one and six, where one indicates that a bicyclist experiences an extremely comfortable level of riding and six indicates that the bicyclist is “extremely uncomfortable” riding in those conditions. The R^2 value for the model was 0.89, indicating that 89 percent of the variance in the index is explained by the variables included in the model. It should be noted that the BCI model is for mid-block street segments only as the ratings do not account for major intersections along the routes. Below is the equation used to calculate the Bicycle Compatibility Index (BCI) model, along with the variable definitions, and adjustment factors.

$$BCI = 3.67 - 0.966BL - 0.41BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL = presence of a bicycle lane or paved shoulder $\geq$ 0.9 m; *no = 0, yes = 1*

BLW = bicycle lane (or paved shoulder) width *m (to the nearest tenth)*

CLW = curb lane width *m (to the nearest tenth)*

CLV = curb lane volume *vph in one direction*

OLV = other lane(s) volume – same direction *vph*

SPD = 85th percentile speed of traffic *km/h*

PKG = presence of a parking lane with more than 30 percent occupancy; *no = 0, yes = 1*

$AREA$ = type of roadside development; *residential = 1, other type = 0*

$AF = f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes

f_p = adjustment factor for parking turnover

f_{rt} = adjustment factor for right-turn volumes

Adjustment factors are presented in **Table 2** below.

Table 2. BCI Adjustment Factors

Hourly Curb Lane Large Truck Volume*	f_t
≥ 120	0.5
60 – 119	0.4
30 – 59	0.3
20 – 29	0.2
10 – 19	0.1
< 10	0.0

* - Large trucks are defined as all vehicles with six or more tires.

Parking Time Limit (minutes)	f_p
≥ 15	0.6
16 – 30	0.5
31 – 60	0.4
61 – 120	0.3
121 – 240	0.2
241 – 480	0.1
> 480	0.0

Hourly Right-Turn Volume*	f_{rt}
> 270	0.1
< 270	0.0

* - Includes total number of right turns into driveways or minor intersections along a roadway segment.

Table 3 below shows bicycle compatibility index ranges associated with levels of service designations and compatibility level qualifiers.

Table 3. BCI Ranges Associated with LOS and Compatibility Levels

Level of Service	BCI Range	Compatibility Level
A	< 1.50	Extremely High
B	1.51 - 2.30	Very High
C	2.31 - 3.40	Moderately High
D	3.41 - 4.40	Moderately Low
E	4.41 - 5.30	Very Low
F	> 5.30	Extremely Low

The BCI method was applied in different studies such as the South Carolina East Coast Greenway Route (Davis et al., 2005). Since the BCI was developed for urban and suburban roadway segments, the authors had to adapt the analysis procedure for comparative evaluation for rural roadways.

The BCI procedure seems to be most suitable for applying in this research due to the fact that it depends on several factors that are considered as variables in this study. These factors include the number of through lanes, curb-lane width, presence and width of bicycle lane, and the 85th percentile speed. Moreover, the model has a relatively high R^2 value of 0.89.

The BLOS model also has a high R^2 value, although the two cannot be compared directly, since the dependent variables are not exactly the same, are qualitative in nature, and we don't have complete information about how the subjects were instructed before reporting their assessments.

2.3.2. Bicycle Master Plans:

Several jurisdictions have recently developed bicycle master plans. This subsection presents some of the work performed in this field.

Rockville Bicycle Master Plan:

The City of Rockville, Maryland, USA, adopted the "Bikeway Master Plan" (2004) on April 26, 2004. Its purpose is to outline a vision for improving bicycling in the city over a 10-year period. Other than general guidelines and recommendations, the study indicates that bicycle LOS scores were calculated for over 100 roadway segments. The results also indicate that a number of roadways in the proposed bikeway network are comfortable for typical bicyclists without bicycle lanes or paths. BLOS was used as a factor in the analysis, and width constraints were taken into consideration. The challenge in this study is that not very many streets in Rockville were built wide enough to accommodate new bicycle lanes. The proposed bikeway network was mostly based on connecting roadway segments between the city center and different locations around the city limits, and to connect different points within the city with each other. No bicycle demand model was generated for this plan.

Studies performed within this effort showed that bicycle conditions have been improved by changing lane striping. The bicycle level of service was improved from “D” to “C” when the vehicular travel lanes were narrowed to add bicycle lanes. Field measurements also showed that the 85th percentile speeds decreased from 39 mph to 34 mph after the changes were made. Although this could be considered a result of interaction between bicycles and vehicles, and thus represents a reduction in the traffic flow, it could also be considered an improvement to traffic safety. The bicycle level of service model used in the study is identical to the Bicycle Level of Comfort Model used by the Maryland Department of Transportation (2002) to measure bicycling suitability on state-owned roadways in the Twenty Year Bicycle and Pedestrian Access Master Plan (MDOT, 2002).

Washington, DC, Bicycle Master Plan:

The draft of this master plan was published in August 2004, and the final plan was completed in April 2005 (District of Columbia Bicycle Master Plan, 2005). Toole Design Group was the prime consultant for the development of the District of Columbia Bicycle Master Plan, which included the analysis of existing conditions for nearly 500 miles of the District's roads and the identification of a route network of on-road improvements based on existing conditions and public input. The Bicycle Master Plan also included policy and design guidelines and general goals and recommendations such as improving and expanding the bicycle route system and providing bicycle facilities on roadways.

Similar to Rockville’s Bikeway Master Plan, the proposed bicycle network for the District of Columbia was more focused on establishing a system that connects different locations around the city.

Philadelphia Bicycle Plan

A set of design guidelines was published for the Philadelphia Bicycle Plan. BLOS was also used for this plan, and before-and-after BLOS analysis was conducted for streets where bicycle lanes were recommended. Preliminary results showed an increase in bicyclist's comfort level when bicycle lanes were added. A final Master Plan report for Philadelphia was not published.

Bicycle Master Plan in Baltimore, MD:

In early 2005, through a conversation with Mr. Frank Murphy, the lead traffic engineer for the City of Baltimore, Maryland, USA, it was found that the City was about to start working on a bicycle master plan. The same consultant who worked on the bicycle master plans for both the City of Rockville and the District of Columbia, Toole Design Group, is currently conducting the study. Mr. Murphy also stated that due to limited funds, the scope of this study was expected not to exceed the scope of work performed in Rockville or the District of Columbia. This means that the study would include general guidelines and recommendations and some BLOS for the city streets, but with no application for bicycle demand models or analysis of its impact on traffic flow. Only information about existing BLOS would be available.

2.3.3. Bicycle Facilities and Operational Analysis Research:

This subsection provides an overview of research conducted in reference to bicycle operational analysis, bicycle facilities, their relation with bicycle commuting, and network connectivity for bicycling.

In a review of the basic research in bicycle traffic science, traffic operations, and facility design, Taylor and Davis (1999) presented a comprehensive review of published basic research in bicycle traffic science. Research related to this study included topics in reference to traffic flow at intersections, capacity and level of service for bicycle lanes, computer simulation and geometric design concerns such as bicycle facility width.

The only study referring to traffic flow at intersections was Ferrara and Lam (1979). The authors of that study conducted observational experiments on bicycle-automobile mixed-traffic behavior at intersections. For capacity and level of service for bicycle lanes, the authors referred to a study by Allen et al. (1998), who evaluated bicycle-lane capacity and LOS by treating bicycle lanes as a one-way separate path. The study, however, did not take into account the interaction among cyclists, motor vehicle traffic, and other adjacent roadway factors such as the presence of parking. Lastly, in reference to the geometric design (e.g., bicycle facility width), the authors referred to the AASHTO's Guide for the Development of Bike Facilities (1999).

In an effort to evaluate the potential impact of banning the portion of non-motorized vehicles from sharing travel space with motorized vehicles, Hossain and McDonald (1998) conducted a study in Dhaka, Bangladesh. Traffic data were collected and a micro-simulation model was developed for this study. The result was a 30% reduction in corridor travel time for motorized vehicles, which indicates there is a benefit (at least for motorized traffic) for splitting motorized and non-motorized vehicles into separate lanes in Dhaka.

In the field of bicycle facilities, Krizek and Johnson (2004) studied the effect of facility access on bicycling behavior and estimated the effect of household proximity to a bicycle facility on the propensity for bicycle use. The results showed that subjects living less than 400 meters from an on-road facility had statistically significantly increased tendencies for bicycle use compared with subjects living more than 1,600 meters from an on-road facility. Due to the fact that some factors influencing the choice to ride a bicycle were not included in this study, the authors considered the results not to be overly promising for bicycle planners and advocates.

While looking at bicyclists' preferences when using bicycle facilities, Tilahun, Krizek, and Levinson (2004) looked into bicyclist performance when it comes to the use of trails for their commute. In this study, the authors found that bicyclists were willing to travel up to twenty minutes more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements. Although the use of bicycle trails is outside the scope of our research, it is interesting to find that bicyclists have a different perspective than motorists when it comes to travel time versus safety.

In the same area of interest, Dill and Carr (2003) conducted an analysis to confirm that higher levels of bicycle infrastructure are positively correlated with higher rates of bicycle commuting in major U.S. cities. Data were collected in 43 cities using the 2000 Census release data, and included Washington, DC, and Baltimore, MD, where the percentage of bicycle commuters were 1.42% and 0.26%, respectively. The analysis did not indicate, however, the existence or direction of a cause-effect relationship between cycling and infrastructure.

In the field of bicycle-automobile mixed traffic, Taylor (1998) examined lowering automobile speeds and adjusting the intersection cycle length to improve conditions for bicyclists, and to provide more progression for both modes of transportation. He developed a mathematical program to generate multimodal progression design, and in an example, demonstrated an improvement caused by increasing the cycle length by 25 percent. In order to achieve this multimodal progression, it was assumed that both modes would not interfere with each other (e.g. presence of bicycle lane or wide curb lane). It is recommended, however, to assess the trade-offs between increasing automobile delay and improving progression for bicycles. In the same research, Taylor examined the gap acceptance for both motorists and bicyclists when crossing intersections, and the behavior of bicyclists when being alerted of a yellow change interval, indicating that they need more time than motorists, and thus, different methods of providing the signal change warning. These are details that are perhaps not yet included in microscopic simulation models that include bicycles, because this is a young research area. In time, as many of these details as are reliably understood should be incorporated, and simulation models should be assessed in part on their inclusion of such elements.

In an effort to measure network connectivity for bicycling and walking, Dill (2004) conducted a study and found that increased network connectivity could reduce travel distances for all modes, and provide a wider range of routes to choose from. Four measures of connectivity for bicycling and walking were applied to the Portland, Oregon regional network: street network density, connected node ratio, intersection density and link-node ratio. Although all four measures were positively correlated, they did not consistently assign the same level of connectivity for a tract. More research was recommended.

In the same area of research, while assessing some bicycle facilities, Krizek and Roland (2004) studied the factors affecting discontinuities of on-street bicycle lanes in urban settings. The purpose of this paper was to understand better the severity of the instances where separate on-street bicycle facilities end and to determine the bicyclists' discomfort when encountering such instances. The study identified a few elements that contribute to higher levels of discomfort such as lane-discontinuity on the left side of the street and having parking after the discontinuity. This research suggests that the continuity of bicycle facilities is important.

Several studies also pointed to benefits of using bicycles as a mode of transportation. In a research paper presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., Krizek (2004) identified bicycling benefits, which include social transportation benefits (congestion, air quality, energy), user transportation benefits, social benefits (livability and option value), user safety benefits, user health benefits, and agency benefits from right-of-way preservation. As a conclusion, it was suggested that benefits should be estimated on a regional scale.

This section reviewed different topics in bicycle research such as bicycle performance measures, bicycle facilities, and bicycle operational analysis studies. The section identified tools applied to measure bicycle performance such as the BLOS and the BCI. It showed that separating non-motorized vehicles, such as bicycles, and motorized vehicles is beneficial, and adding exclusive bicycle lanes has a potential effect on vehicle's speed. It also highlighted the benefits of establishing bicycle lanes, especially when they are connected in a bicycle network. Finally, the section provided examples of bicyclists' preference as they would choose a longer route to switch to a more comfortable bicycle facility. Those are important justifications for allowing bicycle lanes in urban transportation networks, as shown by the work conducted by local jurisdictions to incorporate bicycles in their master plans. Examples included cities like the District of Columbia, Rockville, and Baltimore, Maryland, USA.

2.4. Mobility and Accessibility

Important factors that should be considered when planning an urban transportation network are the mobility and accessibility of all the modes of transportation in the network or transportation system. Mobility is the freedom or ease of movement that people experience when traveling from place to place. It represents the movement of people or goods and assumes that any increase in travel mileage or speed benefits society. A transportation system needs multimodal transportation and/or alternative routes to reach destinations to provide the greatest level of mobility.

In a publication by the Federal Highway Administration (FHWA, May 2003), mobility was defined as the ability to access goods, services, and destinations. The report described the United States as a very mobile nation: In 2000, Americans traveled more than 2.7 trillion vehicle miles, almost triple the vehicle miles traveled in 1970 (Highway Statistics, 2004). Mobility focuses on how long it takes to get from point A to point B, the availability of travel choices, and travel time reliability. The report went on to describe that improving mobility can be achieved by reducing congestion and creating mode choices. Increasing mobility is a benefit of reduced congestion and improving mobility often yields emission benefits as well.

Ease of travel, convenience, and travel time are considerations in mobility. They are affected by the system's LOS, which is affected by the system's capacity and efficiency. When demand exceeds capacity, LOS declines, travel times increase and mobility is impaired.

The United States Census (2000) showed that 87.5 percent of workers got to work by private vehicles, 3.1 percent by bicycle/walk, 2.8 percent by bus/trolley bus and 1.6 percent used the subway. It also showed that the average length of commuting increased by 14 percent from 22.4 minutes in 1990 to 25.5 minutes in 2000.

In a study to estimate the benefits of different mobility enhancements (Schrank, 2002), the author recommends that cities need to use a diverse set of solutions to deal with reducing congestion and improving mobility. Some of these solutions include traffic signal coordination, HOV lanes, and public transportation. After analyzing 75 urban areas, the report shows that public transportation accounted for almost 40 percent reduction of total delays in very large areas (over 3 million population, such as the San Francisco/Oakland area in California, USA) and 16.4 percent for large urban areas (over 1 million and less than 3 million population, such as the Baltimore area in Maryland, USA). The HOV reduction in hours of delay was estimated to be around 0.9 percent. The data used for this study were the travel time, speed and passenger volume data.

Some of the data could be estimated from route schedules and passenger-loading information could be collected by public transportation systems.

The Texas Transportation Institute (2005) prepared a study to identify the keys to estimating mobility in urban areas, and divided the mobility measures in two groups: one related to the traveler and the other related to a corridor or a region. The mobility measures related to the traveler mainly consisted of travel time and delays, and the area mobility measure focused on congestion.

In conclusion, it is recommended for this study to measure mobility in a transportation network by quantifying person-miles, ton-miles and travel speeds. Those measures are good indicators for mobility and for the extent of congestion. In case of a corridor study, where those measures might not provide a good indication of a mobility level, it can be measured by determining the travel time needed to reach a specific attraction from a specific point.

Accessibility refers to the ability to reach desired services, activities or destinations. Improving accessibility also benefits society, and mobility is one way to achieve this goal. Accessibility to a city center refers to the ease of access major downtown destinations such as courthouse, post office, library, City hall, downtown entertainment area, employment centers or government agencies. Barnes and Davis (1999) suggested that measuring accessibility is essential to evaluate how well a transportation system accomplishes its objective of making it possible for people to access destinations. The report recommends the use of accessibility as a framework to compare different systems, modes, and combinations of policies. The report did not define, however, a method to measure accessibility.

Wadell and Ulfarsson (2003) suggested that measuring the travel time to the CBD, employment or to population could serve as a regional accessibility measure. This method, however, is more suitable for use when dealing with a transportation network. Graphs and Geographic Information System (GIS) maps can show contour lines identifying different areas with different levels of access to a specific destination.

Accessibility can be measured by quantifying the number of households that are connected to a specific center of attraction through bicycle lanes, bus lanes or other mode of transportation. It can also be measured by determining the number of people who can reach a destination such as a CBD within a specific time-period, such as 15-minute period, using a specific mode of transportation.

2.5. Environmental and Safety Impacts

The environment and safety impacts are two essential components when evaluating a transportation project. Some research used a unit environment cost and a unit accident cost to determine the environmental and safety impacts on different traffic alternatives. An example will be provided later in this chapter two, section six. Other efforts were made to better predict them and to measure their economical impact, and they are presented in this section.

2.5.1. Environmental Impact

Several environmental factors can be impacted by a transportation project and they include, but not limited to, disturbance of wetlands and streams, disturbance of wildlife and plant life, noise impact, impact on land use, and impact on air quality (temperature, odors, pollutants, and air movement). Since this research deals with an existing road, the impact on wetlands, streams, wildlife, and plant life is not considered in the study.

Land use and transportation systems are interactive and interdependent. The two systems feed each other and possibly impact each other, however, the change can be slow. This topic is further discussed in chapter five. This study assumes a given uniform land use mix across the corridor or network, and therefore, the impact on land use is not considered, and the study limited the environment impact on the air quality and emission rates.

This section highlights some of the efforts made to connect a relationship between transportation and its effect on air quality. In the areas of motorized transportation modes, emission models such as MOBILE6 (2003) - authorized by the Environmental Protection Agency (EPA) - estimate pollutants including hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x), and were used to evaluate the environmental impacts of different transportation alternatives (Sivanandan and Rakha, 2004). It should be also noted that several traffic simulation models such as Synchro, CORSIM and VISSIM (2004) generate reports with fuel consumption and emissions rates.

In an effort to analyze regional transportation and land development policies, Rodiev (2005) used MEPLAN, the integrated land use and transportation model. NO_x emissions results were obtained from the DTIM2 and EMFAC7F emissions models.

Another example - where the environmental impact of a transportation project was investigated - took place in the City of Syracuse, New York, USA. A congestion mitigation and air quality fund was obtained to develop a design to reconstruct Clinton Square in an effort to promote economic development while improving the air quality of the area. To measure air quality improvements, both CO and NO_x were measured and they were reduced by approximately 15 percent (Faulkner, 2005). In the United Kingdom and Australia, volatile organic compounds (VOC) are also measured. VOCs are some of the main precursors of ground level ozone, which are toxic to plants and can cause breathing difficulties in humans (Environment Agency, 2006).

It should be also noted that some efforts were made to evaluate the positive impact on the environment when people use non-motorized mode of transportation instead of the motorized modes. For example, Krizek (2004) reviewed and interpreted literature that evaluates the economic and social benefits of bicycle facilities and proposed methods for their estimations. The paper touched on the environmental benefits in the areas of energy and air quality.

2.5.2. Safety Impact

Traffic safety is one of the most important factors that should be taken into consideration during the design phase of any transportation project. The World Almanac and Book of Facts (1996) revealed that motor-vehicle crashes were one of the ten leading causes of death in the United States and Americans incur $72 billion in crash costs every year. The social costs are obviously very high as well. Those facts lead to the need of an effective solution to evaluate traffic safety.

Although a full research could be devoted to the primary causes of traffic crashes and work related to traffic safety, this section only addresses the most relevant efforts made to evaluate and predict the safety impact of one design over the other, as well as the importance of the lane-width variable in accident prediction models. A subsection has been also dedicated to bicycle safety in specific.

a. Traffic Safety

Huang et al. (2002) analyzed a specific case of the lane configuration allocation. They compared the effects on crashes and injuries of changing road lane-configuration from a four-lane undivided road into three lanes. The concept of this change in lane configuration was called a “Road Diet.” In the new scenario, a middle center turn lane was created and the fourth lane was converted to two bicycle lanes. The study consisted of collecting and comparing crash data before and after the treatment. The authors concluded that a significant reduction (6 percent) in crash frequencies was achieved, but road diet conversions did not affect crash rates or severity of type. The safety disadvantage of the original scenario of the 4-lane road is that drivers can change lanes to pass slower vehicles, which can potentially increase sideswipe crashes. Safety advantages of the modified configuration include reducing vehicle speeds and vehicle interactions during lane changes - which potentially could reduce the number and severity of vehicle-to-vehicle crashes, and improving pedestrian safety since there are fewer lanes to cross and traffic is slower.

The concept applied in the road-diet study is similar to the concept applied in this research because it entertains the idea of modifying the pavement marking to provide a different lane configuration for a road, and then evaluating the impact of this change. The road-diet study, however, limited the evaluation to the safety impacts, while this research is much more comprehensive. An important factor also not considered in this study is the effect of road-diet concept on traffic operations and capacity. The authors acknowledged, however, that if the average daily traffic (ADT) is above 20,000 vehicles, there is a greater likelihood that traffic congestion would increase. More research was also recommended to study the factors attributing to lower speeds, fewer conflicts, etc.

There were also some contradictory conclusions when it came to analyzing crashes at signalized intersections. While analyzing types of collisions and evaluating crash data at signalized intersections, Keller et al. (2006) concluded that the most important factor when determining the number of pedestrian/bicycle crashes was whether the right-turn lane is channelized on the major road. The study also showed that traffic volumes and speed limits were not found to be significant factors. On the other hand, Chin and Qudus (2003) and Liu and Young (2004) concluded that the traffic volumes are the most important factor in predicting crashes. Also, Oh et al. (2004) found that speed limits are important for the total number of crashes as well as other specific types of crashes.

Zegeer et al. (1981) found that, for two-lane roadways, the number of crashes decreased with lane-width increase up to 12-foot, after that, the crash rates increase.

Tying safety with mobility, Litman (2004) found that empirical evidence indicates that each percentage reduction in total vehicle mileage in an area reduces crashes by 1 to 1.4 percent, all else being equal. Shifting vehicle travel from congested roads to less-congested conditions tends to reduce crashes but increases crash severity due to higher vehicle speeds (Litman, 2004). Mobility management (Travel Demand Management) can be a cost effective traffic safety strategy.

A crash prediction model could be very useful to identify the contribution of road geometrics on the crashes. Earlier models predicted the number of accidents as a random variable that takes values with probabilities following the Poisson distribution with exponential function guaranteeing a positive mean. For example, Dart and Mann (1970) used linear regression models to explain the crashes in Louisiana and calculated that cross slope and poor drainage were important factors.

More recently, negative binomial models have been used in accident modeling to allow for additional variance representing the effect of more variables. An example of this kind of accident prediction models, presented by the Federal Highway Administration (1999), is described below. Pasupathy et al. (2000) recommended an empirical Bayesian approach to take into account crashes history, instead of the Poisson "memoryless" process to produce better models. Despite efforts made in this field by Miaou and Lord (2003), Qin et al. (2004), and Miaou and Song (2005), the most common models used for crashes remains the traditional negative binomial distribution (Lord, 2006).

It should be noted that an accident prediction model is more reliable if based on accident data collected for as many years as possible at a similar site while accounting for the influence of factors changing year-to-year (Lord and Persaud, 2000). Therefore, it is always recommended to apply the model that is more suitable to the site understudy. In this research, the role of a prediction model is not to estimate the number of accidents, but to perform a safety impact comparison among different lane-configuration scenarios for the same transportation network.

The accident prediction model presented by the Federal Highway Administration (1999) was developed with negative binomial regression analysis for data from 619 rural two-lane highway segments in Minnesota and 712 roadway segments in Washington. These roadway segments including approximately 1,130 km (700 mi) of two-lane roadways in Minnesota and 850 km (530 mi) of roadways in Washington. The database available for model development included 5 years of accident data (1985-1989) for each roadway segment in Minnesota and 3 years of accident data (1993-1995) for each roadway segment in Washington. The model predicts the total non-intersection accident frequency for any roadway segment for which the independent variables shown in the equation below are known. The number of predicted accidents was a function of the lane width.

The report concluded that the developed accident prediction algorithm appeared to be a useful tool for predicting the safety performance of rural two-lane highways. This model is described below:

Accident Prediction Model:

This section presents the base model for the accident prediction algorithm. The base model is presented for roadway segments and for four-leg signalized intersections.

Base Model for Roadway Segments

Although the base model for roadway segments was developed for the states of Minnesota and Washington in separate studies by Vogt and Bared (1998), the base model presented below can be used as a reference to compare roadway segments in different states:

$$N_{br} = EXPO\ \exp(0.6409 + 0.1388 STATE - 0.0846 LW - 0.0591 SW + 0.0668 RHR + 0.0084 DD)\ (\Sigma WH_i \exp(0.0450 \mathrm{DEG_i}))\ (WV_j \exp (0.4652\ V_j))(\Sigma WG_k \exp(0.1048 GR_k))$$

where:

N_{br} = Predicted number of total accidents per year on a particular roadway segment;

$EXPO$ = Exposure in million vehicle-miles of travel per year = $(ADT)(365)(L)(10^{-6})$;

ADT = Average daily traffic volume (veh/day) on roadway segment;

L = Length of roadway segment (mi);

$STATE$ = Location of roadway segment (0 in Minnesota, 1 in Washington);

LW = Lane width (ft); average lane width if the two directions of travel differ;

SW = Shoulder width (ft); average shoulder width if the two directions of travel differ;

RHR = Roadside hazard rating; this measure takes integer values from 1 to 7 and represents the average level of hazard in the roadside environment along the roadway segment;

DD = Driveway density (driveways per mi) on the roadway segment;

W_{hi} = Weight factor for the i^{th} horizontal curve in the roadway segment; the proportion of the total roadway segment length represented by the portion of the i^{th} horizontal curve that lies within the segment. (The weights, WH_i, must sum to 1.0.);

DEG_i = Degree of curvature for the i^{th} horizontal curve in the roadway segment (degrees per 100 ft);

WV_j = Weight factor for the j^{th} crest vertical curve in the roadway segment; the proportion of the total roadway segment length represented by the portion of the j^{th} crest vertical curve that lies within the segment. (The weights, WV_j, must sum to 1.0.);

V_j = Crest vertical curve grade rate for the j^{th} crest vertical curve within the roadway segment in percent change in grade per 31 m (100 ft) = $|g_{j2}-g_{j1}|/l_j$;

$g_{jl'}g_{j2}$ = Roadway grades at the beginning and end of the j^{th} vertical curve (percent);

l_j = Length of the j^{th} vertical curve (in hundreds of feet);

WG_k = Weight factor for the k^{th} straight grade segment; the proportion of the total roadway segment length represented by the portion of the k^{th} straight grade segment that lies within the segment. (The weights, WG_k, must sum to 1.0.); and

GR_k = Absolute value of grade for the k^{th} straight grade on the segment (percent).

The variables in the model are set to the following nominal or base conditions (default values):

Roadside hazard rating (*RHR*) = 3

Driveway density (*DD*) = 3 driveways /km (5 driveways/mile)

Horizontal curvature = none

Vertical curvature = none

Grade = Level (0 percent)

In this case, the base model in the equation reduces to:

$N_{br} = (ADT)\ (L)\ (365)\ (10^{-6})\ \exp\ (0.8833 - 0.0846\ LW - 0.0591\ SW)$

Base Model for Four-Leg Signalized Intersections

The base model for four-leg signalized intersections is presented below:

$N_{bi} = \exp(-5.46 + 0.60 ln\ ADT_1 + 0.20 ln\ ADT_2 - 0.40\ LT - 0.018\ PLT + 0.11G + 0.026\ PT + 0.041ND_1)$

where:

N_{bi} = Total intersection-related accident frequency for any four-leg signalized intersection

ADT_1 = Average daily traffic volume (vehicles/day) on the major road

ADT_2 = Average daily traffic volume (vehicles/day) on the minor road

LT = Presence of protected left-turn signal phase on one or more major-road approaches; = 1 if present; = 0 if not present

PLT = Percentage of minor-road traffic that turns left at the signal during the morning and evening hours combined

G = Grade rate for all vertical curves (crests and sags) within 76 m (250 ft) of the intersection along the major and minor roads

PT = Percentage of trucks (vehicles with more than four wheels) entering the intersection for the morning and evening peak hours combined

ND_1 = Number of driveways within 76 m (250 ft) of the intersection on the major road.

This model was developed with negative binominal regression from data for 49 four-leg signalized intersections, 18 in California and 31 in Michigan during a three-year period (1993-1995). The formula can be simplified when the following variables in the model are set to the following nominal or base conditions (default values):

Presence of protected left-turn signal phase (LT) = No left-turn phase

Percentage of minor-road traffic turning left (PLT) = 28.4 percent

Grade rate for vertical curves within 76 m (250 ft) of the intersection (G) = No vertical curves

Percentage of trucks entering the intersection (PT) = 9.0 percent

Number of driveways within 76 m (250 ft) of the intersection on the major road (ND_1) = 0 driveways

With the nominal or base values of LT, PLT, G, and PT given above, the base model reduces to: $N_{bi} = \exp(-5.73 + 0.60 \ln ADT_1 + 0.20 \ln ADT_2)$

From one point, the issue is simple because reducing vehicle mileage should reduce crashes. From another point, it is complex because there are other travel impacts that have various impacts on crash rates and severity.

All the above-mentioned studies in predicting the number of accidents and their estimated costs had potential use in this research when assessing safety impact for each alternative. The accident prediction model, specifically the one for roadway segments, is the most adequate to apply in this study because its formula is a function of the lane width, which would be useful for comparing the different scenarios in this study.

b. Bicycle Safety

Since traffic safety is an important factor in the evaluation process, safety of non-motorized modes of transportation such as bicyclists, a part of this factor, should also be considered. This subsection highlights bicycle safety research.

In this field, Kroll and Ramey (1977) studied the effects of bicycle lanes on drivers and bicyclists' behavior, and McHenry and Wallace (1985) evaluated the wide curb lanes as shared lane bicycle facilities. The studies found that drivers made fewer wide swerves or close passes when passing bicyclists on streets with bicycle lanes.

Another bicycle safety study was conducted by Harkey and Stewart (1997) to evaluate shared-used facilities for bicycles and motor vehicles. They found that a 3-foot bicycle lane provides sufficient space for bicycles and autos to interact safely. It was determined, however, that a 4-foot lane would be safer for cyclists.

A study was also conducted in San Francisco (Alta Planning & Design, 2004) researching bicycle safety, and specifically the shared-lane pavement markings. The study concluded that the markings increased the distance of cyclists from parked cars as well as the distance between cyclists and passing vehicles. The critical evaluation is that the distribution of the distance between cyclists and parked vehicles narrowed. Although the average did not change dramatically, cyclists riding closest to the parked cars moved further away.

Finally, Van Houten and Seiderman (2005) researched how pavement markings influence bicycle and motor vehicle positioning. This study was conducted in Cambridge, MA. They found out that before bicycle lanes were constructed, when motorists were asked about what made them most aware of cyclists on the street, the most common response was: “nothing.” After bicycle lane installation, the most common answer was “the bicycle lane.”

These studies support qualitative motivations for bicycle lanes, but the literature is silent on more quantitative results that might be used for prediction. This is not surprising; this type of modeling is difficult even for motor vehicle safety impacts, which is a vastly busier research space. It is concluded that pavement marking identifying a bicycle lane, and the width of this lane, play a role in improving bicycle safety. Those factors are included in the BCI formula as described earlier, and therefore, the best that can be done in this proposed method is to use the BCI to evaluate bicycle safety.

2.6. Lane-use-related research

So far the studies mentioned in the previous sections only evaluated the implementation of exclusive lanes and their effect on travel time. These studies did not actually develop a method to justify and design different lane-uses in a congested urban street network.

In an effort to develop a macroscopic methodology for urban transportation planning and policy analysis, Schonfeld (1977) used multivariate optimization techniques to choose among a wide range of alternatives. The study analyzed options such as traffic management, vehicle design, service policy, pricing, financing and regulations options, and touched on space allocation for different transportation modes. However, some of the model limitations included the omission of important modes such as bicycles and local street buses, as well as safety impact.

In a search for the optimal road space allocation among competing transportation modes, Xu (1993) used the total cost of a road system (user time costs, operating costs, and other costs) for comparison. A logit model was used for modal split and the planning software MINUTP (1991) for trip assignment. One of the shortcomings of this study is that bicycles and vehicles were modeled in separate networks due to lack of information in reference to the relationship and interaction between bicycles and vehicles. Although many factors determine the road capacity such as type of area, existence of parking activity, lane width and heavy vehicles (Federal Highway Administration, 2003), Xu's study considered lane width to be the only variable to determine lane capacity. Accessibility and mobility were not measured in the study and environmental impact was not considered at a satisfactory level; a unit environment cost per vehicle-mile was included in the total cost. Accident impact was also considered as an accident rate for each mode multiplied by the total distance traveled by this mode. Better assessments can be applied such as predicting accident occurrence for a specific lane configuration.

In an effort to estimate how adding a high-occupancy vehicle (HOV) lane, high-occupancy toll (HOT) lane, or a mixed flow lane to an existing freeway affects delay, Dahlgren (2002) constructed a model to estimate the change in delays when adding a new lane on a freeway. The author used a logit model to estimate the probability that a particular individual will use an HOV lane. This is a common method of assigning trips to modes, but it does not acknowledge the feedback loop that is generated. The attractiveness of the modes is affected by their usage, which is in turn affected by their attractiveness. As mentioned before, this dissertation uses sensitivity analysis as a first step towards understanding these interactions.

The only known effort to develop quantitative models for justifying bus-lane design alternatives, based on the average person travel time for all road users, was presented by Gan et al. (2003). They considered the overall average person travel time under two treatments: with and without a bus-only lane. The CORSIM simulation model was used to generate data from different alternatives and to estimate the bus and non-bus travel speeds under these alternatives. CORSIM, however, does not simulate bicycle lanes.

In an ongoing study, Kuhn et al. (2003) investigate the issues surrounding the efficient operation of managed lanes using various operating strategies to develop a managed lanes manual. The objective of this study is to help the Texas Department of Transportation make informed planning, design, and operational decisions when considering these facilities for their jurisdictions. The study's objective is similar to the one that needs to be achieved in this research, except that it focuses on major freeway projects in Texas and includes HOV and HOT lanes. It should be also noted that the managed lanes study in Texas is scheduled for completion in 2007.

Finally, it should be noted that there is a relationship between the lane width and the roadway capacity. A FHWA report (2003) recommended a procedure for estimating highway capacity, which was based on an adjusted saturation flow rate:

Capacity = $S_o N f_W f_{HV} f_p f_a PHF$

The adjustment factor for lane width (f_W) is calculated as follow:

$f_W = 1 + (W - 12)/30$

W = Lane width (minimum 8 feet and maximum 16 feet)

The formula suggests that for each foot, more or less than 12-foot lane, the lane capacity increases or decreases by 3.33 percent, respectively. This concept should be taken into consideration when identifying different lane-use scenarios since allocating a specific width for a travel lane will impact the lane capacity.

2.7. Combining modal split and equilibrium assignment model

Conventional planning models consist of four steps: trip generation, trip distribution, mode choice, and route assignment. The mode choice allocates trips among several modes of transportation and an assignment model is then solved for each mode of transportation. One criticism of this process is that it is a sequential process, while most users in reality choose the mode and the route at the same time. Thus, some research efforts have been devoted to this concept while modeling network equilibrium.

As mentioned in chapter one, different lane-use scenarios are expected to affect the average speed for each transportation mode, and thus, the travelers' decision on mode of transportation choice and route assignment are expected to change as well. A model combining modal split and equilibrium assignment would be very useful in this research. However, this is a very complex topic and a reliable model is not yet available. The topic deserves to be studied under separate research, and once a reliable model is available, it would be an important tool to use in this decision-making study. Meanwhile, it is suggested to use sensitivity analyses as an acceptable solution to determine the effect of the traffic flow change of one or more modes of transportation on measures of effectiveness.

Although this topic of combining mode choice and equilibrium assignment is not utilized in this study, especially since the case study is dealing with a corridor rather than a transportation network, some of the efforts made in this field are included in this literature review because they could be incorporated in a similar research in the future, where a network equilibrium is necessary.

Abdulaal and Leblanc (1979) developed a method for combining modal split and equilibrium assignment models in which users can choose modes and routes, simultaneously. This model was developed by extending Wardrop's (1952) route choice principle – which assumes that travelers choose the route with minimum disutility – to include mode choice as well. Although the advantage of their combined models over existing models was not proven, preliminary results were encouraging. Three years later, Leblanc and Abdulaal (1982) extended their study to combine their model with interdependent travel impedances. During this study, the authors recognized the fact that different kinds of travelers perceive the time-cost tradeoff differently, and thus included distinct groups of travelers in the model. The model has the advantage of recognizing the interaction between distribution, mode split and assignment phases. As an extension of such concept, efforts were made to combine distribution, mode split and assignment (Florian and Nguyen, 1978), and furthermore, Safwat and Magnanti (1988) combined them with trip generation.

Maruyama et al. (2001) claimed that all of the above-mentioned models were rarely applied to real-world transportation systems. They developed a combined modal split/assignment model for the Tokyo Metropolitan Area in order to evaluate relevant transport policy. The mode choice – between autos and trains – was based on the use of a logit model and the modal split/assignment model was formulated using a mathematical problem as suggested by Sheffi (1985).

Another study in multimodal network equilibrium was performed by Oketch (2000). The author introduced a modeling approach suitable for mixed traffic streams with nonstandard vehicles such as motorcycles, bicycles, three-wheeled vehicles and pedestrian-pulled carts in major streets with faster traffic. This is an important reference work for scenarios involving international applications of the proposed method. The model adopts a detailed lateral movement modeling approach in which both longitudinal and lateral motions of a vehicle are included. The model was calibrated using data from Nairobi, Kenya, and yielded reliable results. However, since the data used to test the model contained a low presence of nonstandard vehicles, it is not known if the model would be reliable if the traffic is composed of a high number of these types of vehicles.

Another model was developed by Wu and Lam (2003) in Hong Kong where modal split and stochastic assignment models were combined for congested networks with motorized and non-motorized transport modes. In this study, the non-motorized modes, such as walking, served to compliment motorized trips, e.g. transit passengers having to walk to reach transit stops. Although motorized modes were represented by the transit mode only and the non-motorized modes were represented by the walking mode only, the interaction between walking and transit modes was taken into account. The authors concluded that further studies were recommended to assess this method when applied to real-world, large-scale transportation networks.

In a recent correspondence with one of the authors, it was learned that the model was extended to include four modes: auto, bus, metro, and walking. It was further explained that as the commonly used modes in Hong Kong are auto, walking and multiple-transit modes, the model did not address the bicycle mode.

As mentioned at the beginning of this section, combining modal split and equilibrium assignment is a topic of ongoing research, and any attempt to do it would represent a thesis contribution in its own right. Because the field is not mature, it would be inappropriate to simply choose one of the preliminary models and apply it. The preferred approach, taken in this dissertation, is to focus on related and supporting ideas from sensitivity analysis that do not rely on as many modeling assumptions, and thus can be studied with greater confidence. The drawback, of course, is that this approach does not “solve” the equilibrium assignment problem.

2.8. Multimodal simulation software

An essential step to evaluate the performance of any transportation network is to predict how its different modes would function and at what level they would operate. Travel speeds and delays are among the indications needed to perform this kind of evaluation. Traffic simulation software emerged in the last decade as a powerful tool to provide such evaluation and this section highlights some of them.

As mentioned earlier, the CORSIM (1998) simulation model was used in previous research to generate traffic data and to estimate travel speeds. Although CORSIM is one of the most widely used and accepted models in the United States in the recent years, it does not provide one important feature needed in this study, bicycle lane simulation.

De Cea et al. (2003) presented a computer package developed by the government of Chile under the name of “ESTRAUS” to simulate the operation of alternative network configurations and evaluate strategic development plans for urban transportation systems. The model is able to consider a variety of demand models and trip assignment behaviors, including multiple user classes and combined travel modes that interact on the same network. It considers the effects of congestion on the road network as well as in each public transportation service network. Although the model included a metro network, a shared taxi network, and combined modes such as metro/bus and shared taxi/metro, it did not include a bicycle mode. The model also assumed all vehicles would compete for the same common road capacity, with the exception of the exclusive bus lanes and the metro lines. The bus lanes were coded in separate links, and the metro lines operated over an independent network.

Another software system designed for travel demand modeling for multimodal analysis is VISUM (2004). It allows users to integrate all relevant modes of transportation, including bicycles, into one consistent network model. One of the assignment procedures offered by VISUM is the user-optimal equilibrium, fulfilling the strict Wardrop (1952) definition. VISSIM is a microscopic traffic simulation model for multimodal traffic flows including cars, buses, trucks, and bicycles. In partnership, VISUM and VISSIM help to analyze the effectiveness of transportation alternatives including mode shift, regional route choice, and operational impacts. VISSIM was the platform chosen for this study since it provides all the features needed in this research. It should be noted that typically, micro-simulation software is used to simulate operations but not optimize traffic signal timing and network operations. Therefore, a combination of software can be used to analyze a transportation system: For example, Synchro for capacity analysis and signal optimization and VISSIM for detailed micro-simulation of the network. Several studies applied this combination in their analysis such as a case study by Mosseri, Hall, and Meyers (2004) of Ocean Parkway in New York.

PARAMICS is another software tool that was also considered for this study. In a comparison between VISSIM and PARAMICS, Choa, Milam, and Stanek (2001) noticed that although PARAMICS is developed by a Scottish company and VISSIM by a German company, they are increasingly used the US. They are very similar in so many ways as they generate simulation results better matching field conditions and traffic engineering principles than other software. VISSIM, however, is more flexible in measuring delays since it can measure it between any two points in the network versus total delay only for PARAMICS.

Milam and Choa (2002) also showed that VISSIM's set-up time is slightly less than PARAMICS'. They pointed out that VISSIM is path-based for routing decisions compared to PARAMICS' link-based, and that VISSIM can include more multi-operations such as the rail transit and bicycles. VISSIM's explicit bicycle model allows for the following:

a) Bicycles behave similar to regular vehicles, and are treated the same way as other vehicle types. The user may define how bicycles use the lane (e.g., in the middle of the lane, or to the right/left side), and how to yield to other vehicle types or to pedestrians at various speeds. This means that the bicycle can be modeled, and allow other vehicles to pass in the same lane if defined lateral clearances are met. This theory is applicable through a road segment as well as at intersections where bicycles and vehicles are performing turning movements.

b) Bicyclists also are bound to the car-following models that regular vehicles use such as reaction to stopped cars. They also respond to signal indications similar to regular vehicle types, or not, as determined by the user.

c) Bicycles use the space that is left besides other vehicles (or besides other bicycles) within a lane. PARAMICS can only let a bicycle follow another vehicle in the lane. It must do a lane change to pass by.

d) In reference to "storage" of bicycles waiting at a red light, bicycles fill out the space very tightly, i.e., they do not queue up like cars where one is waiting behind the other and each car needs one segment of a lane. In VISSIM, bicycles can work like PARAMICS when bicycles are modeled like cars. The software has been used in Beijing, China, where bicycle traffic with extremely high volumes had been modeled. It was also found that the development of VISSIM 's particular bicycle-flow model had been result of the market entry in China. China's traffic engineers had requested the bicycle model. VISSIM is recommended for this study, as it will be described in section 3.4.3.

2.9. Decision Making

A national survey conducted by The Urban Transportation Monitor (Rathbone, 2004) among transportation professionals showed that traffic engineers, transportation planners, and transit professionals often interact with elected officials on transportation issues. Some of the issues provided by the respondents to the survey included traffic congestion, bicycle lanes and bicycle paths, parking, safety and geometric improvements, transit operations and improvements, and environmental issues. All of these issues are important to this research, and require transportation professionals and elected officials to make decisions.

While reviewing literature for decision-making options, two topics were investigated; the Pareto Frontier Concept and the multimodal decision-making framework.

2.9.1. Pareto Frontier Concept

In an effort to learn about the equity issues with respect to bicycles, transit, and the Pareto Frontier Concept, two studies related simultaneously to the Pareto Frontier and transportation were reviewed: one in reference to air quality and the other to highway management activities.

Sampson, Guttorp, and Holland (2001) monitored air quality in network design using Pareto Optimality methods for multiple objective criteria. In this paper, it was explained that one design could dominate another design if all its numerical criteria values are equal to or less than those of the second design. A design that is not dominated by any other design is said to be Pareto optimal, and the Pareto optimal set is the set of all Pareto optimal designs.

The authors concluded that the Pareto optimal design calculations provide an effective way to make decisions in the context of multiple objectives since it allows better understanding (compared with optimization of a single criterion) of the trade-offs necessary to obtain greater relative efficiency on given criteria.

In the other paper presented by Fwa, Chan and Hoque (2000), the authors acknowledged the fact that a decision process involved in highway management activities required a multi-objective consideration to address the competing requirements of different objectives. Solutions obtained from single-objective analysis are sub-optimal with respect to ones derived from multi-objective formulations. A genetic-based algorithm was developed to identify better solutions by comparing the relative strength of the generated solutions with respect to each of the adopted objectives. All non-dominated solutions represent the Pareto Frontier. The optimization process continues seeking new solutions to improve this frontier until a set of globally non-dominated solutions is found. This is the Pareto optimal set and it defines the Pareto optimal frontier. Although different objectives were identified in this study, the optimization problem dealt with monetary units for all objectives, to minimize the maintenance cost. This obviously simplifies the challenge, but might not be the best method to use in our research, which deals with several objectives with different units. Furthermore, the condition of being non-dominated in a multi-dimensional space is quite weak, so identifying the Pareto Frontier, while clearly demarcating the losing alternatives, may nonetheless yield an enormous number of candidates that still have to be considered.

2.9.2. Multi-Objective Decision-Making

The multi-objective decision-making framework allows the incorporation of multiple and conflicting objectives into a process where all of them are equally considered regardless of whether they can be estimated in monetary or non-monetary terms. Tzeng and Chen (1993) used multi-objective decision-making and non-linear programming techniques to generate a series of non-inferior solutions. They combined a weighing method with pair-wise comparison to obtain a compromise solution for the flow pattern. This method was applied on the Taipei network system to evaluate travel time, air pollution, and traveled distance, and to determine optimum flow patterns. They concluded that when non-traffic related factors were taken into account, the approach was more reasonable and suitable than conventional approaches. A weakness of this method is that it allows the analyst to represent his/her feeling toward improving one objective at the cost of another before the final result of the analysis is determined and presented to the decision-makers.

A few transportation investment projects have also used the multi-objective decision-making approach - as presented by Chowdhury, Tan, and William (2002) - to choose the alternative that best provides the project's objectives. Their multi-objective decision support framework consisted of identifying objectives, selecting measures of effectiveness (MOEs), identifying their values, identifying sets of alternatives, and then selecting the best alternative by applying methods such as the multi-attribute utility method or the minimum tolerance method.

The multi-attribute utility method is based on utility functions. A utility function represents the relationship between the utility and the attribute values. This method consists of: a) developing a utility graph to determine a utility for each known value of an attribute, b) identifying a single utility function to create a mathematical relationship between each attribute and corresponding utility, c) determining the weight of each attribute to determine the relative importance of each attribute, and d) calculating the overall utility for each alternative. The alternative with the highest score or utility is the most preferred solution.

The minimum tolerance method is similar to the multi-attribute utility method except that it ranks alternatives based on the minimum tolerance values of selected criteria rather than the maximum utility value. The method shows the urgency of a project with respect to the tolerance values, which represent the difference between actual conditions and acceptable or standard conditions. Negative tolerance values of a project criterion indicate a higher sense of urgency related to the program. This method consists of: a) identifying the goal value based on policy objectives, b) calculating the individual tolerance value for all criteria, c) scaling the tolerance value to zero, and d) summing the tolerance scale values for all criteria for each alternative. The alternative with the lowest total tolerance value is the recommended solution.

