JOINT TRANSPORTATION RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Identifying Strategies to Improve Lane Use Management in Indiana

Chaitanya Paleti

Srinivas Peeta

Kumares C. Sinha

SPR-3600 • Report Number: FHWA/IN/JTRP-2014/09 • DOI: 10.5703/1288284315503

RECOMMENDED CITATION

Paleti, C., Peeta, S., & Sinha, K. C. (2014). *Identifying strategies to improve lane use management in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2014/09). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284315503

AUTHORS

Chaitanya Paleti
Graduate Research Assistant
Lyles School of Civil Engineering
Purdue University

Srinivas Peeta, PhD
Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University
(765) 494-2209
peeta@purdue.edu
Corresponding Author

Kumares C. Sinha, PhD
Olson Distinguished Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University

ACKNOWLEDGMENTS

The authors acknowledge the assistance and valuable feedback from the members of Study Advisory Committee: Samy Noureldin (PA), Brad Steckler (INDOT), Jim Sturdevant (INDOT), Joseph Gustin (INDOT), Gary Mroczka (INDOT), Roy Nunnally (INDOT), John Weaver (INDOT), Stephanie Belch (Indianapolis MPO), and Joyce Newland (FHWA). We would like to thank Brad Steckler of INDOT for his helpful feedback during the entire project. We would also like to thank INDOT and the Indianapolis MPO for providing data related to the project. The project was funded by the Joint Transportation Research Program of Purdue University in conjunction with the Indiana Department of Transportation and the Federal Highway Administration. We acknowledge and appreciate their support and assistance.

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure. https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at: http://docs.lib.purdue.edu/jtrp/

NOTICE

COPYRIGHT

Print ISBN: 978-1-62260-309-1
ePUB ISBN: 978-1-62260-310-7

Cover photo: oksana.perkins / Shutterstock.com

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-2014/09		

4. Title and Subtitle	5. Report Date
Identifying Strategies to Improve Lane Use Management in Indiana	August 2014
	6. Performing Organization Code
7. Author(s) Chaitanya Paleti, Srinivas Peeta, and Kumares C. Sinha	8. Performing Organization Report No. FHWA/IN/JTRP-2014/09
9. Performing Organization Name and Address Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051	10. Work Unit No.
	11. Contract or Grant No. SPR-3600
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

The limited funding available for roadway capacity expansion and the growing funding gap, in conjunction with the increasing congestion, creates a critical need for innovative lane use management options for Indiana. Various cost-effective lane use management strategies have been implemented in the US and worldwide to address these challenges. However, all the strategies have their own costs, operational characteristics, and additional requirements for field deployment. Hence there is a need for systematic simulation-based methodology to perform a comprehensive study to identify congested corridors and the specific set of lane use management strategies that are effective in Indiana.

A systematic simulation-based methodology is proposed for evaluating lane use management strategies. A 10-mile stretch of the I-65 corridor south of downtown Indianapolis was selected as the study corridor using traffic analysis. The demand volumes for the study area were determined using subarea analysis. Its performance was evaluated using a microsimulation-based analysis in the context of alleviating congestion for three strategies: reversible lanes, high occupancy vehicle (HOV) lanes and ramp metering. Furthermore, an economic evaluation of these strategies was performed to determine the financial feasibility of their implementation.

Results from this analysis indicated that reversible lanes and the ramp metering strategies improved traffic conditions on the freeway in the major flow direction. Implementation of the HOV lane strategy resulted in improved traffic flow conditions on the HOV lanes but aggravated congestion on the general purpose (GP) lanes. The HOV lane strategy was found to be economically infeasible due to low HOV volume on these lanes. The reversible lane and ramp metering strategies were found to be economically feasible with positive net present values (NPV), with the NPV for the reversible lane strategy being the highest.

17. Key Words	18. Distribution Statement
microsimulation, VISSIM, Indiana, subarea analysis, calibration, validation, demand estimation, dynamic, lane use management	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

IDENTIFYING STRATEGIES TO IMPROVE LANE USE MANAGEMENT IN INDIANA

Introduction

In the context of increasing demand and growing funding deficits, the primary objectives of the study are: (a) develop guidelines on the conditions in which to adopt lane use management strategies in Indiana, (b) identify potential corridors/sites to implement these strategies, and (c) assess the expected costs and benefits of these strategies for one of the identified corridors/sites.

The study develops a systematic simulation-based methodology to evaluate lane use management strategies for Indiana. A 10-mile stretch of the I-65 corridor south of downtown Indianapolis was selected to demonstrate the methodology.

Findings

Assessment of the impact of reversible lane strategy implementation on the I-65 corridor indicated that this strategy improved traffic flow conditions. Average travel speed in the major flow direction (NB I-65 stretch during the morning peak) is higher under the reversible lane scenario when compared to the base case scenario (representing existing conditions). While the minor flow direction (SB I-65 stretch during morning peak) experienced lower flow speeds and higher congestion compared to the base case, comprehensive economic evaluation indicated that this strategy is an effective and viable option.

Microsimulation analysis of high occupancy vehicle (HOV) lane strategy indicated travel speed improvement on the HOV lanes but resulted in reduced speeds on the general purpose (GP) lanes when compared to the base case scenario. Also, the person throughput increased due to the implementation of HOV lanes compared to the base case scenario. Furthermore, the travel time savings (expressed in monetary terms) in the major flow direction were positive due to the improved person throughput. However, economic analysis of the HOV lanes indicated that this strategy is not feasible for implementation.

Microsimulation analysis of traffic predictive ramp metering strategy implemented for I-65 at the Raymond ramp location indicated improved flow speeds on the I-65 corridor. However, the average travel time on the ramp increased due to the ramp signal. The net present value (NPV) was positive implying the economic feasibility of this strategy.

A comparison of the three lane use management strategies illustrated that reversible lane and ramp metering strategies are found to be economically feasible with positive NPVs. However, the NPV for reversible lane strategy is found to be the highest and therefore is the preferred lane use management strategy for the I-65 corridor stretch analyzed. HOV lane strategy was found to be economically infeasible due to low HOV volume on these lanes.

The study also presents recommendations for the implementation of the three lane use management strategies. The implementation of the reversible lanes strategy is recommended when the minor flow direction has at least two lanes and the ratio of major to minor direction flows is greater than a threshold value (at least 1.7:1). Similarly, the implementation of HOV lanes is feasible only when a minimum occupancy level (at least 600–800 vhphpl) exists on the HOV lanes.

Similarly, the feasibility of ramp metering needs to be evaluated using the combined volume of the ramp and the freeway. Single lane ramp metering is recommended when the ramp volume is between 1200 and 1400 vph, and dual lane metering when the ramp volume is greater than 1400 vph. A comprehensive list of recommendations is presented in Chapter 12 of this report.

Implementation

Findings from this study can be used in the decision-making process of implementation of lane use management strategies on the I-65 corridor. The study provides a simulation-based methodological framework to evaluate the various strategies. It also provides recommendations on the traffic conditions under which the various lane use management strategies could be identified as potential candidates for simulation-based analysis to determine the strategy to implement.

As future congestion bottleneck areas arise in Indiana, the associated corridors could be analyzed for the effectiveness of lane use management strategies.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background and Motivation

The growing congestion problem poses a substantial challenge to the US economy and the quality of life in the United States (US). The total congestion cost for the delay time and fuel was estimated as $121 billion in 2011, or about $818 per average commuter. Compounding the problem of congestion are the challenges of increasing funding gap and environmental concerns due to construction of new facilities (Eisele, Schrank, & Lomax, 2011). The National Surface Transportation Policy and Revenue Commission estimates that an annual investment of over $130 billion is needed for improvements and maintenance to accommodate these trends (NSTPRSC, 2007). The continued growth in travel demand, the worsening congestion, and inadequate funds have prompted the federal, state and local planning agencies to explore and implement various congestion pricing strategies to fund new capacity as well as to efficiently manage and improve performance of existing infrastructure facilities.

In the United States and worldwide, various cost-effective lane use management strategies have been implemented to address congestion. They include ramp metering, high occupancy vehicle (HOV) lanes, reversible lanes, high occupancy toll (HOT) lanes, truck-only lanes, and transit lanes. Some of them, such as lane pricing and HOT lanes, are revenue-generating strategies. All strategies have their own costs, operational characteristics, and additional requirements for field deployment. Hence, there is a need for systematic guidelines/recommendations for simulation-based analysis to identify the specific set of lane use management strategies that are effective and finally to select the optimal cost-effective strategy for a given corridor. Past studies (Collier & Goodin, 2002; Meyer, Saben, Shephard, & Drake, 2006; Skowronek, Ranft, & Cothron, 2002; Stockton, Grant, Hill, McFarland, Edmonson, & Ogden, 1997; Stokes & Bensen, 1987) focused on analyzing and evaluating implementation of various strategies, with respect to local or regional conditions and do not focus on all the aspects of simulation modeling. Therefore, a methodological framework is required for INDOT to define the scope of the study, to perform initial modeling and calibration, and evaluation of strategies using the developed model.

This study provides a simulation-based methodological framework to evaluate the various strategies. A 10-mile stretch of I-65 south of downtown Indianapolis is used as a case study for analysis of the lane use management strategies using VISSIM microsimulation.

Microsimulation (or microscopic simulation) models simulate the interactions of road traffic and other forms of transportation in microscopic detail. This involves considering, each vehicle such as individual cars and buses, in the model as a unique entity having its own goals and behavioral characteristics. Furthermore, each entity possesses the ability to interact with other entities in the model unlike models that provide a simplified aggregated representation of traffic. PTV VISSIM, which is a commercial microscopic multi-modal traffic flow simulation software package, is used in this study. VISSIM has been widely used for state-of-art transportation planning and operational analysis.

The three lane use management strategies that are considered in this study are: reversible lanes, high occupancy vehicle (HOV) lanes and ramp metering. Performance of these three strategies is evaluated using a microsimulation based analysis in the context of alleviating congestion. Also, sensitivity analysis is conducted for different demand levels to assess the impact of these strategies. Furthermore, economic evaluation of these strategies is performed to determine the financial feasibility of their implementation.

1.2 Problem Statement

The limited funding available for roadway capacity expansion and growing funding gap, in conjunction with the increasing congestion and the need to ensure the efficient utilization of the existing facilities, creates a critical need for innovative lane use management options for Indiana. While some lane use management strategies can be adopted seamlessly, and other may require some infrastructure/operational changes, there is a need for INDOT to identify which set of lane use management strategies could be adopted under different traffic situations, and the potential corridor in which to adopt them over a 5–10 year framework.

In this context, there is a need to: (a) perform an organized literature review to understand the operational characteristics and impacts of the strategies, (b) identify the potential corridors that may require implementation of such strategies in the near future in Indiana, (c) identify the factors affecting the operational feasibility of each strategy in Indiana for the selected corridor, (d) assess expected costs and benefits of each strategy for the selected corridor, and (e) develop a systematic simulation-based methodology that can assist the INDOT planners to evaluate various strategies on other potential corridors.

1.3 Overall Objectives

The primary objectives of this study are to: (a) identify a potential corridor to implement lane use management strategies, (b) assess the expected costs and benefits of these strategies, (c) provide a systematic simulation-based methodology to evaluate various strategies that can be implemented in Indiana, and (d) provide recommendations to identify potential candidate strategies for analysis based on the traffic conditions.

1.4 Work Plan

This section summarizes the key components of the overall methodological framework used for the microsimulation analysis. The flowchart complementing the overall methodology is presented in Figure 1.1.

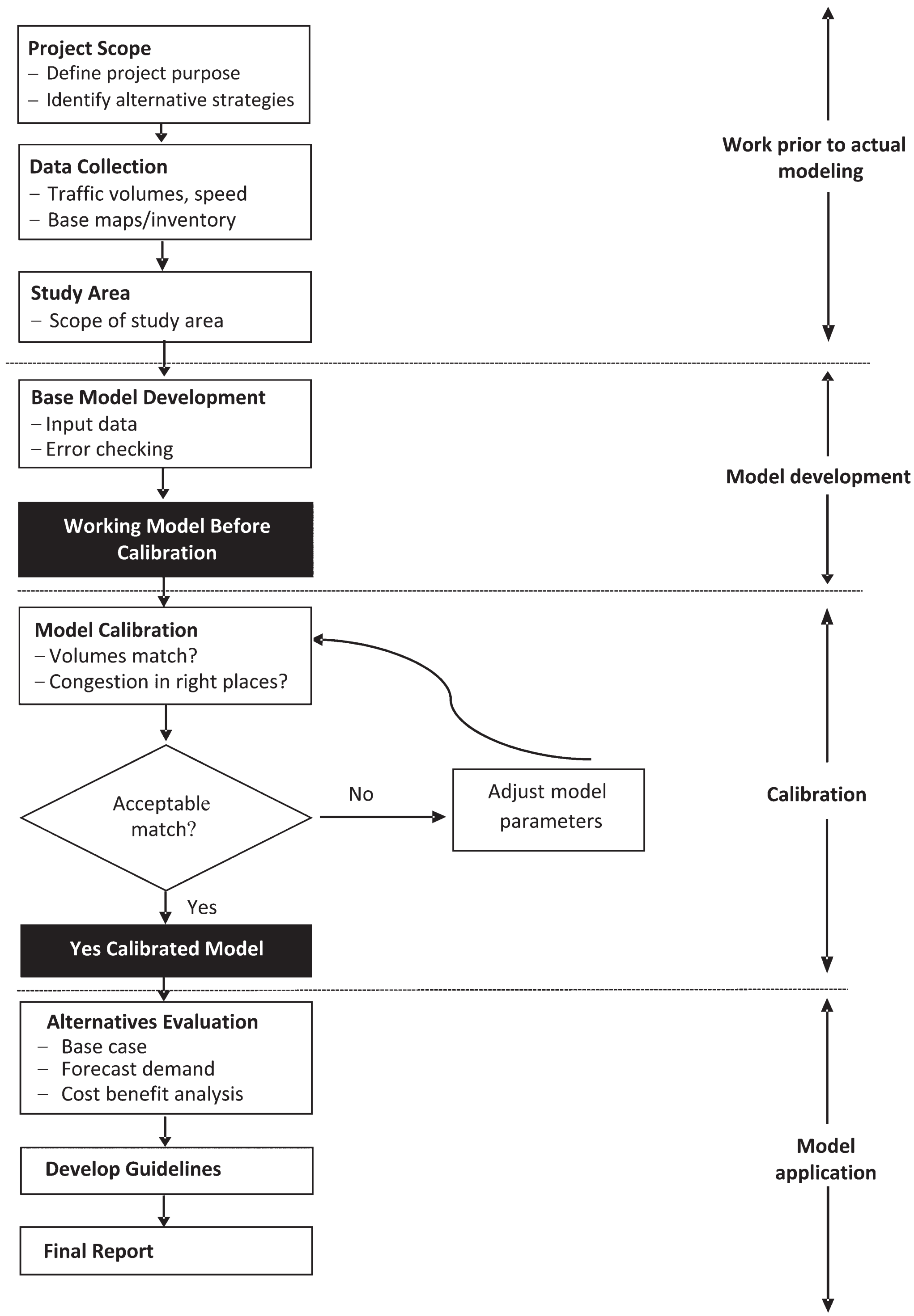

Figure 1.1 Integrated microsimulation analysis framewor.

The overall methodology comprises of four stages: pre-modeling, model development, model calibration, and finally model application.

Pre-modeling stage comprises of tasks such as defining the scope of the project, identifying and collecting preliminary data for project implementation, and defining the study area and its scope.

Model development stage comprises of tasks such as coding the network in VISSIM, checking for errors and debugging as and when necessary.

Model calibration stage includes tasks like calibration and validation of the network implemented in VISSIM to ensure that the base model replicates the existing conditions on the field.

Model application is the stage where the three lane use management strategies are evaluated using the microsimulation based analysis. This stage also includes tasks such as performing economic evaluation and documenting the final report.

Figure 1.2 presents the simulation-based methodology adopted in this study. Three lane use management strategies (reversible lanes, HOV lanes and ramp metering) are identified as the feasible set of strategies based on the past studies and input from INDOT personnel. This is followed by literature review of the three strategies. Based on this, data required for the analysis is identified and collected from various sources such as INDOT and Indianapolis MPO travel demand model.

Using this data, traffic analysis is performed to identify the I-65 stretch south of downtown Indianapolis as a congested corridor suitable for implementation of the strategies. The boundaries of the study area are then defined by exploring routes which a commuter might consider as an alternative to the I-65 corridor. This is followed by the estimation of demand volume for the study area using subarea analysis and TransCAD tools. This along with the other data is used to code the microsimulation model in VISSIM. The final model is thoroughly checked for errors and is calibrated and validated using the orthogonal experiment design method. This is followed by the microsimulation analysis of the three lane use management strategies.

Strategies i = 1, 2 and 3 (in Figure 1.2) represent the three strategies—reversible lanes, HOV lanes and ramp metering, respectively. For each of these strategies, different scenarios (j=1, 2, ……n) corresponding to different demand levels are tested. For the HOV lane strategy evaluation, additional scenarios are tested. This includes the evaluation of the HOV lane strategy under the assumption that there is a 10% increase in the HOV2+ (vehicles with two or more occupants) vehicles due to car-pooling after the first year of implementation of the HOV lane strategy.

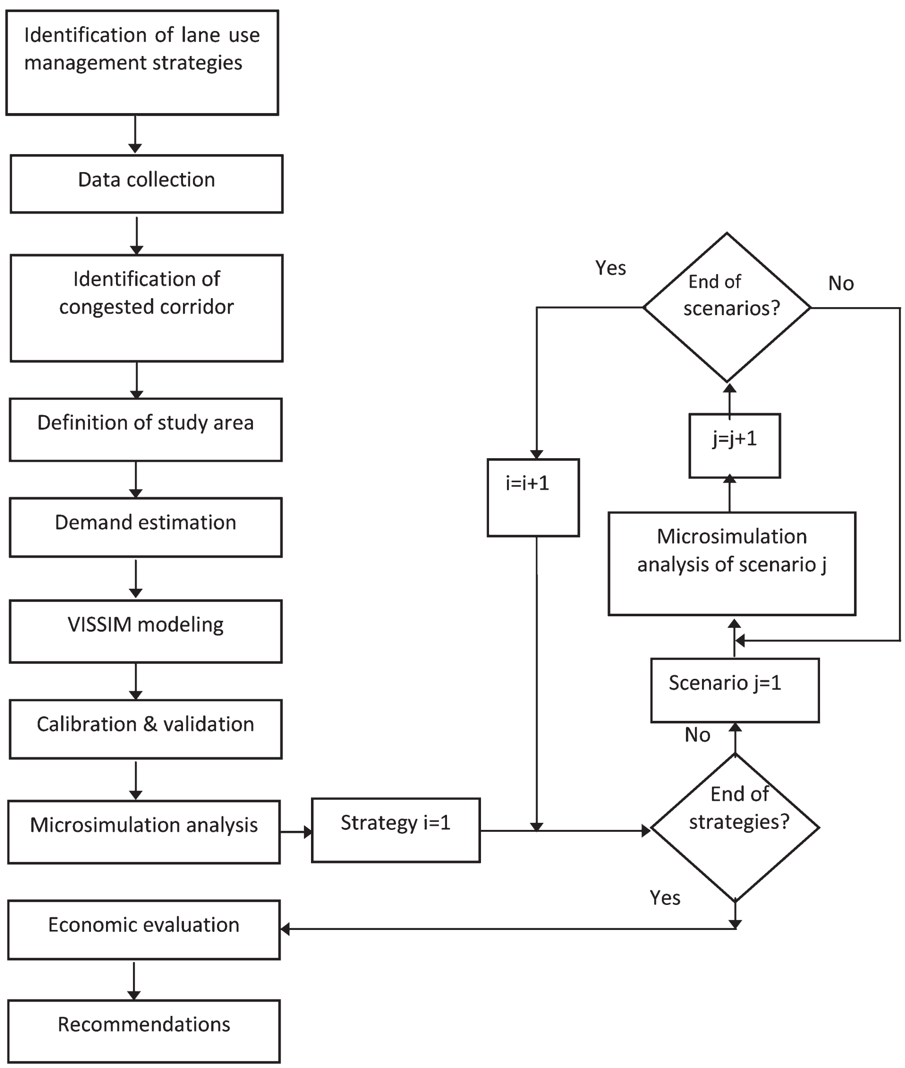

Figure 1.2 Simulation-based methodology.

After the simulation-based analysis, cost-benefit analysis of the three strategies is performed to evaluate the economic feasibility. Based on the findings from literature review, simulation based analysis, and the economic evaluation, recommendations are developed for the consideration of each strategy.

The remainder of this study is organized as follows. The next chapter presents the literature review in the context of the three strategies under consideration. Chapter 3 presents the data collection efforts followed by description of the study area in the Chapter 4. Details of model development and VISSIM modeling are described in Chapters 5 and 6 respectively. Chapters 7 to 9 discuss the results of evaluation of reversible lanes, HOV lanes and ramp metering strategies respectively. The final chapter provides some concluding comments.