The multi-attribute utility method and the minimum tolerance method were considered for this research due to the fact that the type of the decision problem here is discrete, i.e., a finite number of the decision alternatives can be pre-defined. They were not selected, however, because they are highly reliant upon decision-makers input. If the attribute weights are not accurate, the output of the decision-making process will not be valid.

In another approach presented by Chowdhury and Tan (2005), the authors suggested a tool based on multi-objective analysis for aiding investment decisions using a set of objectives and constraints. This decision-making analysis framework used the constraint multi-objective programming tool. It does not provide a single solution or alternative, rather a set of best alternatives from all available options. This method consists of identifying the objectives, selecting alternatives, selecting MOEs, formulating a constraint model, solving the constraint model, and selecting the preferred alternative.

Examples of the objectives in this case include minimizing cost of delays, and increasing mobility, accessibility, and traffic safety. Examples of MOEs include vehicle-hours of delay, vehicle-miles traveled, bicycle LOS, and emission rates. During the phase of solving the constraint model, a value for each alternative is calculated. After determining the lower and upper bounds, the constraint model is formulated. The multi-objective problem is then transformed into a single objective problem using the constraint method. One of the objectives is chosen as the “primary objective” and all other objectives are formulated as constraints. After running an optimization algorithm with different constraint values, best alternatives are identified. Objective values are then transformed into a 0-to-1 scale.

The results can be effectively communicated with the decision-makers using a value path graph. The graph presents the objective function values and trade-offs among objectives so the decision-makers could make an informed decision. This approach is not influenced by decision makers’ input, and therefore, is better than the multi-attribute utility approach which is highly reliant upon this input. A modified version of this multi-objective method is suggested for this research, as described in chapter three. The advantage of this method is that it is not influenced by decision-makers' input, and a decision can be made pending on the objectives that are most important for the decision-makers to achieve at the time when the decision is made.

2.10. Summary of Literature Review

Chapter two sheds some lights on a variety of work previously performed in several fields related to this research. It provides insights of previous efforts in those areas while exploring the most promising method to solve the problem.

Those areas include studies about exclusive lanes for buses and bicycles and their performance measures. The chapter includes work performed to assess the environmental and safety impacts when implementing a transportation system, as well as methods to measure mobility and accessibility. It also highlights some lane-use research, in addition to work performed in combining modal split and equilibrium assignment models to assess the possibility of including those concepts in the study. Multimodal simulation computer programs were also provided as well as some literature review related to applying multi-objective decision-making techniques to solve similar transportation problems.

The role of literature review was to provide the base on which this research was built. The topics discussed in this chapter lead to the research methodology and the tasks that need to be performed to implement the decision-making method for roadway lane designation. This next step is presented in chapter three.

Chapter III: RESEARCH METHODOLOGY and TASKS

3.1. The Purpose of the Study

This study develops a decision method that can be used to justify and design different lane-use allocations in an urban street network. It is an effort to determine a way to identify a lane-allocation scenario that can contribute to reduce congestion and improve efficiency with minimum resources, such as pavement markings and traffic signs. The core of the suggested method to achieve this goal consists of identifying different alternatives of lane usage and evaluating the outcome of each alternative. The method involves the application of traffic simulation software, assessment of the performance of different modes of transportation, and summarizing the results in appropriate form to be presented to decision-makers.

In this chapter, the research methodology is presented, followed by a detailed description of the tasks performed to conduct the study. It is beneficial to begin this chapter by highlighting the performance measures related to this study.

3.2. Performance Measures

Performance measures are the primary tools for quantitatively assessing the impact and achievements of plan implementation. They provide a framework within which data that are generated and collected can be presented in a meaningful way. They are results-oriented, meaning they are focused on assessing the outcomes or effectiveness of a specific scenario or alternative. They are presented to decision makers for evaluation, and for the purpose of this study, the following measures could be included:

a. Traffic Congestion Measures

Traffic congestion can be measured in different ways. It could be reflected by measuring the occupied miles of travel as a percentage of total vehicle-miles traveled, road level of service (LOS) and volume-to-capacity (v/c) ratio, vehicle-hours of delay, or by measuring the percentage of transit mode share on corridors. High levels of occupied miles of travel can indicate that the system is not operating efficiently. In reference to road LOS and v/c ratio, Tumlin et al. (2005) identified 0.80 as low (free-flow conditions) and 1.20 as high (congested conditions). Finally, the percentage of transit mode-share is the ratio of transit person trips to total person trips on congested facilities during a peak hour, and it is favorable to have a higher percentage of transit mode-share.

Delay is also an important factor to be measured when assessing traffic congestion. Travel time and delay time are common measures used to assess congestion. For example, they were included in the measures evaluated in the Eugene-Springfield Area TransPlan study (LCOG, 2002). Travel time and average delay are the measures applied in this research.

b. Vehicle Miles Traveled and Trip Length Measures

Measuring vehicle miles of travel and the average trip length (shorter is better) are also two ways to assess the efficiency of a network. They are more beneficial to use in a network study – rather than a corridor study - where vehicles have different options of paths to reach the same destination.

c. Mode Choice Measures

One important factor to evaluate when assessing road efficiency is mode share, which is the number of trips taken by non-auto modes (other than vehicles). A higher number represents a more efficient road, assuming that the passenger density on other modes is higher than it is for autos.

More specific assessments to each mode of transportation include BLOS (Landis, et al. 1997), and BCI (FHWA, 1998) for bicycles. One of the two bicycle performance measures, the BCI, is applied in this study, as described in detail in chapter two. Transit performance measures such as frequency, span of service, reliability, loading, and travel speed were also mentioned in the previous chapter.

d. Environmental Measures

Environmental factors concerning wetlands and streams disturbance, wildlife and plant life disturbance, as well as land use, are not simple to measure. On the other hand, noise levels and vehicle emissions are some of the common environmental measures. Vehicle emissions such as carbon monoxide represent a measure of air quality impact, and obviously lower emissions are better for the environment. Vehicle emissions (CO, NOx, and VOC) were measured in this study to assess the environmental impacts.

e. Transportation System Measures

While the previous set of performance measures reflected impacts of the region’s demand for transportation, the following performance measures reflect impacts of the region’s supply of transportation, and they include:

1. Ratio of bikeway miles to arterial and collector miles
2. Percentage of roadways in fair or good condition: provides a summary of the overall pavement condition of the region’s roadways.
3. Percentage of households within ¼ mile of a transit stop.
4. Percentage of households with access to 10-minute transit service.
5. Parking: In areas where low competition between parking and travel demand exists, it is preferred to maintain all parking. When this competition increases, limited parking removal or significant parking reduction is recommended.

These measures are not applied in this study because the road conditions and households data are not included in the scope of the study. Those measures, however, can be considered for a more comprehensive transportation planning analysis for an urban network.

3.3. Design of the Study/Research Methodology

The method proposed to allocate the limited road space in a congested urban street network among different lane-uses consists of developing a model that helps selecting the configuration that provides the best outcome. An ideal, but not realistic outcome, would provide the lowest travel time for all modes of transportation, the highest

Bicycle Compatibility Index for bicycles, the best total mobility and accessibility, and best safety and environmental impacts. Since it is not possible to achieve an optimal solution for each of the study's objectives, a multi-objective decision-making framework is applied with the understanding that, where this process is applied to an actual decision-making event, some subjective preference must ultimately lead to a single choice.

This section describes the research methodology, followed by a section describing the tasks required to implement the suggested method to demonstrate an application for this method, and a case study is provided in the next chapter.

The research methodology starts by selecting a road segment or an urban transportation network, and several different possible lane-use allocation scenarios are identified. In general, this step should be achieved while taking into consideration the policies of the jurisdiction's master plan, in relation to road classification and role, as well as the guidelines - related to lane widths - identified in the Policy on Geometric Design of Highways and Streets (AASHTO, 2001) and the Guide for the development of bicycle facilities (AASHTO, 1999).

Traffic data are collected and they include: current lane configurations, distribution of modes across the lanes, free flow speed, existing traffic flow numbers for each transportation mode per hour, and occupancy rate for passenger cars as well as buses. Other collected data include traffic control devices, road characteristic data, and transit information (frequency, stops, etc.).

A micro-simulation software package - VISSIM (2004) - is used to model existing traffic conditions and to determine the average speed for each travel mode. The model is then applied to other alternatives with different road-lane allocations. During the modeling phase, one of two important factors should be considered. The first factor is the impact of a new alternative on the travel speed for different modes. The outcome of VISSIM, which provides the average travel speed for each mode, should answer this question. The other factor is: since it is expected that some users would choose a new mode of transportation, as a reflection of the new scenario of lane-use, which might potentially create new congestion patterns, how will the change in mode choice affect the performance of the transportation system? To answer this question, a sensitivity analysis is suggested to provide an understanding of how the model responds when mode choice changes in response to change of travel speed. In the future, a reliable travel demand model could be useful in projecting mode choice and route assignments as reflection of the lane-use configuration.

Using the average speed results, users' cost, delays cost, and operating costs for the different transportation modes are calculated. Other measures of effectiveness for bicycle performance, safety, environmental impact, mobility, and accessibility are also evaluated. These measures include the Bicycle Compatibility Index (BCI), the number of predicted accidents corresponding to a specific lane configuration, emissions rates, the travel time needed to reach a specific attraction from a specific point, and the number of people who can reach a Central Business District (CBD) within a specific time period.

The multi-objective decision-making framework is applied to incorporate the multiple objectives into a process where all of them are considered regardless of whether they can be estimated in monetary or non-monetary terms. The results are then presented to decision makers, and they choose the preferred scenario after evaluating the performance measures of all objectives.

3.4. Tasks

This section describes the tasks performed to develop the proposed method after selecting a specific urban network. These tasks include: 1) identifying the different alternatives for the road allocation among different types of lanes; 2) collecting traffic data; 3) applying a traffic simulation model; 4) applying the BCI for bicycles; 5) computing travel speeds, cost of delays, and operating costs; 6) measuring mobility and accessibility; 7) evaluating environmental and safety impacts; 8) making a decision to choose the preferred alternative; and finally 9) conducting final sensitivity analysis, if needed.

3.4.1. Identifying Different Alternatives

The different alternatives for allocating the road space among the different lane uses are identified using the following equality:

$n_m w_m + n_b w_b + n_c w_c + n_p w_p = W/2$, where

n_m and w_m are the number and width of mixed-traffic lanes, respectively

n_b and w_b are the number and width of exclusive bus lanes

n_c and w_c are the number and width of bicycle lanes

n_p and w_p are the number and width of on-street parking lanes

W = total available road width

This equality represents the available space of the road in one travel direction. The widths of each lane type should be within a range acceptable by traffic standards such as the Policy on Geometric Design of Highways and Streets (AASHTO, 2001). The number of bus, bicycle, and on-street parking lanes should only take the value of zero or one. It should also be taken into consideration that a travel lane could replace a combination of an on-street parking and a bicycle lane during different times of day. Finally, to value the continuity through the network for particular lane types, an effort should be made to apply the same lane-allocation scenario to all segments of the same road.

3.4.2. Collecting Traffic Data

Traffic data are collected at each road in an urban street network during several periods of the day: morning peak period, evening peak period, and during non-peak hours. A study could be limited to demonstrate one of these periods. The traffic data include: the free flow traffic speed, number of vehicles, buses and bicycles per hour, and occupancy rates for both passenger vehicles and buses. Transit information, road characteristics, and traffic control data should also be collected to best simulate the existing conditions of traffic operations on this section of the road. Traffic control data include pavement markings identifying lane-use and lane configuration, traffic signs such as stop signs, speed limit signs, and traffic signal timing and phases.

3.4.3. Applying a Traffic Simulation Model

The use of VISSIM (2004) model is suggested in this study to generate data for different alternatives. This model is recommended for the following reasons: a) It has a microscopic simulation model capable of modeling detailed design features and visualizing traffic animation, b) its parameters have been calibrated to US conditions, c) it can analyze a wide range of traffic, geometric and control conditions, and produces a relatively rich set of performance measures, d) it is capable of modeling bus operations including different bus routes and bus stations within a network, e) it is a comprehensive software system designed for multimodal analysis including bicycle lanes, f) it allows the integration of all relevant modes of transportation into one consistent network model, and g) other than the average travel speed for each mode, the output of this software includes other measures of effectiveness such as total travel time, delays, and emissions that could be used to compare alternatives.

3.4.4. Applying the BCI for Bicycles

This task consists of calculating the Bicycle Compatibility Index (BCI) for each scenario. BCI is the bicycle performance measure described earlier to be applied in this study. The general equation to calculate the BCI for each scenario is as follow:

$$\mathit{BCI} = 3.67 - 0.966\mathit{BL} - 0.41\mathit{BLW} - 0.498\mathit{CLW} + 0.002\mathit{CLV} + 0.0004\mathit{OLV} + 0.022\mathit{SPD} + 0.506\mathit{PKG} - 0.264\mathit{AREA} + \mathit{AF}$$

3.4.5. Computing Travel Speeds, Cost of Delays, and Operating Costs

The next step is to compute the user cost, delay cost, and the operating costs for each mode of transportation. The users' cost depends largely on the average speed of the corresponding mode of transportation, which is one of the software outcomes. The users' cost could be limited to the time they spend in the transportation system, or could be extended to include wait time, fare cost for transit, and operating cost for private vehicles. The cost of delays for users is computed by multiplying the total delay time users experience while traveling within the corridor by an estimated average hourly user time value.

The travel value of time is highly variable (Small et al., 2005) and depends on several factors, which include the type of trip, travel conditions, traveler preferences, mode of transportation, and time of day. For example, people with full time jobs traveling during peak periods on congested roadways and crowded buses tend to have a higher time value, and therefore, are willing to pay more for travel time compared to retired or unemployed people. An example of a lower travel time value is a recreational drive or train trip where people enjoy the experience (Mokhtarian, 2005)

Travel time values can be estimated differently for different portions of a trip. The US Department of Transportation (1997) used the following travel time values for evaluating transportation projects (per person-hour in 1997 U.S. Dollars): in-vehicle time $8.90, out-of-vehicle time, $17.00, and commercial truck, $16.50. In another example, TransFund New Zealand (1998) uses standard travel time values with detailed instructions for applying the following values (in 1998 NZ Dollars per hour) for travel work purpose: $21.30 for auto driver, $19.25 for light commercial driver, $15.80 for heavy commercial driver, and $21.30 for cyclist, pedestrian, and bus passenger. Those values are reduced during non-peak periods by 50% for pedestrians, cyclists, and standing bus passengers, by 66% for auto and light commercial drivers, and by 75% for auto passengers and seated bus passengers.

The operating cost for each mode of transportation is determined by multiplying the total number of miles traveled by each mode by its related unit operating cost. This unit cost is determined through collecting financial data about fleet maintenance costs available from a local government jurisdiction; in the study case, maintenance costs were obtained from the City of Rockville, Maryland, USA. Fuel cost for idle time is also calculated. More details about the operating and idling costs are presented in chapter four, section 5.

3.4.6. Measuring Mobility and Accessibility

As Litman (2003) concluded that there is no single convenient and comprehensive way to measure transportation performance, measuring mobility and/or accessibility is one of the challenges facing this study.

a. Mobility

Mobility refers to the movement of people or goods. The increase in travel mileage or speed is perceived to benefit society. In case of a transportation network, mobility can be measured by quantifying person-miles, ton-miles and travel speeds. It can also be measured by determining the travel time needed to reach a specific attraction from a specific point. The latter method is applied in this study as will be described in the next chapter where a case study is demonstrated.

b. Accessibility

Accessibility refers to the ability to reach desired services, activities or destinations. Improving accessibility also benefits society, and mobility is one way to achieve this goal. As mentioned earlier, there are several ways to measure accessibility. Determining the number of people who can reach a specific destination within a specific time-period, such as a 15-minute period, using a specific mode of transportation, is more practical and suitable for application in this study.

One issue here is that both mobility and accessibility better represent a network system rather than a specific route. Therefore, a better assessment of mobility and accessibility can be made for an urban network rather than a section of a road.

3.4.7. Evaluating Environmental and Safety Impacts

Although the environmental and accident cost can be estimated using unit environment cost and unit accident cost, this study considers more accurate methods of measuring the environment and safety impacts.

a. Measuring Environmental Impact

Methods proposed by Krizek (2004) to estimate and evaluate the economic benefits of bicycle facilities, and emission models applications such as MOBILE6 (2003) were investigated. It has been determined that comparing emissions generated by the

MOBILE6 model for each scenario is a reasonable approach in this study. For each average travel speed generated by VISSIM (2004), the emission model's run provides emission rates for carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC), among other emissions. Volatile Organic Compounds are one of the main precursors of ground level ozone, which is toxic to plants and can cause breathing difficulties in humans (Environment Agency, 2006). For each scenario, emission rates are accumulated for all vehicles including emission rates from idling. A total number for CO, NOx, and VOC generated from the transportation system is calculated for each scenario.

b. Measuring Safety Impact

Accident prediction models were investigated to predict the number of potential accidents corresponding to each alternative. The model suggested to be applied in this study is the one presented by the Federal Highway Administration (1999) for roadway segments where the number of predicted accidents is a function of the lane width, as described in the previous chapter. The model described for a four-leg signalized intersection can also be used. However, it does not include variables for lane widths, but rather for left-turn movements, presence of protected left-turn signal phase on the major road, percentage of trucks, number of driveways near the intersection, and average daily traffic volume on both the major and minor roads.

Bicycle safety is also considered when assessing safety impact. As mentioned in the previous chapter, research showed that the existence of a bicycle lane contributed to safety improvement; drivers make fewer wide swerves when passing bicyclists on streets with bicycle lanes. Bicycle lanes also influence bicycle and motor vehicle positioning, and increase motorist awareness of cyclists on the street. Since it is not possible to quantify safety impacts for cyclists in this study, it is reasonable to apply the results obtained when computing the BCI to assess bicycle safety, as previously suggested.

3.4.8. Making a Decision

Several objectives have been identified for this research, including but not limited to: reducing costs and travel time, improving mobility and accessibility, increasing safety, reducing emissions, and improving bicycle operation. Each of these objectives is determined for each suggested alternative when evaluated, but many of them, such as improving air quality, cannot be transformed into a single monetary dimension. Therefore, a multi-objective decision-making framework is employed to incorporate the multiple and conflicting objectives into a process where all of them are equally considered regardless of whether they can be estimated in monetary or non-monetary terms.

The suggested multi-objective decision-making framework is a modified version of the method proposed by Chowdhury and Tam (2005) presented in the previous chapter. The suggested method consists of identifying the objectives, selecting lane configuration scenarios, selecting MOEs, calculating the values of MOEs for each scenario, and transforming the values into a 0-to-100 scale. The scenario scoring the highest value among the other scenarios receives 100 percent while the other scenarios receive a value less than 100 percent and correspondent to the performance level at the same objective. The results are then presented to decision-makers in the form of charts demonstrating the result of each objective when corresponding to a specific scenario. Different charts are provided to emphasize the result of specific objectives (travel time and delays for example), and one comprehensive chart can demonstrate a summary of all objective performances.

This suggested method differs from the one presented by Chowdhury and Tam (2005) since it eliminates the constraint model. Instead, the limits of each performance will be presented as the top and bottom values of each objective's result accumulated from the outcome of all considered scenarios. The benefits of this modified method are twofold; first, there is no real benefit of knowing the optimal value of one objective unless it is a possible value associated with one of the identified scenarios. Second, this is a simplified method that has a better chance for application in the real world. It is unlikely that transportation planners and/or engineers would have the tools and resources to formulate and solve a constraint model. Transforming the performance values into a relative comparison, and presenting them in the form of charts, is more likely to be achieved with available resources. As mentioned earlier, this method is not influenced by decision-makers input, and a decision can be made pending on the objectives that are most important for the decision-makers to achieve at the time when the decision is made.

3.4.9. Conducting Final (Sensitivity) Analysis

Sensitivity analysis can be conducted, if needed, to further analyze the results and to provide an understanding of how the model responds when input are changed. The input change in this study could be the mode choice, the number of passengers per auto and per bus, the number of passenger vehicles, buses, and bicycles, lane width, and user time value.

3.5. Summary of Research Methodology

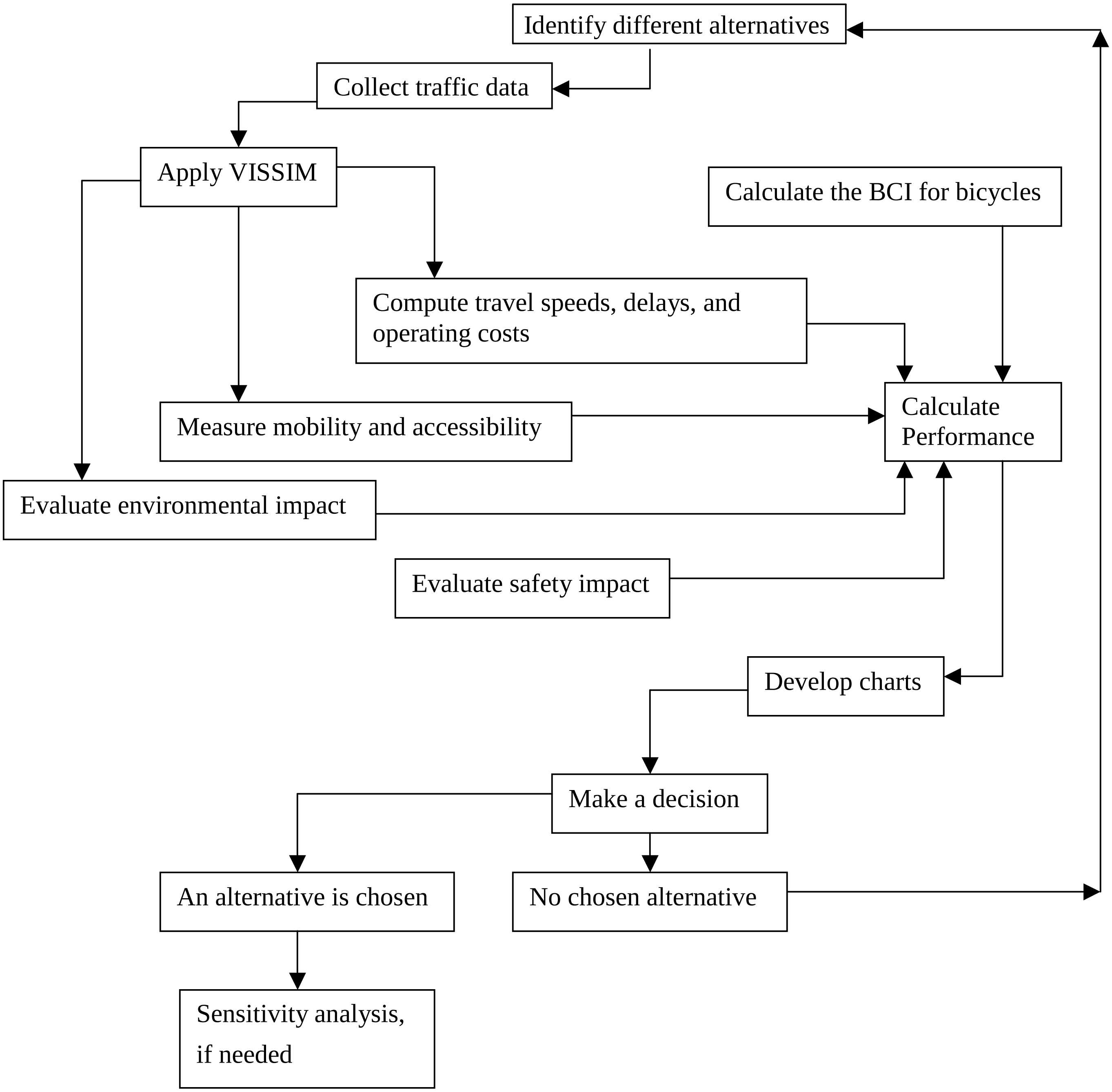
In this chapter, an overview of the performance measures was provided and a detailed description of the research methodology was presented. Tasks required to perform the suggested decision method for roadway lane designation were discussed. The tasks include: 1) identifying the different alternatives for the road allocation among different types of lanes; 2) collecting traffic data; 3) applying a traffic simulation model; 4) applying the BCI for bicycles; 5) computing travel speeds, cost of delays, and operating costs; 6) measuring mobility and accessibility; 7) evaluating environmental and safety impacts; 8) preparing charts and making a decision to choose the preferred alternative; and finally 9) conducting final sensitivity analysis, if needed. **Figure 1** summarizes the suggested procedure to perform the decision-making method for roadway lane-use designation among the variable modes of transportation.

There are two different ways this method can be employed. First, when the potential scenarios are limited to a small number, all scenarios can be evaluated and the results presented to the decision-makers. This can be applied in studies for short corridors, relatively small networks, or narrow roadways where the options are limited. Second, in case of large networks, where large number of scenarios can be generated automatically, a method of assigning weights to the measures of effectiveness, such as the analytical hierarchy process (AHP) can be applied (Saaty, 1980). This process incorporates both qualitative and quantitative factors, based on priorities set by decision-makers, and simplifies complex decisions to a set of one-on-one comparisons (Tighe and Smith, 2005).

The AHP consists of setting up the hierarchy for priorities, comparing characteristics of each factor, establishing priority vector, conducting a pair-wise comparison of scenarios/alternatives, establishing priority vectors for alternatives in priority matrices, and obtaining the overall ranking of alternatives. This process was applied to make a recommendation for the best transportation system management in the town of Bremen (Boulter, 1999).

Although it is not specifically recommended to apply the AHP in the proposed method in this research, since it includes input from stakeholders, it might be necessary to apply in some cases to narrow the number of scenarios to be evaluated in a comprehensive way.

Figure 1. Tasks required to perform the decision-making method for roadway lane designation



Chapter IV: NUMERICAL EXAMPLE AND RESULTS

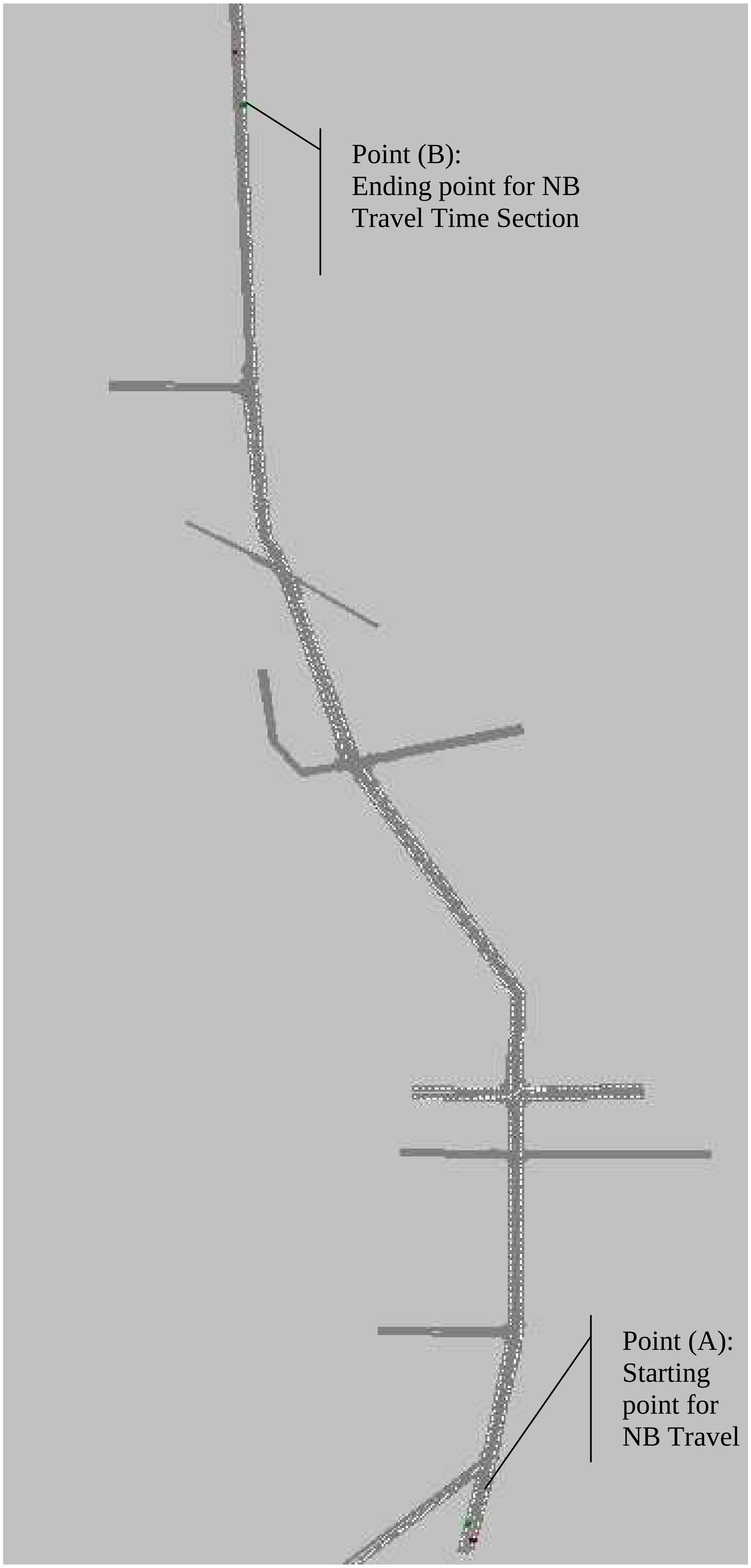
In this chapter, a numerical example is presented where the suggested method to assess lane-use allocation among a variety of viable modes is applied. The example is for an existing section of a roadway adjacent to the Alderwood Mall, located at 3000 184th Street, SW, Lynnwood, Washington, USA. The original model of this section was prepared as a VISSIM demonstration for a traffic simulation in an urban roadway. The model was modified with different lane configurations to present different scenarios to be compared. The section is approximately 1.3 miles long and includes six major signalized intersections and three bus stops in each direction. **Figure 2** shows the starting and ending points of the traveled section.

While presenting this numerical example, the tasks described in the previous chapter were followed in the same order: 1) identifying different alternatives for the road allocation among different types of lanes; 2) collecting traffic data; 3) applying a traffic simulation model; 4) applying the BCI for bicycles; 5) computing travel speeds, cost of delays, and operating costs; 6) measuring mobility; 7) measuring accessibility; 8) evaluating environmental impact; 9) evaluating safety impact; 10) making a decision to choose the preferred alternative; and finally 11) conducting final sensitivity analysis, if needed.

4.1. Identifying Different Alternatives

The different alternatives for allocating the road space among the different lane uses were identified using the following equality as described earlier:

Figure 2 - Travel Section (NB & SB)



$n_m w_m + n_b w_b + n_c w_c + n_p w_p = W/2,$

This equality represents the available space of the road in one travel direction. Since scenarios include mixed traffic, exclusive bicycle, and exclusive bus lanes, three random scenarios were chosen for a road width of $W = 52$ feet (26 feet in each direction) as shown in **Figures 3, 4, and 5**:

1. Two 13-foot mixed-traffic lanes
2. One 12-foot mixed-traffic lane and one 14-foot exclusive bus lane
3. Two 10.5-foot mixed-traffic lanes and one 5-foot bicycle lane

Although scenarios are usually limited to a handful of options, in some cases - where the road is relatively wide - a dozen or more potential options might be possible. Some form of automated scenario generation could be a useful future research idea, although it is difficult to replace the human judgment and experience that normally leads to those choices.

Figure 3 - Lane Configuration for Scenario # 1

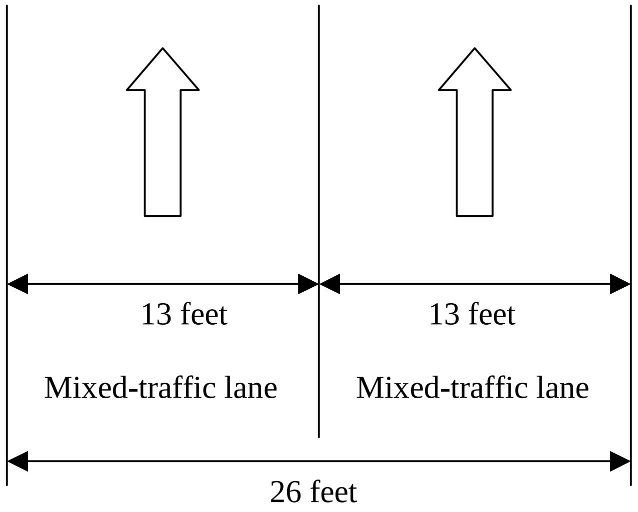


Figure 4 - Lane Configuration for Scenario # 2

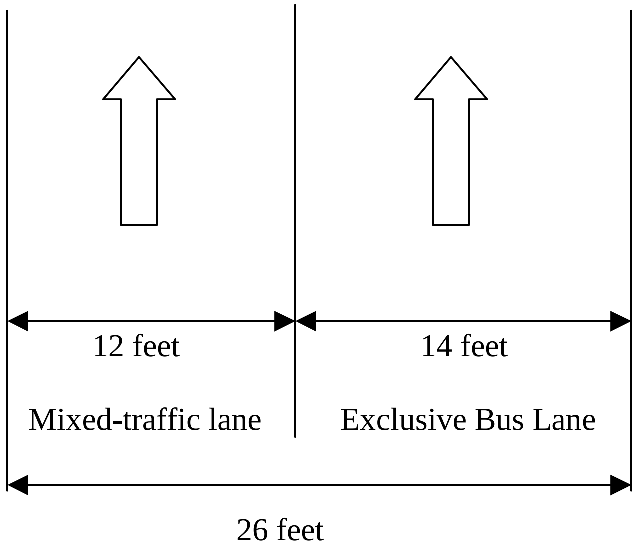
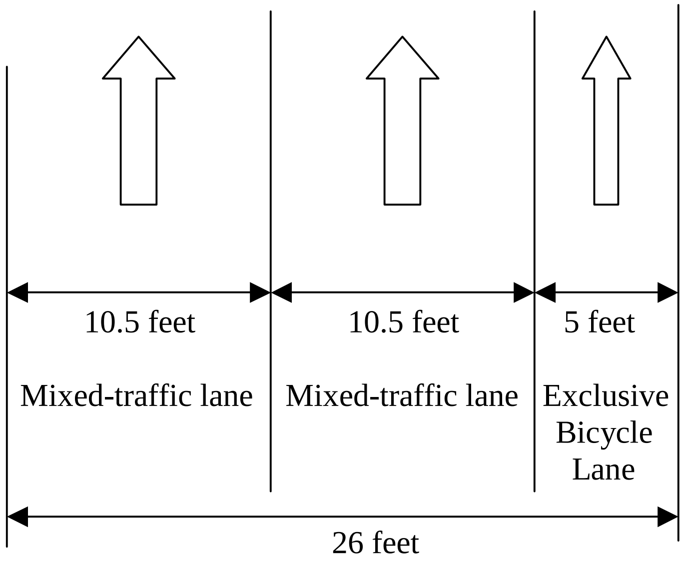


Figure 5 - Lane Configuration for Scenario # 3



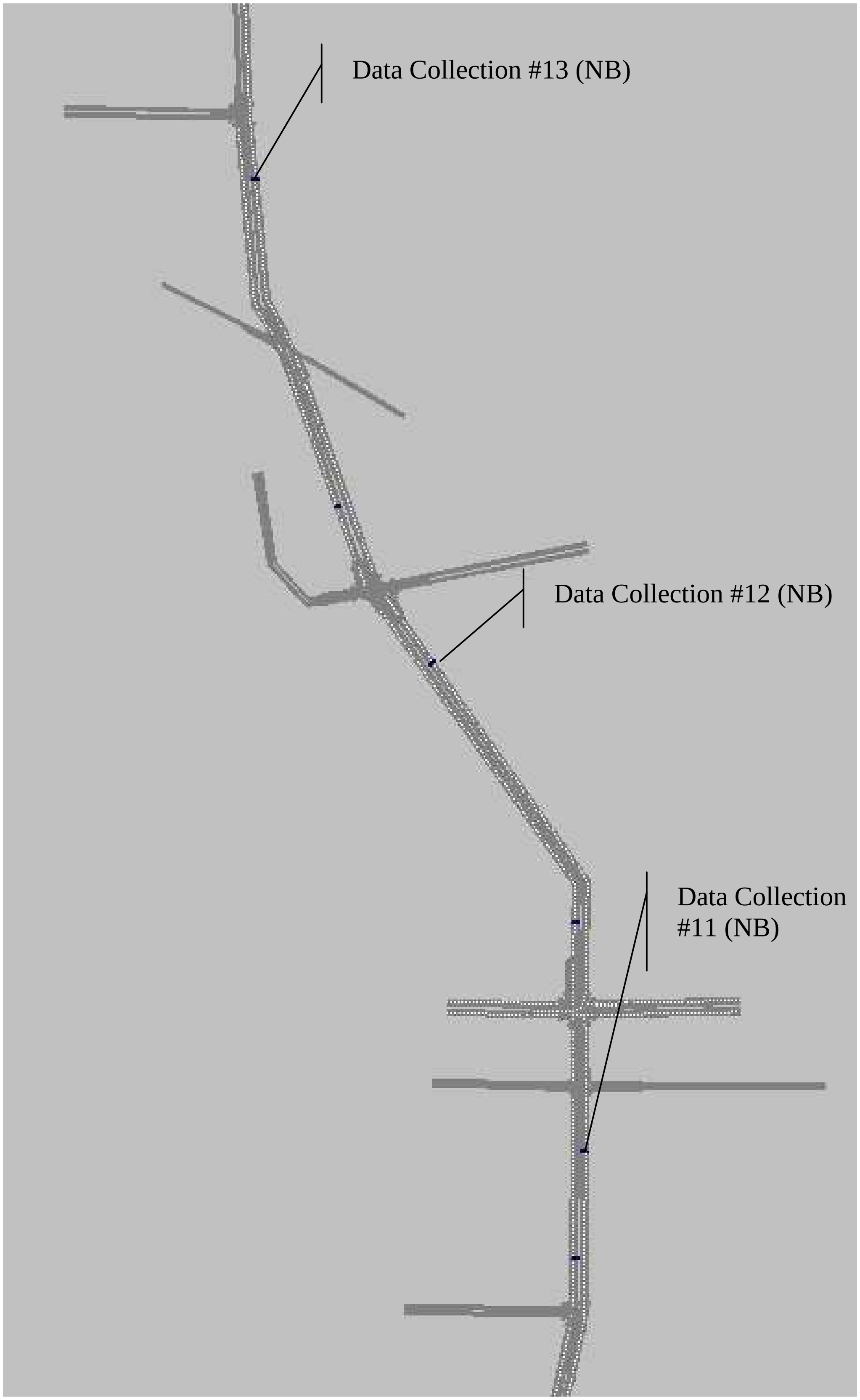
4.2. Traffic Data

Existing traffic data for flow, speed, road characteristics, and traffic control devices were applied for each scenario. The bicycle flow rate in this example is 16 bicycles per hour, and the bus flow rate is 12 buses per hour for all three scenarios. Although the traffic flow on the main road consists of approximately 1,500 vehicles per hour, only 60 passenger vehicles make the full trip in the corridor from the upstream point (A) to the downstream point (B) shown in figure 2 for the northbound traffic. VISSIM uses routes instead of turning movements at intersections, and the input is in origin-destination format. Only those vehicles that pass over both the starting and ending points are captured. The occupancy rates for buses and vehicles were estimated to be 20 and 1.2 passengers per vehicle, respectively. Road characteristics and traffic control data were also incorporated in this example to best simulate the existing conditions of traffic operations on this section of the road.

4.3. Applying a Traffic Simulation Model

As mentioned earlier, the traffic simulation software VISSIM was the model selected to generate data for the different scenarios applied in this study. The software allows the integration of the different transportation modes available in this example into one consistent network model. Detailed outputs for each scenario are provided in **Appendix A**. The raw numbers coming from the output include travel times, delays, average standstill time per vehicle, and average stops per vehicle for each mode of transportation. Speed data are also collected at three different points as shown in **Figure 6.**

Figure 6 - Data Collection Points for Speeds



Tables 4 through 7 summarize some of the average outputs of several runs of the model for each scenario, and include average travel speed, average travel time, and average delay for each mode of transportation. The travel time is the time spent in the corridor from point (A) upstream to point (B) downstream. The average travel speed is the distance traveled between point (A) and point (B), divided by the total travel time, and the delay time is the difference between the theoretical (ideal) travel time and the real travel time. The theoretical travel time is the time that would be required if there were no other vehicles, no signal controls, and no other stops in the corridor or network.

Table 4. Summary of the VISSIM Output for Scenario #1; Two 13-foot Mixed-traffic lanes

Scenario # 1	**Average Travel Speed (mph)**	**Average Travel Time (seconds)**	**Average Delay (seconds)**
Passenger Vehicle	**22.55**	**203.0**	**63.6**
Bus	**14.96**	**306.0**	**87.1**
Bicycle	**13.15**	**348.1**	**51.7**

The table above summarizes the results of scenario #1, which consists of two 13-foot mixed traffic lanes. It shows that although passenger vehicles and buses share the same lanes, buses are slower when averaged over the entire roadway. This occurs because buses have to stop to load and unload passengers. The average travel speed for bicycles is slightly less than the one for buses. It should be noted here that the average travel speed shown in the table is the total traveled distance (6,714.6 feet) divided by the total travel time, which includes both moving and idling times.

Table 5. Summary of the VISSIM Output for Scenario #2; One 12-foot Mixed Traffic Lane and one 14-foot Exclusive Bus Lane

Scenario # 2	Average Travel Speed (mph)	Average Travel Time (seconds)	Average Delay (seconds)
Passenger Vehicle	**18.79**	**243.8**	**104.5**
Bus	**14.71**	**311.3**	**91.0**
Bicycle	**12.80**	**357.7**	**61.5**

Table 5 summarizes the results of scenario #2, which consists of one 12-foot mixed-traffic lane, and one 14-foot exclusive bus lane. It shows that by separating the mixed traffic from buses, mixed traffic suffered from using one lane instead of two. The average travel time for mixed traffic increased from 203.0 to 243.8 seconds (20 percent increase). Bicycles in this scenario were traveling with the buses in the exclusive bus lane, and their average travel time increased by 9.6 seconds (2.8 percent). Their average speed, however, was slightly less than the case of scenario # 1.

The interesting outcome of this scenario is that although buses have their exclusive lane, their average delay increased from 87.1 to 91.0 (4.5 percent), and the bus travel time was nearly unchanged. It increased from an average of 306.0 seconds in scenario # 1 to 311.3 seconds in scenario # 2, i.e. by 1.7 percent. This could be explained by the fact that the benefit of having an exclusive bus lane was offset either by the interaction between buses and bicycles sharing the same lane, or the right-turn movements performed by the mixed traffic, which would cause the buses to stop more frequently. It could also be an indication that in this road section, buses are not influenced by passenger vehicles, and the exclusive bus lane did not make much difference for buses' travel performance.

In order to further investigate the reason behind this result, a new scenario (# 2b) was applied. This scenario is identical to scenario # 2, except that bicycles were not included. This new scenario resulted in the outcome shown in **Table 6** below.

Table 6. Summary for Scenario #2b; similar to Scenario #2 without Bicycles

Scenario # 2b	**Average Travel Speed (mph)**	**Average Travel Time (seconds)**	**Average Delay (seconds)**
Passenger Vehicle	**17.4**	**263.2**	**125.4**
Bus	**14.7**	**311.8**	**92.6**

In summary, the results of scenario # 2b confirmed that the mixed traffic is suffering from traveling in one lane instead of two. The average travel time for buses did not improve in this scenario compared to scenario # 2, which included bicycles. Another model run for this scenario provided an average travel time of 307.4 seconds, which is within 1.2 percent of the original result generated by scenario # 2. Therefore, it is most likely that the interaction between bicycles and buses did not have impact on the buses' travel time, and it is most probably that the exclusive bus lane is not justified in this case since it did not help the buses and, at the same time, had negative impact on passenger vehicles.

Table 7 below shows the outcome of running the model with scenario #3, which consists of two 10.5-foot mixed-traffic lanes and one 5-foot bicycle lane. Scenario # 3 - compared to scenario # 1 - has a small effect on passenger vehicles and buses. The average travel time increased by 3.0 seconds for autos (1.5 percent) and 7.9 seconds for buses (2.6 percent). Another important note is that both the bicycle average travel time and average travel speed did not change much even though the bicycles have their own exclusive lane in this scenario. Also, there was approximately a 5.7 and 4.1 percent increase in the average delay for passenger vehicles and for buses, respectively. For any project with a set of alternatives, this type of analysis and discussion is possible. The nature of the differences in outputs tends to be intuitive, although the magnitudes of the changes need the thorough analysis to qualify accurately. Importantly, however, there are “winners” and losers” with each scenario, and these must be considered against one another in order for a decision to be made. This will be further discussed later in this chapter under section 11.

Table 7. Summary of the VISSIM Output for Scenario #3; Two 10.5-foot Mixed Traffic Lanes and one 5-foot Exclusive Bicycle Lane

Scenario # 3	**Average Travel Speed (mph)**	**Average Travel Time (seconds)**	**Average Delay (seconds)**
Passenger Vehicle	**22.23**	**206.0**	**67.2**
Bus	**14.59**	**313.9**	**90.7**
Bicycle	**12.90**	**355.0**	**58.8**

Visual tools tend to be very powerful at illuminating differences and tradeoffs in performance measures. To this end, charts were developed to summarize the results of the analysis described above. The charts in **Figures 7, 8 and 9** provide comparisons of scenarios for the average speed, average travel time, and average delay time for each transportation mode in each scenario.

Figure 7. Average Speed Comparison

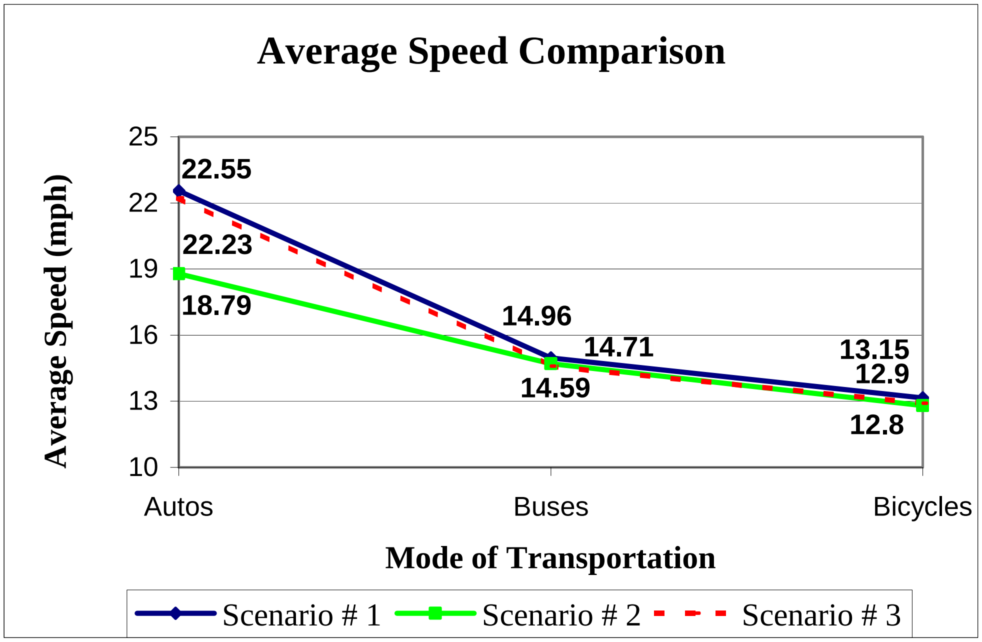


Figure 8. Average Travel Time Comparison

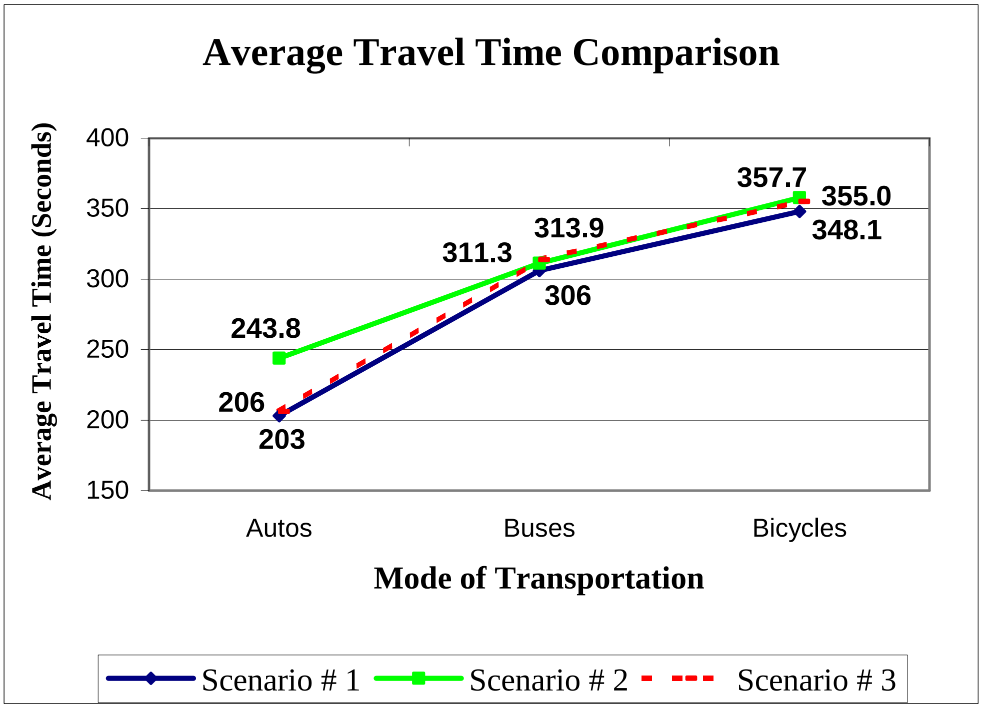
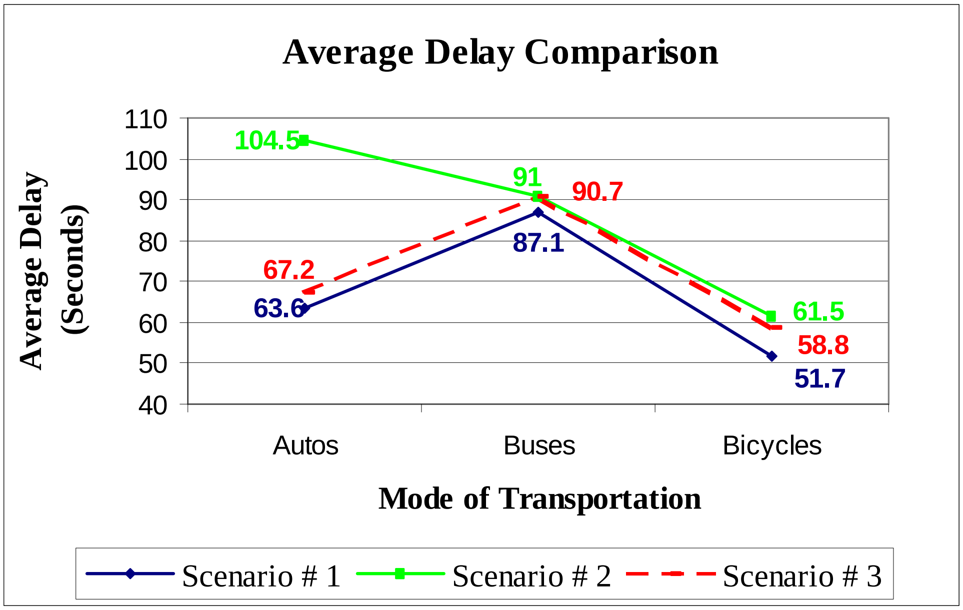


Figure 9. Average Delay Time Comparison



4.4. Applying the BCI for bicycles

As mentioned earlier, the Bicycle Compatibility Index (BCI) is the bicycle performance measure applied in this study to evaluate the compatibility or suitability of bicycle travel along the roadway understudy. Using the general equation, previously described in section 2.3.1, to calculate the BCI for each of the three scenarios resulted in the following outcome:

$$BCI = 3.67 - 0.966BL - 0.41BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

<u>Scenario # 1:</u>

$$BCI = 3.67 - 0.966(0) - 0.41(0) - 0.498(4.0) + 0.002(1209/2) + 0.0004(1209/2) + 0.022(41.98) + 0.506(0) - 0.264(0) + (0) = 4.05$$

Scenario # 2:

$BCI = 3.67 - 0.966(0) - 0.41(0) - 0.498(4.3) + 0.002(12) + 0.0004(1161) + 0.022(37.8) + 0.506(0) - 0.264(0) + (0) = 2.85$

Scenario # 3:

$BCI = 3.67 - 0.966(1) - 0.41(1.5) - 0.498(3.2) + 0.002(1199/2) + 0.0004(1199/2) + 0.022(39.7) + 0.506(0) - 0.264(0) + (0) = 2.81$

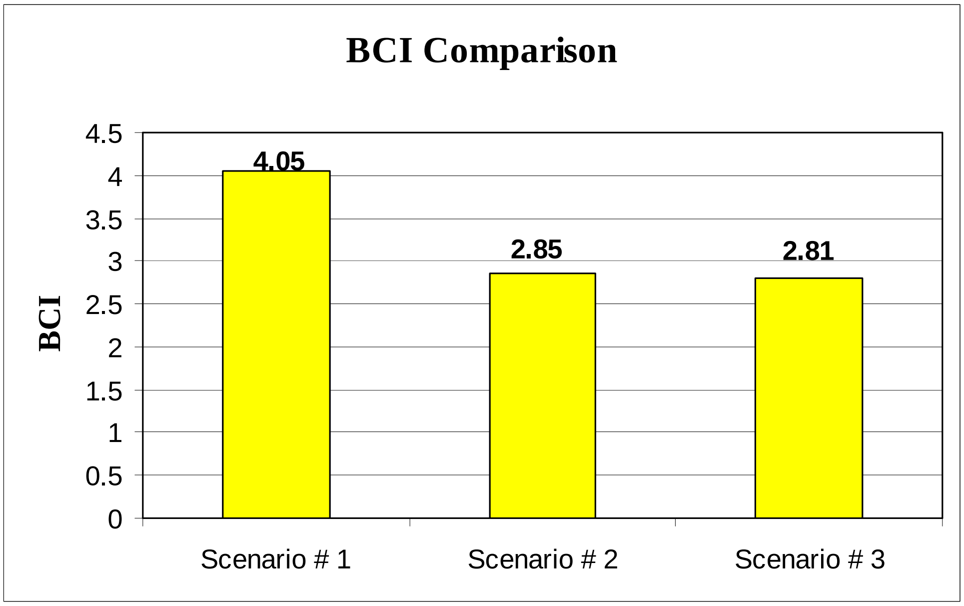
From the results above, it is clear that scenario # 3 has the lowest BCI, a value of 2.81, which is equivalent to a level of service C, a moderately high compatibility level. The BCI for scenario # 2 was a close second with a value of 2.85, also equivalent to a level of service C. Scenario #1 had the highest value of 4.05, equivalent to a level of service D, a moderately low compatibility index, which is approximately 42 and 44 percent higher that the related values for scenarios # 2 and # 3, respectively.

This result was expected since scenario # 3 includes an exclusive lane for the bicycles, and therefore, provides a high BCI. It was followed by scenario # 2 where bicycles and buses share a wide lane, and finally, a narrower shared-lane – for scenario # 1 - was the least favorable for bicyclists. **Figure 10** shows the BCI comparison for the three scenarios.

4.5. Computing Travel Speeds, Cost of Delays, and Operating Costs

The average travel speed was computed earlier (see Figure 7) for each mode of transportation. To compute the users' cost, the average travel time was simply multiplied by an estimated average hourly user time value of $20 per hour. It should be noted here that the users' cost in this example is limited to the time spent in the transportation system between points A and B. A more detailed analysis could take into consideration the time spent from door to door to include wait time, e.g. at the bus stop, and walking time. Vehicle operating cost could be added to the users' cost, as it will be explained in the next few pages.

Figure 10. BCI Comparison



<u>Scenario # 1:</u>

Users' cost for auto user = (203.0/3600) x $20/hour = $1.13

Users' cost for bus user = (306.0/3600) x $20/hour = $1.70

Users' cost for bicycle = (348.1/3600) x $20/hour = $1.93

<u>Scenario # 2:</u>

Users' cost for auto user = (243.8/3600) x $20/hour = $1.35

Users' cost for bus user = (311.3/3600) x $20/hour = $1.73

Users' cost for bicycle = (357.7/3600) x $20/hour = $1.99

Scenario # 3:

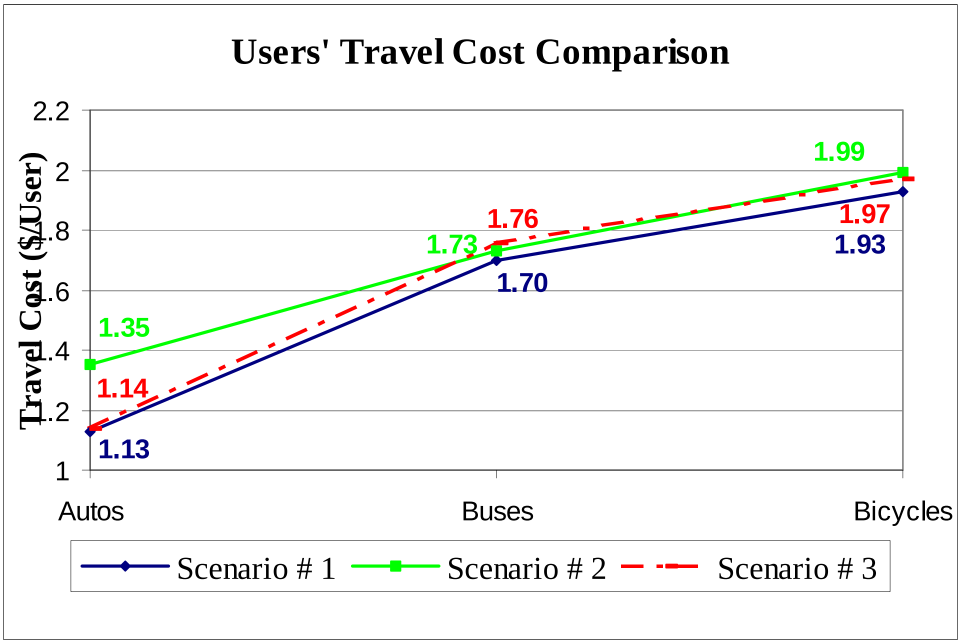
Users' cost for auto user = (206.0/3600) x $20/hour = $1.14

Users' cost for bus user = (313.9/3600) x $20/hour = $1.76

Users' cost for bicycle = (355.0/3600) x $20/hour = $1.97

The results of the users' costs for the different modes of transportation (shown is **Figure 11**) reflect the results obtained from the average total travel time that users spent in the corridor from point (A) upstream to point (B) downstream.

Figure 11. Users' Travel Cost Comparison



The average travel time includes the time when the mode of transportation is moving in addition to the delay time when it is stopping/idling. It is noted that in scenario #2, the users' cost for auto users is approximately 19 percent higher than the related values for the other two scenarios.

In order to distinguish the cost of delay, the users' delay cost was also calculated. The computation is similar to the one applied to obtain the total user cost. In this case, the estimated average hourly user time value is multiplied by the average delay time users experience while traveling within the corridor instead of the average travel time. The result is as follow:

Scenario # 1:

Users' delay cost for vehicle user = (63.6/3600) x $20/hour = $0.35

Users' delay cost for bus user = (87.1/3600) x $20/hour = $0.48

Users' delay cost for bicycle = (51.7/3600) x $20/hour = $0.29

Scenario # 2:

Users' delay cost for vehicle user = (104.5/3600) x $20/hour = $0.58

Users' delay cost for bus user = (91.0/3600) x $20/hour = $0.50

Users' delay cost for bicycle = (61.5/3600) x $20/hour = $0.34

Scenario # 3:

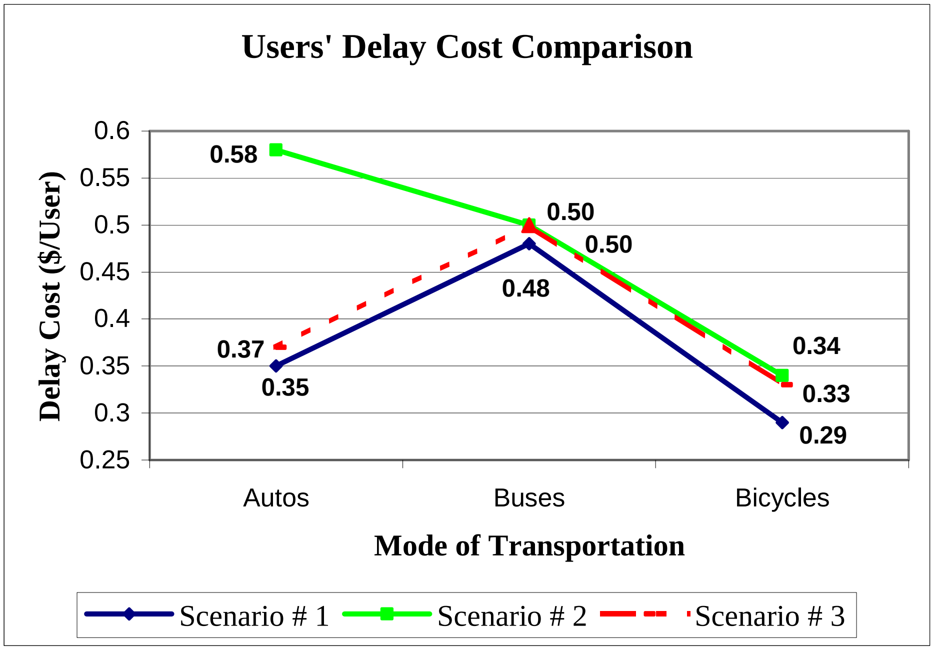
Users' delay cost for vehicle user = (67.2/3600) x $20/hour = $0.37

Users' delay cost for bus user = (90.7/3600) x $20/hour = $0.50

Users' delay cost for bicycle = (58.8/3600) x $20/hour = $0.33

The results of the users' delay costs for the different modes of transportation reflect the results obtained from the average delay time that users spent in the corridor from point A upstream to point B downstream. It should be noted here that in scenario #2, the users' delay cost for auto users is approximately 66 and 57 percent higher that the related values for scenarios # 1 and # 3, respectively. **Figure 12** presents a comparison of users' delay cost for each mode of transportation for the three scenarios.

Figure 12. Users' Delay Cost Comparison



The operating cost for each mode of transportation is determined by multiplying the total number of miles traveled by each mode by its related unit operating cost. This unit cost is determined through collecting financial data about fleet maintenance costs available from a local government agency: the City of Rockville, in Montgomery County, Maryland, USA. **Table 8** below summarizes operational costs for different types of vehicles as an average of total cost spent during calendar year (2005) for different types of vehicles. More details of operational costs are attached in **Appendix B**.

Table 8. Vehicles' Operational Costs per Mile

Vehicle Type	Repair ($/mile)	Maintenance ($/mile)	Fuel ($/mile)	Total Operational Cost ($/mile)
Sedan	**0.137**	**0.030**	**0.111**	**0.278**
Police Cruiser	**0.214**	**0.020**	**0.203**	**0.436**
Pickup < 5000 GVW	**0.220**	**0.029**	**0.144**	**0.393**
4 x 4 Sport Utility	**0.216**	**0.037**	**0.133**	**0.385**
Minivan	**0.237**	**0.025**	**0.166**	**0.428**
Bus	**0.426**	**0.026**	**0.290**	**0.742**

Although these data are not from the same jurisdiction as the case study, this is irrelevant. The point is that such data exist at the jurisdiction level and anyone applying these methods could determine them.

Since this case study is only comparing scenarios on a corridor, and there is only one route from point (A) to point (B), the distance traveled between the two points is the same for all vehicles. The operational cost comparison would be more meaningful in case of a network when drivers can choose different routes and thus, travel different distances, which would produce different operational costs. It can also be applied to compare different scenarios with different traffic flows for each mode of transportation since the operation cost of a passenger vehicle is less than that of a bus.

In order to compare operational costs for the different scenarios in this case study, the operational costs during the travel are added to the costs of idle time. **Table 9** summarizes the average idle time for each unit of mode of transportation for each of the three scenarios. The average idle time (seconds) is calculated by multiplying the average number of stops per vehicle and the average standstill time per vehicle (seconds), obtained from VISSIM's outputs.

Table 9. Average Idle Time per Mode of Transportation (in Seconds)

Total Idle Time per Unit Mode of Transp. (Seconds)	**Passenger Vehicle (Avg. Idle time x Avg. # of stops)**	**Bus (Avg. Idle time x Avg. # of stops)**	**Bicycle (Avg. Idle time x Avg. # of stops)**
Scenario # 1	35.8 x 2.4 = 85.92	25.0 x 1.7 = 42.5	36.1 x 2.6 = 93.90
Scenario # 2	43.4 x 2.74 = 118.9	24.6 x 1.74 = 42.8	46.8 x 3.03 = 141.8
Scenario # 3	39.3 x 2.5 = 98.25	29.5 x 2.1 = 61.95	40.2 x 2.5 = 100.5

Fuel expenses - during idling - per vehicle per trip can be calculated assuming a typical vehicle burns about 1 gallon of gasoline per idling hour (GPS Fleet Solutions, 2006), for a cost of $3/gallon, which was the US national's average price in August 2006 (USA Today). Of course, fuel costs change over time, and some agreement would have to be reached among the involved parties as to what an appropriate value would be. For future projects, this could be a point of some contention, and one could perform sensitivity analysis with respect to fuel price, or run full sets of analyses that are identical except for competing choices of fuel price. In this study, the cost of fuel used during idling was added to the operational cost during traveling and the total operating costs of autos and buses traveling between upstream point (A) and downstream point (B) were calculated as follows:

Scenario # 1:

Operating cost for autos: [$3 (85.92)/3600 + 0.278 * 1.3] * 60 autos = $26.0

Operating cost for buses: [$3 (42.5)/3600 + 0.742 * 1.3] * 12 buses = $12.0

Total operating cost: $38.0

Scenario # 2:

Operating cost for autos: [$3 (118.9)/3600 + 0.278 * 1.3] * 60 autos = $27.6

Operating cost for buses: [$3 (42.8)/3600 + 0.742 * 1.3] * 12 buses = $12.0

Total operating cost: $39.6

Scenario # 3:

Operating cost for autos: [$3 (98.25)/3600 + 0.278 * 1.3] * 60 autos = $26.6

Operating cost for buses: [$3 (61.95)/3600 + 0.742 * 1.3] * 12 buses = $12.2

Total operating cost: $38.8

It is noted that the operating cost for an auto in scenario # 2 is approximately 6.2 and 3.8 percent higher that the related values for scenarios # 1 and # 3, respectively. The comparison for buses did not show more than 1.7 percent deviation among all three scenarios. For the total operating cost, scenario # 2 is approximately 4.2 and 2.1 percent higher than scenario #1 and scenario # 3, respectively. **Figure 13** shows a comparison of total operating cost for both autos and buses for each of the three scenarios.

4.6. Measuring Mobility

As mentioned previously, mobility can be calculated by quantifying the travel time needed to reach a specific point of attraction such as a CBD. By reviewing the travel time results of the three scenarios, the following summarizes the total travel time used by 60 autos, 12 buses, and 16 bicycles to travel between upstream point (A) and downstream point (B):

Total Travel Time for scenario # 1: (60 x 203) + (12 x 306) + (16 x 348.1)

= 21421.6 vehicle-seconds = 5.95 vehicle-hours

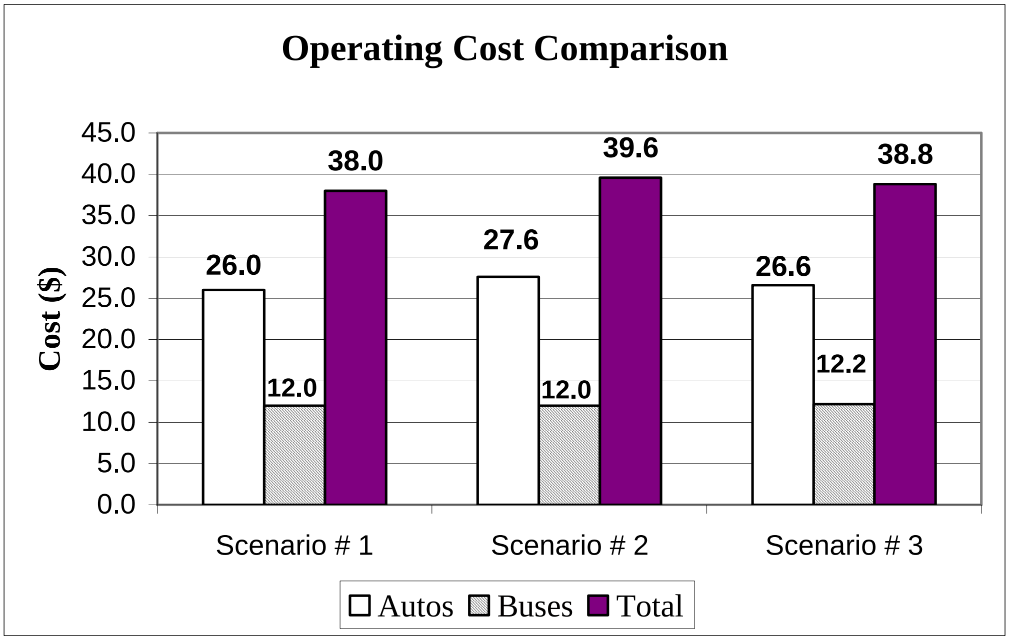
Total Travel Time for scenario # 2: (60 x 243.8) + (12 x 311.3) + (16 x 357.7)

= 24087 vehicle-seconds = 6.69 vehicle-hours

Total Travel Time for scenario # 3: (60 x 206.0) + (12 x 313.9) + (16 x 355.0)

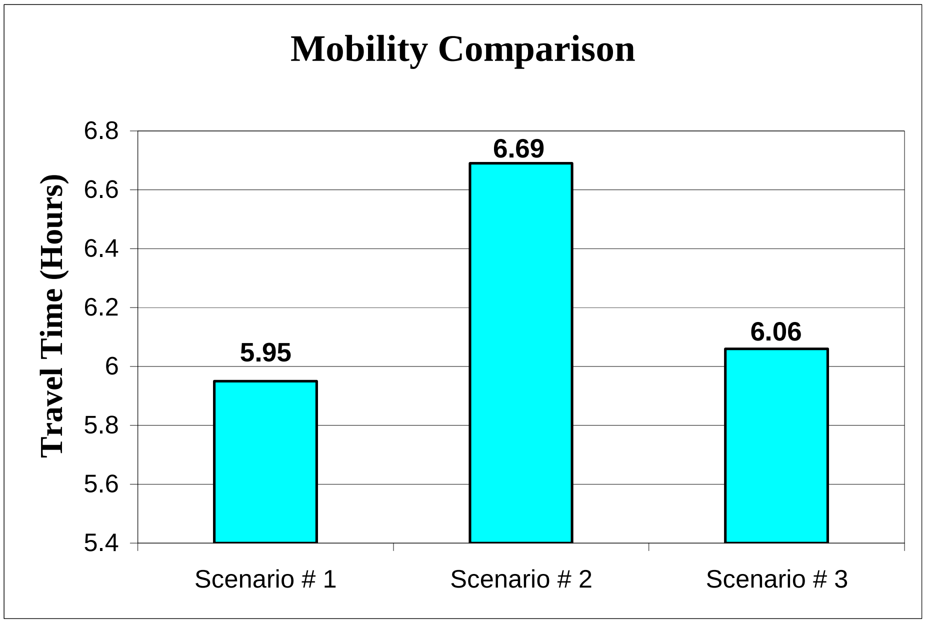
= 21807 vehicle-seconds = 6.06 vehicle-hours

Figure 13. Total Operating Cost Comparison



The results shown suggest that scenario #2 has the highest total travel time, approximately 12.4 and 10.4 percent higher that the related values for scenarios # 1 and # 3, respectively. Since this is the time used by the same number of autos, buses and bicycles to travel the same distance, it is clear that the longer travel time is caused by the delay, and is a negative factor when assessing mobility in this case. **Figure 14** shows a comparison of mobility for each of the three scenarios in terms of travel time in hours.

Figure 14. Mobility Comparison



The meaning of the specific locations (A) and (B) in this case study is not important. The point is that any measure of mobility has to be given context, and one way to do this is to pick - for the specific site under study - a location for which it is appropriate to measure travel times.

4.7. Measuring Accessibility

Accessibility can be evaluated by quantifying the number of people that can reach a specific point of attraction such as a CBD in a specific amount of time. In order to calculate this quantity for the example provided, data were collected at a specific point (point # 13, as shown in figure 6) for each of the three scenarios for the northbound traffic. This point is close to the end of the corridor, which should give a good indication of the rate by which vehicles are accessing the final destination.

In scenario # 1, data collected at this point showed that 84 autos, 3 buses, and 2 bicycles crossed this point during the first 900 seconds of the data collection period. This is compared to 80 autos, 3 buses, and 1 bicycle for scenario # 2, and 88 vehicles, 3 buses, and 2 bicycles for scenario # 3.

To compare the three scenarios, the total number of persons crossing data collection point #13 during the one-hour period are accumulated, taking into consideration the estimated numbers of passengers of 1.2/auto, 20/bus, and 1/bicycle). The results were as follows:

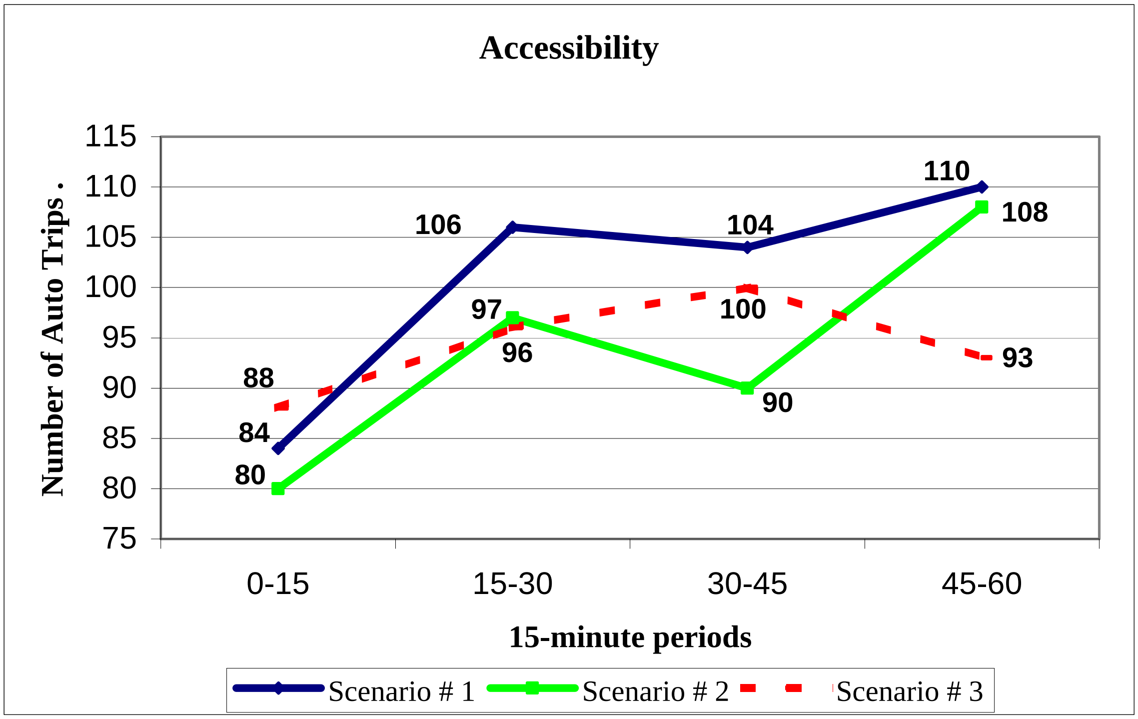
Scenario #1: (84 + 106 + 104 + 110)*1.2 + 12*20 + 15*1 = 740 persons.

Scenario #2: (80 + 97 + 90 + 108)*1.2 + 12*20 + 13*1 = 703 persons.

Scenario #3: (88 + 96 + 100 + 93)*1.2 + 12*20 + 16*1 = 708 persons.

The results for accessibility suggest that scenario # 1 provides the highest number of persons accessing a specific point at the end of the corridor, followed by scenario # 3. It should also be noted that the result is not different during each of the four 15-minute periods independently, as scenario #1 has consistently provided high number compared to the other two scenarios. **Figure 15** shows a comparison of accessibility for the three scenarios in terms of number of trips for autos broken down into four 15-minute periods.

Figure 15. Accessibility Comparison



Similar to what was previously mentioned when assessing mobility, accessibility can be better assessed in a case of a network rather than a corridor because each passenger and mode of transportation will have a variety of route choices to reach a specific point of attraction. In a transportation network, similar method can be used to measure accessibility. The analyst should also consider quantifying the number of households that are connected to the center of attraction through bicycle lanes, bus lanes or other mode of transportation

4.8. Evaluating Environmental Impact

The environmental impact is assessed by comparing emission data generated by MOBILE6 (2003) for each alternative. MOBILE6, a model authorized by the Environmental Protection Agency, can provide emission rates for both idling time and traveling time. The emissions due to idling are calculated for autos and buses by multiplying the their respective idling times by the idling emission rate. It is the product of the average number of stops, the average standstill time per vehicle, and the number of vehicles. The emissions generated during travel time are calculated for each segment of the corridor by multiplying the emission rates (grams/mile) related to the mean speed on this segment by the vehicle-miles traveled (see **Appendix C** for a sample of a Mobile6 run for one of the average speeds). Emission defaults applied in this study are those for Montgomery County, Maryland, USA, and are provided by the Motor Vehicle Department, reflecting the different mix of vehicles licensed in the county. **Table 10** summarizes the emission rates for idling and for traveling at different speeds (10 mph to 32 mph), and **Table 11** below summarizes the rates calculated for the three scenarios.

The results indicate that the emission rates for scenario # 1 were the least, followed very closely by emissions (VOC and NOx) generated by scenario # 3. The emissions resulting from scenario # 2 were clearly more than those of the other two scenarios in all three categories. For example, the VOC rates for scenario # 2 were approximately 15 percent more than those for scenario # 1. The NOx and CO rates were approximately 4 and 6 percent more than the related values resulting from scenario # 1. **Figure 16** shows a comparison of the environmental impact in terms of grams of emissions generated for each scenario.

Table 10. Emission Rates for Idling and for Traveling at Different Speeds (10 mph to 32 mph)

Emission Rates (gms/mi)	Speed (mph)											
	Idling (gms/hr)	10	11	12	13	14	15	16	17	18	19	20
VOC	7.3781	0.5268	0.4897	0.4587	0.4326	0.4101	0.3907	0.3716	0.3549	0.3399	0.3266	0.3146
CO	33.0512	4.7347	4.4940	4.2934	4.1237	3.9783	3.8522	3.7268	3.6163	3.5179	3.4299	3.3508
NOx	3.1603	0.8775	0.8399	0.8085	0.7819	0.7592	0.7394	0.7201	0.7030	0.6879	0.6743	0.6621
PM2.5	0.0439	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176
SO2	0.0196	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078

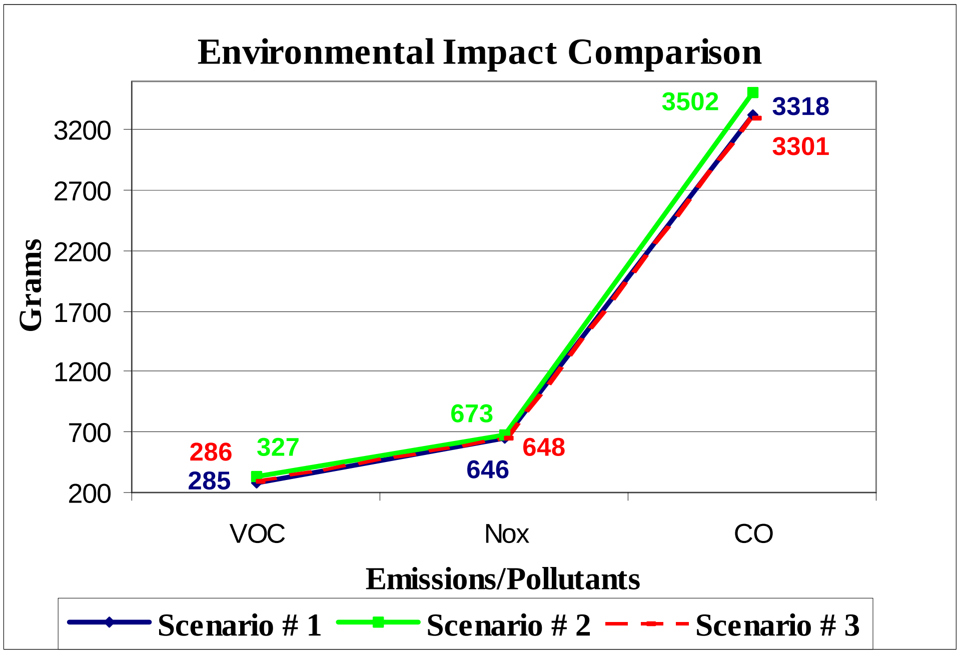
Emission Rates (gms/mi)	Speed (mph)											
	21	22	23	24	25	26	27	28	29	30	31	32
VOC	0.3046	0.2955	0.2872	0.2796	0.2726	0.2663	0.2605	0.2551	0.2501	0.2454	0.2409	0.2367
CO	3.2954	3.2451	3.1992	3.1571	3.1183	3.0996	3.0824	3.0664	3.0514	3.0374	3.0472	3.0562
NOx	0.6509	0.6406	0.6312	0.6227	0.6148	0.6082	0.6021	0.5964	0.5910	0.5861	0.5836	0.5812
PM2.5	0.0176	0.0176	0.0175	0.0175	0.0175	0.0175	0.0176	0.0175	0.0175	0.0175	0.0175	0.0175
SO2	0.0078	0.0078	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079

Emission Rates (gms/mi)	Idling (gms/hr)	
	Auto	Bus
VOC	7.9442	2.3110
CO	33.1779	32.1368
NOx	2.1043	55.9068
PM2.5	0.0296	0.5373
SO2	0.0180	0.0400

Table 11. Environmental Impact Comparison

	VOC (grams)	NOx (grams)	CO (grams)
Scenario # 1	285	646	3,318
Scenario # 2	327	673	3,502
Scenario # 3	286	648	3,301

Figure 16. Environmental Impact Comparison



4.9. Evaluating Safety Impact

To evaluate the three scenarios taking into consideration the different lane widths, the accident prediction algorithm described in chapter three is applied. It should be noted here that although this model was generated for rural two-lane highways, it was applied in this study to compare results, which are effected by different lane widths, and not necessarily to predict the actual number of accidents for each of the three scenarios.

Using a value of 10,000 vehicles/day for the ADT, and 1.3 miles for L, the equation is simplified to N_{br} = (4.745) exp (0.8833 – 0.0846 LW – 0.0591 SW), and the predicted number of total accidents per year on the corridor under study is as follows for each scenario:

Scenario #1: (4.745) exp (0.8833 – 0.0846 x 13 – 0.0591 x 0) = 3.8

Scenario #2: (4.745) exp (0.8833 – 0.0846 x 12 – 0.0591 x 0) = 4.1

Scenario #3: (4.745) exp (0.8833 – 0.0846 x 10.5 – 0.0591 x 0) = 4.7

It is noted that in scenario #3, the predicted number of accidents is higher by approximately 15 and 24 percent than the related values for scenarios # 2 and # 1, respectively. The narrower lane is the main factor affecting this result.

In reference to the intersections, the model described earlier for a four-leg signalized intersection is not applied in this case study since it does not include variables for lane widths, but rather for factors that have the same value for each scenario. These factors include left-turn movements, presence of protected left-turn signal phase on the major road, percentage of trucks, number of driveways near the intersection, and average daily traffic volume on both the major and minor roads.

A factor that was also considered when assessing safety and the predicted number of crashes is the number of stops experienced by all transportation modes throughout the corridor for each scenario. It is reasonable to predict that the increase in the number of stops is positively related to the potential number of rear-end accidents. **Table 12** below summarizes the number of stops experienced by all transportation modes for each of the three scenarios.

Table 12. Average Number of Stops for Each Mode of Transportation

	Average Number of Stops/Vehicle		
	Autos	Buses	Bicycles
Scenario # 1	2.4	1.7	2.6
Scenario # 2	2.7	1.45	3.33
Scenario # 3	2.5	2.1	2.5

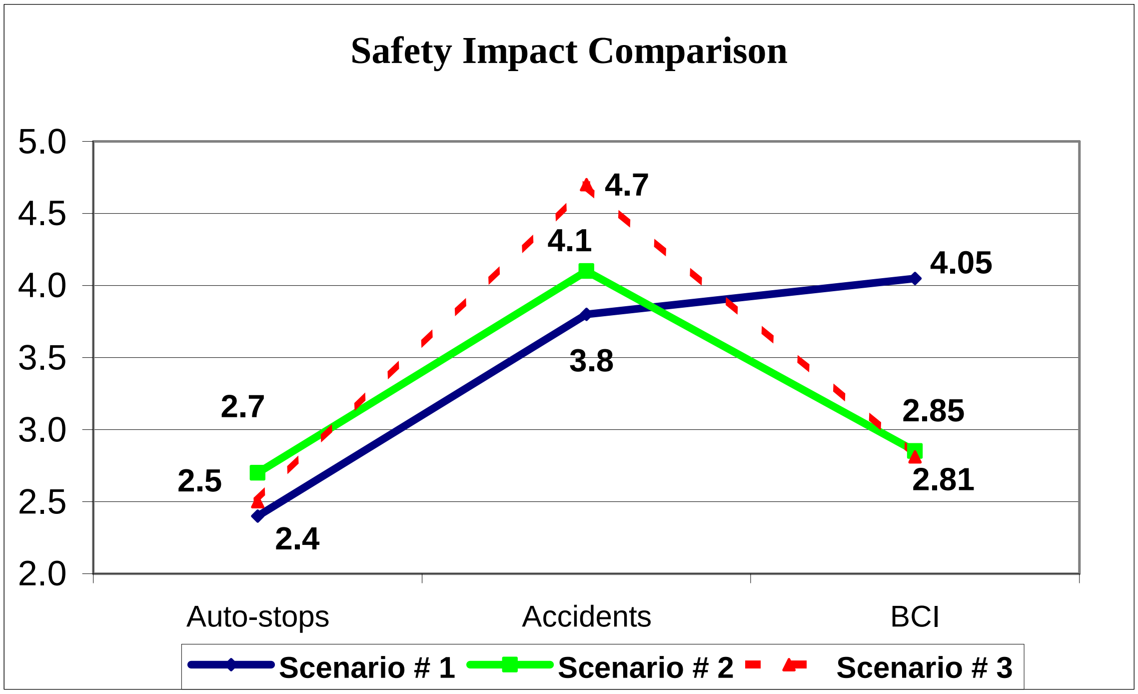
It is noted that scenario # 1 experienced the least average number of auto stops, followed by scenario # 3. Although it is very unlikely that the bicycles or buses would experience rear-end accidents, it should be noted that the highest average number of stops for buses and bicycles were experienced by scenario # 3 and scenario # 2, respectively.

From the above, it looks that so far, scenario # 1 provides the best impact on safety since it has the lowest predicted number of accidents and the least number of stops. However, having bicycles in their own exclusive lane should improve safety for bicycles and reduce the interactions and conflicts between bicyclists and motorists. Therefore, a category of bicycle safety was added to this analysis to point out the factor of bicycle safety.

As suggested in the previous chapters, since the existing of pavement marking and the width of bicycle lane are important factors to assess bicycle safety, the BCI is applied to assess bicycle safety for each scenario. Looking at the three scenarios in this case study, it is reasonable to say that the third scenario, which includes a 5-foot bicycle lane, is the safest of the three scenarios for bicyclists and for motorists from the point of the interaction between them. The second scenario should also be favorable for bicyclists from a safety point of view since they share the road with buses only on a 14-foot lane, which is a very wide lane. It should be noted that the results obtained when the BCI was applied matched this result as the third scenario was ranked first among the three scenarios, followed by the second scenario and finally the first scenario was ranked last.

Figure 17 summarizes the safety impact for each scenario by showing a comparison of average number of stops for autos, predicted number of total accidents per year along the corridor, and the BCI (for bicycle safety) for each of the three scenarios. Scenario # 1 provides the best safety impact for motor vehicles and scenario # 3 for bicycles.

Figure 17. Safety Impact Comparison



4.10. Making a Decision

A multi-objective decision-making framework is employed to incorporate the multiple objectives into a process where they are all equally considered regardless of whether they can be estimated in monetary or non-monetary terms. The suggested multi-objective decision-making framework for this study presents the data in a form that would be used for such an endeavor. Charts were prepared for presentation to decision-makers demonstrating the result of each objective when corresponding to a specific scenario. In one comprehensive chart, where all objectives are presented, each objective value is transformed into a scale of 0-100. The scenario scoring the highest value among the other scenarios receives 100 percent while the other scenarios receive a value less than 100 percent and correspondent to the performance level at the same objectives. The advantage of this method is that it is not influenced by decision makers' input, which consists of assigning a weight for each objective before the final results are presented. By applying the suggested method, a decision can be made pending on the objectives that are most important for the decision-makers to achieve at the time when the decision is made.

Tables 13 and 14 present a summary of the objective results in true values and in percentages, respectively. The same information is also provided graphically in **Figure 18**. The results show that the performance levels for 16 objectives favor scenario # 1. It was clear that the major weakness of this scenario is the bicycle-related objectives (BCI, and thus, bicycle safety). Scenario # 3 clearly comes second overall, with best results in three objectives and levels of performance within 6 percent or less of the leading scenario in 14 other objectives. The major strengths of this scenario are the bicycle-related objectives, and its major weakness is its highest predicted number of accidents. Scenario # 2, which provides the worst performance in 13 out of the 19 measured categories, comes in last place. It should be noted, however, that scenario # 2 provides good results for all bus-related objectives and comes close second for BCI and bicycle safety.

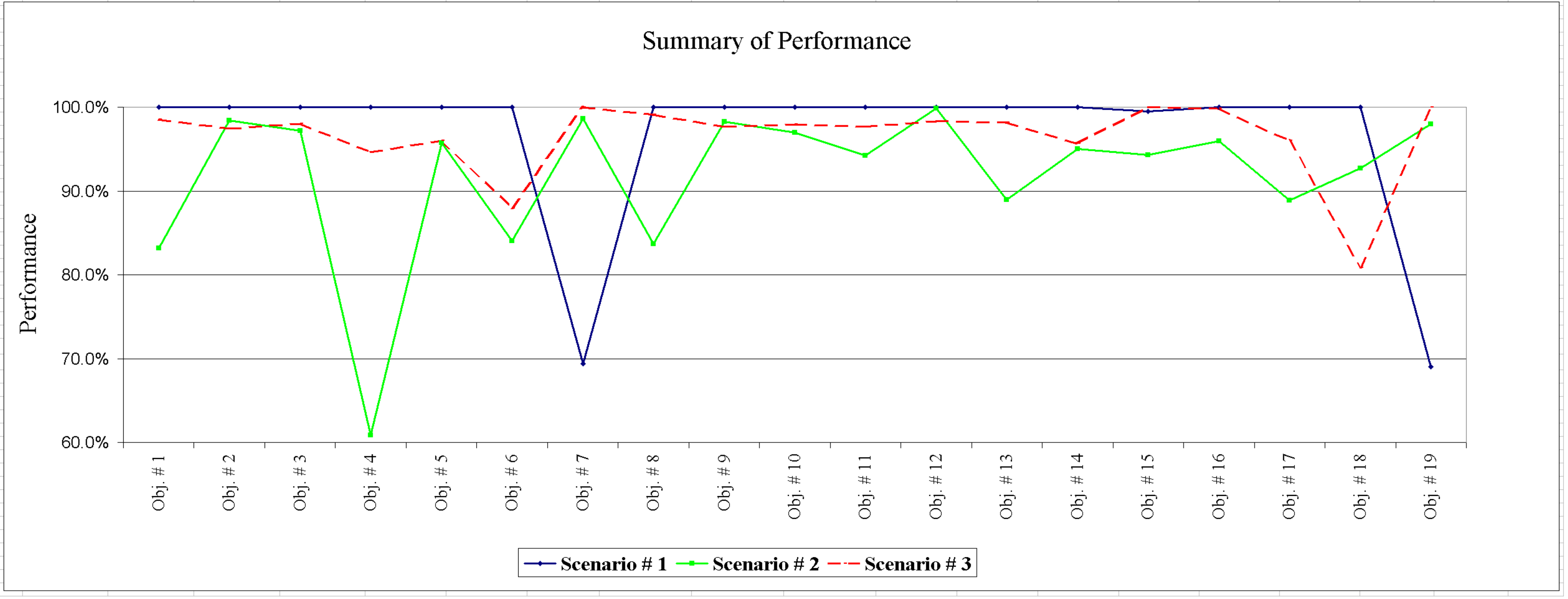
Table 13. Summary of Objectives' Results

	Avg. travel time for auto (Seconds)	Avg. travel time for bus (Seconds)	Avg. travel time for bicycle (Seconds)	Average Delay for auto (Seconds)	Average Delay for bus (Seconds)	Average Delay for bicycle (Seconds)	BCI	User Travel Cost for auto ($)	User Travel Cost for bus ($)	User Travel Cost for bicycle ($)	Operating Cost for autos ($)	Operating Cost for buses ($)	Mobility (Hours)	Accessibility (Trips)	Environmental Impact (CO) (gms)	Environmental Impact (NOx) (gms)	Average Number of Auto-stops	Number of Predictible Accidents	Bicycle Safety
Scenario # 1	**203**	**306**	**348**	**63.6**	**87.1**	**51.7**	4.05	**1.13**	**1.7**	**1.93**	**26.04**	**11.99**	**5.95**	**740**	3318	**646**	**2.4**	**3.8**	69
Scenario # 2	244	311	358	104.5	91	61.5	2.85	1.35	1.73	1.99	27.63	12.01	6.69	703	3502	673	2.7	4.1	98
Scenario # 3	206	314	355	67.2	90.7	58.8	**2.81**	1.14	1.74	1.97	26.65	12.19	6.06	708	**3301**	647	2.5	4.7	**100**

Table 14. Summary of Objectives' Results (in Percentage - 100% being best)

	Avg. travel time for auto (Seconds)	Avg. travel time for bus (Seconds)	Avg. travel time for bicycle (Seconds)	Average Delay for auto (Seconds)	Average Delay for bus (Seconds)	Average Delay for bicycle (Seconds)	BCI	User Travel Cost for auto ($)	User Travel Cost for bus ($)	User Travel Cost for bicycle ($)	Operating Cost for autos ($)	Operating Cost for buses ($)	Mobility (Hours)	Accessibility (Trips)	Environmental Impact (CO) (gms)	Environmental Impact (NOx) (gms)	Average Number of Auto-stops	Number of Predictible Accidents	Bicycle Safety
	Obj. # 1	**Obj. # 2**	**Obj. # 3**	**Obj. # 4**	**Obj. # 5**	**Obj. # 6**	**Obj. # 7**	**Obj. # 8**	**Obj. # 9**	**Obj. # 10**	**Obj. # 11**	**Obj. # 12**	**Obj. # 13**	**Obj. # 14**	**Obj. # 15**	**Obj. # 16**	**Obj. # 17**	**Obj. # 18**	**Obj. # 19**
Scenario # 1	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	69.4%	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	99.5%	**100.0%**	**100.0%**	**100.0%**	69.0%
Scenario # 2	83.2%	98.4%	97.2%	60.9%	95.7%	84.1%	98.6%	83.7%	98.3%	97.0%	94.2%	99.8%	88.9%	95.0%	94.3%	96.0%	88.9%	92.7%	98.0%
Scenario # 3	98.5%	97.5%	98.0%	94.6%	96.0%	87.9%	**100.0%**	99.1%	97.7%	98.0%	97.7%	98.4%	98.2%	95.7%	**100.0%**	99.8%	96.0%	80.9%	**100.0%**

Figure 18. Summary of Performances for the Three Scenarios



It should also be noted here that although all 19 objectives are important, it is not necessary to present them all to decision-makers in order to allow them choosing their preferred scenario. Several factors are expected to influence the decision of which objectives to be evaluated, such as the specific interests of the decision-makers, the purpose of the project, and its location.