2. LITERATURE REVIEW

2.1 Reversible Lanes

Reversible lane is a lane in which traffic may travel in either direction, depending on certain traffic conditions. The advantage of this strategy is that the directional capacity of the lane can be increased without adding new lanes that usually requires additional capital investment and may even have adverse environmental impacts. Also, the frequency, duration and length of maintaining reversible lanes can be decided according to the needs of the specific traffic agency. Reversible lanes have been used as strategies to address a variety of needs, particularly for unbalanced peak-period traffic flows, planned special events (work zones, football games, concerts), and emergency conditions (evacuation). In the U.S., reversible lanes have been used in several states including Alabama, Arizona, California, Connecticut, Florida, Georgia, Kentucky, Maryland, Michigan, Nebraska, New York, Ohio, and Texas.

Studies indicate that one of the reasons agencies are reluctant to implement reversible lanes is the popular belief that it can be confusing to drivers, and be challenging in terms of safety and feasibility. Therefore, agencies may require additional personnel and resources to configure, enforce, and maintain safe and efficient traffic flow (Highways, 1989). However, a NCHRP study has shown that drivers have adapted readily to this strategy and consider it as effective utilization of the infrastructure. The wide appeal of reversible lane roadways was demonstrated in the results of a 2001 WSDOT survey, in which broad public support was shown for the state's reversible freeways. Similarly, the Maryland DOT found a high level of public acceptance for reversible lanes (Wolshon & Lambert, 2004).

2.1.1 Warrants

Warrants for implementation of reversible lanes are discussed below. Warrants are guidelines that justify or "warrant" the implementation of lane use management strategies to reduce traffic congestion and improve freeway/traffic congestions by specifying conditions that must be maintained and observed prior to their application.

- AASHTO states that reversible lanes are justified when "more than 65% of traffic moves in one direction during peak hours" (Wolshon & Lambert, 2004) with no fewer than two lanes for the minor-flow direction.
- Average speed should decrease by a fourth during peak hours while the ratio of major to minor flow measured as vehicles per hour (vph) should always stay between 2:1 and 3:1.
- Other professional transportation organizations have stated that structures like bridges and tunnels warrant reversible lanes since expansion and addition of lanes is almost impossible.
- The cost of implementation and maintenance should not exceed the cost of constructing/expanding existing lanes and structures.

2.2 HOV Lanes

In the U.S., California, Minneapolis, Texas, Washington and Washington, D.C. initially implemented HOV lanes. By 2002, over 130 HOV lane projects involving 2,400 lane miles had been implemented in the U.S. Most of these projects were proposed with the preliminary objective of reducing congestion by inducing more people to travel in fewer vehicles.

The Washington State DOT, Texas Transportation Institute, and Virginia DOT reported the benefits of HOV lanes ranging from induced demand for HOV lanes to travel time savings. Because HOV lanes carry vehicles with a higher number of occupants, they have the potential to move more people in a smaller number of vehicles, in comparison to the adjoining general purpose travel lanes, during congested travel periods.

For example, on I-95 in northern Virginia during the morning peak travel period (6:00 to 9:00 a.m.), HOV lanes carried 54% of the people in 27% of the total vehicles on only 40% of the freeway lane capacity (two HOV lanes in comparison to three general purpose lanes). Similarly, commuters using HOV lanes in Texas saved an average of 2 to 18 minutes during the peak hours. Benefit-cost ratios for HOV lanes in Texas have been estimated to range from 6:1 to 48:1, in comparison to a base case involving the addition of the same number of general purpose lanes (Obenberger, 2004).

HOV lanes enable multiple occupant vehicles (carpools, large families, shared transit) to travel on special lanes that experience a lower vph, enabling faster transit times for such vehicles while reducing the congestion in ordinary/other lanes. While capable of significantly reducing the congestion, increasing average vehicle occupancy levels, and reducing fuel consumption levels, a systematic implementation of such systems is necessary to ensure their success and prevent failures as seen in the CALTRANS system in 1994 (Bhargava, Oware, Labi, & Sinha, 2006). The following are some warrants that justify the implementation of such a system, classified on the basis of approach (design methodology) (Bhargava et al., 2006).

2.2.1 Warrants on the Basis of Congestion, Population, and Service Levels

- The implementation of such a system should ensure significant reduction in congestion of the targeted areas.
- Certain levels of congestion should be met to justify the need for such systems. These figures depend on various factors such as number of lanes, vehicles per hour, average speed of traffic and timing of such congestion. For example: the Texas DOT has specified that any corridors with over 25,000 vehicles per lane (daily) are prime candidates for the implementation of such a system.
- Implementation of such a system should be conducive to the adaptation of carpools and HOV methods by the local populace.
- A minimum size of the local populace is needed before any such system can be successful by preventing the number of stops made by HOVs during transit.
- Decisions on occupancy restrictions for use of such lanes must be based on the basis of the average occupancy rates prevalent in that region.
- Users on this section of freeway are making long trips (Stockton, Benz, Rilett, Skowronek, Vadali, & Daniels, 2000).

2.2.2 Physical Design Warrants

- Freeway geometry should enable the modification of existing lanes or addition of a new lane for such specific use without affecting the efficiency of transit by the general populace (SOV and mass transit systems for example).
- Allowing access to the HOV lanes without needing to change lanes rapidly thereby reducing the risk of collisions (Boyle, 1986).
- Ramp construction (as discussed above) that lead directly to designated HOV lanes.
- Optimal locating of park and ride lots to increase the carpooling tendency of road users.
- General warrants that specify special programs and ideas that can be implemented to improve HOV usage (Boyle, 1986).
- Guidelines to let buses/mass transit use HOV lanes that specify a percentage reduction in overall congestion and numbers for increased users.
- Guidelines for incident management and effective response systems including real time monitoring and data collection (Cambridge Systematics, 2002).
- Guidelines on how much time should be saved on average per trip on average to justify the implementation of such methods.

2.3 Ramp Metering

Ramp metering is the use of traffic signals at freeway on-ramps to control the flow of traffic entering the freeway. The primary objectives of the ramp metering include managing traffic demand to reduce congestion, improving the efficiency of merging and reducing accidents - all of which lead to improved mainline freeway flow (FHWA, 2010).

Ramp metering is advantageous because it can be implemented fairly readily, requiring only the installation of stoplights and extended lanes on entrance ramps, and coordination of these lights and freeway sensors by computers and telemetry. The success of early ramp metering applications in the late 1950s and throughout the 1960s in US cities such as Chicago, Los Angeles, Minneapolis and Seattle led to the implementation and expansion of ramp metering systems in many states in the US including Arizona, California, Colorado, Georgian, Nevada, Ney York, Ohio, Pennsylvania, Texas, Virginia, and Florida, as well as in other countries including Australia, Canada and UK (FHWA, 2010). However, ramp metering has not been used as a strategy in the state of Indiana (Bhargava et al., 2006).

Field studies on ramp metering systems in two U.S. states (Minnesota and California) suggest that they are successful in decreasing traffic and increasing the output flow through a freeway (Cambridge Systematics, 2001; Kim & Cassidy, 2010). The Minnesota Department of Transportation reports that ramp meters have reduced freeway travel times by 22%, increased the reliability of freeway travel time by 91%, and reduced crashes by 26% reduction (Cambridge Systematics, 2001). In Germany, ramp metering effectively prevented the drop in traffic speed normally associated with merges and enabled the harmonization of traffic flow on major controlled-access roadways. Also, it was found that ramp metering reduced crashes involving person and property damage by up to 40% with no negative effects on the adjacent roadway network (FHWA, 2010). Warrants for implementing ramp metering are discussed below.

2.3.1 Warrants

Ramp metering is warranted if congestion occurs on freeways thereby slowing down traffic by reducing the freeway operating speeds as specified in (Bhargava et al., 2006) or if there is a high frequency of crashes while ensuring that local transportation system management objectives such as maintenance of certain levels of service (with preferential treatment to mass transit and carpools) and efficient usage of other on-ramps during peak demand times are met. These systems are also useful during times of "special congestion", referring to short-period traffic caused by events such as concerts, rallies, games.

These warrants are split into two categories: (1) individual warrants which set specific guidelines to validate the need for a ramp metering system, and (2) overall warrants which place conditions on the individual warrants for implementation.

- Individual warrants describe specific conditions that can justify the implementation of ramp metering systems for areas of the freeway with high congestion and frequent crashes while maintaining a certain level of service. They also question the effects that implementing such a system will have on improving vehicle occupancy rates (by improving the persons/mobility ratio), on balanced usage of the freeway and the total volume of traffic within that system. They also provide a framework for planners to determine if local social conditions (such as large gatherings) and freeway geometries allow a safe implementation of such a method.

- Overall warrants provide a checklist for planners to follow in order to make an efficient decision on the implementation of such a system. If the individual warrants for collision frequencies, level of service, mode shifts (from HOV to SOV), balancing demand for ramps and special congestion events are satisfied, then a certain method of implementation is justified. If the ramp plus freeway volume is greater than a certain number that takes into account the number of lanes and vehicles per hour (vph) while also exceeding 2100 vph, then another method is specified. This allows inexperienced DOTs to implement these methods with relative ease.

3. DATA COLLECTION

This section describes the data collection efforts and the data preparation procedure used to estimate the input data of demand required for the microsimulation analysis. The type of data collected, its source, and the intended purpose for collecting such data is discussed in the data collection sub-section presented below.

Color coded maps indicating the level of service (LOS) of the freeways, running through Indiana, are obtained from the INDOT Traffic Division. These LOS maps are used to identify a potential list of congested corridors.

Data from loop detectors, monitoring each lane of the freeway sections at different locations along the freeway, is obtained from the INDOT Traffic Division. This field data comprises of vehicular counts and average speed measured at 30sec intervals every day. This data, collected from January 2012 through April 2012 for each of the potentially congested freeways identified using the LOS maps, is used to identify a congested corridor for the microsimulation based analysis.

Aerial images of the study area acquired from Google maps, along with the information from the geographical files obtained from the Indianapolis MPO travel demand model are used to build the network model in VISSIM. Detailed modeling of signalized intersections is performed by incorporating the signal timing information obtained from INDOT traffic division and the Indianapolis city office.

Further, output files from the Indianapolis MPO travel demand model are acquired from the Indianapolis MPO office. These files consist of information regarding network characteristics, such as free flow speed, speed limits, origins and destination (O-D) pairs, and also information on traffic flow patterns, such as daily traffic flow volume, average daily speeds etc. Part of this data is used to identify the congested corridor for subsequent analysis, while the rest is used for validation and calibration purposes. Additionally, demand for the Indianapolis region network, in the form of O-D matrices for the AM peak duration, are obtained from the Indianapolis MPO office. The Indianapolis regional O-D data is used to estimate the demand, for the study area under consideration, using further analysis which is discussed below.

4. STUDY AREA

This section describes the procedure used to identify the study corridor along with the basis for defining the study area.

4.1 Identification of a Congested Corridor for the Simulation Based Analysis

The objective of this section is to present the methodology adopted to identify a congested corridor for the microsimulation study. The first step is to determine the performance measures and the corresponding thresholds to quantify congestion. Previous studies (Cambridge Systematics, 2004; Eisele et al., 2011; Grant, Beverly, Day, Winick, Bauer, Chavis, & Trainor, 2011; Qu, 2010) have used a variety of performance measures to identify congested conditions on roadways. A list of various performance metrics used in past studies along with the measurements from which they are derived are listed in the Table 4.1.

Traditionally, Long Range Transportation Plans (LRTP), developed by MPO's, primarily use LOS based metrics. However, they are not effective in portraying the complete picture just by itself. For instance, while LOS based metrics can indicate presence of congestion, they cannot quantify the degree of congestion once congested conditions are reached. Consequently, some studies (Gunawardena & Sinha, 1994) attempted to address this by using traffic flow volume based metrics. However, the volume based metrics may fail in cases where high traffic volume does not necessarily imply congestion, especially if the vehicles are maintaining a minimum threshold speed (>45mph for instance). Therefore, a two-step process is employed to find the most congested corridor. In the first step, LOS based metrics are used to narrow down on a list of potentially congested corridors. In the next step, both traffic flow volume and average speed based metrics are used to arrive at the most congested corridor, from the list formed in step 1. Patterns of average daily traffic volumes in the months of January and April are observed to identify a typical day of the week for the comparative analysis of freeway congestion. Duration of congestion during the typical analysis day is quantified using performance measures based on average speed. Freeway with the longest duration of congestion on a typical day of a week is used as the study corridor. The threshold values of various performance metrics used to quantify congestion are discussed below.

As mentioned above, in the first step, a LOS level of E/F is an indication of congested conditions, while a LOS level of D is used to indicate near congested corridors (Central Midlands Council of Governments, 2009; Felsburg Holt & Ullevig, 2010). For the second step, speed expressed as the percentage of the free flow

TABLE 4.1
Performance measures to identify congested corridors

Basis of Measure	Performance Metrics
Traffic flow	Vehicle throughput; lost throughput productivity
Level of service (LOS)	LOS maps
Speed	Travel speed; % free flow speed
Travel time	Travel delay; annual delay per person; travel time index; travel rate
Reliability	Buffer index
Derived parameters	Density; VMT in congested area

speed is used as the metric to quantify congestion instead of absolute speed values to account for the different speed limits on the corridors. Threshold value of percentage free flow speed less than 75% is adopted to identify congested conditions on freeway segments (Eisele et al., 2011).

4.1.1 Results

For the analysis, six most congested corridors are identified based on the LOS maps. Freeway locations operating at LOS E or F conditions both in the year 2010 and 2015 are included in the list of potentially congested corridors. The six potentially congested corridors identified using LOS maps are listed in Table 4.2. Typical LOS maps for the year 2010 along with the location of the congested corridors are shown in the Figure 4.1. Further analysis of volume and speed data performed to identify the study corridor is presented below.

Figure 4.2 shows the typical traffic patterns, i.e., daily volumes, on these highway segments during different days of the month. It can be immediately observed that the data for a period of one week contains all the necessary information for analysis, as the weekly pattern just repeats itself all through the month. Furthermore, given that traffic volumes might vary significantly within a week, the longest duration of congestion for each freeway segment, is identified by observing the distribution of traffic volumes for each day of a typical week. Figure 4.3 shows the day-to-day variation of percentage of time for which the freeway segment is congested during a typical week at different locations on I-69. Two observations can be made from this plot. Firstly, the highest percentage of time wherein the freeway is congested is at the 3.7 mile marker for all the days. Secondly, among all the different days, I-69 has the longest duration of congestion on a Wednesday (i.e., Day 4) at the 3.7 mile marker. Similarly, the most congested segment and its corresponding day is found for each of the six freeways. Additionally, in order to capture seasonal variation of traffic patterns, the aforementioned analysis is performed both for the months of January and April. It is expected that due to inclement weather in winter, the average speed is lower for the month of January in comparison to April. The findings validate the initial expectations in that the congestion was more pronounced for January compared to April, for all the freeway corridors. Lastly, comparison of the congestion conditions (at the most congested freeway segment and day-of-week) in January and April, as shown in Figure 4.4, indicates that I-65 is the most congested corridor and is thus used for subsequent simulation analysis.

TABLE 4.2
List of potentially congested corridors identified using LOS maps

Corridor	Details
I-65	South side of Indianapolis
I-65	Louisville to Clarksville
I-65	North of Indianapolis to Lebanon
I-69/I-465	—
I-70	Through central Indianapolis
I-80/I-94	Borman Expressway

4.2. Study Area

The location of the study area in the Indianapolis region is presented in Figure 4.5(a), while the schematic diagram of the study area is shown Figure 4.5(b). A 10-mile stretch of the I-65 corridor extending from downtown of Indianapolis (mile post 110) to the south side of Indianapolis (mile post 100) was selected.

There are four ramp locations (at mile posts 109, 107, 103, and 101, respectively) and one freeway interchange (at mile post 106) on this 10-mile section. A 10-mile stretch is selected so that the potential travel time savings due to implementation of various lane use management strategies on I-65 are realized by the commuters using this facility.

Additionally, the study area comprises of all major (functionally classified as freeways, state roads, major and minor arterials) roadway facilities within a 2 mile distance on either side of the I-65 corridor. This enables holistic evaluation of lane use management strategies considering the effects of their implementation on adjacent road network. A 2 mile boundary on the either side of I-65 corridor is identified by investigating the alternative routes to I-65 which a commuter may choose. Furthermore, the study area also comprises of all the other minor roads considered in the Indianapolis MPO TDM within the boundaries described above so as to use the data from the MPO TDM.

4.3 Demand Estimation

For the simulation based analysis, the dynamic assignment (DA) module in VISSIM is used. DA in

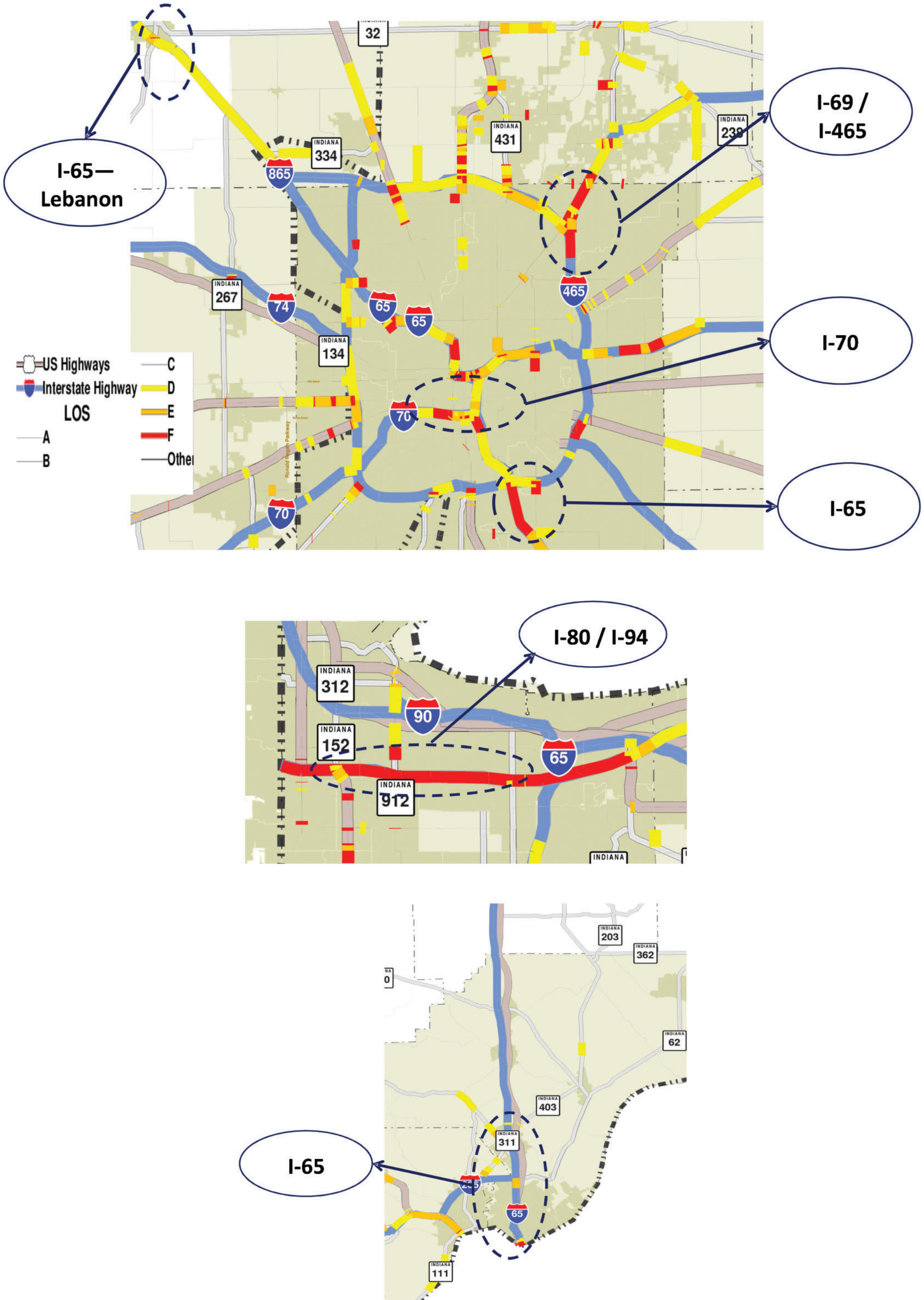

Figure 4.1 Map indicating LOS in the year 2010 on the six potential corridors considered for identification of a congested corridor for the simulation based analysis.

VISSIM is different from the conventional dynamic traffic assignment procedure which only accounts for the temporal variation of demand during the assignment process. DA refers to the process of assigning vehicle routes, in a simulation model, based on traffic conditions which change during the simulation period. Unlike the static assignment case, where it is required to identify alternative routes and the percentage of

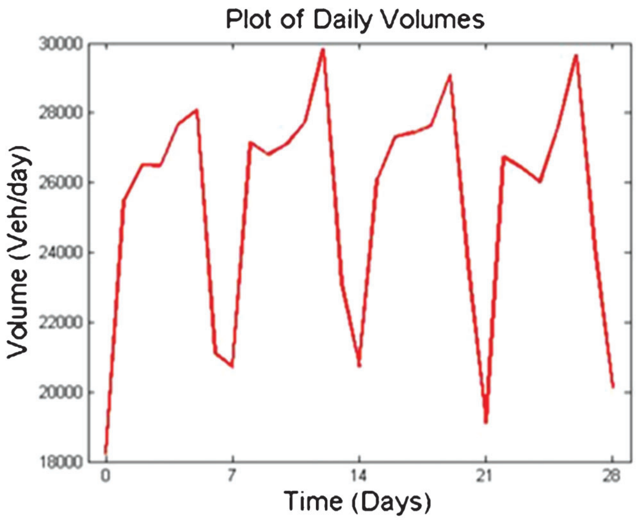

Figure 4.2 Traffic flow pattern on I-69 corridor for the month of January.