4.11. Variability of the Results

As mentioned in the previous section, the results in general show that the performance levels for scenario # 1 are higher than those of the other two scenarios, except for the BCI, and thus, bicycle safety. Scenario # 2 has the lowest performance levels for auto-related objectives, and scenario # 3 has the highest BCI and the lowest safety level of performance. It should be noted, however, that although some of the results are clearly in favor of a specific scenario or another, some results for objectives' performance levels are statistically indistinguishable. **Table 15** provides the sample means and standard deviations of all objectives compared in this study.

The table shows that examples of objectives with performance levels that are statistically indistinguishable across scenarios include travel time for bicycles, travel speed for buses, and auto and bus-operating costs. Other objectives, such as travel time and delay for autos, provide similar results for scenarios # 1 and # 3, and clearly low performance levels for scenario # 2. Another example of a clear poor performance is in scenario # 1 for the BCI, while the other two scenarios provide similar results with a slight advantage for scenario # 3. **Figures 19** and **20** provide this information graphically and illustrate some objectives with clear winners, and others with results statistically indistinguishable.

Table 15. Means and Standard Deviations for Study Objectives

Objective	Scenario # 1		Scenario # 2		Scenario # 3	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Travel Time (auto)	203.0	2.6	243.8	6.2	206.0	2.0
Travel Time (bus)	306.0	8.1	311.3	4.7	313.9	4.8
Travel Time (bike)	348.1	4.0	357.7	7.3	355.0	5.6
Travel Speed (auto)	22.6	0.3	18.8	0.5	22.2	0.2
Travel Speed (bus)	15.0	0.4	14.7	0.2	14.6	0.2
Travel Speed (bike)	13.2	0.2	12.8	0.3	12.9	0.2
BCI	4.05	0.04	2.85	0.02	2.81	0.01
Mobility	5.95	0.06	6.69	0.10	6.06	0.03
Accessibility	740	27.2	703	13.9	708	20.5
Auto User's Cost ($)	1.13	0.01	1.35	0.03	1.14	0.01
Bus User's Cost ($)	1.70	0.05	1.73	0.03	1.74	0.03
Bike User's Cost ($)	1.93	0.02	1.99	0.04	1.97	0.03
Accidents	3.83	0.05	4.07	0.09	4.68	0.09
Auto Operating Cost	26.04	0.32	27.63	0.42	26.65	0.29
Bus Operating Cost	11.99	0.08	12.01	0.10	12.19	0.11
VOC (Grams)	285.0	8.7	327.1	8.4	286.1	7.5
NOx (Grams)	646.2	20.1	673.0	7.1	647.5	14.2
CO (Grams)	3,318.4	104.2	3,502.2	51.3	3,300.7	75.1

4.12. Growth in Demand

As a follow up to the previous section, more analyses were performed to assess possible changes in the ranking of scenarios in the future. An annual 2 percent growth in demand was projected, and the three scenarios were evaluated for 10 and 20 years into the future, with a total growth of approximately 22 and 49 percent, respectively. **Table 16** provides the detailed measures of effectiveness for each objective for the 10-year and 20-year analyses.

Figure 19. Variability for Travel Time for Autos and Bicycles

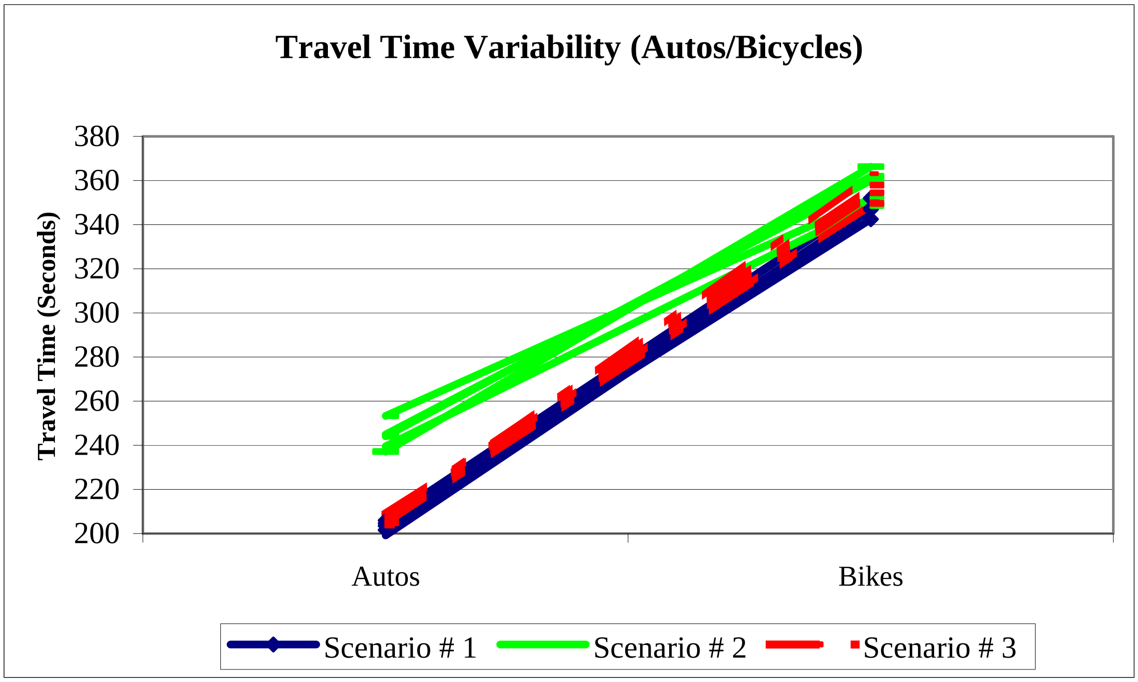


Figure 20. Variability for BCI and Predicted Number of Accidents

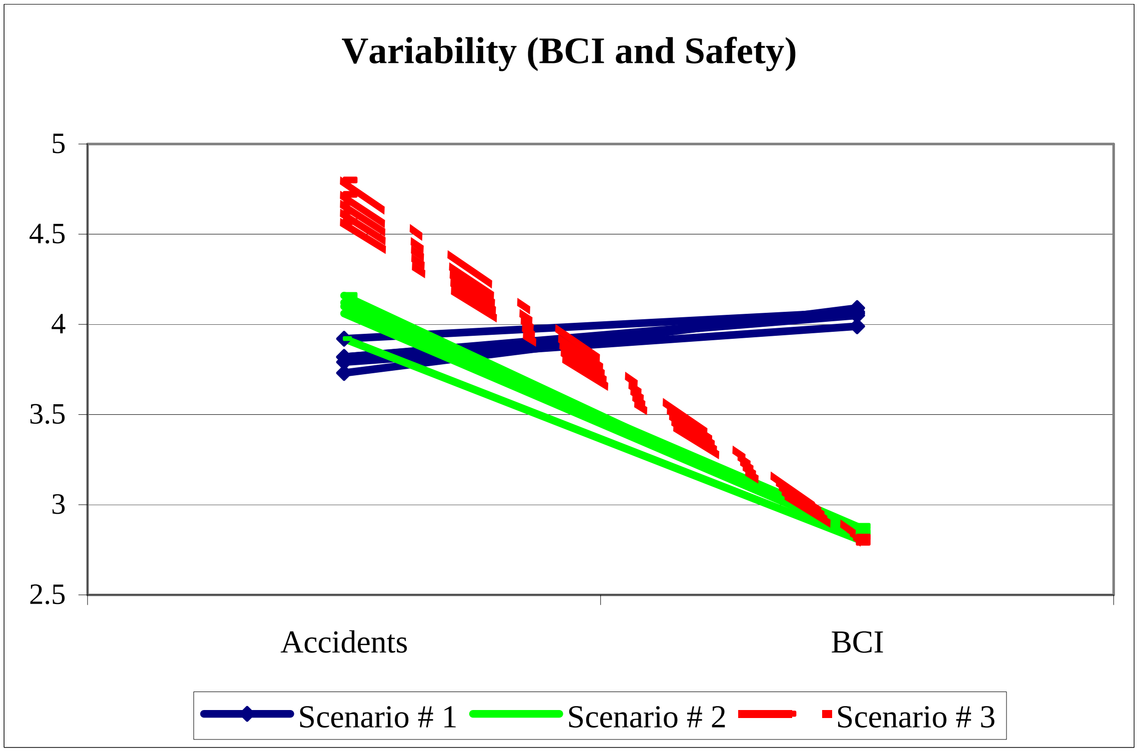


Table 16. Measures of Effectiveness for the 10-year and 20-year Projections

Objective	10 Years			20 Years		
	Scenario # 1	**Scenario # 2**	**Scenario # 3**	**Scenario # 1**	**Scenario # 2**	**Scenario # 3**
Travel Time (auto)	216.3	456.4	217.9	365.6	608.1	311.5
Travel Delay (auto)	77.7	319.8	80.2	226.4	468.2	173.3
Travel Time (bus)	331.5	425.5	318.2	476.9	521.4	418.6
Travel Delay (bus)	110.1	204.6	96.8	256.5	301.5	197.9
Travel Time (bike)	372.9	483.4	357	515.3	532.2	336.7
Travel Delay (bike)	75.5	185.7	60.3	216.7	234.6	73.5
Travel Speed (auto)	21.2	10.0	21.0	12.8	7.5	15.0
Travel Speed (bus)	13.8	10.8	14.4	9.7	8.8	11.0
Travel Speed (bike)	12.3	9.5	12.8	9.0	8.6	14.1
BCI	4.17	2.38	2.94	4.14	2.36	2.85
Mobility (Veh.-hours)	7.8	13.6	7.7	15.0	21.4	12.1
Accessibility	854	740	846	914	776	893
Auto User's Cost ($)	1.20	2.54	1.21	2.03	3.38	1.73
Bus User's Cost ($)	1.84	2.36	1.77	2.65	2.90	2.33
Bike User's Cost ($)	2.07	2.69	1.98	2.86	2.96	1.87
Accidents	4.66	5.07	5.76	5.80	6.24	7.13
Auto Operating Cost	33.3	80.8	33.8	91.0	211.0	59.8
Bus Operating Cost	15.4	16.8	15.0	28.4	26.7	22.3
VOC (Grams)	353	525	352	578	623	509
NOx (Grams)	790	869	776	1126	984	1013
CO (Grams)	3976	4650	3950	5355	5019	5068
Idle time (auto)	44.3	109.4	46.8	116.0	178.7	73.2
# stops (auto)	2.5	8.2	2.6	6.3	13.3	4.8
Total Idle Time (auto)	112.1	891.6	120.7	779.0	2380.3	364.2
Idle Time (bus)	42.5	57.7	31.8	113.1	102.6	66.7
# Stops (bus)	2.5	3.9	2.1	6.2	6.1	4.8
Total Idle Time (bus)	106.3	222.1	68.1	733.8	621.8	329.5

a) Ten-year Growth

From the table above, the measures of effectiveness for the ten-year growth show that scenario # 1 continues to provide better results than scenario # 2 in all categories, except for the BCI. In fact, due to the substantial increase in travel times for all modes of transportation in scenario # 2, the gap between the two scenarios substantially increases. The same can be said when comparing scenario # 2 and scenario # 3, since the latter consistently provides higher levels of performance, except for the BCI and safety measures, where scenario # 2 provides better measures. It should be noted that the improvement in the BCI for scenario # 2 is due to the slower traffic flow in this scenario.

When comparing scenarios # 1 and # 3, a slight change is noticed in the buses and bicycles' travel times and delays, as well as for mobility, where scenario # 3 starts to show a small advantage over scenario # 1. On the other hand, scenario # 1 still provides best results in safety, and scenario # 3 provides a better BCI than scenario # 1.

In summary, the ten-year growth shows that scenario # 3 starts to have a slight advantage over scenario # 1 in almost all categories except for safety, and scenario # 2 starts to experience substantial delays for all the modes of transportation. **Figures 21** and **22** summarize some of those results.

Figure 21. Average Travel Time Comparison for the 10-Year Projection

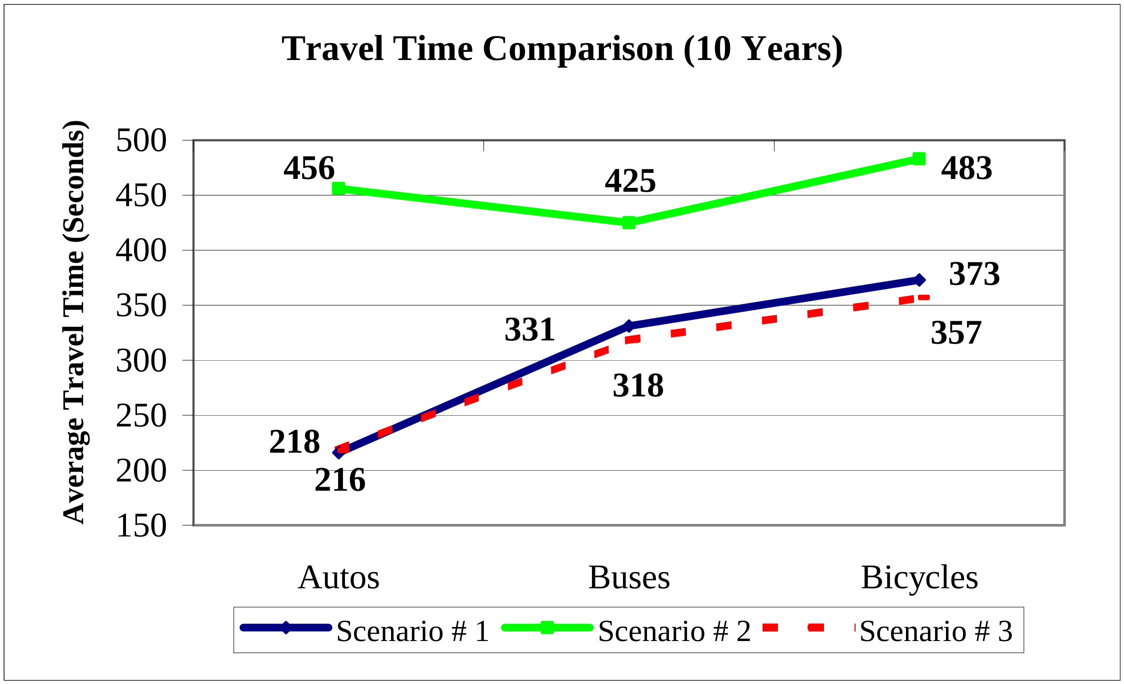
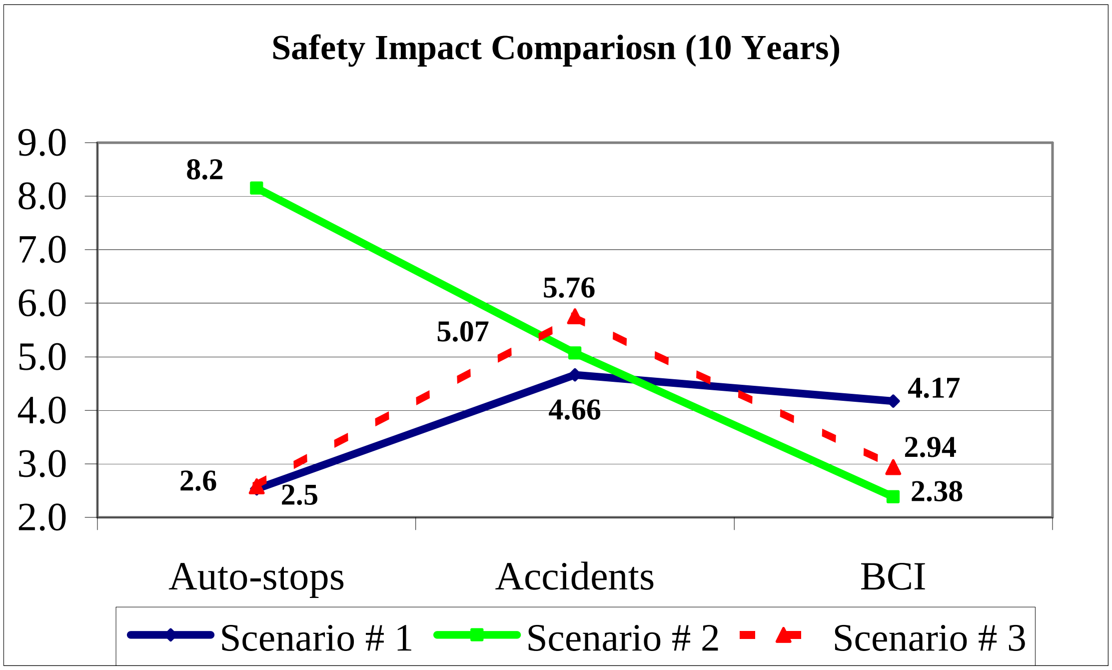


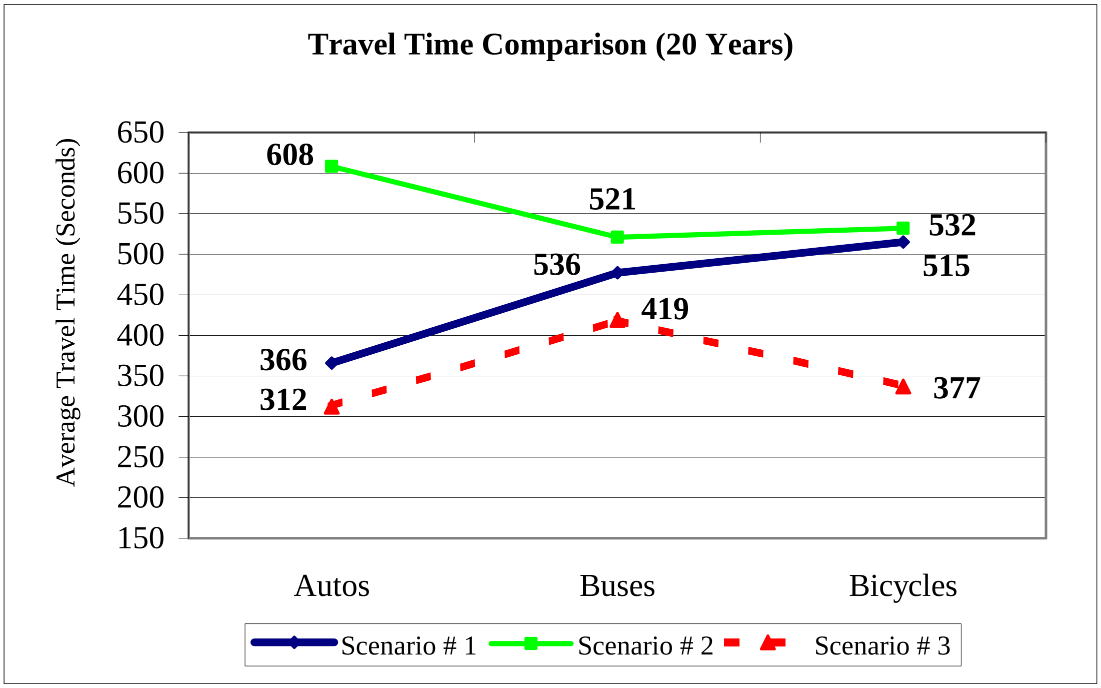
Figure 22. Safety Impact Comparison for the 10-Year Projection



b) Twenty-year Growth

The measures of effectiveness for the twenty-year growth did not change much from the ten-year growth results for the BCI and safety measures. However, the 49 percent increase in traffic flow has negatively impacted scenario # 1 the most. The travel times and delays have increased for all modes of transportation for all three scenarios, but more so in the case of scenario # 1. This latter scenario continued to provide better results than scenario # 2 for auto-related objectives, but the gap decreased in the bus and bicycle-related objectives. When compared to scenario # 3, scenario # 1 was behind in all objectives, except for safety impact. In the 20-year analysis, it was clear that scenario # 3 is the best scenario in this case. This could be explained by the fact that when traffic is highly congested, it is beneficial to separate the non-motorized from the motorized vehicles. This is in support of the study conducted by Hossain and McDonald (1998) as described earlier in chapter two. **Figures 23** and **24** summarize some of the related results.

Figure 23. Average Travel Time Comparison for the 20-Year Projection



In conclusion to this section, transportation planners should have a responsibility of projecting a reasonable growth rate in demand that would best fit the location under study and the expected new developments in the region. This rate should be applied in the proposed method to allow assessing the performance of the different scenarios in the future. **Figure 25** summarizes the travel time comparison for current traffic flow, and for the 10 and 20-year projections for all three scenarios. It is clear that in 10 years, scenario # 2 will performed poorly, and in 20 years, scenario # 3 will have the edge over scenario # 1, while scenario # 2 will continue to provide the lowest performance measures.

Figure 24. Safety Impact Comparison for the 20-Year Projection

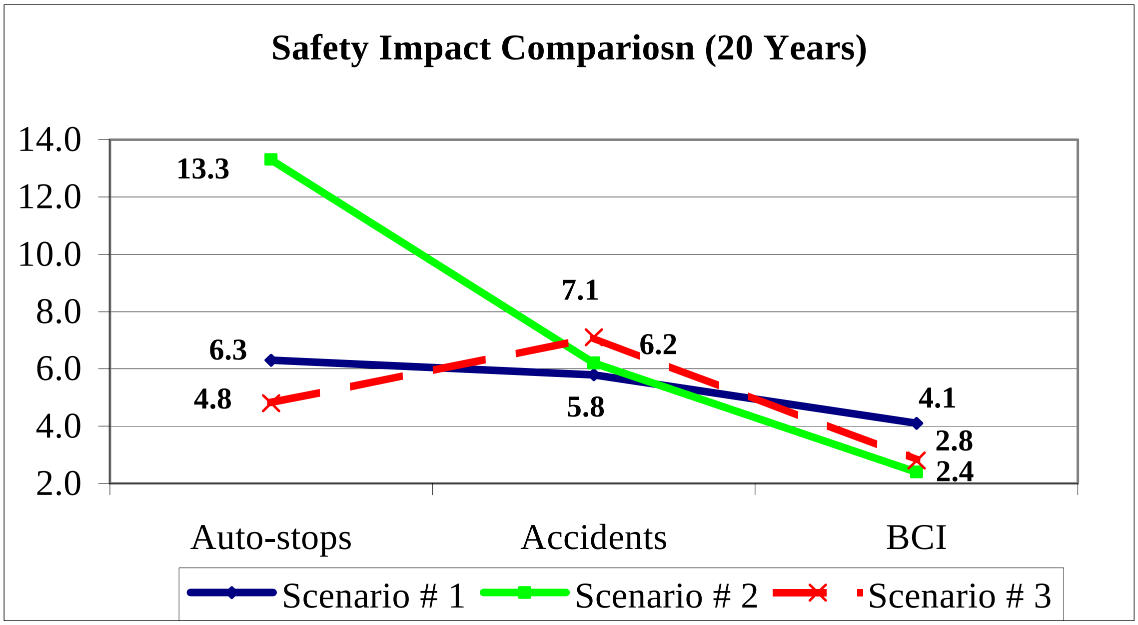
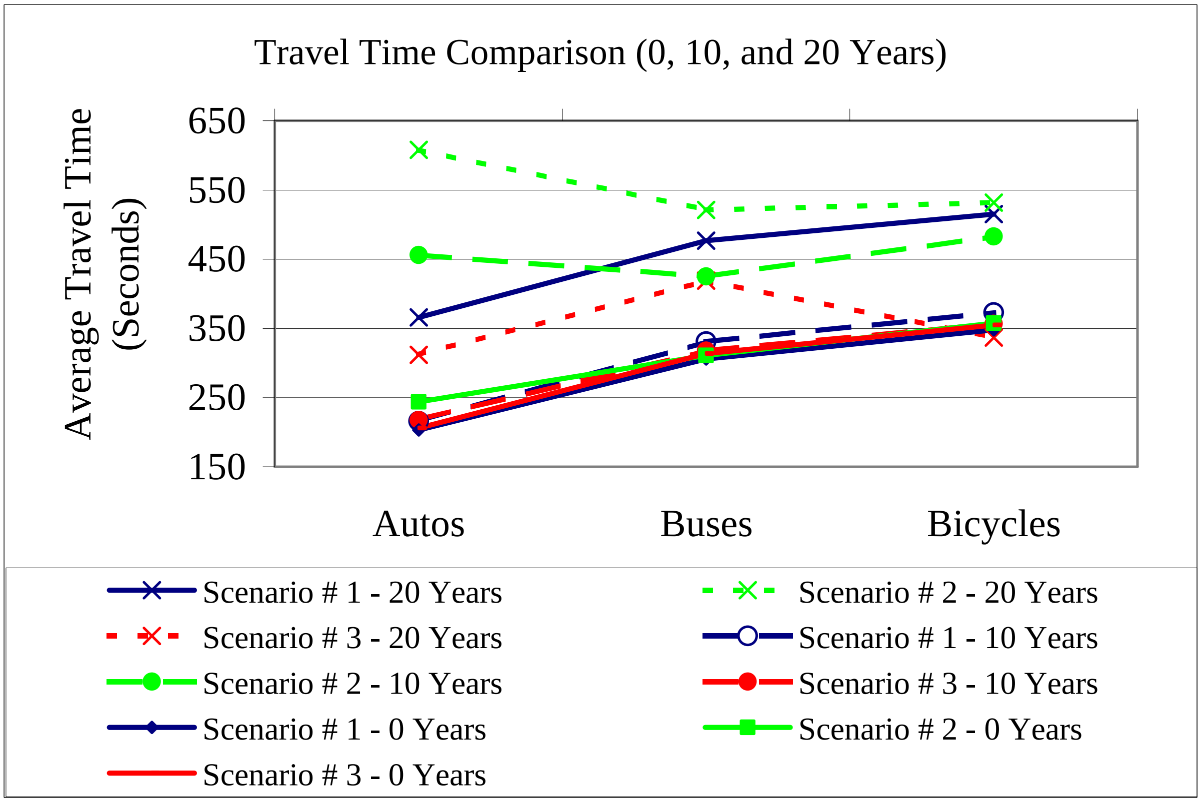


Figure 25. Average Travel Time Comparison for the 0, 10, and 20-Year Projections



4.13. Conducting Sensitivity Analysis

A sensitivity analysis was conducted to provide an understanding of how the model responded when inputs were changed. Some of the input change in this study include mode choice, number of passengers per auto and per bus, number of autos, buses, and bicycles, user time value, fuel cost per gallon, and lane width. Examples of sensitivity analysis provided in this chapter include: 1) mode choice; 2) autos and buses' occupancy; 3) lane-width analysis; and 4) number of buses and number of bicycles.

For the first two analyses, only the occupancy numbers change, but not the total number of vehicles (autos, buses and bicycles). The objectives affected in those two cases are limited to the users' costs for travel and for delay. Since the cost of delay is included in the total cost of travel, the users' costs of travel are compared for all three scenarios. Although the numbers of vehicles are not changing in the third analysis as well, the travel time is influenced by the change in lane width. In the fourth analysis, where numbers of buses and bicycles are changing, performances for all objectives are expected to change. The travel time is the focus of comparison for the last two analyses.

Mode Choice Analysis

For the mode choice analysis, the total number of passengers moving from the upstream point (A) to the downstream point (B) does not change. This number was assumed at the beginning of the case study to be 312 passengers (60 autos x 1.2 passengers/auto + 12 buses x 20 passengers/bus). When the same 312 vehicle passengers use different modes of transportation, it is found that for a similar occupancy for autos and buses, scenario # 1 provides the least users' cost, followed closely by scenario # 3, and scenario #2 was further behind them. It is also shown that when more passengers occupy a bus, the performance of scenario # 2 - for users' costs – improves, in relation to the other two scenarios. For example, when comparing the total users' costs, including the operating cost, in the case of 5 passengers occupying an auto and 1 occupying a bus, the cost for scenario # 2 was approximately 17 and 16 percent higher than the user's cost for scenario # 1 and scenario # 3, respectively. When the number of passengers occupying an auto and a bus were 1 and 21, respectively, the user's cost for scenario # 2 was only about 4 and 2 percent higher than the cost for scenarios #1 and #3, respectively.

It was also clear that Scenario # 1 was still the best scenario among the 3 scenarios, regardless if users decided to change their choice of mode of transportation, as long as the same number of vehicles on the road did not change. **Figure 26** and **Table 17** summarize the results of the mode choice sensitivity analysis.

Figure 26. Sensitivity Analysis for Mode Choice

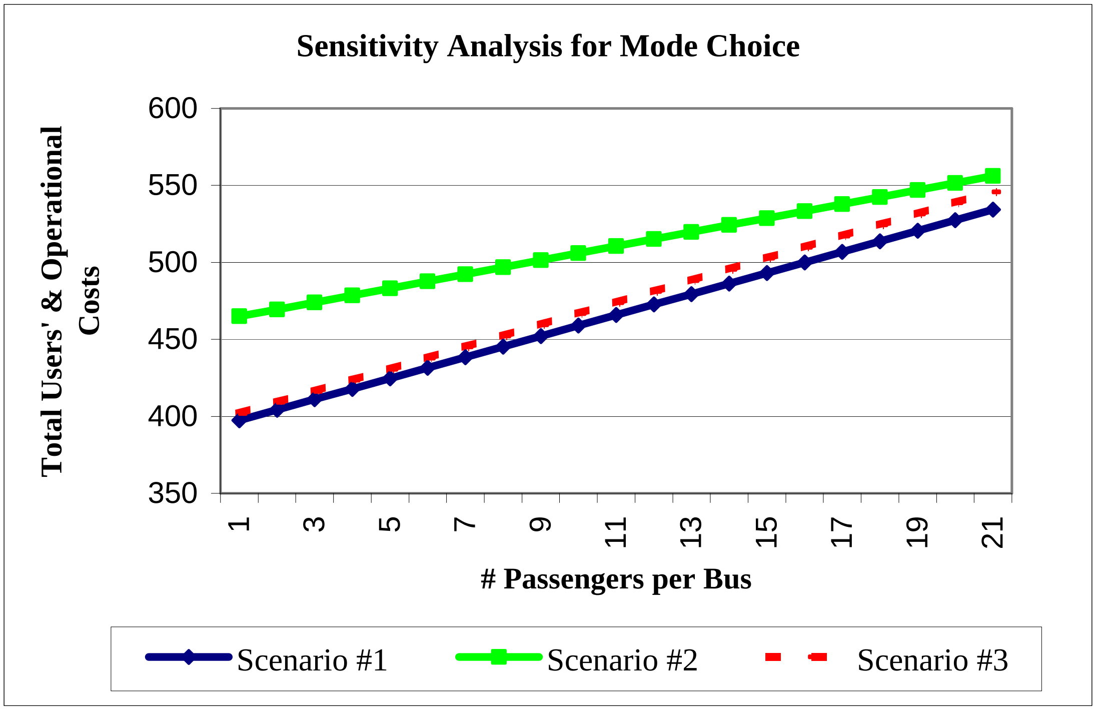


Table 17. Sensitivity Analysis for Mode Choice: Same 312 Vehicle-Passengers With Different Mode of Transportation

			Scenario # 1			Scenario # 2			Scenario # 3					
Case #	# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Total cost incl. Op. $ Scenario #1	Total cost incl. Op. $ Scenario #2	Total cost incl. Op. $ Scenario #3
a	5	1	339.00	20.40	359.40	405.00	20.76	425.76	342.00	20.88	362.88	397.38	464.92	401.79
b	4.8	2	325.44	40.80	366.24	388.80	41.52	430.32	328.32	41.76	370.08	404.22	469.48	408.99
c	4.6	3	311.88	61.20	373.08	372.60	62.28	434.88	314.64	62.64	377.28	411.06	474.04	416.19
a	4.4	4	298.32	81.60	379.92	356.40	83.04	439.44	300.96	83.52	384.48	417.90	478.60	423.39
d	4.2	5	284.76	102.00	386.76	340.20	103.80	444.00	287.28	104.40	391.68	424.74	483.16	430.59
e	4	6	271.20	122.40	393.60	324.00	124.56	448.56	273.60	125.28	398.88	431.58	487.72	437.79
f	3.8	7	257.64	142.80	400.44	307.80	145.32	453.12	259.92	146.16	406.08	438.42	492.28	444.99
g	3.6	8	244.08	163.20	407.28	291.60	166.08	457.68	246.24	167.04	413.28	445.26	496.84	452.19
h	3.4	9	230.52	183.60	414.12	275.40	186.84	462.24	232.56	187.92	420.48	452.10	501.40	459.39
I	3.2	10	216.96	204.00	420.96	259.20	207.60	466.80	218.88	208.80	427.68	458.94	505.96	466.59
j	3	11	203.40	224.40	427.80	243.00	228.36	471.36	205.20	229.68	434.88	465.78	510.52	473.79
k	2.8	12	189.84	244.80	434.64	226.80	249.12	475.92	191.52	250.56	442.08	472.62	515.08	480.99
l	2.6	13	176.28	265.20	441.48	210.60	269.88	480.48	177.84	271.44	449.28	479.46	519.64	488.19
m	2.4	14	162.72	285.60	448.32	194.40	290.64	485.04	164.16	292.32	456.48	486.30	524.20	495.39
n	2.2	15	149.16	306.00	455.16	178.20	311.40	489.60	150.48	313.20	463.68	493.14	528.76	502.59
o	2	16	135.60	326.40	462.00	162.00	332.16	494.16	136.80	334.08	470.88	499.98	533.32	509.79
p	1.8	17	122.04	346.80	468.84	145.80	352.92	498.72	123.12	354.96	478.08	506.82	537.88	516.99
q	1.6	18	108.48	367.20	475.68	129.60	373.68	503.28	109.44	375.84	485.28	513.66	542.44	524.19
r	1.4	19	94.92	387.60	482.52	113.40	394.44	507.84	95.76	396.72	492.48	520.50	547.00	531.39
s	1.2	20	81.36	408.00	489.36	97.20	415.20	512.40	82.08	417.60	499.68	527.34	551.56	538.59
t	1	21	67.80	428.40	496.20	81.00	435.96	516.96	68.40	438.48	506.88	534.18	556.12	545.79

* - For a similar occupency for autos and buses, scenario # 1 provides the least users' cost, followed closely by scenario # 3, and scenario #2 is further behind them.

* - It is also shown that the more passengers are occupying a bus, the more scenario # 2 improves compared to scenarios # 1 and 3 when comparing total users' cost. However, scenario # 2 will never surpass scenarios # 1 and # 3 (with the current total vehicle-passengers in this specific case) since the occupancy rate for a vehicle cannot be under 1.

* - It is clear that Scenario # 1 is still the best scenario among the 3 scenarios, regardless if users decide to change their choice of mode of transportation, as long as the same number of vehicles on the road does not change.

Autos and buses' Occupancy Analysis

In the case of sensitivity analysis for the number of passengers occupying autos and buses (i.e., ridership), several runs were performed with different occupancy numbers.

Differently than the mode choice sensitivity analysis, in this case, the total number of passengers did not have to stay unchanged at 312. The runs were performed for occupancy rates of 1.0, 1.1, 1.2, 1.5, and 1.75 passengers per auto while the occupancy number for buses ranged between 1 and 40. In other words, for each specific number of passengers in an auto, a table was generated with different numbers of passengers in a bus, and ranged between 1 and 40. **Tables 18a through 18e** summarize the results.

In all five cases analyzed, while increasing the number of passengers per bus, the gap in users' cost decreases between scenarios # 2 and 3. For example, in the case of 1.2 passengers per auto, the difference in the total users' cost went down from 15 percent (with one passenger per bus) to 10.3 percent (with 40 passengers per bus). On the other hand, the gap increases between scenario # 1 and the other two scenarios.

Lane-Width Analysis

This analysis was applied in this case study to assess the effect of modifying the lane width on one scenario rather than comparing different scenarios with different lane-use allocation. Scenario 2b, which consists of one 12-foot mixed-traffic lane and one 14-foot exclusive bus lane, was analyzed using different lane widths for each lane while keeping the full width for this travel direction to 26 feet. The following scenarios were analyzed: 10-foot mixed-traffic lane and 16-foot exclusive bus lane, 11-foot mixed-traffic

Table 18a. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.0 Passengers/Auto)

		Scenario # 1			Scenario # 2			Scenario # 3		
# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)
1	1	67.80	20.40	88.20	81.00	20.08	101.08	68.40	20.88	89.28
1	2	67.80	40.80	108.60	81.00	41.52	122.52	68.40	41.76	110.16
1	3	67.80	61.20	129.00	81.00	62.28	143.28	68.40	62.64	131.04
1	4	67.80	81.60	149.40	81.00	83.04	164.04	68.40	83.52	151.92
1	5	67.80	102.00	169.80	81.00	103.80	184.80	68.40	104.40	172.80
1	6	67.80	122.40	190.20	81.00	124.56	205.56	68.40	125.28	193.68
1	7	67.80	142.80	210.60	81.00	145.32	226.32	68.40	146.16	214.56
1	8	67.80	163.20	231.00	81.00	166.08	247.08	68.40	167.04	235.44
1	9	67.80	183.60	251.40	81.00	186.84	267.84	68.40	187.92	256.32
1	10	67.80	204.00	271.80	81.00	207.60	288.60	68.40	208.80	277.20
1	11	67.80	224.40	292.20	81.00	228.36	309.36	68.40	229.68	298.08
1	12	67.80	244.80	312.60	81.00	249.12	330.12	68.40	250.56	318.96
1	13	67.80	265.20	333.00	81.00	269.88	350.88	68.40	271.44	339.84
1	14	67.80	285.60	353.40	81.00	290.64	371.64	68.40	292.32	360.72
1	15	67.80	306.00	373.80	81.00	311.40	392.40	68.40	313.20	381.60
1	16	67.80	326.40	394.20	81.00	332.16	413.16	68.40	334.08	402.48
1	17	67.80	346.80	414.60	81.00	352.92	433.92	68.40	354.96	423.36
1	18	67.80	367.20	435.00	81.00	373.68	454.68	68.40	375.84	444.24
1	19	67.80	387.60	455.40	81.00	394.44	475.44	68.40	396.72	465.12
1	20	67.80	408.00	475.80	81.00	415.20	496.20	68.40	417.60	486.00
1	21	67.80	428.40	496.20	81.00	435.96	516.96	68.40	438.48	506.88
1	22	67.80	448.80	516.60	81.00	456.72	537.72	68.40	459.36	527.76
1	23	67.80	469.20	537.00	81.00	477.48	558.48	68.40	480.24	548.64
1	24	67.80	489.60	557.40	81.00	498.24	579.24	68.40	501.12	569.52
1	25	67.80	510.00	577.80	81.00	519.00	600.00	68.40	522.00	590.40
1	26	67.80	530.40	598.20	81.00	539.76	620.76	68.40	542.88	611.28
1	27	67.80	550.80	618.60	81.00	560.52	641.52	68.40	563.76	632.16
1	28	67.80	571.20	639.00	81.00	581.28	662.28	68.40	584.64	653.04
1	29	67.80	591.60	659.40	81.00	602.04	683.04	68.40	605.52	673.92
1	30	67.80	612.00	679.80	81.00	622.80	703.80	68.40	626.40	694.80
1	31	67.80	632.40	700.20	81.00	643.56	724.56	68.40	647.28	715.68
1	32	67.80	652.80	720.60	81.00	664.32	745.32	68.40	668.16	736.56
1	33	67.80	673.20	741.00	81.00	685.08	766.08	68.40	689.04	757.44
1	34	67.80	693.60	761.40	81.00	705.84	786.84	68.40	709.92	778.32
1	35	67.80	714.00	781.80	81.00	726.60	807.60	68.40	730.80	799.20
1	36	67.80	734.40	802.20	81.00	747.36	828.36	68.40	751.68	820.08
1	37	67.80	754.80	822.60	81.00	768.12	849.12	68.40	772.56	840.96
1	38	67.80	775.20	843.00	81.00	788.88	869.88	68.40	793.44	861.84
1	39	67.80	795.60	863.40	81.00	809.64	890.64	68.40	814.32	882.72
1	40	67.80	816.00	883.80	81.00	830.40	911.40	68.40	835.20	903.60

Table 18b. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.1 Passengers/Auto)

		Scenario # 1			Scenario # 2			Scenario # 3		
# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)
1.1	1	74.58	20.40	94.98	89.10	20.76	109.86	75.24	20.88	96.12
1.1	2	74.58	40.80	115.38	89.10	41.52	130.62	75.24	41.76	117.00
1.1	3	74.58	61.20	135.78	89.10	62.28	151.38	75.24	62.64	137.88
1.1	4	74.58	81.60	156.18	89.10	83.04	172.14	75.24	83.52	158.76
1.1	5	74.58	102.00	176.58	89.10	103.80	192.90	75.24	104.40	179.64
1.1	6	74.58	122.40	196.98	89.10	124.56	213.66	75.24	125.28	200.52
1.1	7	74.58	142.80	217.38	89.10	145.32	234.42	75.24	146.16	221.40
1.1	8	74.58	163.20	237.78	89.10	166.08	255.18	75.24	167.04	242.28
1.1	9	74.58	183.60	258.18	89.10	186.84	275.94	75.24	187.92	263.16
1.1	10	74.58	204.00	278.58	89.10	207.60	296.70	75.24	208.80	284.04
1.1	11	74.58	224.40	298.98	89.10	228.36	317.46	75.24	229.68	304.92
1.1	12	74.58	244.80	319.38	89.10	249.12	338.22	75.24	250.56	325.80
1.1	13	74.58	265.20	339.78	89.10	269.88	358.98	75.24	271.44	346.68
1.1	14	74.58	285.60	360.18	89.10	290.64	379.74	75.24	292.32	367.56
1.1	15	74.58	306.00	380.58	89.10	311.40	400.50	75.24	313.20	388.44
1.1	16	74.58	326.40	400.98	89.10	332.16	421.26	75.24	334.08	409.32
1.1	17	74.58	346.80	421.38	89.10	352.92	442.02	75.24	354.96	430.20
1.1	18	74.58	367.20	441.78	89.10	373.68	462.78	75.24	375.84	451.08
1.1	19	74.58	387.60	462.18	89.10	394.44	483.54	75.24	396.72	471.96
1.1	20	74.58	408.00	482.58	89.10	415.20	504.30	75.24	417.60	492.84
1.1	21	74.58	428.40	502.98	89.10	435.96	525.06	75.24	438.48	513.72
1.1	22	74.58	448.80	523.38	89.10	456.72	545.82	75.24	459.36	534.60
1.1	23	74.58	469.20	543.78	89.10	477.48	566.58	75.24	480.24	555.48
1.1	24	74.58	489.60	564.18	89.10	498.24	587.34	75.24	501.12	576.36
1.1	25	74.58	510.00	584.58	89.10	519.00	608.10	75.24	522.00	597.24
1.1	26	74.58	530.40	604.98	89.10	539.76	628.86	75.24	542.88	618.12
1.1	27	74.58	550.80	625.38	89.10	560.52	649.62	75.24	563.76	639.00
1.1	28	74.58	571.20	645.78	89.10	581.28	670.38	75.24	584.64	659.88
1.1	29	74.58	591.60	666.18	89.10	602.04	691.14	75.24	605.52	680.76
1.1	30	74.58	612.00	686.58	89.10	622.80	711.90	75.24	626.40	701.64
1.1	31	74.58	632.40	706.98	89.10	643.56	732.66	75.24	647.28	722.52
1.1	32	74.58	652.80	727.38	89.10	664.32	753.42	75.24	668.16	743.40
1.1	33	74.58	673.20	747.78	89.10	685.08	774.18	75.24	689.04	764.28
1.1	34	74.58	693.60	768.18	89.10	705.84	794.94	75.24	709.92	785.16
1.1	35	74.58	714.00	788.58	89.10	726.60	815.70	75.24	730.80	806.04
1.1	36	74.58	734.40	808.98	89.10	747.36	836.46	75.24	751.68	826.92
1.1	37	74.58	754.80	829.38	89.10	768.12	857.22	75.24	772.56	847.80
1.1	38	74.58	775.20	849.78	89.10	788.88	877.98	75.24	793.44	868.68
1.1	39	74.58	795.60	870.18	89.10	809.64	898.74	75.24	814.32	889.56
1.1	40	74.58	816.00	890.58	89.10	830.40	919.50	75.24	835.20	910.44

Table 18c. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.2 Passengers/Auto)