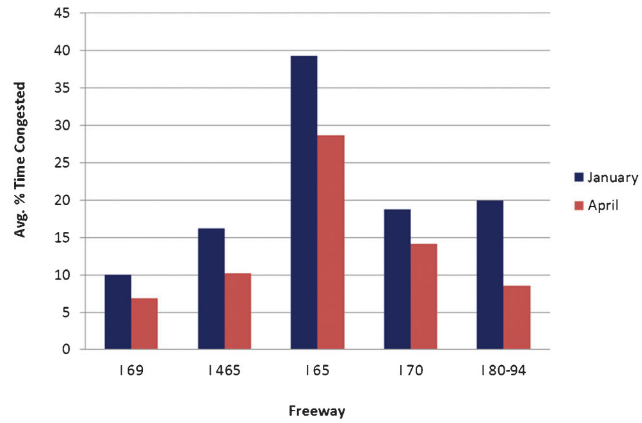

Figure 4.4 Monthly variation of congestion conditions on different freeways.

vehicles using each route, DA module lets each vehicle select the best route based on multinomial logit models. It is an iterative process that converges to a path assignment based on vehicle travel time and delay between origin and destination (O-D) points in the network. Therefore, before the start of any calibration and model application, there is a need to estimate the existing demand, required for the DA analysis, for the study network in the form of O-D matrices.

In general, direct survey, four step travel demand model (TDM), and models based on traffic counts on links, are the three major methods used for estimating regional O-D matrices. Direct survey can be further subdivided into number plate matching, household survey, and road side survey. However, all these survey based methods are time consuming and costly. Four step TDM, which is the most common aggregate transportation planning model, has been severely criticized for its inflexibility and inaccuracy. Methods based on traffic flow counts, to estimate the regional O-D matrices, can be divided into entropy based, statistical based, and heuristic based methods. However, these methods require an initial seed matrix and their accuracy depends on the proximity of the seed matrix to the actual O-D matrix. Nonetheless, since the data for the regional O-D matrices is already available, from Indianapolis MPO's TDM, subarea analysis can be used. Subarea analysis is particularly effective for estimating the study area (subregional) O-D matrices, as the trips are evaluated based on an actual network. Hence, they effectively capture network interactions in and around the study area (Martchouk & Fricker, 2009).

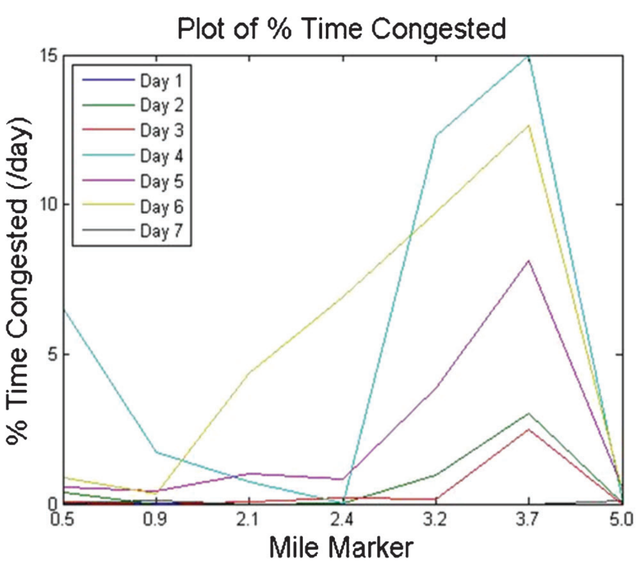

Figure 4.3 Within week variation of congestion conditions on I-69.

Subarea analysis is performed using the tools available in TransCAD software. For the subarea analysis, the study area O-D trip data is subdivided into internal-internal, external-external, internal-external, and external-internal trips based on the location of the origin/destination with respect to the study area. For the internal-internal trips, since the origin and destination points are both inside the subarea, the regional values pertaining to the O-D pair can be simply retained to form the subarea O-D matrix. For the external-external trips, since both origin and destination points fall outside the study area, only O-D pairs whose paths pass through the study area are considered. The external entry and exit points for each of these paths through the study area are identified and subsequently flow values are appended to the subarea O-D matrix. For calculating the internal-external and external-internal O-D trips, first a regular traffic assignment is performed for all O-D pairs using the entire regional network and its corresponding O-D matrix. Next, the flow for all the paths for the O-D pairs is recorded. From this complete set, only paths corresponding to internal-external and external-internal

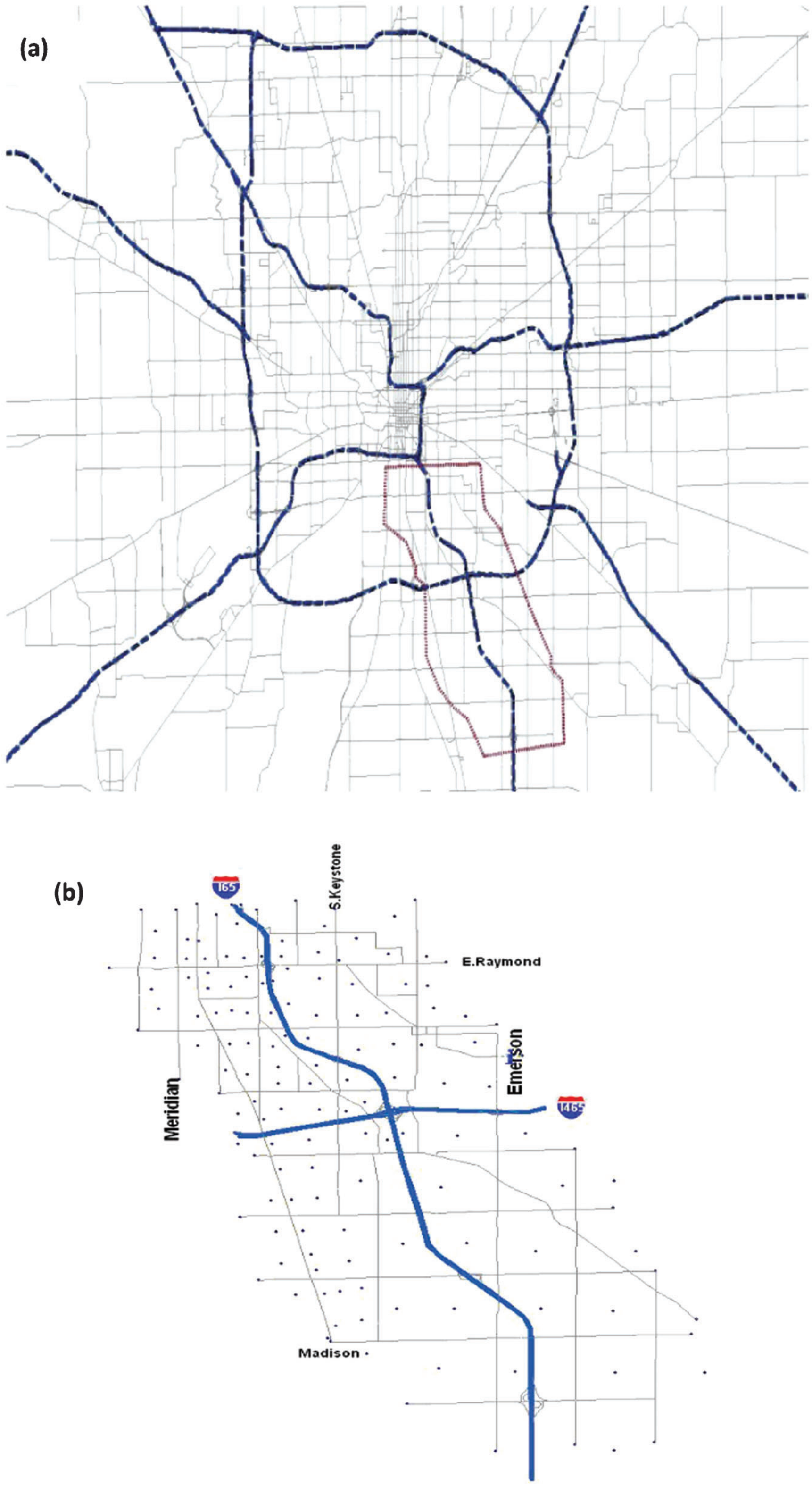

Figure 4.5 Study area of the Indianapolis region (a) with the schematic diagram of the study area (b).

trips are used. The O/D point falling outside the study area is replaced with the external node at which it leaves the study area, hence creating new O-D pairs relevant to the study area. The demand for these O-D pairs is then appended to complete the subarea O-D matrix.

4.3.1 Demand Estimation Results

The first step of the simulation analysis is to estimate the O-D demand for all pairs among the 157 traffic analysis zones in the study region using subarea analysis. In this study, separate subarea analysis is performed for each of the AM Peak, PM peak, and off-peak periods. Traffic volumes obtained from the subarea analysis for different time periods are aggregated to obtain the total daily traffic volume for each O-D pair. These daily traffic volumes, obtained from subarea analysis, are then compared with the daily traffic volumes obtained from the region-wide Indianapolis MPO's TDM. Figure 4.6(a) presents the results of this comparison analysis at different links of the freeway, while Figure 4.6(b) shows the corresponding locations in the transportation network on freeway links. The results indicate that the traffic volumes obtained from subarea analysis is closely correlated to TDM values, validating the results from subarea analysis. A similar comparative analysis is performed for different arterial links in the transportation network (Figure 4.7). While the subarea analysis results

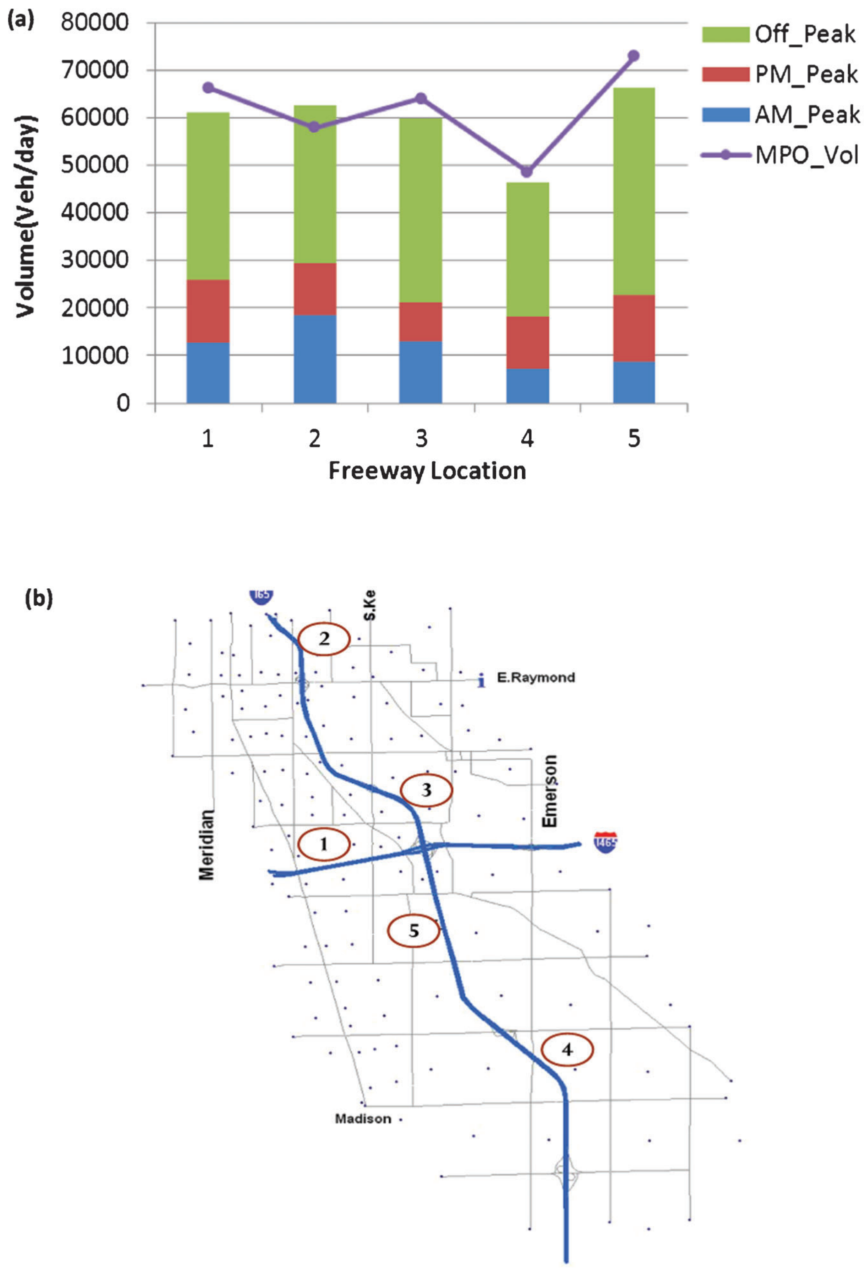

Figure 4.6 Validation of subarea analysis using traffic flow volumes on freeway links.

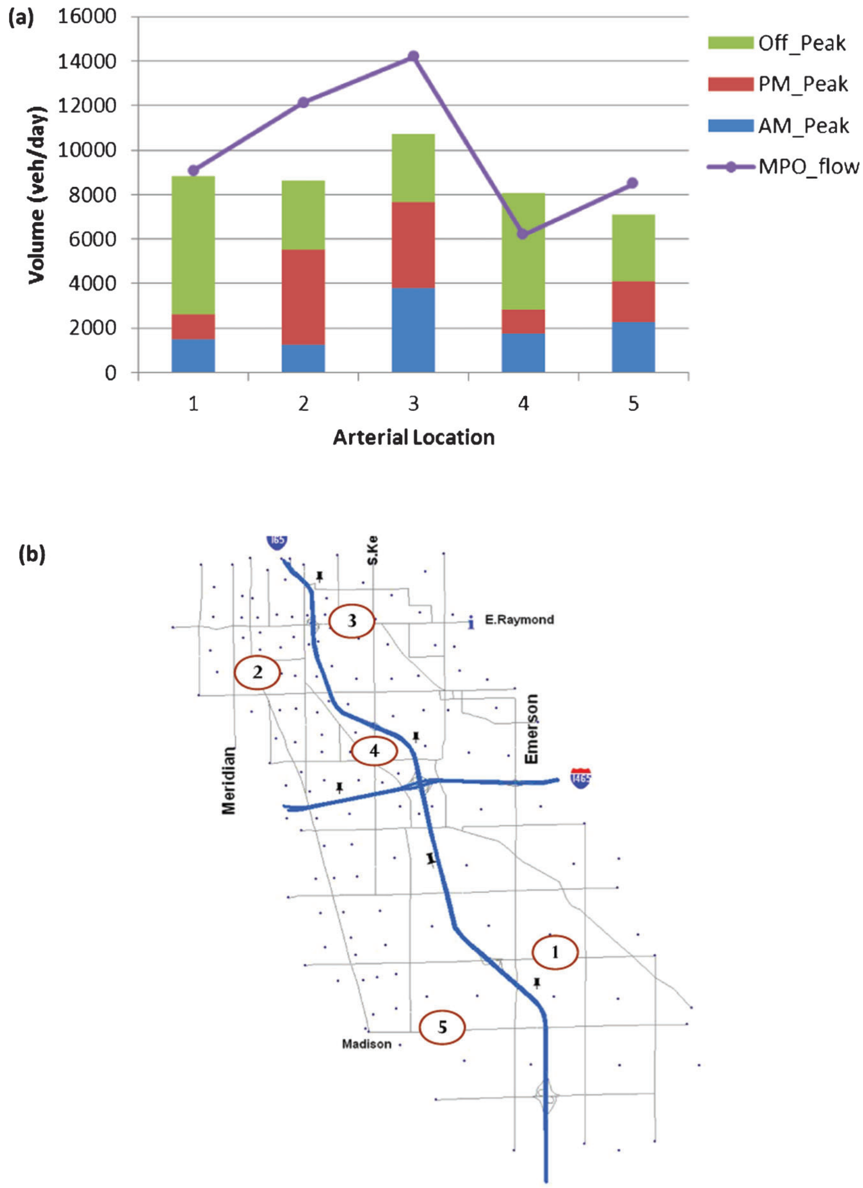

Figure 4.7 Validation of subarea analysis using traffic flow volumes on arterial links.

are reasonably close to the TDM volumes, the differences in traffic volumes on arterial links seem to be more pronounced compared to the freeway links.

5. MODEL DEVELOPMENT

Microsimulation model to replicate the existing traffic conditions is constructed in VISSIM. Extensive error checks are performed to avoid cases of abnormal vehicle behavior and to ensure that all the traffic controls and rules are appropriately coded in to the model. Thus verified model is used for further calibration and validation purposes. The following discussion describes the calibration methodology used to identify the set of parameter values for the microsimulation model which best represents the local traffic conditions.

The default model parameters in microsimulation software could not produce accurate results for the study area. Therefore, the parameter values are adjusted to appropriately predict local traffic conditions. General guidelines provided by Dowling, Skabardonis, and Alexiadis (2004) and Park and Qi (2005) are used to arrive at the calibration procedure used in this study. Network model programmed in VISSIM is initially evaluated by running the model with default parameters. Link travel times on I-65 freeway are used to check for the appropriateness of the model. From these runs, it is observed that the model with default parameters overestimated travel times and therefore required calibration. Based on the discussions in Dowling, Skabardonis, and Alexiadis (2004) and Park and Qi (2005) and by observing the simulation model, significant parameters that have impact on the driver behavior are identified. Experimental design methods are used to define 25 different parameter sets for calibration runs. Performance measures along with goodness-of-fit test statistics are identified to evaluate the calibration parameter sets. Parameter set with best goodness-of-fit statistics is selected. Finally, validation of the best calibration parameter set is performed by comparing the travel times on I-65 corridor from simulation and the MPO TDM. Brief description of the selection of calibration parameters, performance measures, and the experimental design method is presented below.

5.1 Identification of Calibration Parameters

This section discusses the VISSIM car following and lane changing parameters along with their acceptable ranges used in the calibration process. Based on modeling experience and guidelines in (Dowling, Skabardonis, & Alexiadis, 2004), the set of parameters selected for the calibration process along with their corresponding defaults values and their variation ranges are presented in Table 5.1. CC0, CC1 and CC4/CC5 are the three car following parameters while safety reduction factor and waiting time before diffusion are the lane change parameters used during calibration process. The ranges of parameter values used for calibration are defined using the guidelines provided in Dowling, Skabardonis, and Alexiadis (2004) and Park and Qi (2005). Furthermore, five levels (values) for each parameter, obtained by equally dividing the interval of variation, are used in this study.

5.2 Experimental Design

Parameter sets used for calibration are selected using orthogonal experiment design (OED) method and each parameter set is run for three times with different random seed values to account for stochasticity of VISSIM simulation. The total number of simulation runs to account for all combinations of the selected calibration parameters and their corresponding levels along with the multi-runs is large ($3 \times 5^5 = 9375$). Therefore, OED method is used to limit the number of combinations to a practical amount while still reasonably covering the entire parameter surface. This method provides an orthogonal array that randomly samples the entire design space broken into equal-probability regions and ensures that the complete range of every parameter is sampled (Park & Qi, 2005; Park, Won, & Yun, 2006). Twenty-five different parameter sets are identified using the OED method and their appropriateness is evaluated using the performance measures discussed below.

5.3 Selection of Performance Parameters

Two performance measures were selected for the calibration and validation process. The first measure of performance is the traffic volume on freeway and

TABLE 5.1
Description of parameters selected for calibration

Selected Calibration Parameters	Description	Default Values	Variation Range Min.	Variation Range Max.
CC0 (ft)	It is defined as the desired distance between stopped cars. This parameter impacts the capacity of the freeway during congestion.	4.90	4.0	10.0
CC1 (sec)	It represents the headway time in seconds and is defined as the time the driver wants to keep between following vehicles.	0.90	0.7	1.2
CC4/CC5	These are dimensionless parameters which represent the coupling between leader and follower accelerations. Smaller absolute values indicate driver behaviors that are more sensitive to changes in the speed of the preceding vehicle.	−0.35	−2.4	−0.2
Safety reduction factor	The safety distance reduction factor impacts a driver's aggressiveness while making a lane change.	0.6	0.0	0.8
Waiting time before diffusion (sec)	The waiting time before diffusion is the maximum amount of time a vehicle will wait for a gap to change lanes before being removed from the network.	60	2.0	30

arterial links, whereas the second measure is travel time on the I-65 corridor. These measures were selected because of their ease of collection from field and VISSIM output files, and availability of such data from the Indianapolis MPO TDM. Root mean square percentage error (RMSPE) and average GEH (Geoffrey E. Havers) statistics are used as goodness-of-fit statistics to evaluate various calibration parameter sets. Both these measures are scale independent and are most commonly used in various forecast studies (Barceló, 2010; Swanson, 2008). GEH, calculated according to Equation 5.1, is an empirical statistic used both in research and in practice to measure the difference between the observed and simulated values of interest (Dowling et al., 2004). GEH values in the range of 0–5 convey that the simulated volume is closely correlated to the observed traffic volume, while those in the range of 5–10 convey that.