		Scenario #1			Scenario #2			Scenario #3		
# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)
1.2	1	81.36	20.40	101.76	97.20	20.76	117.96	82.08	20.88	102.96
1.2	2	81.36	40.80	122.16	97.20	41.52	138.72	82.08	41.76	123.84
1.2	3	81.36	61.20	142.56	97.20	62.28	159.48	82.08	62.64	144.72
1.2	4	81.36	81.60	162.96	97.20	83.04	180.24	82.08	83.52	165.60
1.2	5	81.36	102.00	183.36	97.20	103.80	201.00	82.08	104.40	186.48
1.2	6	81.36	122.40	203.76	97.20	124.56	221.76	82.08	125.28	207.36
1.2	7	81.36	142.80	224.16	97.20	145.32	242.52	82.08	146.16	228.24
1.2	8	81.36	163.20	244.56	97.20	166.08	263.28	82.08	167.04	249.12
1.2	9	81.36	183.60	264.96	97.20	186.84	284.04	82.08	187.92	270.00
1.2	10	81.36	204.00	285.36	97.20	207.60	304.80	82.08	208.80	290.88
1.2	11	81.36	224.40	305.76	97.20	228.36	325.56	82.08	229.68	311.76
1.2	12	81.36	244.80	326.16	97.20	249.12	346.32	82.08	250.56	332.64
1.2	13	81.36	265.20	346.56	97.20	269.88	367.08	82.08	271.44	353.52
1.2	14	81.36	285.60	366.96	97.20	290.64	387.84	82.08	292.32	374.40
1.2	15	81.36	306.00	387.36	97.20	311.40	408.60	82.08	313.20	395.28
1.2	16	81.36	326.40	407.76	97.20	332.16	429.36	82.08	334.08	416.16
1.2	17	81.36	346.80	428.16	97.20	352.92	450.12	82.08	354.96	437.04
1.2	18	81.36	367.20	448.56	97.20	373.68	470.88	82.08	375.84	457.92
1.2	19	81.36	387.60	468.96	97.20	394.44	491.64	82.08	396.72	478.80
1.2	20	81.36	408.00	489.36	97.20	415.20	512.40	82.08	417.60	499.68
1.2	21	81.36	428.40	509.76	97.20	435.96	533.16	82.08	438.48	520.56
1.2	22	81.36	448.80	530.16	97.20	456.72	553.92	82.08	459.36	541.44
1.2	23	81.36	469.20	550.56	97.20	477.48	574.68	82.08	480.24	562.32
1.2	24	81.36	489.60	570.96	97.20	498.24	595.44	82.08	501.12	583.20
1.2	25	81.36	510.00	591.36	97.20	519.00	616.20	82.08	522.00	604.08
1.2	26	81.36	530.40	611.76	97.20	539.76	636.96	82.08	542.88	624.96
1.2	27	81.36	550.80	632.16	97.20	560.52	657.72	82.08	563.76	645.84
1.2	28	81.36	571.20	652.56	97.20	581.28	678.48	82.08	584.64	666.72
1.2	29	81.36	591.60	672.96	97.20	602.04	699.24	82.08	605.52	687.60
1.2	30	81.36	612.00	693.36	97.20	622.80	720.00	82.08	626.40	708.48
1.2	31	81.36	632.40	713.76	97.20	643.56	740.76	82.08	647.28	729.36
1.2	32	81.36	652.80	734.16	97.20	664.32	761.52	82.08	668.16	750.24
1.2	33	81.36	673.20	754.56	97.20	685.08	782.28	82.08	689.04	771.12
1.2	34	81.36	693.60	774.96	97.20	705.84	803.04	82.08	709.92	792.00
1.2	35	81.36	714.00	795.36	97.20	726.60	823.80	82.08	730.80	812.88
1.2	36	81.36	734.40	815.76	97.20	747.36	844.56	82.08	751.68	833.76
1.2	37	81.36	754.80	836.16	97.20	768.12	865.32	82.08	772.56	854.64
1.2	38	81.36	775.20	856.56	97.20	788.88	886.08	82.08	793.44	875.52
1.2	39	81.36	795.60	876.96	97.20	809.64	906.84	82.08	814.32	896.40
1.2	40	81.36	816.00	897.36	97.20	830.40	927.60	82.08	835.20	917.28

Table 18d. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.5 Passengers/Auto)

		Scenario # 1			Scenario # 2			Scenario # 3		
# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)
1.5	1	101.70	20.40	122.10	121.50	20.76	142.26	102.60	20.88	123.48
1.5	2	101.70	40.80	142.50	121.50	41.52	163.02	102.60	41.76	144.36
1.5	3	101.70	61.20	162.90	121.50	62.28	183.78	102.60	62.64	165.24
1.5	4	101.70	81.60	183.30	121.50	83.04	204.54	102.60	83.52	186.12
1.5	5	101.70	102.00	203.70	121.50	103.80	225.30	102.60	104.40	207.00
1.5	6	101.70	122.40	224.10	121.50	124.56	246.06	102.60	125.28	227.88
1.5	7	101.70	142.80	244.50	121.50	145.32	266.82	102.60	146.16	248.76
1.5	8	101.70	163.20	264.90	121.50	166.08	287.58	102.60	167.04	269.64
1.5	9	101.70	183.60	285.30	121.50	186.84	308.34	102.60	187.92	290.52
1.5	10	101.70	204.00	305.70	121.50	207.60	329.10	102.60	208.80	311.40
1.5	11	101.70	224.40	326.10	121.50	228.36	349.86	102.60	229.68	332.28
1.5	12	101.70	244.80	346.50	121.50	249.12	370.62	102.60	250.56	353.16
1.5	13	101.70	265.20	366.90	121.50	269.88	391.38	102.60	271.44	374.04
1.5	14	101.70	285.60	387.30	121.50	290.64	412.14	102.60	292.32	394.92
1.5	15	101.70	306.00	407.70	121.50	311.40	432.90	102.60	313.20	415.80
1.5	16	101.70	326.40	428.10	121.50	332.16	453.66	102.60	334.08	436.68
1.5	17	101.70	346.80	448.50	121.50	352.92	474.42	102.60	354.96	457.56
1.5	18	101.70	367.20	468.90	121.50	373.68	495.18	102.60	375.84	478.44
1.5	19	101.70	387.60	489.30	121.50	394.44	515.94	102.60	396.72	499.32
1.5	20	101.70	408.00	509.70	121.50	415.20	536.70	102.60	417.60	520.20
1.5	21	101.70	428.40	530.10	121.50	435.96	557.46	102.60	438.48	541.08
1.5	22	101.70	448.80	550.50	121.50	456.72	578.22	102.60	459.36	561.96
1.5	23	101.70	469.20	570.90	121.50	477.48	598.98	102.60	480.24	582.84
1.5	24	101.70	489.60	591.30	121.50	498.24	619.74	102.60	501.12	603.72
1.5	25	101.70	510.00	611.70	121.50	519.00	640.50	102.60	522.00	624.60
1.5	26	101.70	530.40	632.10	121.50	539.76	661.26	102.60	542.88	645.48
1.5	27	101.70	550.80	652.50	121.50	560.52	682.02	102.60	563.76	666.36
1.5	28	101.70	571.20	672.90	121.50	581.28	702.78	102.60	584.64	687.24
1.5	29	101.70	591.60	693.30	121.50	602.04	723.54	102.60	605.52	708.12
1.5	30	101.70	612.00	713.70	121.50	622.80	744.30	102.60	626.40	729.00
1.5	31	101.70	632.40	734.10	121.50	643.56	765.06	102.60	647.28	749.88
1.5	32	101.70	652.80	754.50	121.50	664.32	785.82	102.60	668.16	770.76
1.5	33	101.70	673.20	774.90	121.50	685.08	806.58	102.60	689.04	791.64
1.5	34	101.70	693.60	795.30	121.50	705.84	827.34	102.60	709.92	812.52
1.5	35	101.70	714.00	815.70	121.50	726.60	848.10	102.60	730.80	833.40
1.5	36	101.70	734.40	836.10	121.50	747.36	868.86	102.60	751.68	854.28
1.5	37	101.70	754.80	856.50	121.50	768.12	889.62	102.60	772.56	875.16
1.5	38	101.70	775.20	876.90	121.50	788.88	910.38	102.60	793.44	896.04
1.5	39	101.70	795.60	897.30	121.50	809.64	931.14	102.60	814.32	916.92
1.5	40	101.70	816.00	917.70	121.50	830.40	951.90	102.60	835.20	937.80

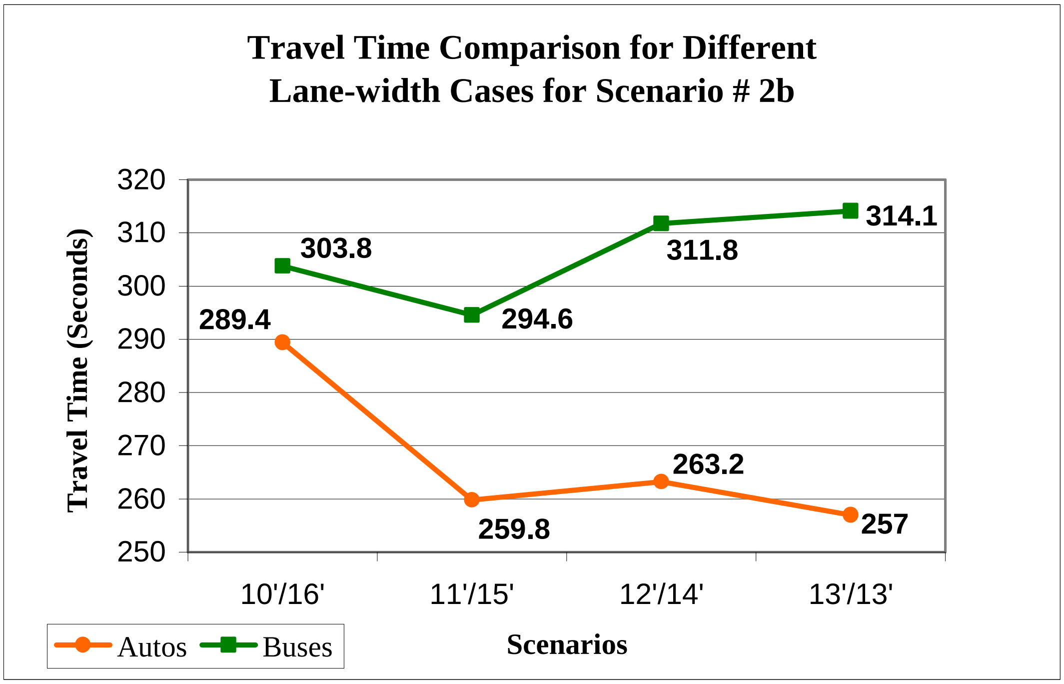
Table 18e. Sensitivity Analysis for Number of Passengers Occupying Autos and Buses (1.75 Passengers/Auto)

		Scenario # 1			Scenario # 2			Scenario # 3		
# Passengers per auto	# Passengers per bus	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)	Users' Cost for 60 autos ($)	Users' Cost for 12 buses ($)	Total Users' Costs ($)
1.75	1	118.65	20.40	139.05	141.75	20.76	162.51	119.70	20.88	140.58
1.75	2	118.65	40.80	159.45	141.75	41.52	183.27	119.70	41.76	161.46
1.75	3	118.65	61.20	179.85	141.75	62.28	204.03	119.70	62.64	182.34
1.75	4	118.65	81.60	200.25	141.75	83.04	224.79	119.70	83.52	203.22
1.75	5	118.65	102.00	220.65	141.75	103.80	245.55	119.70	104.40	224.10
1.75	6	118.65	122.40	241.05	141.75	124.56	266.31	119.70	125.28	244.98
1.75	7	118.65	142.80	261.45	141.75	145.32	287.07	119.70	146.16	265.86
1.75	8	118.65	163.20	281.85	141.75	166.08	307.83	119.70	167.04	286.74
1.75	9	118.65	183.60	302.25	141.75	186.84	328.59	119.70	187.92	307.62
1.75	10	118.65	204.00	322.65	141.75	207.60	349.35	119.70	208.80	328.50
1.75	11	118.65	224.40	343.05	141.75	228.36	370.11	119.70	229.68	349.38
1.75	12	118.65	244.80	363.45	141.75	249.12	390.87	119.70	250.56	370.26
1.75	13	118.65	265.20	383.85	141.75	269.88	411.63	119.70	271.44	391.14
1.75	14	118.65	285.60	404.25	141.75	290.64	432.39	119.70	292.32	412.02
1.75	15	118.65	306.00	424.65	141.75	311.40	453.15	119.70	313.20	432.90
1.75	16	118.65	326.40	445.05	141.75	332.16	473.91	119.70	334.08	453.78
1.75	17	118.65	346.80	465.45	141.75	352.92	494.67	119.70	354.96	474.66
1.75	18	118.65	367.20	485.85	141.75	373.68	515.43	119.70	375.84	495.54
1.75	19	118.65	387.60	506.25	141.75	394.44	536.19	119.70	396.72	516.42
1.75	20	118.65	408.00	526.65	141.75	415.20	556.95	119.70	417.60	537.30
1.75	21	118.65	428.40	547.05	141.75	435.96	577.71	119.70	438.48	558.18
1.75	22	118.65	448.80	567.45	141.75	456.72	598.47	119.70	459.36	579.06
1.75	23	118.65	469.20	587.85	141.75	477.48	619.23	119.70	480.24	599.94
1.75	24	118.65	489.60	608.25	141.75	498.24	639.99	119.70	501.12	620.82
1.75	25	118.65	510.00	628.65	141.75	519.00	660.75	119.70	522.00	641.70
1.75	26	118.65	530.40	649.05	141.75	539.76	681.51	119.70	542.88	662.58
1.75	27	118.65	550.80	669.45	141.75	560.52	702.27	119.70	563.76	683.46
1.75	28	118.65	571.20	689.85	141.75	581.28	723.03	119.70	584.64	704.34
1.75	29	118.65	591.60	710.25	141.75	602.04	743.79	119.70	605.52	725.22
1.75	30	118.65	612.00	730.65	141.75	622.80	764.55	119.70	626.40	746.10
1.75	31	118.65	632.40	751.05	141.75	643.56	785.31	119.70	647.28	766.98
1.75	32	118.65	652.80	771.45	141.75	664.32	806.07	119.70	668.16	787.86
1.75	33	118.65	673.20	791.85	141.75	685.08	826.83	119.70	689.04	808.74
1.75	34	118.65	693.60	812.25	141.75	705.84	847.59	119.70	709.92	829.62
1.75	35	118.65	714.00	832.65	141.75	726.60	868.35	119.70	730.80	850.50
1.75	36	118.65	734.40	853.05	141.75	747.36	889.11	119.70	751.68	871.38
1.75	37	118.65	754.80	873.45	141.75	768.12	909.87	119.70	772.56	892.26
1.75	38	118.65	775.20	893.85	141.75	788.88	930.63	119.70	793.44	913.14
1.75	39	118.65	795.60	914.25	141.75	809.64	951.39	119.70	814.32	934.02
1.75	40	118.65	816.00	934.65	141.75	830.40	972.15	119.70	835.20	954.90

lane and 15-foot exclusive bus lane, and 13-foot lane for each. **Figure 27** shows the summary of the travel time comparison, and the detailed results for these cases are attached in **Appendix D.**

The analysis shows that for autos, there was a clear reduction (approximately ten percent) in travel time when the mixed-traffic lane width increased from 10 to 11 feet. After that, when the auto-lane width increased beyond 11 feet, the travel time for autos slightly changed within 2.5 percent. In case of buses, there was a slight reduction (approximately three percent) in travel time when the exclusive bus lane width was reduced from 16 to 15 feet. After that, when the bus lane width was reduced to 14 feet and then to 13 feet, the travel time for buses increased by 5.8 and 6.6 percent, respectively. The graph suggests that if an exclusive bus lane were implemented in this case study, the scenario of 11-foot mixed-traffic lane and 15-foot exclusive bus lane would provide the least travel time.

Figure 27. Travel Time Comparison for Different Lane-Width Cases – Scenario 2b



Analysis for Number of Buses and Bicycles

Another example of sensitivity analysis applied in this case study was to change the number of buses and bicycles, while keeping the same number of autos in the corridor. Three new cases were evaluated for each of the three scenarios where the following numbers were applied:

a. 36 buses and 16 bicycles.
b. 60 buses and 16 bicycles.
c. 12 buses and 60 bicycles.

The results showed that the different numbers of buses and bicycles did not have much impact on the final results. Similar to the original case, scenario # 1 continued to provide best performance for autos, followed closely by scenario # 3. It was noticed that travel times for buses increased when the number of buses increased in all cases, while this was not necessary in the case of bicycles. Travel times for bicycles stayed without significant change throughout the analysis, except for scenario # 1 in case (b), when it increased by more than 10 percent. For the same case, travel times for bicycles increased by 4 percent in scenario # 2, and did not change in scenario # 3. The results are reasonable since bicyclists would be sharing a 13-foot lane with 60 buses and other vehicles in scenario # 1. The situation is better in scenario # 2 when they share a 14-foot exclusive bus lane with 60 buses, but without autos. In scenario # 3, bicycles stay in their exclusive bicycle lane with minimum interaction with other motor vehicles.

When comparing the different cases for scenario # 1 to its original case, the travel times for autos, buses, and bicycles, increased by 6.2, 3.6, and 5.2 percent, respectively, in case (a). In case (b), the increase went up to 6.8, 7.8, and 15 percent, and the changes were below 3.4 percent for all three modes in case (c). **Figures 28 and 29** show the summary of the travel time and emission rate comparisons, respectively, for the different cases of scenario # 1, and the detailed results for these cases are attached in **Appendix E.**

Figure 28. Travel Times for Four Different Cases – Scenario # 1

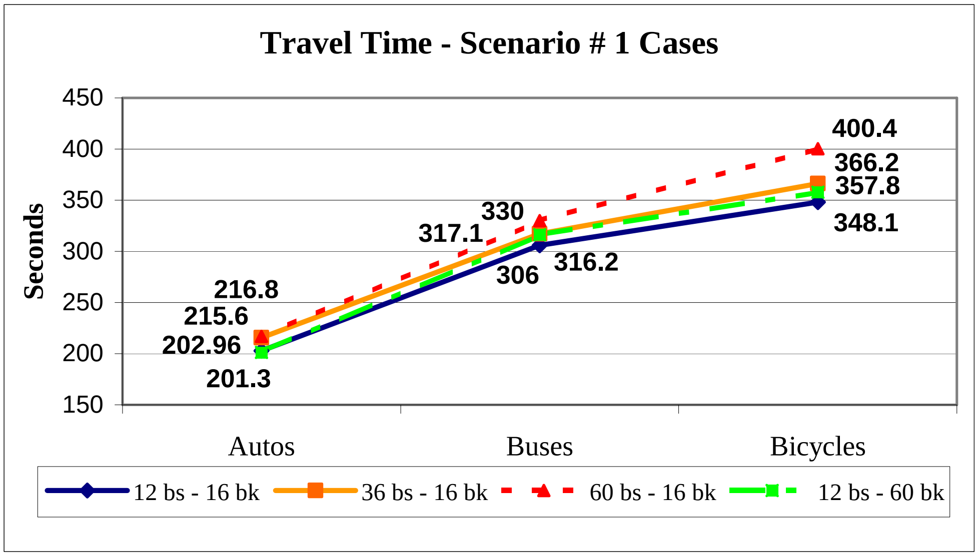
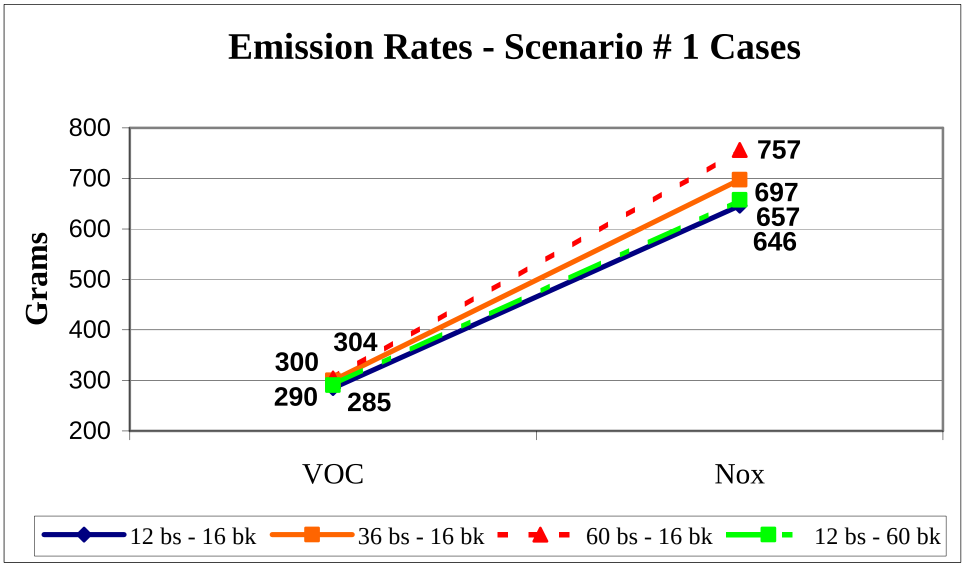


Figure 29. Emission Rates for Four Different Cases – Scenario # 1



4.14. Experimental Survey

In an effort to provide a complete case study, a survey was prepared and given to two groups; one group consisted of transportation professionals from different jurisdictions, and the other group consisted of elected and non-elected officials who frequently make decisions on transportation-related projects, and most of the times, they are not transportation professionals.

The survey included two sets of questions: the first set consisted of general questions about traffic congestion, major challenges, and potential solutions to reduce it, and the second set consisted of questions related to choices of a preferred scenario, where several charts were displayed. Some questions were related to a single objective and others were related to more than one objective where different scenarios performed differently. Another question in the survey concerned the final chart displaying all 19 objectives included in this study for all three scenarios and the respondents were required to review the chart and make their choice of a preferred scenario. The survey is attached in **Appendix F.**

The survey has two objectives. First, is to find out if there is a general recognition, especially from the officials, that traffic congestion exists in their jurisdiction, if they have put any thoughts or effort to address this matter, and if there was any interest in the multimodal concept as a potential solution. The second objective is to see how clear the charts are, and if non-transportation professionals can easily interpret them and respond to the questions. Ten transportation professionals and eight officials responded to the survey, and the results were as follows:

4.14.1. Transportation-professionals' Survey Results:

The transportation professionals who responded to the survey were those in charge of the traffic divisions of their respective jurisdictions in the state of Maryland, USA, and they included the ten following jurisdictions: City of Baltimore, City of Frederick, City of Gaithersburg, Anne Arundel County, Baltimore County, Calvert County, Carroll County, Harford County, Howard County, and Frederick County. This was a good mix of jurisdictions, where some are considered to be - or to be near - a big city such as Baltimore, MD, and others are not very close to big cities, such as Howard County.

All ten jurisdictions agreed that they have a traffic congestion problem, and nine out of ten said that it was a priority for them to reduce congestion. All jurisdictions agreed that right-of-way availability is the main challenge to pursuing traffic congestion solutions, followed by the lack of construction funds.

All jurisdictions, except for Howard County, stated that there was an effort to promote some multimodal concept, but only 6 have pursued the installation of some bicycle lanes, supported light-rail extension, installed bus shelters, or subsidized bus service. The top three factors that would encourage those transportation professionals to pursue a solution to reduce congestion were to have a solution that does not require additional right-of-way (90%), to address traffic safety (70%), and to include transit accommodations (60%). Bicycle lanes and environmental impacts received 4 votes each. Finally, all jurisdictions, except for Harford County, are either working on or have already completed a bicycle master plan.

When asked about the their preferred scenario, they chose scenario # 1 as their favorite in all categories independently, except for the bicycle-related objectives, where scenario # 3 had better results with the exclusive bicycle lane. Overall, after understanding the lane configuration for all scenarios and after reviewing all results, seven out of ten participants chose scenario # 3, even though it did not have the majority of best levels of performance. Some explained that this would be their preferred scenario since the percentage of trucks on this road is not high. Some concerns, however, were raised about the 10.5-foot lane being slightly narrow. The three opinions favoring scenario # 1 raised concerns about potential sideswipe accidents with the narrower lanes, and they did not want to sacrifice safety for a low number of bicyclists. One participant suggested that scenario # 1 would be preferred if this was a part of a traffic operation solution for an existing condition, but scenario # 3 would be favored if the decision was a part of a long-term master-plan goal to encourage different modes of transportation.

4.14.2. Officials' survey results:

The officials who responded to the survey were all from the City of Rockville, Maryland, USA. The eight officials consisted of three council members, the city manager, the deputy city manager, two assistants to the city manager, and the director of the public works department.

Interpreting the charts and choosing a preferred scenario were the main purpose of conducting this survey with officials. It was interesting also to see their perspective on the traffic congestion issue and how they see the challenges to solve this problem.

All officials agreed that there was a traffic congestion problem in Rockville, and the majority agreed that reducing congestion had been a priority for the City. Unlike the transportation professionals who agreed that the right-of-way availability was the main challenge to pursue a traffic congestion solution, officials voted for the challenge of building consensus as the main challenge. It was followed by the lack of construction funds, and the right-of-way issue came in last.

All officials supported the promotion of the multimodal concept, but when asked about the most encouraging factors for them to support a solution to reduce congestion, no need to purchase right-of-way came in first place, followed by addressing traffic safety and including transit accommodations. Addressing environment impacts came in close fourth, and accommodating bicycle lanes was the least important factor. It should be noted that this order is very similar to the order resulting from the transportation professional survey.

When comparing any two performances, of which one is related to the safety impact, the officials leaned toward choosing the safer scenario, even if it meant more travel time or less bicycle compatibility. It was interesting to see the officials divided when making a final choice at the time all performances were displayed in one chart. One half of the officials chose scenario #1, which is ranked first among the three scenarios in the majority of the objectives. They explained that bicycle lanes would not be used by enough bicyclists to justify lower levels of performance in safety, emission rates, and travel time. On the other hand, the other officials chose scenario # 3 stating that providing a bicycle lane is very important, and the difference in levels of performance for the other objectives were not much worse to convince them otherwise.

The survey's results were very useful in this study. It showed that although transportation professionals and officials did not agree on the order of the challenges in pursuing a solution for traffic congestion, they agreed that the right-of-way and the lack of funds are two major challenges. They also agreed on the most important factors for them to support a solution, and those factors were: no need to purchase right-of-way, addressing traffic safety, and including transit accommodations. Finally, when reviewing the charts displaying the performance measures of all three scenarios, almost all officials had no trouble interpreting the charts and they made intelligent decisions. It should be noted that the officials were not provided with any presentations explaining the charts, but in reality, they would be exposed to a presentation about the project and the performance measures. This should make it even easier for them to interpret the charts and to make an informed decision. Finally, despite the fact that the officials did not unanimously agree on a final selection, they had all the information they needed to clearly understand the advantages and disadvantages of each scenario. This would allow them to be engaged in a productive discussion before a final decision is made.

4.15. Summary of Numerical Example

In this chapter, a numerical example was presented to demonstrate the suggested method to allocate and compare lane-use scenarios among viable modes of transportation. A short corridor - 1.3 miles long - with six signalized intersections and three bus stops was the scene of the experiment. Tasks implemented to demonstrate the suggested method included identifying three different scenarios, applying traffic data into a traffic simulation model, and computing several factors to determine the objectives of the study.

For each of the three scenarios, the following measures of performance were evaluated: average travel speed, travel time, and delay for each of the three modes of transportation, bicycle compatibility index, users' travel and delay costs, and operating costs for all modes. Mobility, accessibility, and environmental and safety impacts were also evaluated for each scenario.

Throughout the process, charts were developed to compare specific objectives for each of the three scenarios. Performance levels for the 19 objectives were summarized and presented in a single chart where their values were displayed. A sensitivity analysis was also conducted to provide an understanding of how the model responds when input are changed. Several different examples of the sensitivity analysis were provided.

Finally, a survey was conducted where decision makers answered some questions and reviewed the charts. They agreed that the right-of-way and the lack of funds were two major challenges to reduce congestion, and the majority of transportation professionals preferred scenario # 3 in the case study, while the officials were divided between scenarios # 1 and # 3.

Chapter V: ASSUMPTIONS AND LIMITATIONS

In a study with such a high number of inputs and variables, assumptions had to be made to both simplify and facilitate the process. There are also limitations to the study that have to be identified and should be considered as opportunities for future research to improve and enhance the application of the suggested method. In this chapter, the study assumptions and limitations are presented. It is important, however, to distinguish between the assumptions and limitations of the study itself, and those of the case study presented in the previous chapter.

5.1. Study Assumptions

The right-of-way width in this study is assumed to be fixed from curb to curb for each travel direction (e.g., 26-foot wide in the case study). The assumption is that this is the room available to explore different lane-use allocation scenarios, and it is up to the transportation engineers and planners to decide how to best allocate the road among different lane-uses with an existing road width already in place. Although this might be the case in most cities where right-of-way and resources are limited, it is probably possible in some areas to widen the road and allow more space to accommodate a parking lane, a bicycle lane, or an extra mixed-traffic lane. Thus, the methods developed as a part of this research should be useful in a variety of situations, but there is a limit to how many cases can be reported. Most important is the understanding of the methods used and some of the sensitivities.

Land use and transportation systems are interactive as they form a combination on which people and businesses make their local decisions. Transport strategies change accessibility, which subsequently affects land use. In turn, land use impacts trip generation, and thus, affecting the performance of the transport system (Ortuzar and Willumsen, 1994). For example, commuting time and cost influence the choice of a place to live, and business location decisions are affected by the amount of traffic congestion and by the location of the employee’s residence. Since land use systems and transportation are interdependent, it is challenging to find a model to predict one from the other.

The suggested method is assumed to be applied in a uniform land use mix across all scenarios, and therefore, the type of land use had no effect in the study. For example, when calculating the BCI in the case study, the factor “AREA” was assumed to be zero, for a non-residential area, throughout the corridor. Also other adjustment factors for truck volumes, parking turnover, and right-turn volumes were assumed to be zero for all scenarios. Those factors, however, could be taken into consideration in a more detailed analysis while applying the suggested method.

The study assumed that it was important to ensure continuity and accessibility. Therefore, an effort was made in this area by suggesting a similar scenario of lane use to all segments of the road, i.e. the existence of an exclusive bus lane or bicycle lane was consistent along the different sections of the road. This matter is more tangible when accessibility is evaluated for each scenario.

The effects of traffic signals and other traffic control devices were assumed to be important factors in the analysis, and therefore, were included in the model by coding the related information in the simulation model. No effort, however, was made to optimize the traffic signals' timing.

In the case study, three scenarios were identified. There are probably other scenarios that could have been added for comparisons sake. For example, a seven-foot parking-lane could be provided along with a six-foot bicycle lane and a 13-foot travel lane for mixed traffic. In some cases, parking might be necessary, but it obviously comes at the expense of road capacity. If the transportation engineers and planners are looking for all possibilities, then extra effort should be made to identify more scenarios, as will be discussed in the next chapter. In the case study, however, it was assumed that parking is available on the private properties adjacent to the corridor, and therefore, the three suggested scenarios – with no parking lanes - were the most promising for this case.

In the same line of thoughts, it should be noted that some flexibility could exist to allow different uses for the same scenario as a reflection of the various traffic conditions during different times of the day. For example, a 12-foot bus lane can be replaced during non-peak periods with a seven-foot parking lane and a five-foot bicycle lane, but a mixed-traffic lane cannot replace a bicycle lane alone. Another example would be to add a traffic lane during one peak period and/or remove a lane during the other peak period pending or the flow of traffic during rush hours, as implemented on Connecticut Avenue in Washington, D.C, USA. It is obvious that such alternatives should be set (i.e., pavement markings) before implementation to allow the feasibility of such outcome.

More specific assumptions applied in the three scenarios include the number of bus stops (3) and signalized intersections (6) that exist along the 1.3-mile corridor. About 1000 vehicles were spotted on any given section on the northbound travel lanes of the road, but only 60 vehicles, 12 buses, and 16 bicycles made the trip from point (A) upstream to point (B) downstream. The performance measures of these three types of transportation modes were analyzed. Other vehicles entered and exited the corridor at different points between (A) and (B) but their performance was not included in the analysis.

It should be also noted that during the analysis of the scenarios, some assumptions were made such as the $20.00 estimated average hourly user time value, and the $3.00 cost of a gallon of fuel. These values can obviously be different from a city to another city, from time to time, and even from a person to person using different mode of transportation, as described in chapter three. It was assumed that these amounts were reasonable and were adequate to conduct a comparison among the scenarios as long as the same values were applied for all scenarios. A sensitivity analysis can also be applied to assess the effect of change in those values.

5.2. Study Limitations

Although an honest effort was made to include the major factors into the analysis, it should be acknowledged that the study has some limitations that could be considered or included in future studies. For example, this study did not take into consideration some traffic-signal improvements that can contribute to improve traffic flow such as signal optimization and pre-emption for buses to give them priority for green light. Traffic signal improvements can contribute to the efficiency of traffic flow for different scenarios. Also pedestrian considerations were not included in the study. For example, it is safer for pedestrians to cross less number of lanes, even if the road width does not change. It is also better for pedestrians to cross a shorter distance, but this did not apply to this study since the road width was predetermined.

Although bicycles were included in this study, as well as the BCI level and bicycle safety, the study did not quantify other benefits of bicycling such as social benefits, health benefits, or benefits from right-of-way preservation. Another unforeseen factor is how society would react to the addition of bicycle lanes in the future. Since several cities, such as Philadelphia, PA, Baltimore, MD, and Washington, DC, in the United States, have been active recently in establishing bicycle master plans, there is a good chance that the public will start to be more accepting of the idea of bicycling to work and thus to use the bicycle lanes, especially with the continuous rise in fuel prices.

As mentioned earlier, parking might be necessary, even when it comes at the expense of road capacity. The suggested method does not provide, however, a tool to measure the need of a parking lane or its benefits, especially in a business district. This matter should be dealt with on a case-by-case basis. If it is determined that a parking lane is essential, approximately seven feet of the available road width should be designated for the parking lane. In case the need of a parking lane could not be determined, scenarios could be developed with and without the parking lane, and the performance of the different scenarios should help decision makers to choose their preferred scenario.

It should be noted that the study did not include cost of bus fares in the users' costs, but this factor can be easily added, if needed, especially if the analysis includes factors people consider when deciding which transportation mode to use. Examples of those factors include hours and extent of service, reliability, accessibility, transit information, transfers, cost, appearance, comfort, pedestrian environment and amenities, and time spent walking to the bus stop.

In the case study, although sensitivity analysis was applied for different factors, more sensitivity analyses could be performed. For instance, to evaluate the effect of mode choice on the measures of effectiveness associated with each scenario, mode choice shift from autos to buses and bicycles, and vice versa, could be considered. The case study did look, however, at the effect of increasing the number of all modes of transportation under the growth-in-demand section in the previous chapter. In other cases, where more than 2 traffic lanes could be available, more sensitivity analysis could be performed to measure the impact of the number of mixed traffic lanes on road capacity.

Another limitation of the case study is that it presented a case of a short corridor, and therefore, the results do not offer the full picture of an urban transportation network. The suggested method, however, can be applied on urban transportation networks where an assessment of the ability of the overall transportation network to carry traffic among various destinations can be evaluated. Trips generated from an origin point to a destination point can be applied using different routes. Mobility and accessibility, in this case, will be better evaluated when assessing different routes used under different scenarios to reach a specific point of attraction.

Also, while assessing accessibility, performance measures for percentage of households (or employment) within a specific distance of a transit stop, such as ¼ mile, or with access to transit service within a specific time period, such as 15 minutes, could be beneficial. A higher number in this case suggests a better accessibility is achieved.

Chapter VI: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

In response to the challenge faced by transportation planners and traffic engineers, with the limited road space available on congested urban street networks, this study proposes a decision method for roadway lane designation among different viable modes of transportation. The objective of the study is to develop a multi-objective decision-making method for transportation professionals to apply while designating travel lanes for the various modes of transportation in order to reach the most efficient road allocation scenario. The transportation modes considered in this study include passenger cars (autos), buses, and bicycles. The most efficient scenario was not measured only by delays, travel speeds, and travel times, but also by assessing efficiency for mobility, accessibility, and safety and environmental impacts.

It has been noticed that in the recent years, several major cities in the United States such as Philadelphia, PA, Baltimore, MD, and Washington, DC, have been developing bicycle master plans. This is beneficial for smart growth as well as for the environment and for people's economy and health. These bicycle master plans, however, did not consider many factors, which this study is trying to address. The plans were based mostly on selecting several roads, where space is available, to build a bicycle network. Factors such as travel time, traffic safety, and environmental impacts, were not included in the assessment. The point is that these bicycle master plans have not been comprehensive when providing an evaluation for a bicycle network, or more generally for the urban transportation network. This study should be considered by consultants preparing bicycle master plans because it can potentially improve their studies and make it more comprehensive. While assessing the benefits of adding bicycle lanes, different modes of transportation, their effects on each other, and their effects on the transportation system in general, should be considered.

Another area where significant progress has been made in the last decade is the area of computer software application for both travel demand and traffic operations. Software such as VISSIM, PARAMICS, CORSIM, and SYNCHRO, have been upgraded and widely used in the recent years. They are valuable tools to use while developing and comparing different transportation corridors and networks.

Considering the phenomena of traffic congestion challenges, bicycle master plans, and computer software that emerged in the last two decades, a method was proposed in this research to contribute in improving transportation network efficiency and measures of performance. This method consists of identifying different possible lane-use allocation scenarios for the transportation system, evaluating the effect of changing lane allocation among the different transportation modes on the system's efficiency, and selecting the most efficient scenario pending on the measures of performance of each scenario.

The measures of performance in the study include travel speed, travel time, delay time, and users' costs for each mode of transportation, operating cost, BCI comparisons, mobility, accessibility, and safety and environmental impacts. Since it is not possible to achieve an optimal solution for each of the study's objectives, a multi-objective decision making framework was applied with the understanding that some subjective preference must ultimately lead to a single choice.

The study describes how the suggested method was developed, and a numerical example was demonstrated where the proposed method was applied for different scenarios. In this case study, an existing road section was selected in an urban transportation network, and three different possible lane-use allocation scenarios were identified. Traffic data were applied and included distribution of modes across the lanes, free flow speed, existing traffic flow numbers for each transportation mode per hour, and occupancy rate for passenger cars as well as buses.

A traffic simulation software, VISSIM, was used to model existing traffic conditions, and to determine the average speed for each travel mode, among other outcomes such as travel times and delays. The model was applied to all three scenarios with different road-lane allocations. During the modeling phase, one main objective was to evaluate the impact of each scenario on the travel speed for different modes. The outcome of VISSIM, which provides the average travel speed for each transportation mode, helped answering this question.

Using the average speeds, users' costs of travel and delays were calculated, as well as operating costs for the different transportation modes. Other measures of effectiveness for mobility, accessibility, safety, and environmental impacts were also evaluated. Mobility was calculated by quantifying the travel time needed to reach a specific point of attraction such as a Central Business District (CBD), and accessibility was evaluated by quantifying the number of people that can reach a specific point of attraction such as a CBD, or a downstream point (B), in a specific amount of time. Environmental impact was assessed by comparing emission-rate data generated by

MOBILE6 for each scenario, and an accident prediction algorithm was applied to assess the safety impact, along with the BCI to measure bicycle safety.

The question of how to assess the effect of users' decision of changing their mode choice posed itself. There was a possibility that some users would choose a new mode of transportation as a reaction to new congestion patterns created by a new scenario of lane-use. How would the change in mode choice affect the performance of the transportation system in this case? To answer this question, a sensitivity analysis was suggested to provide an understanding of how the model would respond to mode choice changes.

Several other sensitivity analyses were conducted to provide an understanding of how the model responds to input changes. The input change in this study can be the mode choice, the number of passengers per auto and per bus, the number of autos, buses, and bicycles in the system, user time value, fuel cost per gallon, and lane width. Some examples of the sensitivity analyses were provided in the case study such as the mode choice, and vehicles' occupancy. Several runs were also performed for all scenarios while using different numbers of buses and bicycles, and one scenario was assessed with different lane widths.

The multi-objective decision-making framework was applied to incorporate the multiple objectives into a process where all of them are considered regardless of whether they can be estimated in monetary or non-monetary terms. Charts and visual tools were prepared to present the different comparisons of the different scenarios. The case study ended by conducting a survey where two groups responded to different questions about traffic congestion, and about the charts representing the performance measures of the different scenarios. The first group consisted of traffic engineers from different jurisdictions in the state of Maryland, and the other group consisted of elected and non-elected officials who frequently make decisions on transportation-related projects.

The feedback received from both groups was useful and worth mentioning. In the case of the transportation professionals, they all supported the multimodal concept and claimed that their jurisdictions support the installation of bicycle lanes, light-rail extension, bus shelters, or subsidizing bus service. They claimed that the top factors that would encourage them in pursuing a solution for traffic congestion would include the existence of adequate right-of-way, potential improvements to traffic safety, and possible transit accommodations. The majority of them preferred a scenario with a bicycle lane as long as there is no high percentage of heavy vehicles, so that the narrower lanes would not jeopardize safety. Although they ranked traffic safety as one of the most important factors when considering a specific scenario, the transportation professionals felt that commuters would prefer using a shorter path than a safer roadway. This is opposite to bicyclists, who would prefer to ride on a safer - and more comfortable - bicycle route, even if it were a longer path to their destination.

In the case of the officials, building consensus was the most challenging of the factors when considering projects to relieve traffic congestion, followed by the lack of construction funds. They agreed that traffic congestion should be addressed and they supported the promotion of the multimodal concept. When it came to choosing a preferred scenario for lane-use allocation, the officials were divided on a final decision. Half of them chose a scenario with a bicycle lane, regardless if the measures of effectiveness were slightly in favor of another scenario without a bicycle lane. They mentioned that bicycle lanes were very important, and the difference in levels of performance for the other objectives was not much worse to convince them otherwise. The other half preferred the scenario without a bicycle lane, but with slightly better measures, and they claimed that the bicycle lane would not be used by enough bicyclists to justify lower levels of performance in safety, emission rates, and travel time.

In general, the numerical example showed that while the presence of a bicycle lane increases the Bicycle Compatibility Index and bicycle safety, narrowing the travel lanes to accommodate the bicycle lane could lead to a lower performance measure for traffic safety in general. It was also determined that the designation of an exclusive bus lane might not have a substantial positive impact on the bus-related objectives, as much as the negative impact it might have on passenger vehicles, which would have fewer travel lanes to use, such as longer travel times and delays.

More analyses were performed to assess the variability of the results where means and standard deviations were calculated for all objectives. It was clear that some of the results were statistically indistinguishable, and others showed clear winners (or losers). Furthermore, analysis was conducted to assess possible changes in the ranking of scenarios in the future. The three scenarios of the case study were evaluated for the next 10 and 20 years, with a projected annual growth rate. The results showed that in some cases, a change in the ranking of some objectives took place, and in some cases, it was clear that one scenario emerged as the new favorite scenario. This suggests that the growth in demand should be considered while assessing the different scenarios.

This research contributes in different ways to the transportation community; it is an effort to improve corridor or network efficiency. Defining a process to assess whether infrastructure improvement would provide an efficient transportation system is a contribution of this study. The measures of effectiveness included in this research were not assessed simultaneously in previous studies, which adds another dimension to the contribution of this study. It also provides an application for a unique multimodal analysis using a traffic-operations modeling software that became very popular in the recent years.

The results were accumulated and presented in a manner not influenced by decision-makers input. They were simplified to allow those decision makers - who might not be very familiar with transportation projects – to understand the different performance levels of each scenario. Another contribution of this research is the field-testing of a suite of those performance measure charts, which was conducted by engaging transportation professionals and decision makers in participating in the survey described earlier. And finally, some useful observations and recommendations were generated as a result of applying the numerical example described in chapter four.

6.2. Recommendations

This process confirms the need to include engineers, planners, and transit providers, among others, in the design discussions. Traffic management objectives, public safety, and bicycle performance can sometimes conflict with each other. Involvement by the appropriate people is essential to a successful project (West and Lowe, 1997).

As for the process itself, in case of large networks, where large number of scenarios can be generated automatically, a method of assigning weights to the measures of effectiveness, such as the analytical hierarchy process (AHP) can be applied. This process might be necessary to apply in some cases to narrow the number of scenarios to be evaluated in a comprehensive way.

It is also recommended to run the model several times for each scenario with different random number seeds. This should increase the accuracy and validity of the results. Transportation planners should apply a reasonable growth rate projection in demand - that would best fit the location under study - in the proposed method to allow assessing the performance of the different scenarios in the future.

Methods to evaluate each objective should also be reviewed. It is expected that in the future, more software would be available, and potentially reliable models combining mode choice and route assignment will be available. Also, more accurate methods to predict crashes, and better ways of measuring mobility and accessibility should be available. There are also opportunities to add more factors to the analysis, as it will be described in the next section.

While conducting the survey, it was clear that most participants had no trouble interpreting the charts presented to them. It is recommended, however, that the results be provided to decision makers with a brief presentation to ensure they understand the charts. This will ensure their answers correctly reflect their wishes.

Once a scenario is chosen and implemented, it should be monitored and evaluated so that feedback is provided to policy makers and the public. This will assess how the plan is performing and complying with the jurisdiction requirements and needs, and to determine if steps should be taken to keep the plan on course, or to make the plan more effective.

For roads where dramatic changes in operating conditions are expected at different times of day (e.g., heavy traffic in one direction during the AM peak period and in the opposite direction during the PM peak period), the analysis should be conducted for the different peak periods. Flexibility in allocating the lanes for different uses during different peak periods should also be explored and analyzed.

Another component of making the implementation of a plan successful is to increase education among motorists, bicyclists, and pedestrians about traffic safety. For example, Van Houten, et al. (2005) stressed on the importance of motorists looking before opening car doors and of parking as close to the curb as possible when parking next to a bicycle lane. Enforcement should also be available to ensure compliance with traffic rules and regulations

Although the study showed that reducing lane width to accommodate bicycle lanes, or reducing the number of lanes allocated for mixed-traffic use, slightly increased the travel time for motor vehicles, considerations for bicycle facilities and bicycle safety is very important. It is obvious that road capacity is limited and does not grow as fast as the population, and therefore, other modes of transportation (e.g., bicycles and transit) should have opportunities to expand their facilities, especially when no significant impact is expected in reducing motor vehicles' measures of performance. If we continue to respond to congestion by expanding capacity for motor vehicles, while allowing transit to deteriorate, congestion will increase and the networks' ability to move people will decrease.

6.3. Recommendations for Future Research

As mentioned earlier, since this research depends on measuring the performance of different scenarios in different areas, enhancements to the methods of measuring those levels of performance can be valuable when available in the future. Also, the research can be expanded to incorporate more factors to be considered while comparing different lane-use allocation scenarios. This section highlights some of the potential enhancements and new factors to be considered in the future.

One potential enhancement is to use some form of automated scenario generation model to provide as many scenarios as possible. Human judgment and experience should be applied to eliminate some of those scenarios before the analysis begins.

Another important potential enhancements include the use of a reliable model combining mode choice and route assignment, more accurate methods to predict crashes, and better ways of measuring mobility and accessibility. All of which can be applied to the proposed method in an effort to improve the validity and accuracy of the results.

In reference to expanding the research, one obvious area is to apply the suggested method on roads or networks where widening roads is an option. In this case, the scenarios will not be limited to a specific width, but rather to a variety of lane and road widths. The land price, right-of-way acquisition, and construction costs, should be added to the total cost of each scenario when conducting this research.

If the research is expended to include more performance measures for transit, passenger evaluation of the service, such as frequency, reliability and span of service (King County Metro, 2002) should also be factors to include when evaluating the system. Other measures of effectiveness for transit such as cost, safety, parking availability, and comfort level in a transit vehicle should be added to the assessment of each scenario. Those are factors that could be important in a user's decision in choosing his/her mode of transportation.