There is a good match between the modeled and observed traffic volume. However, GEH values greater than 10 imply a mismatch between the modeled and observed traffic volume and needs further investigation. RMSPE is a variation of the standard RMSE norm and is computed as per Equation 5.2. Lower values of RMSPE indicate better accuracy of forecasted values.

$$GEH = \sqrt{\frac{2\times(M-C)^2}{M+C}} \tag{5.1}$$

$$RMSPE = 100 \times \sqrt{\frac{\sum_{i=1}^{N} \frac{M_i - C_i}{M_i}}{N}} \tag{5.2}$$

Where, M and C are the measured and calculated values while N is the number of measurements.

5.4 Calibration Results

Twenty-five different sets of calibration parameters are tested during the simulation analysis. These calibration parameter sets are then ranked based on two criteria: GEH and RMSPE (Root mean squared percentage error). Figure 5.1 presents the performance of different sets of calibration parameters with regards to replicating the observed traffic volumes at 45 locations along the transportation network which includes 15 freeways sections, 10 ramp locations, and 20 arterial locations. It is found that parameter set 8 performs the best both with respect to RMPSE and GEH statistic.

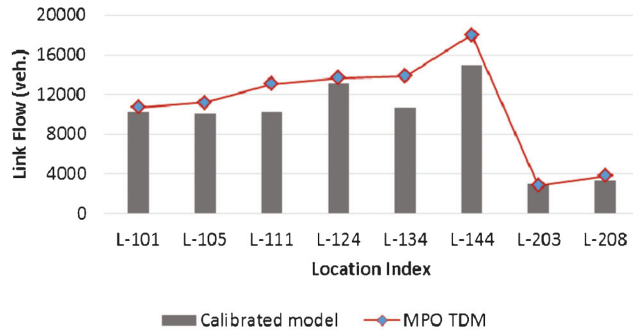

Figure 5.2 Comparison of MPO TDM traffic flow volumes and those obtained from the simulation.

Figure 5.2 presents the comparison between simulated traffic flows obtained using the calibration parameter set 8 and the Indianapolis MPO TDM. X-axis represents the index for location of the link, while the y-axis presents the link flow volume during the morning peak duration. The first six indices along the x-axis represent locations along different freeway segments while L 203 and L 208 represent the ramp locations. It is observed that the calibrated model closely represented the existing traffic conditions.

Subsequently, the performance of the best parameter set identified in the earlier step (i.e., set 8) was analyzed with regard to replicating the travel times from the region-wide Indianapolis MPO travel demand model. Table 5.2 presents the validation results of this analysis for parameter set 8. It can be seen from the results that

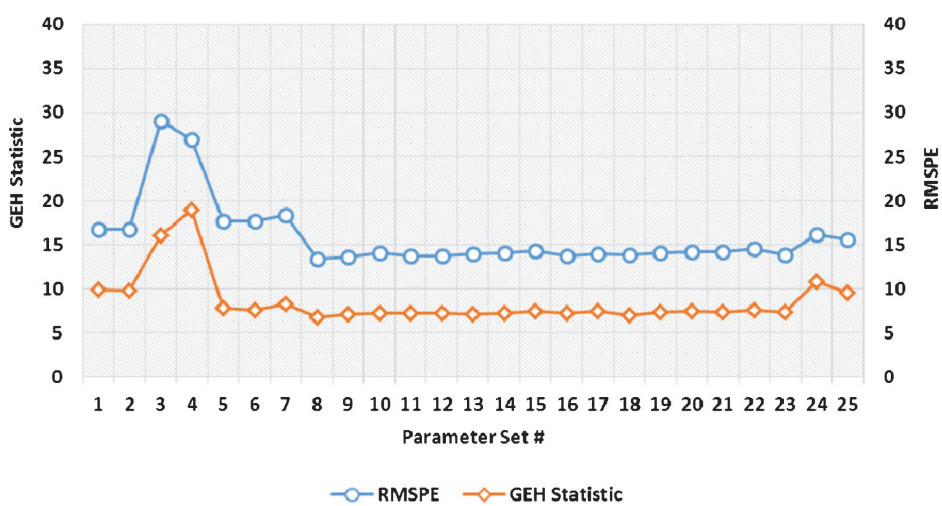

Figure 5.1 Comparison of the performance of calibration parameter sets w.r.t. RMSPE and GEH statistics.

TABLE 5.2
Validation of model using MPO TDM travel times and the travel times from simulation

Location	MPO TDM (sec)	Simulated (sec)	% Difference	GEH Statistic
I-65 NB	779	809	3.85	1.06
I-65 SB	621	668	7.57	1.85
I-465 EB	226	251	10.88	1.59
I-465 WB	229	272	18.78	2.71
Raymond	540	527	−2.41	0.56

the average percentage difference in observed and simulated travel times is 7.7 and the average GEH statistic value is only 2.98 which is considered very good for such simulation analysis.

6. VISSIM MODELING DETAILS

6.1 Reversible Lanes

The existing I-65 facility in the study region consists of 3 lanes each in the northbound (NB) and southbound (SB) directions. Under the reversible lanes scenario, the left most lane in the SB direction is converted into a reversible lane to serve the traffic in the NB direction. Thus, in this scenario, there are 4 lanes in the NB direction and 2 lanes in the SB direction. Moreover, the north and south bound traffic lanes are non-contiguous and are divided/median separated. Therefore, entry and exit bays are provided to access and exit the reversible lane. The reversible lane is designed as an express lane similar to that being currently implemented on I-5 in Seattle with one entry point and multiple exit points. Entry bay for the reversible lanes is provided before the I-65 NB and E county Rd interchange. Exit bays are provided before each of the off ramp location ensuring that there is sufficient distance to enable safe weaving and merging maneuvers.

6.2 HOV Lanes

HOV lane strategy is implemented on I-65 corridor both in north and south bound directions by converting the left most general purpose (GP) lane to a HOV lane in the respective directions. The HOV lanes are designed with continuous access minimizing the extent of infrastructural modifications required to facilitate HOV implementation. Based on the analysis of existing SOV and HOV traffic flow patterns acquired from INDOT, a minimum of two or more passengers per vehicle is determined as the requirement to allow HOV lane access. Additionally, the model allows transit vehicles to use the HOV lanes. The economic evaluation performed in this study does not include park-and-ride facilities, transfer centers, and direct access ramps for the HOV facility. However, these along with ridership programs and other support facilities should be planned strategically for successful implementation of HOV lanes strategy.

6.3 Ramp Metering

The I-65 corridor operates at congested conditions in the NB direction during the morning peak duration and vehicles entering from the ramps aggravate the congested conditions. There are a total of five on-ramp locations along the study corridor. The ramps in the SB direction are not considered for ramp metering as the I-65 corridor is not congested in this direction during the analysis period. Performance of metering at each ramp location is evaluated separately in this study. This means that when evaluating implementation of the ramp metering strategy at I-65 and Raymond on-ramp, it is assumed that there are no ramp signals on the other ramps lanes.

A traffic predictive ramp metering strategy based ALINEA algorithm is used to determine the ramp signal timings. ALINEA based traffic predictive ramp metering is sophisticated compared to fixed time metering and unlike the responsive ramp metering algorithms, ALINEA algorithm anticipates the operation problems before they occur (Bhargava et al., 2006).

7. EVALUATION OF REVERSIBLE LANE STRATEGY

The ten mile stretch of I-65 corridor was divided in to six segments to account for the variation in the traffic flow volume and the corresponding travel time savings. Segment 1 is between the southern tip to the E County lane and I65 interchange, segment 2 is between the Southport and E County lane ramp locations, segment 3 is between I-465 interchange and Southport ramp locations, segment 4 is between Keystone ramp and I-465 interchange, segment 5 is between Raymond and Keystone ramp locations and segment 6 is between Raymond and north end of the study corridor.

7.1 Impact on Average Lane Speed

Figures 7.1 and 7.2 present the impact of reversible lane strategy implementation on the average speeds measured at different locations (represented by mile markers) in the NB and the SB directions along the I-65 corridor respectively. Understandably, the additional reversible lane in the NB direction has improved average traffic speeds by up to 40% whereas reduction in the number of lanes in the SB direction decreased average speed by up to 12%. This is because of the

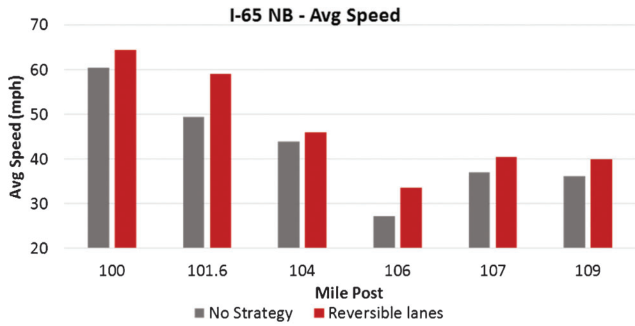

Figure 7.1 Comparison of average speeds NB I-65 before and after scenarios of implementing reversible lane.

increased capacity in the NB direction and reduced capacity in the SB direction. Similar analysis was performed for the future years using the projected traffic conditions and the trends were consistent with that shown in Figures 7.1 and 7.2. However the amount of improvement in average lane speed reduced with time. This is because the freeway demand increases every year thereby further increasing the congestion on freeway regardless of the improvements due to the reversible lane. Also, congestion increases at a higher rate in the SB direction than the rate of growth of total travel time savings. In such a scenario, improvements from reversible lanes seize to exist after a while.

7.2 Economic Evaluation

Economic evaluation of reversible lane strategy implementation during the morning peak duration is presented in this section. Implementation of reversible lanes in the major flow direction (NB) requires disruption to the minor flow direction (SB) traffic flow in order to set up the barriers. However, the time spent to convert the SB direction lane to a reversible lane is not considered during this evaluation.

7.2.1 Travel Time Savings

For estimation of travel time savings during the morning peak duration, it is assumed that the trip purpose for all the automobiles is work related trips.