Several other factors were not incorporated in this model, and thus, are not reflected in the method upon which the road allocation decision is made. These factors could nonetheless be important and incorporated in the decision-making process. Further research is needed to evaluate how to incorporate these factors in the road allocation method. These factors include: environmental, social, economic, safety, and ridership factors.

a) The environmental factor: Each scenario has its related emissions, such as nitrogen oxides and carbon monoxide, and the scenario with minimum emissions should be favored in this category. Although these parts of the environment are incorporated in this study, another element such as noise, which can vary with different alternatives, and its effect, was not taken into consideration. It has been found that traffic noise would increase with the increase of traffic flow, especially with larger vehicles, such as trucks and buses. This is an important factor that often influences the decision making for roads, especially near residential neighborhoods.

Another factor that can be further assessed is pollution and air quality, which varies depending on the quality of pollution control equipment on a vehicle. It is obvious that different vehicles produce different emission rates. Although emission defaults were applied in the case study, as described in chapter four, future research might be needed if more non-conventional vehicles are traveling the roads. Examples of such vehicles include hybrid, electrical, and vehicles using natural gas or alternative fuels.

Finally, some other environmental factors that could be included in the analysis, especially for bigger projects where road widening is needed, include disturbance of wetlands, streams, wildlife, and plant life, and the impact on land use. The land use factor for example, can influence the dynamic of traffic flow.

b) The social factor: The availability of on-street parking might be a crucial aspect, especially on roads adjacent to residences and businesses. Not allowing on-street parking might not be a favorable option due to citizens' opposition. Also, some citizens oppose bicycle lanes in some roads, regardless if the master plans call for them. On-street parking also can be essential for businesses that depend on high turnover such as restaurants, or other stores where customers frequently visit for different services, especially when off-street parking is not adequate or available. This factor can be included in the first step when scenarios are identified, or during the decision-making phase.

c) The economic factor: There are several expenses related to the decision other than the travel user's cost and operating costs. For instance, one such expense is the cost of posting traffic signs, installing pavement marking for special lane usage and for different lane usage during different periods of time, and traffic signal modifications. Maintenance of traffic control devices is also an expense to be considered.

d) The safety factor: Although the safety factor is incorporated in this study for both motor vehicles and bicycles, more safety analysis can be investigated for future research. For example, when a bicycle lane is designated, very often the lane width for motor vehicles is reduced, and thus, there is a potential reduction in travel speeds. The impact of the bicycle lane could be considered as a negative impact on the motor vehicles since travel delay increases, but from safety perspective, it could be a positive impact in some areas where traffic calming is needed.

Also, the potential conflict between bus lanes, bicycle lanes, and on-street parking, as well as safety concerns due to the interaction of different modes of transportation could be taken into consideration in future research.

e) The ridership factor: The increase in gas prices and the designation of exclusive bus lanes might increase bus ridership. Although the effect of this factor was included in the study as a part of the sensitivity analysis, the effect of designating an exclusive bicycle lane on the change in number of bicycle riders is neglected since its effect is minimal and cannot be accurately determined. Future research might investigate this further especially if the idea of bicycling becomes more accepted socially.

Finally, it should be noted that factors, such as signal optimization and pre-emption for buses, can also be incorporated in future research. Traffic operations can benefit from including those components, and could have some effects on the performances of different scenarios.

It is clear that this research can be expended to include many more factors. This study includes the most relevant factors affecting a transportation system. Depending on the size of the project, and the available resources, the analysts and decision makers should determine if some additional factors, such as the ones listed in this section, should be included in the analysis.

Appendix A

Output of the Model

For Original Scenarios:

1, 2, 2b, and 3

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 12, Bikes = 16)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Time Period (secs)	NB							
	Autos		Trucks		Buses		Bicycles	
	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	193.7	11	66	0	297.9	2.4	341.1	1.8
900 - 1800	200.0	19	0	0	308.4	3.2	334.4	2.4
1800 - 2700	207.9	15	83	0	321.3	2.4	357.5	5.0
2700 - 3600	208.3	16	81	0	299.5	3.4	353.0	5.6
Average Wtd	203.0	61	148	1	306.0	11.4	348.1	14.8

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time Period (secs)	NB															
	Autos				Trucks				Buses				Bicycles			
	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	55.2	32.2	2.1	11	20	5	1	0	69.8	15.1	0.7	2	45.1	30.7	2.3	2
900 - 1800	61.1	32.9	2.4	19	0	0	0	0	91.0	26.1	2.0	3	38.0	24.9	2.1	2
1800 - 2700	67.4	38.6	2.6	15	39	21	1	0	106.6	39.2	2.4	2	60.6	42.8	2.9	5
2700 - 3600	68.9	39.7	2.6	16	32	12	1	0	81.6	20.5	1.5	3	56.4	40.2	2.9	6
Total	63.6	35.8	2.4	61	55	21	2	1	87.1	25.0	1.7	11	51.7	36.1	2.6	15

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 12, Bikes = 16) - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	232	222	4	3	3	30	31	30	26	16	2150	94	0.24539	0.58612	3.03743	23.18212	55.37089	286.94528
12	0	900	280	271	4	3	3	26	26	16	23	15	1700	90	0.26632	0.60817	3.09964	24.03807	54.89244	279.76950
13	0	900	91	84	1	3	2	29	30	13	22	16	3500	60	0.25510	0.59639	3.06636	15.38812	35.97569	184.96888
21	0	900	209	202	2	3	2	28	28	17	24	16	3500	139	0.26053	0.60208	3.08242	36.15145	83.54584	427.72402
22	0	900	265	258	3	3	1	28	28	24	21	15	1700	85	0.26053	0.60208	3.08242	22.20074	51.30581	262.66692
23	0	900	193	186	3	3	1	29	29	22	25	15	2150	79	0.25510	0.59639	3.06636	20.08266	46.95100	241.39842
11	900	1800	248	239	4	3	3	30	30	30	28	15	2150	101	0.24539	0.58612	3.03743	24.81420	59.26913	307.14688
12	900	1800	304	291	8	3	2	26	26	23	23	14	1700	98	0.26632	0.60817	3.09964	26.09603	59.59192	303.72122
13	900	1800	113	106	2	3	2	29	29	25	24	16	3500	75	0.25510	0.59639	3.06636	19.10832	44.67311	229.68663
21	900	1800	226	214	4	3	5	28	28	26	24	15	3500	150	0.26053	0.60208	3.08242	39.08731	90.33061	462.45957
22	900	1800	307	293	4	3	6	26	26	24	24	15	1700	99	0.26632	0.60817	3.09964	26.29611	60.04881	306.04987
23	900	1800	229	216	5	3	5	27	27	23	27	15	2150	93	0.26632	0.60817	3.09964	24.83418	56.71042	289.03514
11	1800	2700	224	210	5	3	6	30	30	32	28	16	2150	91	0.25008	0.59104	3.05139	22.81014	53.90985	278.32398
12	1800	2700	295	279	7	3	6	26	26	22	23	15	1700	95	0.26632	0.60817	3.09964	25.26713	57.69907	294.07400
13	1800	2700	114	104	2	3	6	28	29	23	24	15	3500	76	0.25510	0.59639	3.06636	19.33379	45.20022	232.39679
21	1800	2700	243	230	5	3	5	28	28	28	24	14	3500	161	0.26053	0.60208	3.08242	42.02318	97.11538	497.19512
22	1800	2700	321	307	6	3	5	26	26	26	24	15	1700	103	0.27263	0.61482	3.11833	28.17744	63.54288	322.28678
23	1800	2700	222	208	5	3	5	29	29	25	27	15	2150	90	0.25510	0.59639	3.06636	23.06043	53.91270	277.19198
11	2700	3600	239	223	8	3	5	30	31	29	28	16	2150	97	0.24539	0.58612	3.03743	23.91489	57.12112	296.01539
12	2700	3600	323	305	10	3	5	25	26	24	23	14	1700	104	0.27263	0.61482	3.11833	28.38226	64.00477	324.62947
13	2700	3600	122	110	3	3	5	28	29	19	23	15	3500	81	0.25510	0.59639	3.06636	20.57386	48.09936	247.30271
21	2700	3600	242	231	5	3	3	28	28	25	23	15	3500	161	0.25510	0.59639	3.06636	40.97861	95.80339	492.57279
22	2700	3600	297	286	6	3	2	27	27	25	23	15	1700	96	0.26053	0.60208	3.08242	24.94088	57.63826	295.08676
23	2700	3600	227	217	4	3	3	28	28	24	25	15	2150	93	0.26053	0.60208	3.08242	24.11686	55.73397	285.33746

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	1.4829	0.1308	7.94421	2.10426	33.17786	2.311	55.90675	32.13675	12.08318	10.43517	53.40557

Total NB VOC	**284.99**	**gms**
Total NB Nox	**646.24**	**gms**
Total NB CO	**3,318.39**	**gms**

Scenario - 2: One 12-foot mixed traffic lane and one 14-foot exclusive bus lane shared with bicycles (Buses = 12, Bikes = 16)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Time	NB							
Period	Autos		Trucks		Buses		Bicycles	
(secs)	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	234.7	8	70.0	0	303.0	3	349.3	2
900 - 1800	238.0	11	0.0	0	315.5	3	345.3	3
1800 - 2700	251.2	14	64.2	0	314.6	2	366.4	5
2700 - 3600	255.0	11	170.1	1	314.5	3	366.4	6
Average Wtd	243.8	44	82.3	1	311.3	11	357.7	15

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time	NB															
Period	Autos				Trucks				Buses				Bicycles			
(secs)	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	95.1	40.5	2.52	8	22.6	11.9	0.7	0	73.5	21.7	1.3	3	53.3	38.9	2.83	2
900 - 1800	100.2	38.5	2.41	11	0.0	0.0	0.0	0	101.7	27.1	2.1	3	49.6	34.2	2.45	3
1800 - 2700	110.0	46.4	3.05	14	14.4	2.2	0.3	0	97.8	23.1	1.8	2	70.0	52.8	3.02	5
2700 - 3600	116.1	45.9	2.84	11	74.0	31.2	2.0	1	94.6	26.8	2.1	3	69.8	51.4	3.47	6
Total	104.5	43.4	2.74	44	55.5	22.6	1.5	1	91.0	24.56	1.74	11	61.5	46.8	3.03	15

Scenario - 2: One 12-foot mixed traffic lane and one 14-foot exclusive bus lane shared with bicycles (Buses = 12, Bikes = 16) - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	193	183	3	3	4	29	30	33	26	15	2150	79	0.25008	0.59104	3.05139	19.65338	46.44912	239.80593
12	0	900	259	248	4	3	4	17	17	21	24	16	1700	83	0.35487	0.70302	3.61627	29.59241	58.62483	301.56139
13	0	900	87	80	2	3	2	30	31	30	24	16	3500	58	0.24539	0.58612	3.03743	14.15188	33.80200	175.17008
21	0	900	215	208	2	3	2	23	23	22	24	15	3500	143	0.28722	0.63122	3.19918	40.93465	89.96101	455.94427
22	0	900	261	256	1	3	1	12	12	7	23	16	1700	84	0.48968	0.83985	4.49399	41.14974	70.57617	377.64799
23	0	900	183	177	2	3	1	20	20	20	22	13	2150	75	0.32659	0.67430	3.42991	24.33660	50.24701	255.58700
11	900	1800	244	236	3	3	2	28	28	28	24	16	2150	99	0.25510	0.59639	3.06636	25.34570	59.25540	304.66145
12	900	1800	296	282	10	3	1	14	14	11	23	16	1700	95	0.41007	0.75915	3.97829	39.08055	72.34959	379.14273
13	900	1800	103	97	0	3	3	30	31	0	24	16	3500	68	0.24539	0.58612	3.03743	16.75452	40.01846	207.38527
21	900	1800	224	214	3	3	4	24	24	20	21	15	3500	148	0.27965	0.62270	3.15710	41.52346	92.46114	468.78154
22	900	1800	319	307	4	3	5	10	10	8	21	15	1700	103	0.52677	0.87754	4.73467	54.10390	90.13097	486.28967
23	900	1800	216	207	1	3	5	17	17	20	23	15	2150	88	0.35487	0.70302	3.61627	31.21217	61.83369	318.06747
11	1800	2700	232	218	3	3	8	28	29	26	28	15	2150	94	0.25510	0.59639	3.06636	24.09919	56.34120	289.67810
12	1800	2700	272	254	7	3	8	14	14	13	22	15	1700	88	0.41007	0.75915	3.97829	35.91186	66.48341	348.40143
13	1800	2700	99	90	4	3	2	29	31	27	23	15	3500	66	0.25008	0.59104	3.05139	16.41137	38.78689	200.24763
21	1800	2700	239	226	2	3	8	24	24	29	20	16	3500	158	0.28722	0.63122	3.19918	45.50410	100.00317	506.84037
22	1800	2700	306	291	4	3	8	10	10	10	19	15	1700	99	0.52677	0.87754	4.73467	51.89904	86.45793	466.47223
23	1800	2700	203	193	3	2	5	19	19	9	17	16	2150	83	0.33993	0.68789	3.51793	28.09881	56.86192	290.79587
11	2700	3600	231	214	9	3	5	28	28	27	28	16	2150	94	0.25510	0.59639	3.06636	23.99532	56.09835	288.42949
12	2700	3600	306	290	8	3	5	12	12	11	22	15	1700	99	0.48968	0.83985	4.49399	48.24453	82.74448	442.75972
13	2700	3600	119	108	2	3	6	29	30	31	26	16	3500	79	0.25008	0.59104	3.05139	19.72679	46.62262	240.70169
21	2700	3600	225	216	4	3	2	25	25	27	25	15	3500	149	0.27263	0.61482	3.11833	40.66288	91.69877	465.09225
22	2700	3600	285	274	6	3	2	12	12	11	25	16	1700	92	0.48968	0.83985	4.49399	44.93363	77.06593	412.37425
23	2700	3600	218	204	5	4	5	17	17	14	20	15	2150	89	0.35487	0.70302	3.61627	31.50117	62.40622	321.01254

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	1.4644	0.1345	7.94421	2.10426	33.17786	2.311	55.90675	32.13675	11.94464	10.60291	52.91009

Total NB VOC	**327.05**	**gms**
Total NB Nox	**672.95**	**gms**
Total NB CO	**3,502.16**	**gms**

Scenario - 2b: One 12-foot mixed traffic lane and One 14-foot exclusive bus lane (No Bicycles)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks & Buses - Travel Time section = 6714.6 ft
SB Autos/Trucks & Buses - Travel Time section = 6874.1 ft

Time	NB					
Period	Autos		Trucks		Buses	
(secs)	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	232.7	11	0	0	307.4	3
900 - 1800	265.8	14	0	0	324.3	3
1800 - 2700	279.0	14	0	0	303.7	3
2700 - 3600	268.7	18	0	0	314.5	3
Average Wtd	263.2	56	0	0	311.8	11

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks & Buses - Travel Time section = 6714.6 ft
SB Autos/Trucks & Buses - Travel Time section = 6874.1 ft
Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time	NB											
Period	Autos				Trucks				Buses			
(secs)	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	93.3	40.5	2.7	10.5	0	0	0	0	75.3	27.7	1.0	3
900 - 1800	129.7	45.7	2.9	14	0	0	0	0	107.2	38.7	2.5	3
1800 - 2700	141.3	51.4	3.2	14	0	0	0	0	90.0	25.9	1.3	3
2700 - 3600	130.2	44.5	3.3	17.5	0	0	0	0	97.1	36.9	1.7	3
Total	125.4	45.8	3.1	56	0	0	0	0	92.6	33.0	1.6	11

Data Collection:

Data Collection	Aggregation Interval		Number Vehicles		Speed (All Vehicle Types)		
Number	Start Time	End Time	All Veh Types	Bicycles	Min	Max	Mean
11	0	900	228	0	15.2	37.2	29.0
12	0	900	269	0	1.4	35.8	14.4
13	0	900	93	0	20.0	37.8	30.5
21	0	900	203	0	4.6	37.4	24.3
22	0	900	248	0	1.5	34.3	12.2
23	0	900	183	0	1.2	37.8	21.7
11	900	1800	249	0	7.7	37.4	27.5
12	900	1800	292	0	0.9	31.2	12.2
13	900	1800	109	0	17.2	36.5	29.4
21	900	1800	227	0	2.4	36.0	23.0
22	900	1800	302	0	0.6	29.1	10.2
23	900	1800	222	0	1.2	33.0	17.1
11	1800	2700	224	0	13.2	38.4	28.1
12	1800	2700	290	0	1.7	30.2	11.7
13	1800	2700	107	0	20.0	38.0	30.2
21	1800	2700	255	0	1.0	37.2	19.0
22	1800	2700	327	0	2.3	25.7	10.1
23	1800	2700	223	0	1.3	36.2	18.1
11	2700	3600	230	0	14.1	38.5	29.1
12	2700	3600	306	0	1.6	29.4	12.9
13	2700	3600	114	0	16.2	37.4	29.9
21	2700	3600	248	0	4.0	36.5	23.6
22	2700	3600	312	0	1.1	26.1	10.0
23	2700	3600	220	0	1.9	34.3	17.4

Scenario - 3: Two 10.5-foot mixed traffic lanes and one 5-foot bicycle lane

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft

Time Period (secs)	NB							
	Autos		Trucks		Buses		Bicycles	
	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	202.7	9	0.0	0	294.9	3	345.8	2
900 - 1800	208.3	11	142.7	1	323.3	2	361.1	4
1800 - 2700	200.2	12	0.0	0	319.3	3	344.7	5
2700 - 3600	211.9	15	83.4	0	326.8	3	359.6	5
Average Wtd	206.0	47		1	313.9	11	355.0	16

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time Period (secs)	NB															
	Autos				Trucks				Buses				Bicycles			
	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	64.5	35.9	2.4	9	0.0	0.0	0.0	0	75.2	22.0	1.6	3	49.4	34.8	2.4	2
900 - 1800	67.7	42.3	2.5	11	47.5	14.2	1.3	1	94.6	25.9	2.7	2	65.4	48.2	2.8	4
1800 - 2700	62.9	37.0	2.3	12	0.0	0.0	0.0	0	94.1	31.8	1.9	3	48.3	33.3	2.3	5
2700 - 3600	72.9	43.3	2.8	15	34.5	8.0	1.0	0	104.0	39.2	2.4	3	62.9	46.2	2.6	5
Total	67.2	39.3	2.5	47	48.5	12.9	1.3	1	90.7	29.5	2.1	11	58.8	40.2	2.5	16

Scenario - 3: Two 10.5-foot mixed traffic lanes and one 5-foot bicycle lane - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	222	212	4	3	3	29.5	29.7	29.5	28.7	15.7	2150.0	90.5	0.25008	0.59104	3.05139	22.64042	53.50874	276.25311
12	0	900	285	275	5	3	3	23.7	23.9	22.9	24.0	14.6	1700.0	91.9	0.28722	0.63122	3.19918	26.38676	57.98948	293.90480
13	0	900	95	88	1	3	2	30.1	30.6	31.6	27.8	15.4	3500.0	63.0	0.24539	0.58612	3.03743	15.45320	36.91023	191.27767
21	0	900	221	214	2	3	2	29.2	29.5	23.4	25.2	5.2	3500.0	146.3	0.25008	0.59104	3.05139	36.58022	86.45427	446.34320
22	0	900	266	258	4	3	2	23.3	23.3	22.9	23.6	4.7	1700.0	85.6	0.28722	0.63122	3.19918	24.59887	54.06029	273.99069
23	0	900	194	186	3	3	2	29.2	29.4	28.6	26.2	5.1	2150.0	79.1	0.25008	0.59104	3.05139	19.78916	46.77001	241.46262
11	900	1800	241	227	6	3	5	28.9	29.2	29.0	27.9	15.2	2150.0	98.3	0.25510	0.59639	3.06636	25.06870	58.60780	301.33182
12	900	1800	308	292	8	3	5	24.6	24.8	22.9	21.6	14.0	1700.0	99.2	0.27965	0.62270	3.15710	27.73174	61.75083	313.07910
13	900	1800	106	96	3	3	4	30.0	30.7	19.4	28.5	15.5	3500.0	70.5	0.24539	0.58612	3.03743	17.29674	41.31355	214.09677
21	900	1800	247	235	5	3	3	29.0	29.2	27.9	26.5	15.0	3500.0	163.5	0.25510	0.59639	3.06636	41.71138	97.51652	501.38083
22	900	1800	310	299	5	3	3	24.0	24.1	22.0	23.1	15.2	1700.0	99.7	0.28722	0.63122	3.19918	28.63703	62.93485	318.96912
23	900	1800	221	211	4	3	3	29.2	29.4	28.5	26.5	15.3	2150.0	90.0	0.25008	0.59104	3.05139	22.50465	53.18785	274.59642
11	1800	2700	250	236	6	3	5	29.2	29.6	27.2	27.7	15.6	2150.0	101.7	0.25008	0.59104	3.05139	25.42380	60.08703	310.21527
12	1800	2700	295	279	9	3	4	24.8	25.0	23.7	22.8	14.3	1700.0	94.9	0.27965	0.62270	3.15710	26.53123	59.07764	299.52589
13	1800	2700	110	100	2	3	5	29.5	30.2	30.7	27.8	15.3	3500.0	72.7	0.25008	0.59104	3.05139	18.17959	42.96595	221.82313
21	1800	2700	251	238	6	3	4	28.6	28.8	27.6	26.1	15.5	3500.0	166.6	0.25510	0.59639	3.06636	42.50051	99.36143	510.86642
22	1800	2700	302	287	9	3	3	23.1	23.2	21.4	21.8	14.9	1700.0	97.1	0.28722	0.63122	3.19918	27.89721	61.30897	310.72879
23	1800	2700	221	210	6	3	3	29.9	30.2	28.3	27.0	15.0	2150.0	90.1	0.25008	0.59104	3.05139	22.53859	53.26807	275.01060
11	2700	3600	243	231	4	3	5	29.2	29.6	29.2	26.7	15.6	2150.0	99.1	0.25008	0.59104	3.05139	24.77887	58.56279	302.34599
12	2700	3600	310	296	5	3	6	23.8	24.1	19.3	21.2	14.6	1700.0	99.8	0.28722	0.63122	3.19918	28.66786	63.00259	319.31246
13	2700	3600	103	93	1	3	6	29.5	30.4	21.6	27.7	15.8	3500.0	68.1	0.25008	0.59104	3.05139	17.01919	40.22344	207.66421
21	2700	3600	234	225	3	3	3	28.6	28.8	29.6	27.0	15.1	3500.0	154.9	0.25510	0.59639	3.06636	39.51307	92.37714	474.95671
22	2700	3600	319	308	4	3	4	22.5	22.6	23.5	22.8	14.3	1700.0	102.7	0.29555	0.64058	3.24514	30.35514	65.79285	333.30282
23	2700	3600	229	220	3	3	3	29.3	29.6	29.2	25.8	15.8	2150.0	93.2	0.25008	0.59104	3.05139	23.31930	55.11320	284.53657

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	1.2895	0.1887	7.94421028	2.10426088	33.17785531	2.311	55.90675	32.13675	10.68052	13.26263	48.84839

Total NB VOC	**286.08**	**gms**
Total NB Nox	**647.53**	**gms**
Total NB CO	**3,300.67**	**gms**

Appendix B

Operational Costs Details

For Different Types of Vehicles

Active Fleet		
Staff Sedan (1.0)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	76,664.0	0.0
FUEL QTY	4,564.77	4,564.77
METER TOTAL / FUEL QTY (mpg)	16.795	0.000
OPERATIONAL $$	21,337.77	21,337.77
OPERATIONAL CPM	0.278	0.000
FUEL $$	8,477.75	8,477.75
FUEL CPM	0.111	0.000
MAINTENANCE & REPAIR $$	12,860.02	12,860.02
MAINTENANCE & REPAIR CPM	0.168	0.000
MAINTENANCE $$	2,320.43	2,320.43
MAINTENANCE CPM	0.030	0.000
REPAIR $$	10,539.59	10,539.59
REPAIR CPM	0.137	0.000
ACCIDENT $$:	164.40	164.40
ACCIDENT CPM	0.002	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	21,502.17	21,502.17
TOTAL CPM	0.280	0.000
Police Cruiser Marked & Unmarked (1.5)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	414,796.0	0.0
FUEL QTY	44,331.85	44,331.85
METER TOTAL / FUEL QTY (mpg)	9.357	0.000
OPERATIONAL $$	180,897.67	180,897.67
OPERATIONAL CPM	0.436	0.000
FUEL $$	84,026.95	84,026.95
FUEL CPM	0.203	0.000
MAINTENANCE & REPAIR $$	96,870.72	96,870.72
MAINTENANCE & REPAIR CPM	0.234	0.000
MAINTENANCE $$	8,265.96	8,265.96
MAINTENANCE CPM	0.020	0.000
REPAIR $$	88,604.76	88,604.76
REPAIR CPM	0.214	0.000
ACCIDENT $$:	29,230.64	29,230.64
ACCIDENT CPM	0.070	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	210,128.31	210,128.31
TOTAL CPM	0.507	0.000

MOTORCYCLE (1.0)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	2,279.0	0.0
FUEL QTY	165.72	165.72
METER TOTAL / FUEL QTY (mpg)	13.752	0.000
OPERATIONAL $$	594.53	594.53
OPERATIONAL CPM	0.261	0.000
FUEL $$	325.70	325.70
FUEL CPM	0.143	0.000
MAINTENANCE & REPAIR $$	268.83	268.83
MAINTENANCE & REPAIR CPM	0.118	0.000
MAINTENANCE $$	268.83	268.83
MAINTENANCE CPM	0.118	0.000
REPAIR $$	0.00	0.00
REPAIR CPM	0.000	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	594.53	594.53
TOTAL CPM	0.261	0.000

Pickup < 5000 GVW, (1.0)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	46,418.0	0.0
FUEL QTY	3,608.55	3,608.55
METER TOTAL / FUEL QTY (mpg)	12.863	0.000
OPERATIONAL $$	18,248.69	18,248.69
OPERATIONAL CPM	0.393	0.000
FUEL $$	6,704.86	6,704.86
FUEL CPM	0.144	0.000
MAINTENANCE & REPAIR $$	11,543.83	11,543.83
MAINTENANCE & REPAIR CPM	0.249	0.000
MAINTENANCE $$	1,330.34	1,330.34
MAINTENANCE CPM	0.029	0.000
REPAIR $$	10,213.49	10,213.49
REPAIR CPM	0.220	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	18,248.69	18,248.69
TOTAL CPM	0.393	0.000

Pickup 5-10000 GVW (1.3)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	45,462.0	0.0
FUEL QTY	5,934.93	5,934.93
METER TOTAL / FUEL QTY (mpg)	7.660	0.000
OPERATIONAL $$	20,499.03	20,499.03
OPERATIONAL CPM	0.451	0.000
FUEL $$	10,879.35	10,879.35
FUEL CPM	0.239	0.000
MAINTENANCE & REPAIR $$	9,619.68	9,619.68
MAINTENANCE & REPAIR CPM	0.212	0.000
MAINTENANCE $$	1,187.69	1,187.69
MAINTENANCE CPM	0.026	0.000
REPAIR $$	8,431.99	8,431.99
REPAIR CPM	0.185	0.000
ACCIDENT $$:	267.69	267.69
ACCIDENT CPM	0.006	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	20,766.72	20,766.72
TOTAL CPM	0.457	0.000

4x4 Sport Utility (1.1)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	102,014.0	0.0
FUEL QTY	7,364.10	7,364.10
METER TOTAL / FUEL QTY (mpg)	13.853	0.000
OPERATIONAL $$	39,315.81	39,315.81
OPERATIONAL CPM	0.385	0.000
FUEL $$	13,522.19	13,522.19
FUEL CPM	0.133	0.000
MAINTENANCE & REPAIR $$	25,793.62	25,793.62
MAINTENANCE & REPAIR CPM	0.253	0.000
MAINTENANCE $$	3,781.39	3,781.39
MAINTENANCE CPM	0.037	0.000
REPAIR $$	22,012.23	22,012.23
REPAIR CPM	0.216	0.000
ACCIDENT $$:	245.00	245.00
ACCIDENT CPM	0.002	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	39,560.81	39,560.81
TOTAL CPM	0.388	0.000

4x4 Pickup < 5000 GVW (1.1)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	3,023.0	0.0
FUEL QTY	232.19	232.19
METER TOTAL / FUEL QTY (mpg)	13.020	0.000
OPERATIONAL $$	522.16	522.16
OPERATIONAL CPM	0.173	0.000
FUEL $$	522.16	522.16
FUEL CPM	0.173	0.000
MAINTENANCE & REPAIR $$	0.00	0.00
MAINTENANCE & REPAIR CPM	0.000	0.000
MAINTENANCE $$	0.00	0.00
MAINTENANCE CPM	0.000	0.000
REPAIR $$	0.00	0.00
REPAIR CPM	0.000	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	522.16	522.16
TOTAL CPM	0.173	0.000
4x4 Pickup 5-10000 GVW (1.5)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	68,238.0	0.0
FUEL QTY	9,135.52	9,135.52
METER TOTAL / FUEL QTY (mpg)	7.470	0.000
OPERATIONAL $$	31,322.37	31,322.37
OPERATIONAL CPM	0.459	0.000
FUEL $$	16,824.78	16,824.78
FUEL CPM	0.247	0.000
MAINTENANCE & REPAIR $$	14,497.59	14,497.59
MAINTENANCE & REPAIR CPM	0.212	0.000
MAINTENANCE $$	1,933.57	1,933.57
MAINTENANCE CPM	0.028	0.000
REPAIR $$	12,564.02	12,564.02
REPAIR CPM	0.184	0.000
ACCIDENT $$:	1,685.09	1,685.09
ACCIDENT CPM	0.025	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	33,007.46	33,007.46
TOTAL CPM	0.484	0.000

Minivan (1.1)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	53,340.0	0.0
FUEL QTY	4,727.32	4,727.32
METER TOTAL / FUEL QTY (mpg)	11.283	0.000
OPERATIONAL $$	22,849.62	22,849.62
OPERATIONAL CPM	0.428	0.000
FUEL $$	8,846.95	8,846.95
FUEL CPM	0.166	0.000
MAINTENANCE & REPAIR $$	14,002.67	14,002.67
MAINTENANCE & REPAIR CPM	0.263	0.000
MAINTENANCE $$	1,347.83	1,347.83
MAINTENANCE CPM	0.025	0.000
REPAIR $$	12,654.84	12,654.84
REPAIR CPM	0.237	0.000
ACCIDENT $$:	202.33	202.33
ACCIDENT CPM	0.004	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	23,051.95	23,051.95
TOTAL CPM	0.432	0.000
Standard Van 5-10000 GVW (1.3)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	53,127.0	0.0
FUEL QTY	6,050.79	6,050.79
METER TOTAL / FUEL QTY (mpg)	8.780	0.000
OPERATIONAL $$	29,740.78	29,740.78
OPERATIONAL CPM	0.560	0.000
FUEL $$	11,050.17	11,050.17
FUEL CPM	0.208	0.000
MAINTENANCE & REPAIR $$	18,690.61	18,690.61
MAINTENANCE & REPAIR CPM	0.352	0.000
MAINTENANCE $$	1,578.52	1,578.52
MAINTENANCE CPM	0.030	0.000
REPAIR $$	17,112.09	17,112.09
REPAIR CPM	0.322	0.000
ACCIDENT $$:	207.61	207.61
ACCIDENT CPM	0.004	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	29,948.39	29,948.39
TOTAL CPM	0.564	0.000

Crewcab 5-10000 GVW (1.5)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	45,804.0	0.0
FUEL QTY	7,252.44	7,252.44
METER TOTAL / FUEL QTY (mpg)	6.316	0.000
OPERATIONAL $$	32,821.10	32,821.10
OPERATIONAL CPM	0.717	0.000
FUEL $$	13,341.32	13,341.32
FUEL CPM	0.291	0.000
MAINTENANCE & REPAIR $$	19,479.78	19,479.78
MAINTENANCE & REPAIR CPM	0.425	0.000
MAINTENANCE $$	1,207.33	1,207.33
MAINTENANCE CPM	0.026	0.000
REPAIR $$	18,272.45	18,272.45
REPAIR CPM	0.399	0.000
ACCIDENT $$:	320.67	320.67
ACCIDENT CPM	0.007	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	33,141.77	33,141.77
TOTAL CPM	0.724	0.000
General Purpose 10-15000 GVW (2.3)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	3,861.0	0.0
FUEL QTY	462.15	462.15
METER TOTAL / FUEL QTY (mpg)	8.354	0.000
OPERATIONAL $$	4,387.35	4,387.35
OPERATIONAL CPM	1.136	0.000
FUEL $$	1,029.02	1,029.02
FUEL CPM	0.267	0.000
MAINTENANCE & REPAIR $$	3,358.33	3,358.33
MAINTENANCE & REPAIR CPM	0.870	0.000
MAINTENANCE $$	680.05	680.05
MAINTENANCE CPM	0.176	0.000
REPAIR $$	2,678.28	2,678.28
REPAIR CPM	0.694	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	4,387.35	4,387.35
TOTAL CPM	1.136	0.000

General Purpose 15-26000 GVW (3.0)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	1,880.0	0.0
FUEL QTY	418.52	418.52
METER TOTAL / FUEL QTY (mpg)	4.492	0.000
OPERATIONAL $$	2,191.79	2,191.79
OPERATIONAL CPM	1.166	0.000
FUEL $$	736.78	736.78
FUEL CPM	0.392	0.000
MAINTENANCE & REPAIR $$	1,455.01	1,455.01
MAINTENANCE & REPAIR CPM	0.774	0.000
MAINTENANCE $$	243.58	243.58
MAINTENANCE CPM	0.130	0.000
REPAIR $$	1,211.43	1,211.43
REPAIR CPM	0.644	0.000
ACCIDENT $$:	154.82	154.82
ACCIDENT CPM	0.082	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	2,346.61	2,346.61
TOTAL CPM	1.248	0.000

Utility 5-10000 GVW (1.5)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	26,841.0	0.0
FUEL QTY	2,976.28	2,976.28
METER TOTAL / FUEL QTY (mpg)	9.018	0.000
OPERATIONAL $$	10,861.38	10,861.38
OPERATIONAL CPM	0.405	0.000
FUEL $$	5,676.91	5,676.91
FUEL CPM	0.212	0.000
MAINTENANCE & REPAIR $$	5,184.47	5,184.47
MAINTENANCE & REPAIR CPM	0.193	0.000
MAINTENANCE $$	595.89	595.89
MAINTENANCE CPM	0.022	0.000
REPAIR $$	4,588.58	4,588.58
REPAIR CPM	0.171	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	10,861.38	10,861.38
TOTAL CPM	0.405	0.000

Utility 26-36000 GVW (3.2)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	11,550.0	0.0
FUEL QTY	1,999.80	1,999.80
METER TOTAL / FUEL QTY (mpg)	5.776	0.000
OPERATIONAL $$	8,789.92	8,789.92
OPERATIONAL CPM	0.761	0.000
FUEL $$	3,913.70	3,913.70
FUEL CPM	0.339	0.000
MAINTENANCE & REPAIR $$	4,876.22	4,876.22
MAINTENANCE & REPAIR CPM	0.422	0.000
MAINTENANCE $$	1,593.50	1,593.50
MAINTENANCE CPM	0.138	0.000
REPAIR $$	3,282.72	3,282.72
REPAIR CPM	0.284	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	8,789.92	8,789.92
TOTAL CPM	0.761	0.000

Bus 10-15000 GVW (3.5)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	55,688.0	0.0
FUEL QTY	8,331.22	8,331.22
METER TOTAL / FUEL QTY (mpg)	6.684	0.000
OPERATIONAL $$	41,312.06	41,312.06
OPERATIONAL CPM	0.742	0.000
FUEL $$	16,126.36	16,126.36
FUEL CPM	0.290	0.000
MAINTENANCE & REPAIR $$	25,185.70	25,185.70
MAINTENANCE & REPAIR CPM	0.452	0.000
MAINTENANCE $$	1,461.65	1,461.65
MAINTENANCE CPM	0.026	0.000
REPAIR $$	23,724.05	23,724.05
REPAIR CPM	0.426	0.000
ACCIDENT $$:	296.46	296.46
ACCIDENT CPM	0.005	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	41,608.52	41,608.52
TOTAL CPM	0.747	0.000

Dump 15-26000 GVW (3.0)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	10,538.0	0.0
FUEL QTY	1,938.43	1,938.43
METER TOTAL / FUEL QTY (mpg)	5.436	0.000
OPERATIONAL $$	10,802.42	10,802.42
OPERATIONAL CPM	1.025	0.000
FUEL $$	3,823.58	3,823.58
FUEL CPM	0.363	0.000
MAINTENANCE & REPAIR $$	6,978.84	6,978.84
MAINTENANCE & REPAIR CPM	0.662	0.000
MAINTENANCE $$	1,908.97	1,908.97
MAINTENANCE CPM	0.181	0.000
REPAIR $$	5,069.87	5,069.87
REPAIR CPM	0.481	0.000
ACCIDENT $$:	2,082.23	2,082.23
ACCIDENT CPM	0.198	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	12,884.65	12,884.65
TOTAL CPM	1.223	0.000

Dump 26-36000 GVW (3.5)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	42,045.0	0.0
FUEL QTY	10,857.14	10,857.14
METER TOTAL / FUEL QTY (mpg)	3.873	0.000
OPERATIONAL $$	92,023.59	92,023.59
OPERATIONAL CPM	2.189	0.000
FUEL $$	20,490.09	20,490.09
FUEL CPM	0.487	0.000
MAINTENANCE & REPAIR $$	71,533.50	71,533.50
MAINTENANCE & REPAIR CPM	1.701	0.000
MAINTENANCE $$	8,105.05	8,105.05
MAINTENANCE CPM	0.193	0.000
REPAIR $$	63,428.45	63,428.45
REPAIR CPM	1.509	0.000
ACCIDENT $$:	1,456.52	1,456.52
ACCIDENT CPM	0.035	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	93,480.11	93,480.11
TOTAL CPM	2.223	0.000

Refuse Truck Packer/Recycler (4.5)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	73,692.0	0.0
FUEL QTY	27,356.16	27,356.16
METER TOTAL / FUEL QTY (mpg)	2.694	0.000
OPERATIONAL $$	155,340.20	155,340.20
OPERATIONAL CPM	2.108	0.000
FUEL $$	53,916.45	53,916.45
FUEL CPM	0.732	0.000
MAINTENANCE & REPAIR $$	101,423.75	101,423.75
MAINTENANCE & REPAIR CPM	1.376	0.000
MAINTENANCE $$	9,340.25	9,340.25
MAINTENANCE CPM	0.127	0.000
REPAIR $$	92,083.50	92,083.50
REPAIR CPM	1.250	0.000
ACCIDENT $$:	47,395.16	47,395.16
ACCIDENT CPM	0.643	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	202,735.36	202,735.36
TOTAL CPM	2.751	0.000

RECYCLER		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	28,692.0	0.0
FUEL QTY	10,411.52	10,411.52
METER TOTAL / FUEL QTY (mpg)	2.756	0.000
OPERATIONAL $$	45,282.59	45,282.59
OPERATIONAL CPM	1.578	0.000
FUEL $$	20,510.62	20,510.62
FUEL CPM	0.715	0.000
MAINTENANCE & REPAIR $$	24,771.97	24,771.97
MAINTENANCE & REPAIR CPM	0.863	0.000
MAINTENANCE $$	3,873.15	3,873.15
MAINTENANCE CPM	0.135	0.000
REPAIR $$	20,898.82	20,898.82
REPAIR CPM	0.728	0.000
ACCIDENT $$:	588.67	588.67
ACCIDENT CPM	0.021	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	45,871.26	45,871.26
TOTAL CPM	1.599	0.000

Specialty Class Vehicle (2.5)		
	1/1/2005 - 12/31/2005	
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	11,094.0	0.0
FUEL QTY	2,811.46	2,811.46
METER TOTAL / FUEL QTY (mpg)	3.946	0.000
OPERATIONAL $$	21,374.09	21,374.09
OPERATIONAL CPM	1.927	0.000
FUEL $$	5,340.55	5,340.55
FUEL CPM	0.481	0.000
MAINTENANCE & REPAIR $$	16,033.54	16,033.54
MAINTENANCE & REPAIR CPM	1.445	0.000
MAINTENANCE $$	679.23	679.23
MAINTENANCE CPM	0.061	0.000
REPAIR $$	15,354.31	15,354.31
REPAIR CPM	1.384	0.000
ACCIDENT $$:	0.00	0.00
ACCIDENT CPM	0.000	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	21,374.09	21,374.09
TOTAL CPM	1.927	0.000

Combination Unit Leaf Collector (4.0)		
SORT TOTALS		
METER TYPE	TOTALS	MILES
METER TOTAL	-26,439.0	0.0
FUEL QTY	3,786.42	3,786.42
METER TOTAL / FUEL QTY (mpg)	-6.983	0.000
OPERATIONAL $$	29,404.62	29,404.62
OPERATIONAL CPM	-1.112	0.000
FUEL $$	9,690.97	9,690.97
FUEL CPM	-0.367	0.000
MAINTENANCE & REPAIR $$	19,713.65	19,713.65
MAINTENANCE & REPAIR CPM	-0.746	0.000
MAINTENANCE $$	4,186.20	4,186.20
MAINTENANCE CPM	-0.158	0.000
REPAIR $$	15,527.45	15,527.45
REPAIR CPM	-0.587	0.000
ACCIDENT $$:	336.46	336.46
ACCIDENT CPM	-0.013	0.000
OIL QTY	0.00	0.00
METER TOTAL / OIL QTY	0.000	0.000
OTHER FLUID QTY	0.00	0.00
METER TOTAL / OTHER FLUID QTY	0.000	0.000
TOTAL COSTS	29,741.08	29,741.08
TOTAL CPM	-1.125	0.000

Appendix C

Sample of Mobile6 Run

For a 31-mph Average Speed

FILE	RUN	SCEN	CAL_YEAR	POL	VTYPE	GM_MILE	GM_DAY	STARTS	ENDS	MILES	MPG	VMT	Gms_mi*VMT			**gms/mi**
2	1	1	2010	7	1	0.0003	0.009	7.28	5.3799	30.0278	24.1	0.641286	0.000192386		VOC	0.2409
2	1	1	2010	7	2	0.0005	0.019	8.06	5.7548	40.5645	18.52	0.044882	0.000022441		CO	3.0472
2	1	1	2010	7	3	0.0005	0.019	8.06	5.7548	40.5645	18.52	0.150605	7.53025E-05		NOx	0.5836
2	1	1	2010	7	4	0.0005	0.018	8.06	5.7548	38.1072	14.26	0.059125	2.95625E-05		PM2.5	0.0175
2	1	1	2010	7	5	0.0005	0.018	8.06	5.7548	38.1072	14.26	0.027592	0.000013796		SO2	0.0079
2	1	1	2010	7	6	0.0017	0.062	6.88	4.9123	37.4349	10.09	0.016847	2.86399E-05			
2	1	1	2010	7	7	0.0017	0.064	6.88	4.9123	38.4989	9.36	0.000535	9.095E-07			
2	1	1	2010	7	8	0.0014	0.043	6.88	4.9123	29.7667	9.24	0.000205	0.000000287			
2	1	1	2010	7	9	0.0015	0.052	6.88	4.9123	34.2861	7.99	0.000438	0.000000657			
2	1	1	2010	7	10	0.0015	0.053	6.88	4.9123	34.71	8.1	0.001264	0.000001896			
2	1	1	2010	7	11	0.0015	0.052	6.88	4.9123	34.0744	7.42	0.000531	7.965E-07			
2	1	1	2010	7	12	0.0015	0.047	6.88	4.9123	31.7293	7.02	0.000001	1.5E-09			
2	1	1	2010	7	13	0	0	0	0	0	0	0	0			
2	1	1	2010	7	14	0.0001	0.002	7.28	5.1979	14.7459	33.14	0.001714	1.714E-07			
2	1	1	2010	7	15	0.0002	0.004	8.06	5.7548	26.7792	22.15	0.000512	1.024E-07			
2	1	1	2010	7	16	0.0004	0.016	6.65	4.7481	42.7897	12.91	0.005153	2.0612E-06			
2	1	1	2010	7	17	0.0004	0.019	6.65	4.7481	45.5668	11.64	0.001465	0.000000586			
2	1	1	2010	7	18	0.0005	0.028	6.65	4.7481	57.6132	10.18	0.001795	8.975E-07			
2	1	1	2010	7	19	0.0005	0.029	6.65	4.7481	58.6666	9.87	0.000562	0.000000281			
2	1	1	2010	7	20	0.0006	0.036	6.65	4.7481	65.2177	8.7	0.003736	2.2416E-06			
2	1	1	2010	7	21	0.0006	0.042	6.65	4.7481	64.4031	7.53	0.005469	3.2814E-06			
2	1	1	2010	7	22	0.0007	0.095	6.65	4.7481	128.464	6.58	0.005999	4.1993E-06			
2	1	1	2010	7	23	0.0008	0.151	6.65	4.7481	194.7393	6.28	0.022	0.0000176			
2	1	1	2010	7	24	0.0001	0.001	1.35	0.9639	8.092	50	0.005	0.0000005			
2	1	1	2010	7	25	0.0008	0.023	6.88	4.9123	27.2301	6.36	0.000067	5.36E-08			
2	1	1	2010	7	26	0.0011	0.106	6.65	4.7481	94.3934	4.34	0.001	0.0000011			
2	1	1	2010	7	27	0.0008	0.021	6.65	4.7481	27.2301	6.19	0.000933	7.464E-07			
2	1	1	2010	7	28	0.0002	0.01	8.06	5.7548	44.6717	17.01	0.001283	2.566E-07			
2	1	1	2010	8	14	0.0367	0.541	7.28	5.1979	14.7459	33.14	0.001714	6.29038E-05			
2	1	1	2010	8	15	0.0475	1.273	8.06	5.7548	26.7792	22.15	0.000512	0.00002432			
2	1	1	2010	8	16	0.0285	1.218	6.65	4.7481	42.7897	12.91	0.005153	0.000146861			
2	1	1	2010	8	17	0.0229	1.042	6.65	4.7481	45.5668	11.64	0.001465	3.35485E-05			
2	1	1	2010	8	18	0.0267	1.541	6.65	4.7481	57.6132	10.18	0.001795	4.79265E-05			
2	1	1	2010	8	19	0.025	1.467	6.65	4.7481	58.6666	9.87	0.000562	0.00001405			
2	1	1	2010	8	20	0.041	2.671	6.65	4.7481	65.2177	8.7	0.003736	0.000153176			
2	1	1	2010	8	21	0.0424	2.734	6.65	4.7481	64.4031	7.53	0.005469	0.000231886			
2	1	1	2010	8	22	0.0485	6.23	6.65	4.7481	128.464	6.58	0.005999	0.000290952			
2	1	1	2010	8	23	0.0295	5.749	6.65	4.7481	194.7393	6.28	0.022	0.000649			
2	1	1	2010	8	26	0.0904	8.538	6.65	4.7481	94.3934	4.34	0.001	0.0000904			
2	1	1	2010	8	27	0.1315	3.581	6.65	4.7481	27.2301	6.19	0.000933	0.00012269			
2	1	1	2010	8	28	0.0244	1.088	8.06	5.7548	44.6717	17.01	0.001283	3.13052E-05			
2	1	1	2010	9	14	0.1301	1.918	7.28	5.1979	14.7459	33.14	0.001714	0.000222991			
2	1	1	2010	9	15	0.033	0.885	8.06	5.7548	26.7792	22.15	0.000512	0.000016896			
2	1	1	2010	9	16	0.0273	1.17	6.65	4.7481	42.7897	12.91	0.005153	0.000140677			
2	1	1	2010	9	17	0.022	1.001	6.65	4.7481	45.5668	11.64	0.001465	0.00003223			
2	1	1	2010	9	18	0.0257	1.481	6.65	4.7481	57.6132	10.18	0.001795	4.61315E-05			
2	1	1	2010	9	19	0.024	1.41	6.65	4.7481	58.6666	9.87	0.000562	0.000013488			
2	1	1	2010	9	20	0.0521	3.4	6.65	4.7481	65.2177	8.7	0.003736	0.000194646			
2	1	1	2010	9	21	0.054	3.479	6.65	4.7481	64.4031	7.53	0.005469	0.000295326			
2	1	1	2010	9	22	0.0617	7.93	6.65	4.7481	128.464	6.58	0.005999	0.000370138			
2	1	1	2010	9	23	0.0935	18.205	6.65	4.7481	194.7393	6.28	0.022	0.002057			
2	1	1	2010	9	26	0.1151	10.866	6.65	4.7481	94.3934	4.34	0.001	0.0001151			
2	1	1	2010	9	27	0.1674	4.557	6.65	4.7481	27.2301	6.19	0.000933	0.000156184			
2	1	1	2010	9	28	0.0169	0.756	8.06	5.7548	44.6717	17.01	0.001283	2.16827E-05			
2	1	1	2010	10	1	0.0037	0.111	7.28	5.3799	30.0278	24.1	0.641286	0.002372758			
2	1	1	2010	10	2	0.0035	0.143	8.06	5.7548	40.5645	18.52	0.044882	0.000157087			
2	1	1	2010	10	3	0.0035	0.143	8.06	5.7548	40.5645	18.52	0.150605	0.000527118			
2	1	1	2010	10	4	0.0037	0.141	8.06	5.7548	38.1072	14.26	0.059125	0.000218763			
2	1	1	2010	10	5	0.0037	0.141	8.06	5.7548	38.1072	14.26	0.027592	0.00010209			
2	1	1	2010	10	6	0.0289	1.083	6.88	4.9123	37.4349	10.09	0.016847	0.000486878			
2	1	1	2010	10	7	0.0283	1.088	6.88	4.9123	38.4989	9.36	0.000535	1.51405E-05			
2	1	1	2010	10	8	0.0323	0.961	6.88	4.9123	29.7667	9.24	0.000205	6.6215E-06			
2	1	1	2010	10	9	0.028	0.959	6.88	4.9123	34.2861	7.99	0.000438	0.000012264			
2	1	1	2010	10	10	0.0274	0.953	6.88	4.9123	34.71	8.1	0.001264	3.46336E-05			
2	1	1	2010	10	11	0.0285	0.971	6.88	4.9123	34.0744	7.42	0.000531	1.51335E-05			
2	1	1	2010	10	12	0.0304	0.965	6.88	4.9123	31.7293	7.02	0.000001	3.04E-08			

2	1	1	2010	10	13	0	0	0	0	0	0	0	0
2	1	1	2010	10	14	0	0	7.28	5.1979	14.7459	33.14	0.001714	0
2	1	1	2010	10	15	0	0	8.06	5.7548	26.7792	22.15	0.000512	0
2	1	1	2010	10	16	0	0	6.65	4.7481	42.7897	12.91	0.005153	0
2	1	1	2010	10	17	0	0	6.65	4.7481	45.5668	11.64	0.001465	0
2	1	1	2010	10	18	0	0	6.65	4.7481	57.6132	10.18	0.001795	0
2	1	1	2010	10	19	0	0	6.65	4.7481	58.6666	9.87	0.000562	0
2	1	1	2010	10	20	0	0	6.65	4.7481	65.2177	8.7	0.003736	0
2	1	1	2010	10	21	0	0	6.65	4.7481	64.4031	7.53	0.005469	0
2	1	1	2010	10	22	0	0	6.65	4.7481	128.464	6.58	0.005999	0
2	1	1	2010	10	23	0	0	6.65	4.7481	194.7393	6.28	0.022	0
2	1	1	2010	10	24	0.0142	0.115	1.35	0.9639	8.092	50	0.005	0.000071
2	1	1	2010	10	25	0.0619	1.686	6.88	4.9123	27.2301	6.36	0.000067	4.1473E-06
2	1	1	2010	10	26	0	0	6.65	4.7481	94.3934	4.34	0.001	0
2	1	1	2010	10	27	0	0	6.65	4.7481	27.2301	6.19	0.000933	0
2	1	1	2010	10	28	0	0	8.06	5.7548	44.6717	17.01	0.001283	0
2	1	1	2010	11	1	0	0	7.28	5.3799	30.0278	24.1	0.641286	0
2	1	1	2010	11	2	0	0	8.06	5.7548	40.5645	18.52	0.044882	0
2	1	1	2010	11	3	0	0	8.06	5.7548	40.5645	18.52	0.150605	0
2	1	1	2010	11	4	0	0	8.06	5.7548	38.1072	14.26	0.059125	0
2	1	1	2010	11	5	0	0	8.06	5.7548	38.1072	14.26	0.027592	0
2	1	1	2010	11	6	0	0	6.88	4.9123	37.4349	10.09	0.016847	0
2	1	1	2010	11	7	0	0.001	6.88	4.9123	38.4989	9.36	0.000535	0
2	1	1	2010	11	8	0	0	6.88	4.9123	29.7667	9.24	0.000205	0
2	1	1	2010	11	9	0	0.001	6.88	4.9123	34.2861	7.99	0.000438	0
2	1	1	2010	11	10	0	0.001	6.88	4.9123	34.71	8.1	0.001264	0
2	1	1	2010	11	11	0	0.001	6.88	4.9123	34.0744	7.42	0.000531	0
2	1	1	2010	11	12	0	0.001	6.88	4.9123	31.7293	7.02	0.000001	0
2	1	1	2010	11	13	0	0	0	0	0	0	0	0
2	1	1	2010	11	24	0	0	1.35	0.9639	8.092	50	0.005	0
2	1	1	2010	11	25	0	0.001	6.88	4.9123	27.2301	6.36	0.000067	0
2	1	1	2010	12	1	0.0068	0.204	7.28	5.3799	30.0278	24.1	0.641286	0.004360745
2	1	1	2010	12	2	0.0088	0.357	8.06	5.7548	40.5645	18.52	0.044882	0.000394962
2	1	1	2010	12	3	0.0088	0.357	8.06	5.7548	40.5645	18.52	0.150605	0.001325324
2	1	1	2010	12	4	0.0115	0.438	8.06	5.7548	38.1072	14.26	0.059125	0.000679938
2	1	1	2010	12	5	0.0115	0.438	8.06	5.7548	38.1072	14.26	0.027592	0.000317308
2	1	1	2010	12	6	0.0159	0.597	6.88	4.9123	37.4349	10.09	0.016847	0.000267867
2	1	1	2010	12	7	0.0172	0.663	6.88	4.9123	38.4989	9.36	0.000535	0.000009202
2	1	1	2010	12	8	0.0175	0.521	6.88	4.9123	29.7667	9.24	0.000205	3.5875E-06
2	1	1	2010	12	9	0.0203	0.696	6.88	4.9123	34.2861	7.99	0.000438	8.8914E-06
2	1	1	2010	12	10	0.02	0.695	6.88	4.9123	34.71	8.1	0.001264	0.00002528
2	1	1	2010	12	11	0.0219	0.746	6.88	4.9123	34.0744	7.42	0.000531	1.16289E-05
2	1	1	2010	12	12	0.0232	0.736	6.88	4.9123	31.7293	7.02	0.000001	2.32E-08
2	1	1	2010	12	13	0	0	0	0	0	0	0	0
2	1	1	2010	12	14	0.0021	0.031	7.28	5.1979	14.7459	33.14	0.001714	3.5994E-06
2	1	1	2010	12	15	0.0032	0.084	8.06	5.7548	26.7792	22.15	0.000512	1.6384E-06
2	1	1	2010	12	16	0.0054	0.23	6.65	4.7481	42.7897	12.91	0.005153	2.78262E-05
2	1	1	2010	12	17	0.006	0.272	6.65	4.7481	45.5668	11.64	0.001465	0.00000879
2	1	1	2010	12	18	0.0068	0.393	6.65	4.7481	57.6132	10.18	0.001795	0.000012206
2	1	1	2010	12	19	0.007	0.413	6.65	4.7481	58.6666	9.87	0.000562	0.000003934
2	1	1	2010	12	20	0.008	0.521	6.65	4.7481	65.2177	8.7	0.003736	0.000029888
2	1	1	2010	12	21	0.0092	0.595	6.65	4.7481	64.4031	7.53	0.005469	5.03148E-05
2	1	1	2010	12	22	0.0106	1.358	6.65	4.7481	128.464	6.58	0.005999	6.35894E-05
2	1	1	2010	12	23	0.0111	2.157	6.65	4.7481	194.7393	6.28	0.022	0.0002442
2	1	1	2010	12	24	0.0033	0.027	1.35	0.9639	8.092	50	0.005	0.0000165
2	1	1	2010	12	25	0.0258	0.704	6.88	4.9123	27.2301	6.36	0.000067	1.7286E-06
2	1	1	2010	12	26	0.016	1.513	6.65	4.7481	94.3934	4.34	0.001	0.000016
2	1	1	2010	12	27	0.0112	0.306	6.65	4.7481	27.2301	6.19	0.000933	1.04496E-05
2	1	1	2010	12	28	0.0041	0.184	8.06	5.7548	44.6717	17.01	0.001283	5.2603E-06
2	1	1	2010	13	1	0.1017	3.054	7.28	5.3799	30.0278	24.1	0.641286	0.065218786
2	1	1	2010	13	2	0.1017	4.125	8.06	5.7548	40.5645	18.52	0.044882	0.004564499
2	1	1	2010	13	3	0.1017	4.125	8.06	5.7548	40.5645	18.52	0.150605	0.015316529
2	1	1	2010	13	4	0.1015	3.867	8.06	5.7548	38.1072	14.26	0.059125	0.006001188
2	1	1	2010	13	5	0.1015	3.867	8.06	5.7548	38.1072	14.26	0.027592	0.002800588
2	1	1	2010	13	6	0.0451	1.687	6.88	4.9123	37.4349	10.09	0.016847	0.0007598
2	1	1	2010	13	7	0.0451	1.735	6.88	4.9123	38.4989	9.36	0.000535	2.41285E-05
2	1	1	2010	13	8	0.0451	1.341	6.88	4.9123	29.7667	9.24	0.000205	9.2455E-06
2	1	1	2010	13	9	0.0451	1.545	6.88	4.9123	34.2861	7.99	0.000438	1.97538E-05
2	1	1	2010	13	10	0.0451	1.564	6.88	4.9123	34.71	8.1	0.001264	5.70064E-05
2	1	1	2010	13	11	0.0451	1.536	6.88	4.9123	34.0744	7.42	0.000531	2.39481E-05
2	1	1	2010	13	12	0.0451	1.43	6.88	4.9123	31.7293	7.02	0.000001	4.51E-08
2	1	1	2010	13	13	0	0	0	0	0	0	0	0

2	1	1	2010	13	14	0.0068	0.1	7.28	5.1979	14.7459	33.14	0.001714	1.16552E-05
2	1	1	2010	13	15	0.0068	0.181	8.06	5.7548	26.7792	22.15	0.000512	3.4816E-06
2	1	1	2010	13	16	0.027	1.157	6.65	4.7481	42.7897	12.91	0.005153	0.000139131
2	1	1	2010	13	17	0.027	1.232	6.65	4.7481	45.5668	11.64	0.001465	0.000039555
2	1	1	2010	13	18	0.027	1.558	6.65	4.7481	57.6132	10.18	0.001795	0.000048465
2	1	1	2010	13	19	0.027	1.586	6.65	4.7481	58.6666	9.87	0.000562	0.000015174
2	1	1	2010	13	20	0.027	1.763	6.65	4.7481	65.2177	8.7	0.003736	0.000100872
2	1	1	2010	13	21	0.027	1.741	6.65	4.7481	64.4031	7.53	0.005469	0.000147663
2	1	1	2010	13	22	0.027	3.474	6.65	4.7481	128.464	6.58	0.005999	0.000161973
2	1	1	2010	13	23	0.027	5.266	6.65	4.7481	194.7393	6.28	0.022	0.000594
2	1	1	2010	13	24	0.0113	0.091	1.35	0.9639	8.092	50	0.005	0.0000565
2	1	1	2010	13	25	0.0451	1.227	6.88	4.9123	27.2301	6.36	0.000067	3.0217E-06
2	1	1	2010	13	26	0.027	2.552	6.65	4.7481	94.3934	4.34	0.001	0.000027
2	1	1	2010	13	27	0.027	0.736	6.65	4.7481	27.2301	6.19	0.000933	0.000025191
2	1	1	2010	13	28	0.0068	0.302	8.06	5.7548	44.6717	17.01	0.001283	8.7244E-06
2	1	1	2010	14	1	0.0053	0.16	7.28	5.3799	30.0278	24.1	0.641286	0.003398816
2	1	1	2010	14	2	0.0053	0.216	8.06	5.7548	40.5645	18.52	0.044882	0.000237875
2	1	1	2010	14	3	0.0053	0.216	8.06	5.7548	40.5645	18.52	0.150605	0.000798207
2	1	1	2010	14	4	0.0053	0.203	8.06	5.7548	38.1072	14.26	0.059125	0.000313363
2	1	1	2010	14	5	0.0053	0.203	8.06	5.7548	38.1072	14.26	0.027592	0.000146238
2	1	1	2010	14	6	0.0053	0.2	6.88	4.9123	37.4349	10.09	0.016847	8.92891E-05
2	1	1	2010	14	7	0.0053	0.205	6.88	4.9123	38.4989	9.36	0.000535	2.8355E-06
2	1	1	2010	14	8	0.0053	0.159	6.88	4.9123	29.7667	9.24	0.000205	1.0865E-06
2	1	1	2010	14	9	0.0053	0.183	6.88	4.9123	34.2861	7.99	0.000438	2.3214E-06
2	1	1	2010	14	10	0.0053	0.185	6.88	4.9123	34.71	8.1	0.001264	6.6992E-06
2	1	1	2010	14	11	0.0053	0.182	6.88	4.9123	34.0744	7.42	0.000531	2.8143E-06
2	1	1	2010	14	12	0.0053	0.169	6.88	4.9123	31.7293	7.02	0.000001	5.3E-09
2	1	1	2010	14	13	0	0	0	0	0	0	0	0
2	1	1	2010	14	14	0.0053	0.079	7.28	5.1979	14.7459	33.14	0.001714	9.0842E-06
2	1	1	2010	14	15	0.0053	0.143	8.06	5.7548	26.7792	22.15	0.000512	2.7136E-06
2	1	1	2010	14	16	0.0053	0.228	6.65	4.7481	42.7897	12.91	0.005153	2.73109E-05
2	1	1	2010	14	17	0.0053	0.243	6.65	4.7481	45.5668	11.64	0.001465	7.7645E-06
2	1	1	2010	14	18	0.0053	0.307	6.65	4.7481	57.6132	10.18	0.001795	9.5135E-06
2	1	1	2010	14	19	0.0053	0.313	6.65	4.7481	58.6666	9.87	0.000562	2.9786E-06
2	1	1	2010	14	20	0.0053	0.348	6.65	4.7481	65.2177	8.7	0.003736	1.98008E-05
2	1	1	2010	14	21	0.0053	0.344	6.65	4.7481	64.4031	7.53	0.005469	2.89857E-05
2	1	1	2010	14	22	0.0053	0.685	6.65	4.7481	128.464	6.58	0.005999	3.17947E-05
2	1	1	2010	14	23	0.0053	1.039	6.65	4.7481	194.7393	6.28	0.022	0.0001166
2	1	1	2010	14	24	0.0053	0.043	1.35	0.9639	8.092	50	0.005	0.0000265
2	1	1	2010	14	25	0.0053	0.145	6.88	4.9123	27.2301	6.36	0.000067	3.551E-07
2	1	1	2010	14	26	0.0053	0.503	6.65	4.7481	94.3934	4.34	0.001	0.0000053
2	1	1	2010	14	27	0.0053	0.145	6.65	4.7481	27.2301	6.19	0.000933	4.9449E-06
2	1	1	2010	14	28	0.0053	0.238	8.06	5.7548	44.6717	17.01	0.001283	6.7999E-06
2	1	1	2010	15	1	0.002	0.06	7.28	5.3799	30.0278	24.1	0.641286	0.001282572
2	1	1	2010	15	2	0.002	0.081	8.06	5.7548	40.5645	18.52	0.044882	0.000089764
2	1	1	2010	15	3	0.002	0.081	8.06	5.7548	40.5645	18.52	0.150605	0.00030121
2	1	1	2010	15	4	0.002	0.076	8.06	5.7548	38.1072	14.26	0.059125	0.00011825
2	1	1	2010	15	5	0.002	0.076	8.06	5.7548	38.1072	14.26	0.027592	0.000055184
2	1	1	2010	15	6	0.002	0.075	6.88	4.9123	37.4349	10.09	0.016847	0.000033694
2	1	1	2010	15	7	0.003	0.116	6.88	4.9123	38.4989	9.36	0.000535	0.000001605
2	1	1	2010	15	8	0.003	0.089	6.88	4.9123	29.7667	9.24	0.000205	0.000000615
2	1	1	2010	15	9	0.003	0.103	6.88	4.9123	34.2861	7.99	0.000438	0.000001314
2	1	1	2010	15	10	0.003	0.104	6.88	4.9123	34.71	8.1	0.001264	0.000003792
2	1	1	2010	15	11	0.003	0.102	6.88	4.9123	34.0744	7.42	0.000531	0.000001593
2	1	1	2010	15	12	0.009	0.286	6.88	4.9123	31.7293	7.02	0.000001	0.000000009
2	1	1	2010	15	13	0	0	0	0	0	0	0	0
2	1	1	2010	15	14	0.002	0.029	7.28	5.1979	14.7459	33.14	0.001714	0.000003428
2	1	1	2010	15	15	0.002	0.054	8.06	5.7548	26.7792	22.15	0.000512	0.000001024
2	1	1	2010	15	16	0.002	0.086	6.65	4.7481	42.7897	12.91	0.005153	0.000010306
2	1	1	2010	15	17	0.003	0.137	6.65	4.7481	45.5668	11.64	0.001465	0.000004395
2	1	1	2010	15	18	0.003	0.173	6.65	4.7481	57.6132	10.18	0.001795	0.000005385
2	1	1	2010	15	19	0.003	0.176	6.65	4.7481	58.6666	9.87	0.000562	0.000001686
2	1	1	2010	15	20	0.003	0.196	6.65	4.7481	65.2177	8.7	0.003736	0.000011208
2	1	1	2010	15	21	0.003	0.193	6.65	4.7481	64.4031	7.53	0.005469	0.000016407
2	1	1	2010	15	22	0.009	1.156	6.65	4.7481	128.464	6.58	0.005999	0.000053991
2	1	1	2010	15	23	0.009	1.753	6.65	4.7481	194.7393	6.28	0.022	0.000198
2	1	1	2010	15	24	0.001	0.008	1.35	0.9639	8.092	50	0.005	0.000005
2	1	1	2010	15	25	0.003	0.082	6.88	4.9123	27.2301	6.36	0.000067	0.000000201
2	1	1	2010	15	26	0.003	0.283	6.65	4.7481	94.3934	4.34	0.001	0.000003
2	1	1	2010	15	27	0.003	0.082	6.65	4.7481	27.2301	6.19	0.000933	0.000002799
2	1	1	2010	15	28	0.002	0.089	8.06	5.7548	44.6717	17.01	0.001283	0.000002566
2	1	1	2010	1	1	0.2329	6.994	7.28	5.3799	30.0278	24.1	0.641286	0.149355509
2	1	1	2010	1	2	0.1347	5.464	8.06	5.7548	40.5645	18.52	0.044882	0.006045605
2	1	1	2010	1	3	0.146	5.923	8.06	5.7548	40.5645	18.52	0.150605	0.02198833
2	1	1	2010	1	4	0.3254	12.399	8.06	5.7548	38.1072	14.26	0.059125	0.019239275
2	1	1	2010	1	5	0.3466	13.209	8.06	5.7548	38.1072	14.26	0.027592	0.009563387
2	1	1	2010	1	6	0.4049	15.156	6.88	4.9123	37.4349	10.09	0.016847	0.00682135
2	1	1	2010	1	7	0.3661	14.093	6.88	4.9123	38.4989	9.36	0.000535	0.000195864
2	1	1	2010	1	8	0.7522	22.392	6.88	4.9123	29.7667	9.24	0.000205	0.000154201
2	1	1	2010	1	9	0.506	17.35	6.88	4.9123	34.2861	7.99	0.000438	0.000221628
2	1	1	2010	1	10	0.4818	16.723	6.88	4.9123	34.71	8.1	0.001264	0.000608995
2	1	1	2010	1	11	0.5597	19.073	6.88	4.9123	34.0744	7.42	0.000531	0.000297201
2	1	1	2010	1	12	0.7021	22.277	6.88	4.9123	31.7293	7.02	0.000001	7.021E-07

2	1	1	2010	1	13	0	0	0	0	0	0	0	0
2	1	1	2010	1	14	0.4361	6.43	7.28	5.1979	14.7459	33.14	0.001714	0.000747475
2	1	1	2010	1	15	0.1967	5.267	8.06	5.7548	26.7792	22.15	0.000512	0.00010071
2	1	1	2010	1	16	0.1512	6.468	6.65	4.7481	42.7897	12.91	0.005153	0.000779134
2	1	1	2010	1	17	0.1624	7.401	6.65	4.7481	45.5668	11.64	0.001465	0.000237916
2	1	1	2010	1	18	0.2015	11.607	6.65	4.7481	57.6132	10.18	0.001795	0.000361693
2	1	1	2010	1	19	0.2175	12.759	6.65	4.7481	58.6666	9.87	0.000562	0.000122235
2	1	1	2010	1	20	0.2729	17.796	6.65	4.7481	65.2177	8.7	0.003736	0.001019554
2	1	1	2010	1	21	0.3368	21.693	6.65	4.7481	64.4031	7.53	0.005469	0.001841959
2	1	1	2010	1	22	0.3515	45.16	6.65	4.7481	128.464	6.58	0.005999	0.002108649
2	1	1	2010	1	23	0.4154	80.889	6.65	4.7481	194.7393	6.28	0.022	0.0091388
2	1	1	2010	1	24	1.7532	14.187	1.35	0.9639	8.092	50	0.005	0.008766
2	1	1	2010	1	25	1.6701	45.478	6.88	4.9123	27.2301	6.36	0.000067	0.000111897
2	1	1	2010	1	26	0.2934	27.695	6.65	4.7481	94.3934	4.34	0.001	0.0002934
2	1	1	2010	1	27	0.5052	13.756	6.65	4.7481	27.2301	6.19	0.000933	0.000471352
2	1	1	2010	1	28	0.2435	10.877	8.06	5.7548	44.6717	17.01	0.001283	0.000312411
2	1	1	2010	2	1	3.1102	93.392	7.28	5.3799	30.0278	24.1	0.641286	1.994527717
2	1	1	2010	2	2	2.3624	95.83	8.06	5.7548	40.5645	18.52	0.044882	0.106029237
2	1	1	2010	2	3	2.4762	100.447	8.06	5.7548	40.5645	18.52	0.150605	0.372928101
2	1	1	2010	2	4	4.1015	156.298	8.06	5.7548	38.1072	14.26	0.059125	0.242501188
2	1	1	2010	2	5	4.148	158.067	8.06	5.7548	38.1072	14.26	0.027592	0.114451616
2	1	1	2010	2	6	5.3198	199.146	6.88	4.9123	37.4349	10.09	0.016847	0.089622671
2	1	1	2010	2	7	5.898	227.068	6.88	4.9123	38.4989	9.36	0.000535	0.00315543
2	1	1	2010	2	8	7.2046	214.456	6.88	4.9123	29.7667	9.24	0.000205	0.001476943
2	1	1	2010	2	9	6.949	238.255	6.88	4.9123	34.2861	7.99	0.000438	0.003043662
2	1	1	2010	2	10	6.7741	235.131	6.88	4.9123	34.71	8.1	0.001264	0.008562462
2	1	1	2010	2	11	8.2926	282.565	6.88	4.9123	34.0744	7.42	0.000531	0.004403371
2	1	1	2010	2	12	9.2071	292.134	6.88	4.9123	31.7293	7.02	0.000001	9.2071E-06
2	1	1	2010	2	13	0	0	0	0	0	0	0	0
2	1	1	2010	2	14	0.7974	11.758	7.28	5.1979	14.7459	33.14	0.001714	0.001366744
2	1	1	2010	2	15	0.4067	10.892	8.06	5.7548	26.7792	22.15	0.000512	0.00020823
2	1	1	2010	2	16	0.4679	20.023	6.65	4.7481	42.7897	12.91	0.005153	0.002411089
2	1	1	2010	2	17	0.4847	22.085	6.65	4.7481	45.5668	11.64	0.001465	0.000710086
2	1	1	2010	2	18	0.6414	36.955	6.65	4.7481	57.6132	10.18	0.001795	0.001151313
2	1	1	2010	2	19	0.6681	39.195	6.65	4.7481	58.6666	9.87	0.000562	0.000375472
2	1	1	2010	2	20	0.6924	45.157	6.65	4.7481	65.2177	8.7	0.003736	0.002586806
2	1	1	2010	2	21	0.8651	55.717	6.65	4.7481	64.4031	7.53	0.005469	0.004731232
2	1	1	2010	2	22	1.1437	146.926	6.65	4.7481	128.464	6.58	0.005999	0.006861056
2	1	1	2010	2	23	1.4894	290.038	6.65	4.7481	194.7393	6.28	0.022	0.0327668
2	1	1	2010	2	24	9.5963	77.654	1.35	0.9639	8.092	50	0.005	0.0479815
2	1	1	2010	2	25	15.6236	425.434	6.88	4.9123	27.2301	6.36	0.000067	0.001046781
2	1	1	2010	2	26	2.4998	235.966	6.65	4.7481	94.3934	4.34	0.001	0.0024998
2	1	1	2010	2	27	1.4	38.123	6.65	4.7481	27.2301	6.19	0.000933	0.0013062
2	1	1	2010	2	28	0.345	15.411	8.06	5.7548	44.6717	17.01	0.001283	0.000442635
2	1	1	2010	3	1	0.309	9.279	7.28	5.3799	30.0278	24.1	0.641286	0.198157374
2	1	1	2010	3	2	0.2015	8.175	8.06	5.7548	40.5645	18.52	0.044882	0.009043723
2	1	1	2010	3	3	0.3103	12.588	8.06	5.7548	40.5645	18.52	0.150605	0.046732732
2	1	1	2010	3	4	0.5839	22.25	8.06	5.7548	38.1072	14.26	0.059125	0.034523088
2	1	1	2010	3	5	0.8248	31.429	8.06	5.7548	38.1072	14.26	0.027592	0.022757882
2	1	1	2010	3	6	1.8234	68.258	6.88	4.9123	37.4349	10.09	0.016847	0.03071882
2	1	1	2010	3	7	1.8667	71.867	6.88	4.9123	38.4989	9.36	0.000535	0.000998685
2	1	1	2010	3	8	2.2341	66.503	6.88	4.9123	29.7667	9.24	0.000205	0.000457991
2	1	1	2010	3	9	2.126	72.891	6.88	4.9123	34.2861	7.99	0.000438	0.000931188
2	1	1	2010	3	10	2.0833	72.313	6.88	4.9123	34.71	8.1	0.001264	0.002633291
2	1	1	2010	3	11	2.3787	81.052	6.88	4.9123	34.0744	7.42	0.000531	0.00126309
2	1	1	2010	3	12	2.7565	87.462	6.88	4.9123	31.7293	7.02	0.000001	2.7565E-06
2	1	1	2010	3	13	0	0	0	0	0	0	0	0
2	1	1	2010	3	14	1.0726	15.816	7.28	5.1979	14.7459	33.14	0.001714	0.001838436
2	1	1	2010	3	15	0.4571	12.24	8.06	5.7548	26.7792	22.15	0.000512	0.000234035
2	1	1	2010	3	16	1.9101	81.732	6.65	4.7481	42.7897	12.91	0.005153	0.009842745
2	1	1	2010	3	17	1.9885	90.61	6.65	4.7481	45.5668	11.64	0.001465	0.002913153
2	1	1	2010	3	18	2.6088	150.304	6.65	4.7481	57.6132	10.18	0.001795	0.004682796
2	1	1	2010	3	19	2.7623	162.053	6.65	4.7481	58.6666	9.87	0.000562	0.001552413
2	1	1	2010	3	20	3.3487	218.397	6.65	4.7481	65.2177	8.7	0.003736	0.012510743
2	1	1	2010	3	21	4.1695	268.53	6.65	4.7481	64.4031	7.53	0.005469	0.022802996
2	1	1	2010	3	22	4.8224	619.5	6.65	4.7481	128.464	6.58	0.005999	0.028929578
2	1	1	2010	3	23	5.8234	1134.037	6.65	4.7481	194.7393	6.28	0.022	0.1281148
2	1	1	2010	3	24	0.7097	5.743	1.35	0.9639	8.092	50	0.005	0.0035485
2	1	1	2010	3	25	5.7238	155.86	6.88	4.9123	27.2301	6.36	0.000067	0.000383495
2	1	1	2010	3	26	11.041	1042.197	6.65	4.7481	94.3934	4.34	0.001	0.011041
2	1	1	2010	3	27	6.7653	184.22	6.65	4.7481	27.2301	6.19	0.000933	0.006312025
2	1	1	2010	3	28	0.4971	22.206	8.06	5.7548	44.6717	17.01	0.001283	0.000637779

Appendix D

Three Cases

With Different Lane Widths

For Scenario 2b:

- **10-foot Mixed-Traffic Lane and 16-foot Bus Lane**
- **11-foot Mixed-Traffic Lane and 15-foot Bus Lane**
- **13-foot Mixed-Traffic Lane and 13-foot Bus Lane**

Scenario - 2b: 10' Mixed-Traffic Lane + 16' Bus Lane

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft

Time	NB					
Period	Autos		Trucks		Buses	
(secs)	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	234	9	0	0	306.7	3
900 - 1800	264.2	16	0	0	293.7	3
1800 - 2700	322.5	15	365	1	301.6	2
2700 - 3600	318.2	14	0	0	312.3	3
Average Wtd	289.4	54	365	1	303.8	11

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft
Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time	NB											
Period	Autos				Trucks				Buses			
(secs)	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	94.6	41.6	2.22	9	0	0	0	0	82.6	25	2	3
900 - 1800	125.4	40.9	3.19	16	0	0	0	0	84.2	23.5	1.33	3
1800 - 2700	183.9	48.9	3.33	15	221.9	47.6	2	1	87.9	9.2	1	2
2700 - 3600	177.9	44.7	3.14	14	0	0	0	0	105.5	27	2	3
Total	150.2	44.2	3.06	54	221.9	47.6	2	1	90.2	22.3	1.64	11

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)				
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles
11	0	900	227	217	7	3	0	29	29	31	27	0
12	0	900	243	236	4	3	0	16	16	17	26	0
13	0	900	78	73	2	3	0	31	31	26	27	0
21	0	900	189	185	1	3	0	27	27	26	25	0
22	0	900	247	242	2	3	0	14	14	13	27	0
23	0	900	178	174	1	3	0	20	20	9	25	0
11	900	1800	243	233	7	3	0	28	28	24	26	0
12	900	1800	303	292	8	3	0	11	11	11	25	0
13	900	1800	108	102	3	3	0	30	30	33	29	0
21	900	1800	213	208	2	3	0	25	25	28	27	0
22	900	1800	309	302	4	3	0	11	11	9	21	0
23	900	1800	201	194	4	3	0	14	14	12	20	0
11	1800	2700	231	222	6	3	0	29	29	30	28	0
12	1800	2700	310	296	11	3	0	11	11	11	22	0
13	1800	2700	97	89	5	3	0	31	31	27	28	0
21	1800	2700	249	238	8	3	0	18	18	16	21	0
22	1800	2700	300	289	8	3	0	11	11	10	21	0
23	1800	2700	225	219	3	3	0	16	16	15	23	0
11	2700	3600	249	238	8	3	0	29	29	30	27	0
12	2700	3600	311	301	7	3	0	11	11	13	19	0
13	2700	3600	103	98	2	3	0	30	31	30	26	0
21	2700	3600	225	218	4	3	0	24	24	27	28	0
22	2700	3600	319	311	5	3	0	11	11	11	21	0
23	2700	3600	215	209	3	3	0	19	19	17	24	0

Scenario - 2b: 11' Mixed-Traffic Lane + 15' Bus Lane

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft

Time	NB					
Period	Autos		Trucks		Buses	
(secs)	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	215	4	0	0	312.3	3
900 - 1800	220	15	0	0	276.8	3
1800 - 2700	250.9	15	260.3	1	298.4	2
2700 - 3600	316.5	16	326.8	2	292.1	3
Average Wtd	259.8	50	304.6	3	294.6	11

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft
Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time	NB											
Period	Autos				Trucks				Buses			
(secs)	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	75.8	30.4	2.25	4	0	0	0	0	88.5	27.4	2	3
900 - 1800	79.8	36.2	2.73	15	0	0	0	0	67.3	16.7	1.33	3
1800 - 2700	113.3	38.2	2.67	15	128.8	38.2	3	1	79.1	16.1	1.5	2
2700 - 3600	180.5	60.6	4	16	190.5	48.2	4	2	82.5	18.1	1.67	3
Total	121.8	44.1	3.08	50	169.9	44.9	3.67	3	79.4	19.9	1.64	11

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)				
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles
11	0	900	224	217	4	3	0	28	28	31	28	0
12	0	900	260	253	4	3	0	17	17	14	21	0
13	0	900	84	79	2	3	0	30	30	31	27	0
21	0	900	190	185	2	3	0	27	27	26	27	0
22	0	900	239	234	2	3	0	13	13	10	26	0
23	0	900	166	161	2	3	0	21	21	14	25	0
11	900	1800	255	248	4	3	0	28	28	30	28	0
12	900	1800	283	270	10	3	0	16	16	15	24	0
13	900	1800	87	82	2	3	0	31	31	26	27	0
21	900	1800	209	204	2	3	0	27	26	28	27	0
22	900	1800	291	283	5	3	0	12	11	11	22	0
23	900	1800	224	217	4	3	0	15	15	12	21	0
11	1800	2700	233	222	8	3	0	29	29	29	26	0
12	1800	2700	285	273	9	3	0	11	11	12	23	0
13	1800	2700	101	91	7	3	0	30	30	28	26	0
21	1800	2700	241	230	8	3	0	22	22	19	26	0
22	1800	2700	301	290	8	3	0	11	11	11	20	0
23	1800	2700	218	209	6	3	0	20	19	24	24	0
11	2700	3600	259	244	12	3	0	27	27	30	29	0
12	2700	3600	308	296	9	3	0	11	11	11	22	0
13	2700	3600	111	105	3	3	0	30	30	31	28	0
21	2700	3600	243	237	3	3	0	25	25	30	27	0
22	2700	3600	306	298	5	3	0	10	10	10	26	0
23	2700	3600	229	222	4	3	0	16	16	11	26	0

Scenario - 2b: 13' Mixed-Traffic Lane + 13' Bus Lane

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft

Time Period (secs)	NB					
	Autos		Trucks		Buses	
	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	212.4	12	223	1	302.8	3
900 - 1800	268	14	0	0	312.3	3
1800 - 2700	275	12	318.3	1	344.8	2
2700 - 3600	268	15	0	0	306.9	3
Average Wtd	257	53	270.7	2	314.1	11

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft
SB Autos/Trucks, Buses and Bicycles - Travel Time section = 6874.1 ft
Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time Period (secs)	NB											
	Autos				Trucks				Buses			
	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	71.8	30.7	2	12	75.3	14.2	2	1	77.3	25.7	1.67	3
900 - 1800	130.5	51.2	3	14	0	0	0	0	100.6	38.3	2	3
1800 - 2700	138.1	44	2.83	12	182.5	19	1	1	124.9	51.3	2.5	2
2700 - 3600	129.1	44.3	3.13	15	0	0	0	0	98	28	1.67	3
Total	118.5	43	2.77	53	128.9	16.6	1.5	2	97.9	34.4	1.91	11

Data Collection:

Data Collection Number	Aggregation Interval		# Vehicles					Speed (mean)				
	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles
11	0	900	219	209	7	3	0	29	29	27	28	0
12	0	900	241	232	6	3	0	18	18	20	26	0
13	0	900	80	73	4	3	0	31	31	33	28	0
21	0	900	183	179	1	3	0	27	27	28	25	0
22	0	900	230	225	2	3	0	15	15	12	24	0
23	0	900	178	172	3	3	0	22	22	17	28	0
11	900	1800	271	263	5	3	0	26	26	29	25	0
12	900	1800	314	303	8	3	0	12	11	12	20	0
13	900	1800	106	103	0	3	0	31	31	0	28	0
21	900	1800	218	213	2	3	0	23	23	28	27	0
22	900	1800	299	293	3	3	0	11	11	8	23	0
23	900	1800	222	216	3	3	0	17	17	18	24	0
11	1800	2700	245	236	6	3	0	28	28	29	24	0
12	1800	2700	313	300	10	3	0	12	12	12	23	0
13	1800	2700	117	110	4	3	0	29	29	26	27	0
21	1800	2700	237	228	6	3	0	21	21	17	26	0
22	1800	2700	308	300	5	3	0	10	10	9	24	0
23	1800	2700	216	206	7	3	0	20	20	12	21	0
11	2700	3600	256	247	6	3	0	27	27	29	26	0
12	2700	3600	293	283	7	3	0	12	11	11	21	0
13	2700	3600	112	109	0	3	0	30	30	0	26	0
21	2700	3600	230	223	4	3	0	24	24	30	25	0
22	2700	3600	303	296	4	3	0	9	9	15	26	0
23	2700	3600	221	214	4	3	0	15	15	13	27	0

Appendix E

Sensitivity Analysis

For Three New Cases

For Scenario # 1:

- **36 Buses and 16 Bicycles**
- **60 Buses and 16 Bicycles**
- **12 Buses and 60 Bicycles**

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 36, Bikes = 16)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Time	NB							
Period	Autos		Trucks		Buses		Bicycles	
(secs)	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	209.3	6	0	0	313	6	338.4	3
900 - 1800	210.6	13	0	0	319	9	360.2	2
1800 - 2700	222.2	17	0	0	316.3	9	375.8	7
2700 - 3600	214.9	17	178.2	1	318.8	9	370.8	6
Average Wtd	215.6	53	178.2	1	317.1	33	366.2	18

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time	NB															
Period	Autos				Trucks				Buses				Bicycles			
(secs)	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	69.9	35.6	2.67	6	0	0	0	0	93	26.9	2	6	41.8	29.8	2	3
900 - 1800	74	40.9	2.46	13	0	0	0	0	103.3	36.7	2.56	9	63.7	45	3	2
1800 - 2700	83	52.7	2.65	17	0	0	0	0	100	35.4	2.22	9	78	52.9	3.86	7
2700 - 3600	74.5	47.2	2.41	17	43.1	15.2	1	1	96.7	31.6	2.11	9	73.1	50.7	3.83	6
Total	76.6	46.1	2.53	53	43.1	15.2	1	1	98.8	33.2	2.24	33	68.8	47.5	3.44	18

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 36, Bikes = 16) - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	213	195	6	8	4	30	31	29	27	16	2150	87	0.24539	0.58612	3.03743	21.28359	50.83621	263.44545
12	0	900	273	256	6	8	3	26	26	27	21	14	1700	88	0.27263	0.61482	3.11833	23.96399	54.04114	274.09437
13	0	900	113	101	2	7	3	27	28	27	23	16	3500	75	0.26053	0.60208	3.08242	19.51487	45.09879	230.88924
21	0	900	226	214	2	8	2	28	28	36	26	16	3500	150	0.26053	0.60208	3.08242	39.02975	90.19757	461.77848
22	0	900	284	271	4	8	1	27	27	24	25	16	1700	91	0.26632	0.60817	3.09964	24.35248	55.61042	283.42879
23	0	900	223	213	2	7	1	29	29	28	25	17	2150	91	0.25510	0.59639	3.06636	23.16431	54.15555	278.44059
11	900	1800	249	235	2	10	2	30	30	32	28	15	2150	101	0.25008	0.59104	3.05139	25.35592	59.92658	309.38692
12	900	1800	309	290	8	9	2	25	25	22	21	14	1700	99	0.27965	0.62270	3.15710	27.82178	61.95132	314.09559
13	900	1800	107	95	1	9	2	29	30	19	20	15	3500	71	0.25510	0.59639	3.06636	18.09372	42.30108	217.49088
21	900	1800	227	212	2	9	4	27	28	28	25	15	3500	150	0.26053	0.60208	3.08242	39.20244	90.59668	463.82175
22	900	1800	306	289	3	9	5	26	26	26	24	15	1700	99	0.27263	0.61482	3.11833	26.86074	60.57359	307.22665
23	900	1800	236	222	0	9	5	28	28	0	26	15	2150	96	0.26053	0.60208	3.08242	25.03627	57.85872	296.21543
11	1800	2700	251	230	4	9	8	30	31	30	26	15	2150	102	0.25008	0.59104	3.05139	25.55958	60.40792	311.87196
12	1800	2700	318	293	8	9	8	23	24	21	21	14	1700	102	0.28722	0.63122	3.19918	29.40767	64.62847	327.55278
13	1800	2700	116	97	3	9	7	29	31	29	25	15	3500	77	0.25008	0.59104	3.05139	19.22948	45.44726	234.63358
21	1800	2700	224	204	3	9	8	27	27	29	24	16	3500	148	0.26632	0.60817	3.09964	39.54504	90.30358	460.24890
22	1800	2700	285	266	3	8	8	27	27	28	25	15	1700	92	0.26632	0.60817	3.09964	24.43823	55.80623	284.42678
23	1800	2700	208	186	6	9	7	28	29	20	22	15	2150	85	0.26053	0.60208	3.08242	22.06587	50.99413	261.07122
11	2700	3600	227	205	8	9	5	30	31	29	28	16	2150	92	0.24539	0.58612	3.03743	22.68251	54.17756	280.76111
12	2700	3600	330	310	7	8	5	24	24	21	21	12	1700	106	0.28722	0.63122	3.19918	30.51740	67.06728	339.91327
13	2700	3600	126	107	4	9	6	28	29	27	24	16	3500	84	0.25510	0.59639	3.06636	21.30662	49.81249	256.11075
21	2700	3600	227	212	4	9	2	28	28	27	27	16	3500	150	0.26053	0.60208	3.08242	39.20244	90.59668	463.82175
22	2700	3600	292	276	5	9	2	25	26	25	22	15	1700	94	0.27263	0.61482	3.11833	25.63182	57.80225	293.17053
23	2700	3600	227	211	4	9	3	28	29	28	23	16	2150	92	0.25510	0.59639	3.06636	23.57981	55.12695	283.43504

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	1.7171	0.6817	7.94421	2.10426	33.17786	2.311	55.90675	32.13675	15.21640	41.72522	78.87743

Total NB VOC	299.95	gms
Total NB Nox	697.42	gms
Total NB CO	3,439.12	gms

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 60, Bikes = 16)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Time Period (secs)	NB							
	Autos		Trucks		Buses		Bicycles	
	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	216.2	7	0	0	324.1	10	352.3	1
900 - 1800	206.5	11	0	0	317.5	15	403.2	3
1800 - 2700	221.6	12	240	1	345.1	15	396.6	7
2700 - 3600	222.6	10	0	0	331.3	14	413.5	5
Average Wtd	216.8	40	240	1	330	54	400.4	16

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time Period (secs)	NB															
	Autos				Trucks				Buses				Bicycles			
	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	78.1	46.1	3.29	7	0	0	0	0	109.9	38	2.4	10	56.3	42.7	3	1
900 - 1800	69.4	34.7	2.27	11	0	0	0	0	98.9	31.1	2.4	15	104.3	73.2	5.33	3
1800 - 2700	80.1	41.1	2.5	12	107.6	53.7	2	1	124.7	48.5	2.93	15	99.1	71	3.86	7
2700 - 3600	84.7	54.6	3.1	10	0	0	0	0	115.8	44.2	2.5	14	115.2	74.1	6.2	5
Total	77.9	43.6	2.73	40	107.6	53.7	2	1	112.5	40.6	2.57	54	102.4	70.6	4.81	16

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 60, Bikes = 16) - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	224	202	4	14	4	29	29	30	26	15	2150	91	0.25510	0.59639	3.06636	23.26818	54.39840	279.68920
12	0	900	276	255	5	12	4	24	24	24	21	14	1700	89	0.27965	0.62270	3.15710	24.85052	55.33516	280.55140
13	0	900	99	83	1	12	3	29	30	31	23	16	3500	66	0.25510	0.59639	3.06636	16.74092	39.13839	201.22988
21	0	900	240	222	2	14	2	27	27	32	23	15	3500	159	0.26632	0.60817	3.09964	42.36969	96.75384	493.12382
22	0	900	280	265	2	12	1	27	28	18	24	16	1700	90	0.26053	0.60208	3.08242	23.48693	54.27819	277.88440
23	0	900	206	193	1	11	1	29	29	28	24	14	2150	84	0.25510	0.59639	3.06636	21.39842	50.02710	257.21418
11	900	1800	242	225	1	15	1	30	31	33	27	15	2150	99	0.24539	0.58612	3.03743	24.18135	57.75757	299.31361
12	900	1800	314	293	5	15	1	24	24	22	20	14	1700	101	0.28722	0.63122	3.19918	29.03776	63.81553	323.43262
13	900	1800	124	106	1	15	2	27	28	21	23	16	3500	82	0.26053	0.60208	3.08242	21.41455	49.48893	253.36518
21	900	1800	225	205	2	14	4	29	29	29	26	14	3500	149	0.25510	0.59639	3.06636	38.04754	88.95088	457.34063
22	900	1800	303	278	5	15	5	25	26	25	22	15	1700	98	0.27263	0.61482	3.11833	26.59740	59.97973	304.21463
23	900	1800	243	218	5	15	5	25	26	25	22	15	2150	99	0.27263	0.61482	3.11833	26.97692	60.83559	308.55549
11	1800	2700	259	233	2	15	9	29	30	32	27	15	2150	105	0.25008	0.59104	3.05139	26.37423	62.33327	321.81210
12	1800	2700	315	288	4	15	8	25	26	18	21	14	1700	101	0.27263	0.61482	3.11833	27.65076	62.35517	316.26273
13	1800	2700	125	105	0	13	7	27	28	0	23	15	3500	83	0.26053	0.60208	3.08242	21.58725	49.88804	255.40845
21	1800	2700	241	215	3	15	8	27	28	24	24	14	3500	160	0.26053	0.60208	3.08242	41.62022	96.18414	492.42750
22	1800	2700	307	284	0	15	8	26	26	0	22	15	1700	99	0.27263	0.61482	3.11833	26.94852	60.77154	308.23066
23	1800	2700	206	183	4	14	5	28	28	24	24	15	2150	84	0.26053	0.60208	3.08242	21.85370	50.50380	258.56092
11	2700	3600	250	221	9	15	5	30	31	28	26	16	2150	102	0.24539	0.58612	3.03743	24.98074	59.66691	309.20827
12	2700	3600	316	285	10	16	5	23	23	23	21	13	1700	102	0.28722	0.63122	3.19918	29.22272	64.22200	325.49270
13	2700	3600	121	93	6	16	6	28	30	28	23	16	3500	80	0.25510	0.59639	3.06636	20.46112	47.83581	245.94763
21	2700	3600	239	219	3	15	2	28	28	30	23	16	3500	158	0.26053	0.60208	3.08242	41.27482	95.38593	488.34096
22	2700	3600	298	277	4	15	2	26	26	25	22	15	1700	96	0.26632	0.60817	3.09964	25.55296	58.35178	297.40063
23	2700	3600	247	222	4	16	5	27	28	27	25	15	2150	101	0.26053	0.60208	3.08242	26.20322	60.55553	310.02208

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	1.3225	1.5651	7.94421	2.10426	33.17786	2.311	55.90675	32.13675	14.12350	90.28429	94.17701

Total NB VOC	**303.89**	**gms**
Total NB Nox	**756.52**	**gms**
Total NB CO	**3,505.89**	**gms**

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 12, Bikes = 60)

Table of Travel Times:

Average travel times in the section of the corridor in seconds.
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Time Period (secs)	NB							
	Autos		Trucks		Buses		Bicycles	
	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count	Time (secs)	Count
0 - 900	187.6	7	0	0	311.2	2	363	6
900 - 1800	195.6	12	0	0	336	3	352.1	18
1800 - 2700	195.5	12	0	0	298.1	3	356.1	22
2700 - 3600	222.5	11	0	0	317.7	3	363.5	19
Average Wtd	201.3	42	0	0	316.2	11	357.8	65

Table of Delay:

Delay: Average total delay per vehicle (in secs). The total delay is computed for every vehicle completing the travel time section
by subtracting the theoretical (ideal) travel time from the real travel time.
The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other
stops in the network (reduced speed areas are taken into account).
NB Autos/Trucks, Buses and Bicycles - Travel Time section = 6714.6 ft

Stopd: Average standstill time per vehicle (in secs)
Stops: Average number of stops/veh

Time Period (secs)	NB															
	Autos				Trucks				Buses				Bicycles			
	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count	Delay (secs)	Av. Standstill Time/Veh (secs)	Av. Stops/Veh	Count
0 - 900	51.7	27.8	2.14	7	0	0	0	0	83.4	28.7	2	2	64.9	40.3	3.33	6
900 - 1800	56.5	29.5	2.17	12	0	0	0	0	104.7	35.1	2.33	3	54.4	36.7	2.44	18
1800 - 2700	56.3	34.3	2.25	12	0	0	0	0	73.5	14.1	1	3	58.1	42.5	2.36	22
2700 - 3600	81.3	49.6	2.64	11	0	0	0	0	89.8	21.4	2	3	64.7	43.8	2.89	19
Total	62.1	35.8	2.31	42	0	0	0	0	88.3	24.5	1.82	11	59.6	41.1	2.63	65

Scenario - 1: Two 13-foot mixed traffic lanes (Buses = 12, Bikes = 60) - Continued

Data Collection:

Data Collection	Aggregation Interval		# Vehicles					Speed (mean)					Length	VMT	Emission Rates (gms/mi) All Veh Types			Total Emissions (gms)		
Number	Start Time	End Time	All Veh Types	Autos	Trucks	Buses	Bicycles	All Veh Types	Autos	Trucks	Buses	Bicycles	(feet)	(miles)	VOC	NOx	CO	VOC	NOx	CO
11	0	900	212	190	2	3	17	29.5	30.8	24.2	27.1	15	2150	86	0.25008	0.59104	3.05139	21.58817	51.02183	263.41376
12	0	900	278	256	2	3	17	25.1	25.8	19.5	23	15	1700	90	0.27263	0.61482	3.11833	24.40289	55.03091	279.11441
13	0	900	102	83	1	3	15	27.7	30	27.1	23.6	16	3500	68	0.26053	0.60208	3.08242	17.61520	40.70864	208.41330
21	0	900	232	212	2	3	15	26.3	27.2	25.6	22.6	15	3500	154	0.26632	0.60817	3.09964	40.95736	93.52871	476.68636
22	0	900	268	251	3	3	11	26.4	27	22.2	20.9	15	1700	86	0.26632	0.60817	3.09964	22.98051	52.47744	267.46097
23	0	900	217	201	3	3	10	26.9	27.5	26.7	27.2	15	2150	88	0.26632	0.60817	3.09964	23.53283	53.73869	273.88919
11	900	1800	236	224	2	3	7	29.6	30.1	31.2	25.8	15	2150	96	0.25008	0.59104	3.05139	24.03211	56.79788	293.23419
12	900	1800	291	276	6	3	6	24.8	25.2	20.7	21.6	15	1700	94	0.27965	0.62270	3.15710	26.20109	58.34251	295.79876
13	900	1800	93	83	1	3	6	29.2	30.5	26.7	22.9	15	3500	62	0.25008	0.59104	3.05139	15.41674	36.43617	188.11141
21	900	1800	223	201	5	3	14	26.4	27.2	28.1	18.8	15	3500	148	0.26632	0.60817	3.09964	39.36850	89.90044	458.19422
22	900	1800	305	281	6	3	15	25.7	26.4	22.4	22.8	15	1700	98	0.27263	0.61482	3.11833	26.77296	60.37564	306.22265
23	900	1800	205	185	2	3	15	27.9	29	26.8	25.8	15	2150	83	0.26053	0.60208	3.08242	21.74761	50.25864	257.30577
11	1800	2700	259	233	1	3	22	28	29.3	34.3	27.3	15	2150	105	0.25510	0.59639	3.06636	26.90384	62.89815	323.39064
12	1800	2700	305	276	6	3	20	24.8	25.7	17.4	27.5	15	1700	98	0.27965	0.62270	3.15710	27.46162	61.14936	310.02963
13	1800	2700	119	95	2	3	19	26.4	28.6	26.7	25.5	15	3500	79	0.26632	0.60817	3.09964	21.00830	47.97378	244.50723
21	1800	2700	249	225	4	3	17	25.9	26.7	23.7	28.1	15	3500	165	0.27263	0.61482	3.11833	45.00026	101.47998	514.70209
22	1800	2700	318	292	4	3	19	24.6	25.3	20.7	25	14	1700	102	0.27965	0.62270	3.15710	28.63212	63.75573	323.24401
23	1800	2700	218	190	6	3	19	26.9	28.1	25.1	28.8	15	2150	89	0.26632	0.60817	3.09964	23.64128	53.98634	275.15135
11	2700	3600	232	207	8	3	14	28.8	29.6	30.4	28.8	15	2150	94	0.25510	0.59639	3.06636	24.09919	56.34120	289.67810
12	2700	3600	327	298	11	3	15	24.6	25.3	22.8	17.5	14	1700	105	0.27965	0.62270	3.15710	29.44246	65.56014	332.39242
13	2700	3600	137	110	8	3	16	26.2	28.2	24	17.9	15	3500	91	0.26632	0.60817	3.09964	24.18603	55.23032	281.49152
21	2700	3600	224	201	4	3	16	27.1	28.1	30.5	23.4	15	3500	148	0.26053	0.60208	3.08242	38.68435	89.39937	457.69195
22	2700	3600	314	290	4	3	17	25.3	25.9	25.1	23.9	16	1700	101	0.27263	0.61482	3.11833	27.56298	62.15721	315.25872
23	2700	3600	248	225	2	3	18	25.9	26.8	35.2	22.7	15	2150	101	0.27263	0.61482	3.11833	27.53200	62.08735	314.90437

Idling:

	Autos	Buses	Auto Idling Emission Rates (gms/hr)			Bus Idling Emission Rates (gms/hr)			Total Emissions (gms)		
			VOC	NOx	CO	VOC	NOx	CO	VOC	NOx	CO
NB Idling (hrs)	0.9648	0.1362	7.94421	2.10426	33.17786	2.311	55.90675	32.13675	7.97952	9.64735	36.38887

Total NB VOC	**290.34**	**gms**
Total NB Nox	**657.14**	**gms**
Total NB CO	**3,345.96**	**gms**

Appendix F

Decision-Makers’ Survey

Survey for Transportation Decision-Makers

Please check the appropriate box next to your answer to the following questions:

1) Do you believe or consider that there is traffic congestion in your jurisdiction?

☐ Yes

☐ No

☐ Not sure

2) If your answer to question # 1 is yes, has it been a priority for your jurisdiction to pursue solutions to reduce congestion and to improve road capacity?

☐ Yes

☐ No

☐ Not sure

3) What could be the challenge(s) to pursue such solution? If you check more than one, please rank your choices.

☐ Lack of construction funds

☐ Right-of-way is not available

☐ Politics (i.e., unease to build consensus with residents, civic associations, elected officials, etc.)

☐ Other:____

4) Do you support the promotion of the multimodal concept (i.e., transit and bike use)?

☐ Yes

☐ No

☐ Only if it has a significant potential in reducing congestion

5) Which factor(s) would be encouraging for you to support a solution to reduce congestion? If you check more than one, please rank your choices.

☐ No need to purchase right-of-way

☐ The solution includes bike lanes

☐ The solution includes transit accommodations (e.g., bus lanes)

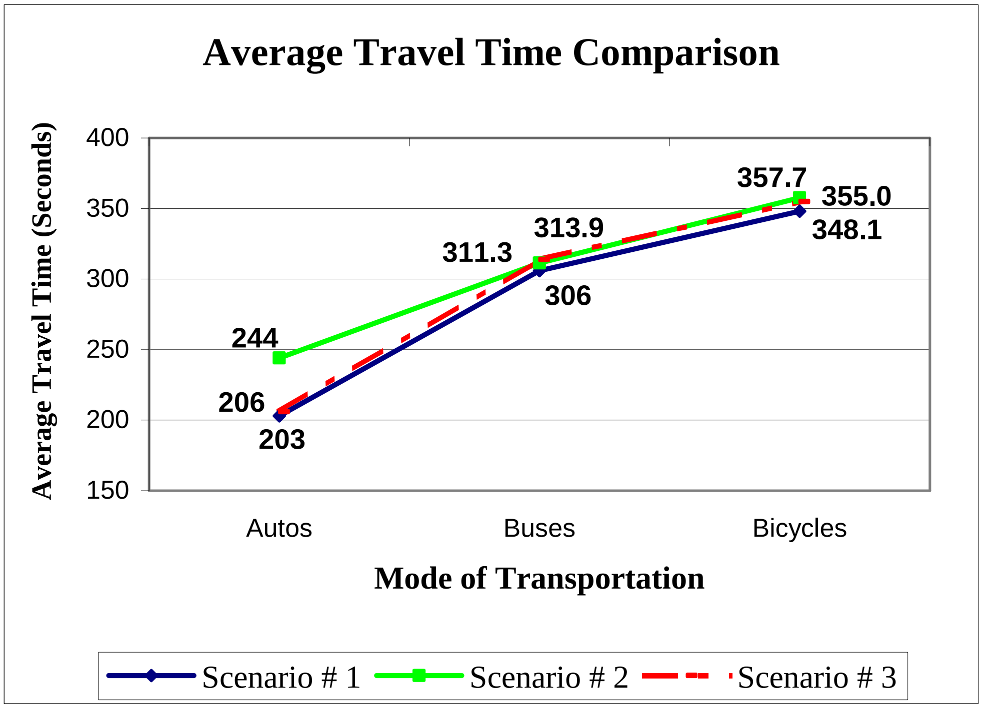
☐ The solution addresses traffic safety

☐ The solution addresses environmental impacts

The following charts present a comparison of performance measures associated with different lane-configuration scenarios suggested for a road section in an effort to reduce congestion and to improve road capacity. Please look at the chart in each question and choose your favorite scenario to be implemented. When answering the question, please assume all other performances/factors are being equal.

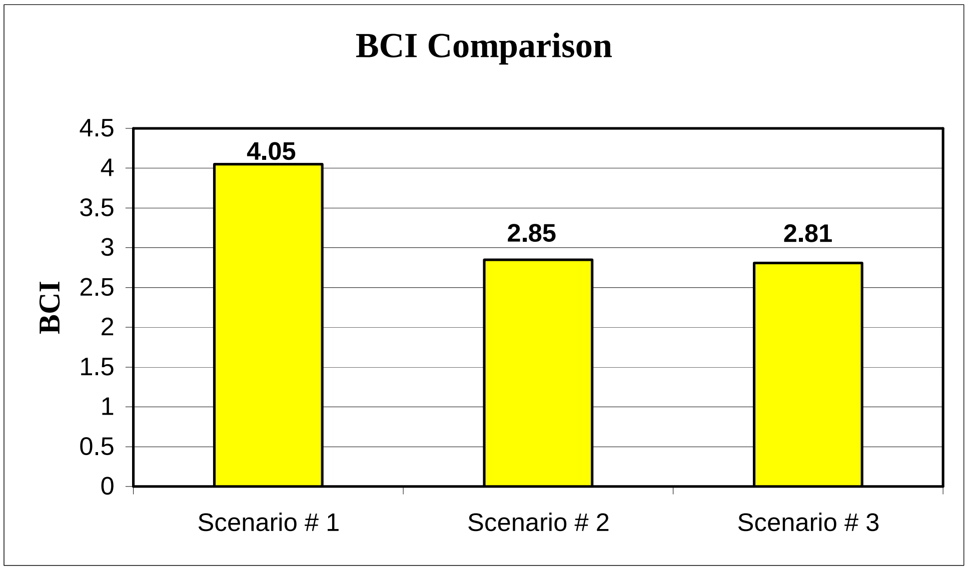
6) When comparing the average travel time for different modes of transportation (autos, buses, and bicycles), which is your chosen scenario?

☐ Scenario # 1 ☐ Scenario # 2 ☐ Scenario # 3



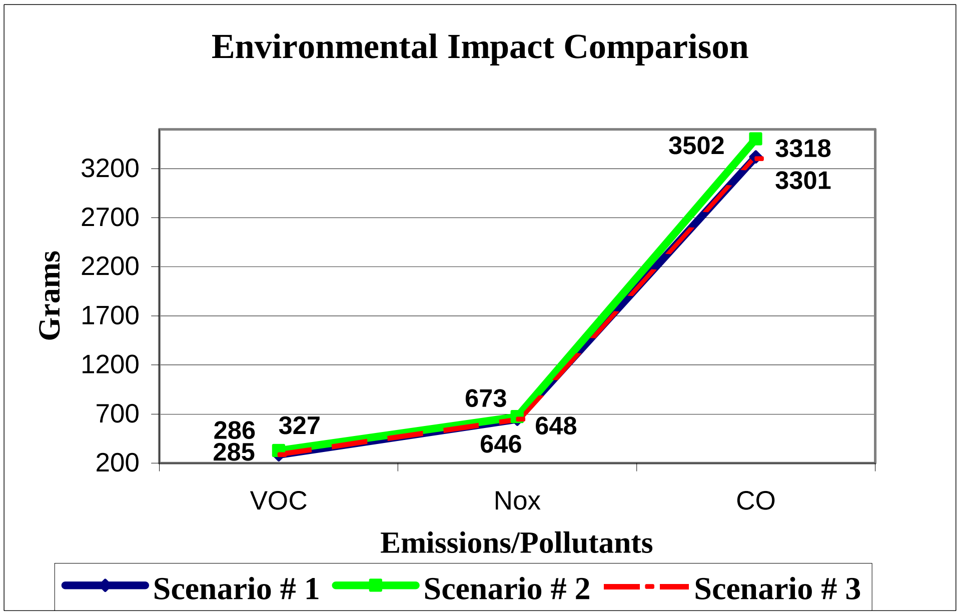
7) When comparing the Bicycle Compatibility Index (BCI) – a bicycle performance measure – for three scenarios, which one is your chosen scenario?
Note: BCI focuses on evaluating the compatibility or suitability of bicycle travel along existing roads. A lower BCI is better.

☐ Scenario # 1 ☐ Scenario # 2 ☐ Scenario # 3



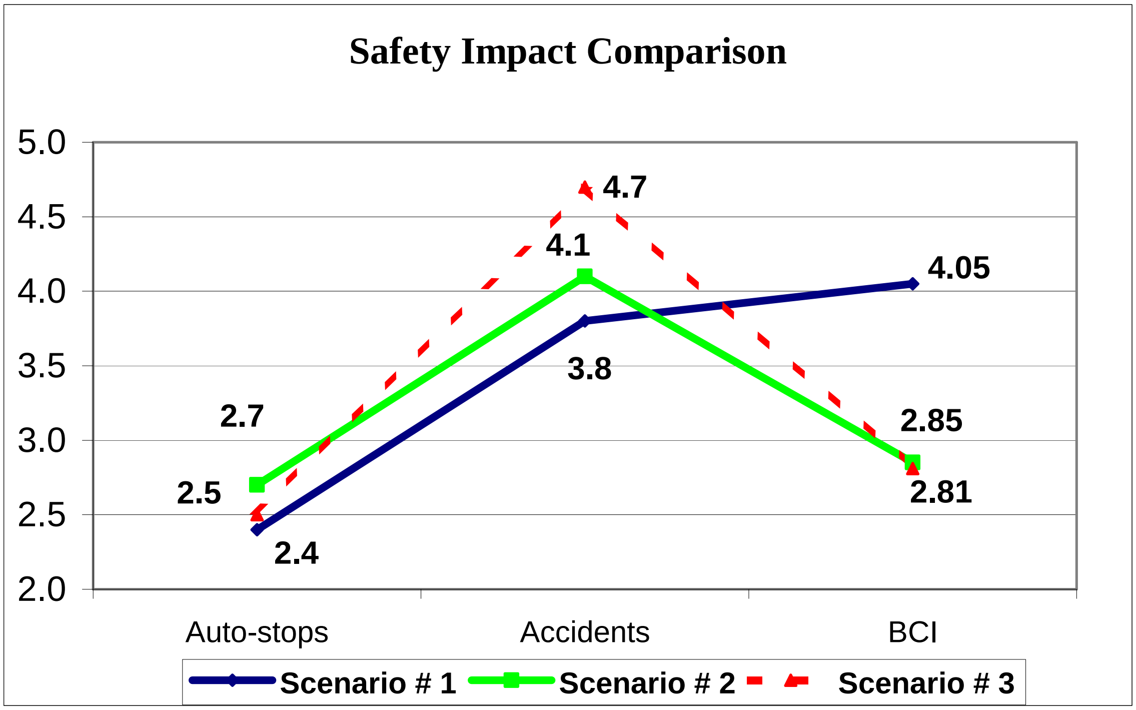
8) When comparing the environmental impact of three different scenarios, which one is your chosen scenario?

☐ Scenario # 1 ☐ Scenario # 2 ☐ Scenario # 3



9) When comparing the safety impact associated with three different scenarios, which one is your chosen scenario?

☐ Scenario # 1 ☐ Scenario # 2 ☐ Scenario # 3



10) Considering both charts in questions 6 and 7 only, which is your preferred scenario?

☐ Scenario # 1

☐ Scenario # 2

☐ Scenario # 3

11) Considering both charts in questions 7 and 8 only, which is your preferred scenario?

☐ Scenario # 1

☐ Scenario # 2

☐ Scenario # 3

12) Considering both charts in questions 7 and 9 only, which is your preferred scenario?

☐ Scenario # 1

☐ Scenario # 2

☐ Scenario # 3

13) Please choose scenario (A) or scenario (B) in the light of their performances shown in the following table:

	Scenario (A)	Scenario (B)
Bicycle Compatibility Index	4.05	2.81 (44% better)
Total travel time (Seconds)	203	206 (1.5% worse)

☐ Scenario # A ☐ Scenario # B

14) Considering the performance results in the table below, please choose scenario (A) or scenario (B)

	Scenario (A)	Scenario (B)
Bicycle Compatibility Index	4.05	2.81 (44% better)
Emission Rates (NOx - Grams)	646	648 (0.3 % worse)

☐ Scenario # A ☐ Scenario # B

15) Please choose scenario (A) or scenario (B) in the light of their performances shown in the following table. Scenario (B) in this case includes a bicycle lane.

	Scenario (A)	Scenario (B)
Number of predicted accidents	3.8	4.7 (24% worse)
Bicycle Compatibility Index	4.05	2.81 (44% better)

☐ Scenario # A ☐ Scenario # B

16) Looking at the chart below with all 19 objectives, which is your chosen scenario?

☐ Scenario # 1

☐ Scenario # 2

☐ Scenario # 3

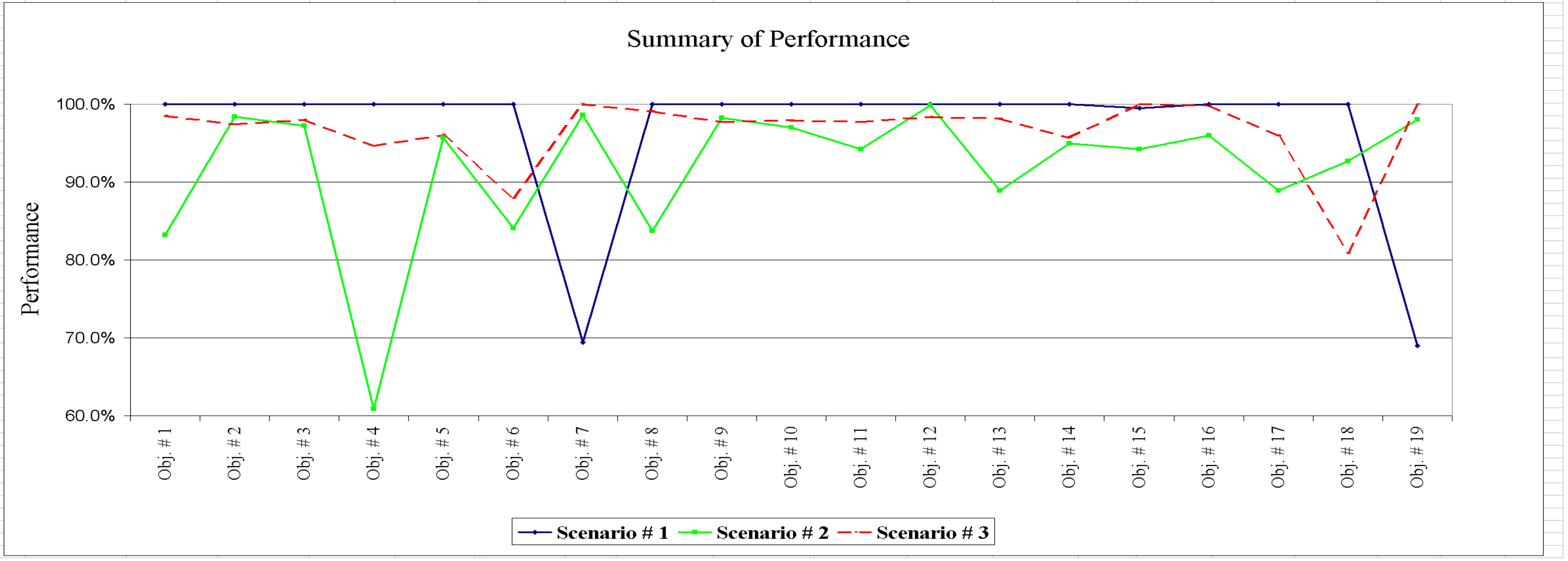
Summary of Objectives' Results

	Avg. travel time for auto (Seconds)	Avg. travel time for bus (Seconds)	Avg. travel time for bicycle (Seconds)	Average Delay for auto (Seconds)	Average Delay for bus (Seconds)	Average Delay for bicycle (Seconds)	BCI	User Travel Cost for auto ($)	User Travel Cost for bus ($)	User Travel Cost for bicycle ($)	Operating Cost for autos ($)	Operating Cost for buses ($)	Mobility (Hours)	Accessibility (Trips)	Environmental Impact (CO) (gms)	Environmental Impact (NOx) (gms)	Average Number of Auto-stops	Number of Predictible Accidents	Bicycle Safety
Scenario # 1	**203**	**306**	**348**	**63.6**	**87.1**	**51.7**	4.05	**1.13**	**1.7**	**1.93**	**26.04**	**11.99**	**5.95**	**740**	3318	**646**	**2.4**	**3.8**	69
Scenario # 2	244	311	358	104.5	91	61.5	2.85	1.35	1.73	1.99	27.63	12.01	6.69	703	3502	673	2.7	4.1	98
Scenario # 3	206	314	355	67.2	90.7	58.8	**2.81**	1.14	1.74	1.97	26.65	12.19	6.06	708	**3301**	647	2.5	4.7	**100**

Summary of Objectives' Results (in Percentage - 100% being best)

	Avg. travel time for auto (Seconds)	Avg. travel time for bus (Seconds)	Avg. travel time for bicycle (Seconds)	Average Delay for auto (Seconds)	Average Delay for bus (Seconds)	Average Delay for bicycle (Seconds)	BCI	User Travel Cost for auto ($)	User Travel Cost for bus ($)	User Travel Cost for bicycle ($)	Operating Cost for autos ($)	Operating Cost for buses ($)	Mobility (Hours)	Accessibility (Trips)	Environmental Impact (CO) (gms)	Environmental Impact (NOx) (gms)	Average Number of Auto-stops	Number of Predictible Accidents	Bicycle Safety
	Obj. # 1	**Obj. # 2**	**Obj. # 3**	**Obj. # 4**	**Obj. # 5**	**Obj. # 6**	**Obj. # 7**	**Obj. # 8**	**Obj. # 9**	**Obj. # 10**	**Obj. # 11**	**Obj. # 12**	**Obj. # 13**	**Obj. # 14**	**Obj. # 15**	**Obj. # 16**	**Obj. # 17**	**Obj. # 18**	**Obj. # 19**
Scenario # 1	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	69.4%	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	99.5%	**100.0%**	**100.0%**	**100.0%**	69.0%
Scenario # 2	83.2%	98.4%	97.2%	60.9%	95.7%	84.1%	98.6%	83.7%	98.3%	97.0%	94.2%	99.8%	88.9%	95.0%	94.3%	96.0%	88.9%	92.7%	98.0%
Scenario # 3	98.5%	97.5%	98.0%	94.6%	96.0%	87.9%	**100.0%**	99.1%	97.7%	98.0%	97.7%	98.4%	98.2%	95.7%	**100.0%**	99.8%	96.0%	80.9%	**100.0%**

Summary of Performances for the Three Scenarios



REFERENCES

- AASHTO, A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, Fourth Edition, 2001.
- AASHTO, Guide for the development of bicycle facilities, American Association of State Highway and Transportation Officials, 1999.
- Abdulaal, M. & Leblanc, L. "Methods for Combining Modal Split and Equilibrium Assignment Models," *Transportation Science*, Vol. 13, No. 4, pp 292-314, 1979.
- Allen, D. P., N. M. Rouphail, J. E. Hummer, and J. S. Milazzo, "Operational Analysis of Uninterrupted Bicycle Facilities", presented at 77th Annual Meeting of the Transportation Research Board, Washington, D.C., 1998.
- Alta Planning and Design, "San Francisco's Shared Lane Pavement Markings: Improving Bicycle Safety," Final Report Prepared for San Francisco Department of Parking and Traffic, February, 2004.
- Barnes, G, and Davis, G., "Understanding Urban Travel Demand: Problems, Solutions, and The Role of Forecasting", Report #2 in the series: Transportation and regional Growth Study, Center for Transportation Studies, University of Minnesota, August 1999.
- Boulter, J., "The Analytic Hierarchy Process," University of Illinois at Urbana-Champaign, Department of Urban and Regional Planning, http://epil.urban.uiuc.edu:8900/sample_essays/essay05/jboul_6.pdf, 1999.
- Chin, H., and Quddus, M., "Applying the Random Effect Negative Binomial Model to Examine Traffic Accident Occurrence at Signalized Intersections," *Accident Analysis and Prevention*, Vol. 35, No. 2, pp 153-159, 2003.

- Choa, F., Milam, R., and Stanek, D., "Corsim, Paramics, and Vissim: What the Manuals Never Told You", presented at 9th Transportation Research Board Conference on the Application of Transportation Planning Methods, Baton Rouge, Louisiana, April 2003.
- Choi, D. and Choi, W., "Effects of an Exclusive Bus Lane for the Oversaturated Freeway in Korea," presented at Institute of Transportation Engineers 65th Annual Meeting, August 1995.
- Chowdhury, M., and Tan, P., "A Case Study on Investment Analysis Using the Constraint Multi-objective Programming Method," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.
- Chowdhury, M., Tan, P., and William, S., "An Interactive Multi-objective Decision Support Framework for transportation Investment," Midwest Regional University, University of Wisconsin-Madison, Project 02-02, December 2002.
- Consdorf, A., "America's Congestion Crisis, Part 1 – The Spreading Slowdown: The Decade Mobility Died," *Better Roads*, Vol. 73, No. 2, pp 34-40, February 2003.
- CORSIM User's Manual, Version 1.04, ITT Systems and Sciences Corporation, March 1998.
- Dahlgren, J., "High-Occupancy Toll Lanes: Where Should They be Implemented?" *Transportation Research Part A*, Vol. 36, pp 239-255, 2002.
- Dart, L., and Mann, L., "Relationship of Rural Highway Geometry to Crash rates in Louisiana," *Highway Research Record* 312, pp 1-14, 1970.

- Davis, W., Sarasua, W., Gode, P., and Gordon, J., "Evaluation of the South Carolina East Coast Greenway Route Using A Modified Bicycle Compatibility Index Procedure," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.
- De Cea, J., Fernandez, J., Dekock, V., Soto, A. and Friesz, T., "ESTRAUS – A Computer Package For Solving Supply-Demand Equilibrium Problems on Multimodal Urban Transportation Networks With Multiple User Classes," presented at 82nd Annual Meeting of the Transportation Research Board, January 2003.
- Dill, J., "Measuring Network Connectivity for Bicycling and Walking," presented at 83rd Annual Meeting of the Transportation Research Board, January 2004.
- Dill, J., and Carr, T., "Bicycle Commuting and Facilities in Major U.S. Cities, If You Build Them, Commuters Will Use Them," *Transportation Research Record* 1828, pp 118-123, 2003.
- District of Columbia Bicycle Master Plan, District Department of Transportation, http://ddot.dc.gov/ddot/cwp/view,a,1245,q,63448.asp, April 2005.
- Environment Agency, "Aerial emissions of volatile organic compounds (VOCs) by sector," http://www.environment-agency.gov.uk/yourenv/432430/432434/432446/434996/?lang=_e, 2006.
- Erdman, J. and Panuska, E., "Exclusive Bus Lane Experiment," *Traffic Engineering*, Vol. 46, No. 7, pp 28-33, 1976.
- Faulkner, T., "Innovative Use of CMAQ Funding to promote Economic Development and Improve Air Quality and Safety," *ITE Journal*, Vol. 75, No. 1, January 2005.

- Federal Highway Administration, “Bicycle Compatibility Index: A Level of Service Concept,” Implementation Manual, FHWA RD-98-095, U. S. Department of Transportation, Federal Highway Administration, Washington, D.C., http://www.hsrc.unc.edu/research/pedbike/98095/index.html, December 1998.
- Federal Highway Administration, “Prediction of the Expected Safety Performance of Rural Two-Lane Highways,” U.S. Federal Highway Administration, PUBLICATION NO. FHWA-RD-99-207, http://www.tfhrc.gov/safety/pubs/99207/index.htm, 1999.
- Federal Highway Administration, “Advancing Mobility and Air Quality,” U.S. Federal Highway Administration, PUBLICATION NO. FHWA-EP-03-045, May 2003.
- Federal Highway Administration, “Highway performance Monitoring System Field Manual Continuing Analytical and Statistical Database,” U.S. Federal Highway Administration, Office of Highway Policy Information, http://www.fhwa.dot.gov/ohim/hpmsmanl/appn7.htm, January 2003.
- Federal Highway Administration, “A Summary of Highway Provisions in SAFETEA-LU,” U.S. Federal Highway Administration, Office of Legislation and Intergovernmental Affairs, Program Analysis Team, http://www.fhwa.dot.gov/safetealu/summary.htm, August 2005.
- Ferrara and Lam, “Analysis of Bicycle Delays at Intersections and Crossings by Computer Simulation”, *Transportation Research Record* 706, TRB, National Research Council, Washington, D.C., pp 36–44, 1979.
- Florian, M. and Nguyen, S., “A Combined Trip Distribution Modal Split and Trip Assignment Model,” *Transportation Research*, Vol. 12, No. 4, pp 241-246, 1978.

- Fu, L., Saccomanno, F., and Xin, Y., “A New Performance Index for Evaluating Transit Quality of Service,” presented at 84th Annual Meeting of the Transportation Research Board, January 2005.
- Fwa T. F., W. T. Chan and K. H. Hoque, "Multi-Objective Optimization for Pavement Management Programming," *Journal of Transportation Engineering*, 126(5), pp 367-364, 2000.
- GPS Fleet Solutions, GPS System Tracks Idle Time and Lowers Fuel Expenses, http://www.passivegps.com/gps_fuel_savings.php, 2006.
- Gan, A., Yue, H., Ubaka, I., and Zhao, F., “Development of Operational Performance and Decision Models for Arterial Bus Lanes,” presented at 82nd Annual Meeting of the Transportation Research Board, January 2003.
- Gayle, S., “Looking at Transportation Planning with an Operations Perspective,” *ITE Journal*, Vol. 73, No. 12, pp 22-26, December 2003.
- Harkey, D., and Stewart, J., “Evaluation of Shared-Used Facilities for Bicycles and Motor Vehicles,” *Transportation Research Record* 1578, pp 111-118, 1997.
- HCM 2000, Highway Capacity Manual, Transportation Research Board, National Research Council, Washington, D.C., 2000.
- Highway Statistics, 2004, U. S. Department of Transportation, Federal Highway Administration, Washington, DC, U.S. Government Printing Office, 2004.
- Huang, H., Stewart, J., and Zegeer, C., “Evaluation of Lane Reduction “Road Diet” Measures and Their Effects on Crashes and Injuries,” *Transportation Research Record* 1784, pp 80-90, 2002.

- Hossain, M. and McDonald, M., “Modeling the Impacts of Reducing Non-motorized Traffic in Urban Corridors of Developing Cities,” *Transportation Research Part A*, Vol. 32, No. 4, pp 247-260, 1998.
- Ivany, D., “Bus Rapid Transit on the Streets of Boston, MA, USA – Making it Fit,” *ITE Journal*, Vol. 74, No. 6, pp 42-45, June 2004.
- Keller, J., Abdel-Aty M., and Brady, P., “Type of Collision Analysis and Crash Data Evaluation at Signalized Intersections,” *ITE Journal*, Vol. 76, No. 2, pp 30-39, February 2006.
- Kimbler, J., “Bus Rapid Transit in Downtown Orlando, FL, USA,” *ITE Journal*, Vol. 75, No. 2, pp 40-42, February 2005.
- King County Metro, “Six Year Transit Development Plan for 2002 to 2007,” Seattle, Washington: King County Department of Transportation, Metro Transit Division, 2002.
- Kittelson and Associates, “TCRP Report: 100 Transit Capacity and Quality Service Manual,” 2nd Edition, Washington, D.C., Transportation Research Board, 1999.
- Krizek, K., “Estimating the Economic Benefits of Bicycling and Bicycle Facilities: An Interpretive Review and Proposed Methods,” presented at 83rd Annual Meeting of the Transportation Research Board, January 2004.
- Krizek, K., and Johnson, P., “The Effect of Facility Access on Bicycling Behavior,” (http://www.hhh.umn.edu/people/kkrizek/facility_access_bicycling_behavior.pdf), 2004.

- Krizek, K., and Roland, R., “What is the End of the Road? Factors Affecting Discontinuities of On-Street Bicycle Lanes in Urban Settings,” *Transportation Research Part D*, Transport and Environment, Vol. 10, No. 1, pp 55-68, 2005.
- Kroll, B., and Ramey, M.R., “Effects of Bike Lanes on Drivers and Bicyclists Behavior,” *Journal of Transportation Engineering*, ASCE, pp 103, 1977.
- Kuhn, B., Goodin, G., Brewer, M., Collier, T., Corthon, A., Fenno, D., Fitzpatrick, K., Skowronek, and Venglar, S., “Managed-lanes Research in Texas,” presented at Institute of Transportation Engineers Annual Meeting, August 2003.
- Landis, Bruce W., Vattikuti, Venkat R., and Brannick, Michael T., “Real-Time Human Perceptions Toward a Bicycle Level of Service,” *Transportation Research Record* 1578, pp 119 – 126, 1997.
- LCOG, “TransPlan, The Eugene-Springfield Transportation System Plan,” Lane Council of Governments, Eugene, Oregon, July 2002.
- Leblanc, L., and Abdulaal, M., “Combined Mode Split-assignment and Distribution-model Split-assignment Models With Multiple Groups of Travelers,” *Transportation Science*, Vol. 16, No. 4, pp 430-442, 1982.
- Litman, T., “Measuring Transportation: Traffic, Mobility and Accessibility,” *ITE Journal*, Vol. 73, No. 10, pp 28-32, October 2003.
- Litman, T., “Safe Travels: Evaluating Mobility Management Traffic Safety Impacts,” Victoria Transport Policy Institute, November 22, 2004.
- Liu, P., and Young, H., “A Neural Network Approach on Studying the Effect of Urban Signalized Intersection Characteristics on Occurrence of Traffic Accidents,”

presented at 83rd Annual Meeting of the Transportation Research Board, January 2004.

- Lord, D., and Persaud, B., “Accident Prediction Models With and Without Trend: Application of the Generalized Estimating Equations Procedure,” *Transportation Research Record* 1717, Highway Traffic Safety: Crash Data, Analysis Tools, and Statistical Methods, pp 102-108, 2000.
- Maryland Department of Transportation, “Twenty Year Bicycle and Pedestrian Access Master Plan,” http://www.mdot.state.md.us/Bicycle/Documents/FINALB.PDF, 2006.
- Maryland State Highway Administration, “MD 28 Rockville Town center Intersection Improvement Study,” Project No. M0843A11, 2006.
- Maruyama, T., Muromachi, Y., Harata, N., and Ohta, K., “The Combined Modal Split/Assignment Model in the Tokyo Metropolitan Area,” *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 4, No. 2, pp 293-304, 2001.
- McHenry, S., and Wallace, M., “Evaluation of Wide Curb Lanes as Shared Lane Bicycle Facilities,” FHWA/MD-85/06 Report, Federal Highway Administration, U. S. Department of Transportation, 1985.
- Miaou, S., and Lord, D., “Modeling Traffic Crash-Flow Relationships for Intersections: Dispersion Parameter, Functional Form, and Bayes versus Empirical Bayes,” *Transportation Research Record* 1840, pp 31-40, 2003.
- Miaou, S., and Song, J., “Bayesian Ranking of Sites for Engineering safety Improvements: Decision Parameter, Treatability Concept, Statistical Criterion and

Spatial Dependence," *Accident Analysis and Prevention*, Vol. 37, No. 4, pp 699-720, 2005.

- Milan, R., and Choa, F., "Recommended Guidelines for the Calibration and Validation of Traffic Simulation Models," 8th TRB Conference on the Application of Transportation Planning Methods, Corpus, Texas, 2002.
- Milton, J., and Mannering, F., "The Relationship Among Highway Geometrics, Traffic-Related Elements and Motor-Vehicle Accident Frequencies," *Journal of Transportation, Business and Economics*, Vol. 25, No. 4, pp 395-413, 1998.
- MINUTP Technical User's Manual, Maryland: Comsis Corporation, 1991.
- MOBILE6, "User's Guide to MOBILE6.1 and MOBILE6.2," U. S. Environmental Protection Agency, EPA 420-R-03-010, August 2003.
- Mokhtarian, P., "The Positive Utility of Travel," *Transportation Research*, Vol. 39A, Issues 2-3, February/March 2005.
- Mosseri, G., Hall, M., and Meyers, J., "VISSIM Micro-simulation Modeling of Complex Geometry and Traffic Control: A Case Study of Ocean Parkway, NY," presented at Institute of Transportation Engineers Annual Meeting, August 2004.
- "National Bicycling and Walking Study," Ten-Year Status Report, FHWA, October 2004.
- National Household Travel Survey, U.S. Department of Transportation, Bureau of Transportation Statistics, NHTS 2001 Highlights Report (BTS03-05), Washington, D.C., 2003.

- Oh, J., Washington, P., and Choi, K., "Development of Accident Predictions Models for Rural Highway Intersections," *Journal of the Transportation Research Board* 1897, pp 18-27, 2004.
- Oketch, T., "A New Modeling Approach for Mixed Traffic Streams Containing Non-motorized vehicles," *Transportation Research Record* 1705, Bicycle and Pedestrian Traffic, pp 61-69, 2000.
- Ortuzar, J. and Willumsen, L., "Modeling Transport", Second Edition, West Sussex, England: John Wiley and Sons, 1994.
- Pasupathy, R., Ivan, J., and Ossenbruggen, P., "Single and Multi-Vehicle Crash Prediction Models for Two-Lane Roadways," United States Department of Transportation, Region I University Center, Project UNCR9-8, 2000.
- Primitivo, C., "Eastern Asia Society for Transportation Studies," Vol. 7, No. 1, April 2002.
- Qin, X., Ivan, J., and Ravishankar, N., "Selecting Exposure Measures in Crash Rate Prediction for Two-Lane Highway Segments," *Accident Analysis and Prevention*, Vol. 36, No. 2, pp 183-191, 2004.
- Rathbone, D., "Interacting With Politicians," The Urban Transportation Monitor, Lawley Publications, October 15, 2004.
- Rockville Bikeway Master Plan, City of Rockville, Maryland, USA, http://www.rockvillemd.gov/masterplan/bike way/index.html, 2004.
- Rodiev, C., "A Multi-Objective Analysis of Regional Transportation and Land Development Policies," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.

- Safwat, K. and Magnanti, T., "A Combined Trip Generation, Trip Distribution, Modal Split and Trip Assignment Model," *Transportation Science*, Vol. 18, No. 1, pp 14-30, 1988.
- Saaty, T., "The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation," McGraw Hill, New York, 1980.
- Sampson, P., Guttorp, P. and Holland, D, "Air Quality Monitoring Network Design Using Pareto Optimality Methods for Multiple Objective Criteria," http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/spatial/sampson.pdf, presented at Joint Statistical Meeting, 2001.
- Sarin, S., Sarna, A., Sharfudin, and Sharme, B., "Experience with Bus Lanes Under Mixed Traffic Conditions," presented at Institute of Transportation Engineers 53rd Annual Meeting, August, 1983.
- Schonfeld, P., "A Macroscopic Methodology for Transportation Policy Analysis," Ph.D. Dissertation, University of California at Berkley, 1977.
- Schrank, D., "Estimating the Benefits of Mobility Enhancements at the Areawide Level," Texas Transportation Institute, 2002.
- Sheffi, Y., "Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods," Prentice-Hall, Inc., Englewood Cliffs, N.J., 1985.
- Sivanandan, R. and Rakha, H., "Vehicle Aggregation Impacts on Fuel Consumption and Emission Estimates," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.

- Small, K., Winston, C., and Yan, J., “Uncovering the Distribution of Motorists’ Preferences for Travel Time and Reliability,” *Econometrica*, 73, pp 1367 – 1382, 2005.
- Taylor, D., “Contributions to Bicycle-Automobile Mixed-Traffic Science: Behavioral Models and Engineering Applications,” Ph.D. Dissertation, University of Texas, Austin, 1998.
- Taylor, D. and Davis, W., “Review of Basic Research in Bicycle Traffic Science, Traffic Operations, and Facility Design,” *Transportation Research Record* 1674, pp 102-110, 1999.
- Texas Transportation Institute, “The Keys to Estimating Mobility in Urban Areas, Applying Definitions and Measures That Everyone Understands,” The Texas A&M System, May 2005.
- Thomson, R., “Study: Metro Area Third in Traffic Congestion,” (http://www.washingtonpost.com), June 2002.
- Tighe, S., and Smith, J., “The Analytic Hierarchy Process as a Tool for Infrastructure Management,” presented at 1st Annual Inter-University Symposium on Infrastructure Management, University of Waterloo, Ontario, Canada, August 2005.
- Tilahun, N., Levinson, D., and Krizek, K., “Trails, Lanes, or Traffic: The Value of Different Bicycle Facilities Using an Adaptive Stated Preference Survey,” http://www.hhh.umn.edu/people/kkrizek/bicycle_facilities_ preference_survey.pdf, 2005.
- TransFund, “Project Evaluation Manual,” TransFund New Zealand, http://www.transfund.govt.nz, 1998.

- Tumlin, J., Walker, J. Hoffman, J. and Hutabarat, R., "Performance measures for the Urban Village transit Network," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.
- Tzeng, G. and Chen, C., "Multi-objective Decision Making for Traffic Assignment," *IEEE Transactions on Engineering Management*, Vol. 40, No. 2, pp 180-187, 1993.
- United States Census 2000, http://www.census.gov.
- USA TODAY, Monday, August 14, 2006.
- USDOT, "Department Guidelines for the Valuation of Travel Time in Economic Analysis," USDOT, http://www.fhwa.dot.gov, April 9, 1997.
- Van Houten, R., and Seiderman, C., "How Pavement Markings Influence Bicycle and Motor Vehicle Positioning: A Case Study in Cambridge, MA," presented at 84th Annual Meeting of the Transportation Research Board, January 2005.
- VISUM/VISSIM: A transportation planning software system distributed by Innovative Transportation Concepts, Inc., http://www.ptvamerica.com/vissim.html, 2004.
- Vogt, A., and J.G. Bared, "Accident Models for Two-Lane Rural Segments and Intersection," *Transportation Research Record* 1635, Transportation Research Board, pp 18-29, 1998.
- Wadell, P. and Ulfarsson, G., "Accessibility and Agglomeration: Discrete-Choice Models of Employment Location by Industry Sector," presented at 82nd Annual Meeting of the Transportation Research Board, January 2003.
- Wardrop, J., "Some Theoretical Aspects of Road Traffic Research," Proceedings of the Institute of Civil Engineers, Part II, pp 325-378, 1952.

- West, James and Lowe, Allen, "Integration of Transportation and Land Use Planning Through Residential Street Design," *ITE Journal*, Vol. 67, No. 8, pp 48-51, 1997.
- The World Almanac and Book of Facts, New Jersey: World Almanac Books, 1996.
- Wu, Z. and Lam, W., "A Combined Modal Split and Stochastic Assignment Model for Congested Networks with Motorized and Non-motorized Transport Modes," *Transportation Research Record* 1831, Travel Demand and Land Use, pp 57-64, 2003.
- Xu, K., "Optimal Road Space Allocation Among Competing Transportation Modes," M.S. Thesis, University of Maryland at College Park, December 1993.
- Zegeer, C., Deen, R., and Mayes, J., "Effect of Lane and Shoulder Width on Accident Reduction on Rural, Two-Lane Roads," *Transportation Research Record* 806, pp 33-43, 1981.