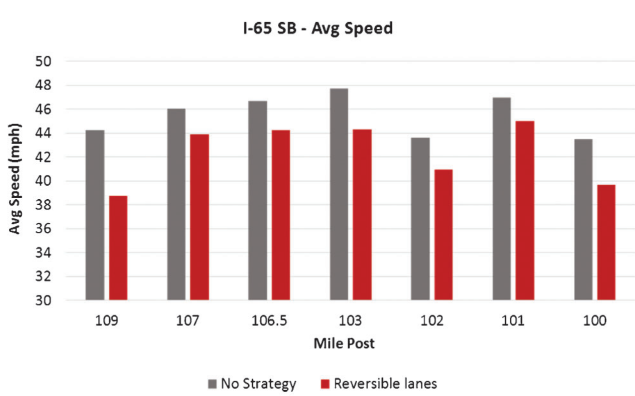

Figure 7.2 Comparison of average speeds BB I-65 before and after scenarios of implementing reversible lane.

The corresponding value of travel time (VOT) for a single occupant vehicle (SOV) is assumed to be $30/hour, while the VOT for automobiles with higher occupancy is equal to occupancy multiplied by $30/hour (NCHRP, 2012). Travel time savings due to implementation of reversible lanes for the base and the future years' projected traffic conditions on the six segment links of I-65 are shown in the Figure 7.3. NB direction which occurs to be the major flow direction during the morning peak duration, has significant travel time savings, while the SB direction have negative travel time savings. This is because of the increased capacity in the NB direction and reduced capacity in the SB direction. Demand in the major flow direction (NB) is met by four lanes (3 existing NB lanes and one reversible lane) in this direction, while the demand in the minor flow direction is accommodated by two lanes (right and the center lanes of the existing SB lanes). Given that the impact of the strategy is opposite in the NB and SB directions and the rate of travel time accrual (in the SB direction) is higher than the rate of travel time savings (in the NB) direction, the net travel time savings follows an inverted U-shaped profile peeking during the 2016–2018 period.

7.2.2 Vehicle Operating Cost (VOC) Savings

A similar segment wise analysis is performed to estimate the VOC savings and the results are presented in the Table 7.1. The VOC savings are determined by estimating the fuel cost savings AASHTO model described by Sinha and Labi (2007). However, it should be noted that the VOC calculations do not take into account the impact of freeway grade, number of stops and speed changes on the VOC values. It is assumed the fuel cost is $3.50 per gallon in 2010 dollars (Oil Price Information Service, n.d.). Furthermore, the free flow speed on I-65 corridor is assumed to be 55 mph and the corresponding values of average fuel consumption (in gallons) per minute of delay by vehicle type and are obtained from (Sinha & Labi, 2007).

For calculating the VOC savings for each vehicle type, the average travel time savings are multiplied by the fuel cost per gallon and the corresponding fuel consumption values. And the total annual average VOC

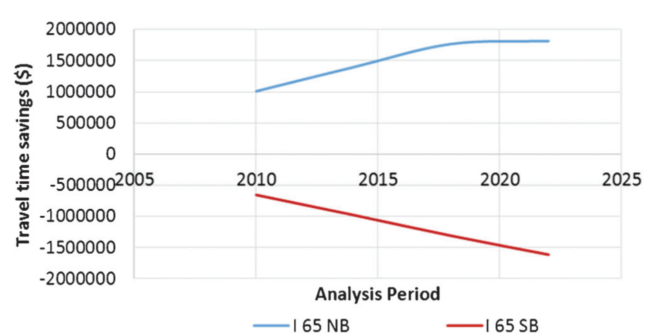

Figure 7.3 Travel time savings (in $) in NB and SB directions due to implementation of reversible lanes.

TABLE 7.1
Annual costs and benefits of implementation of reversible lane strategy on I-65 corridor

Year	VOC Savings ($)	Emission Savings ($)	Travel Time Savings ($)	Total Benefits ($)	PVB ($)	Initial Fixed Cost ($)	Opr & Maint. Cost ($)	Total Costs ($)	PVC ($)	NPV ($)
0	0	0	0	0	0	2,474,000		2,474,000	2,474,000	−2,474,000
1	97,048	192,860	355,304	645,211	614,487	0	62,400	62,400	59,429	555,058
2	97,894	223,162	358,402	679,458	616,288	0	62,400	62,400	56,599	559,690
3	101,811	256,275	372,744	730,830	631,319	0	62,400	62,400	53,903	577,415
4	107,644	288,710	394,099	790,453	650,307	0	62,400	62,400	51,337	598,971
5	114,236	316,980	418,233	849,449	665,566	0	62,400	62,400	48,892	616,673
6	120,430	337,600	440,913	898,943	670,805	0	62,400	62,400	46,564	624,241
7	125,072	347,081	457,907	930,060	660,976	0	62,400	62,400	44,347	616,630
8	127,004	341,937	464,982	933,922	632,115	0	62,400	62,400	42,235	589,881
9	125,070	318,680	457,905	901,655	581,215	0	62,400	62,400	40,224	540,991
10	118,115	273,824	432,443	824,382	506,099	0	62,400	62,400	38,308	467,791
				Net Present Value ($)						**3,273,341**
				Benefit Cost Ratio						**1.90**

savings are determined by summing the VOC savings for all the vehicle types. The annual VOC savings are found to decrease each year due to corresponding reduction in the travel time savings.

7.2.3 Emissions Savings

Reversible lane strategy implementation increases the emissions in the SB direction of I-65 corridor, while it reduces the emissions in the NB directions. Vehicle emissions are influenced by vehicle age, mileage, size, engine power and VMT (vehicle miles travelled). However, in this study, it is assumed that the vehicular emissions rates are influenced by the vehicle type and the VMT. Hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) related costs are estimated in this study. Typical emission rates by freeway vehicle type and mode under average operating conditions along with unit cost ($/kg) of pollutants (Bhargava et al., 2006) are presented in the Table 7.2. Using these values, the annual emission rates are calculated and presented in the Table 7.1 for each year during the analysis period.

7.3 Costs

The costs associated with reversible lane strategy for this study comprise of the following components.

- Construction cost of carriageways which connect the reversible lane and the major flow direction lanes
- Costs of putting up relevant signs
- Costs for pavement markings
- Costs associated with placing barriers separating the reversible lanes from the regular flow lanes
- Operation and maintenance costs

TABLE 7.2
Emission rates of pollutants by mode and the corresponding unit costs (Bhargava et al., 2006)

Vehicle Type	HC	CO	NO_x
Automobiles (g/VMT)	1.88	19.36	1.41
Trucks (g/VMT)	2.51	25.29	1.84
Bus (g/VMT)	2.3	11.6	11.9
Unit cost (/Kg)	**$1.28**	**$0.01**	**$1.28**

In this study, reversible lanes are provided with one access point and multiple egress points as described previously. Since the NB and SB lanes of I-65 are non-contiguous, construction of carriageways is required to facilitate egress and ingress. Therefore a total of six carriageways are required and the length of each of these carriageways is approximately 0.1 mile. Furthermore, it is assumed that the construction cost of such lanes is same as the freeway lane construction cost which is equal to $1,300,000 per lane (Bhargava et al., 2006). Therefore a onetime fixed cost of carriageway construction is equal to $780,000.

The cost of reversible lane signing is assumed to be approximately equal to $26,000 per lane mile (Bhargava et al., 2006). Cost of lane signs is estimated based on the reversible lane signs at the ingress and guide signs egress points. Furthermore, the cost of pavement markings is assumed to be equal to two percent of lane construction cost (Bhargava et al., 2006). Therefore one-time fixed costs of the new lane signs and pavement markings are calculated as $260,000 each.

Implementation of reversible lanes requires placing barriers in the minor flow direction which in this case is SB direction during the morning peak and removing them regularly. Moveable concrete barriers facilitate this and can be performed at a transfer rate of 12 minutes per mile (Barton, 2013). The cost of moveable barrier cost varies from $250,000 to $400,000. However, for this study it is assumed that cost of acquiring a moveable barrier cost is $250,000. Furthermore, it is assumed that 5 feet long concrete barriers are used to separate reversible lanes from the minor flow direction lanes and they are placed at an interval of one in every 20 feet. The cost of barriers is assumed to be $70 per foot (Murray, 1995) and therefore adds up to a total fixed cost of $924,000 for the barriers.

Major component of the operational costs comprises of the operation of moveable barrier to place the concrete barriers. It is assumed that the operator's wage cost is $30 per hour and is required to perform the placing and removal of barriers twice a day each corresponding to the morning and evening peak durations. The maintenance cost is assumed to be negligible. Therefore the annual cost of operation and maintenance cost is estimated as $62,400 using the previous assumption that it takes 12 minutes per mile to place/remove the barriers.

Therefore the total fixed cost is equal to $2,474,000 while the annual cost for implementing the reversible lanes is equal to 62,400. The costs for implementation for each year during the 10 year analysis period are listed in the Table 7.1.

7.3.1 Benefit-Cost Ratio (B/C) and Net Present Value (NPV)

The yearly benefits and costs associated with implementation of reversible lane strategy are listed in the Table 7.1. Total benefits (B) are calculated as the sum of VOC, emissions, and travel time savings. Similarly, total costs are determined as the sum of total initial fixed costs and the annual operation and maintenance costs. Present value of benefits (PVB) and costs (PVC) are estimated using a discount rate equal to 5%. From the above economic evaluation for 10 year analysis period, it is found that the NPV is positive and equal to $3,273,341, while the B/C ratio is 1.90. This indicates the implementation of reversible lanes is economically viable. Although the implementation of this strategy is economically feasible, it may be criticized for increasing congested conditions in the minor flow direction due to reduction in capacity. Appropriate public awareness programs should be taken up to alleviate such effects.

8. EVALUATION OF HOV LANE STRATEGY

Under this scenario, one of the lanes in each direction is changed into a continuous access HOV lane that only allows auto traffic with at least 2 passengers and transit bus services. However, it is very likely that under this scenario people will change their mode of travel to get access to the high speed HOV lane. So, the HOV traffic is likely to increase under this scenario. To capture the effect of this change in demand, we consider two situations under which there is: (1) 0% increase in the HOV traffic due to HOV lane implementation, and (2) 10% increase in the HOV traffic due to HOV implementation.

8.1 Results of Microsimulation Analysis

8.1.1 Impact on the Average Speed

It is expected that the average speed on the HOV lane is higher than that of the GP lanes because of the lower number of HOVs compared to that of the SOVs and trucks. Microsimulation analysis yielded similar results and this trend was consistent across all the scenarios corresponding to the forecasted demands. Figures 8.1 and 8.2 show the typical microsimulation results of average speed variation along the I-65 corridor in the NB and SB directions respectively, for one of the scenarios.

Another interesting observation can be made by looking at the average speed profile of traffic along the GP lanes before and after the implementation of the HOV lane strategy. It can be seen from the Figure 8.3 that the speed of traffic on GP lane has reduced considerably in the HOV lane strategy. This is probably a result of the fact that "Drive Alone" auto traffic that was using all the 3 lanes before the implementation of the HOV lane strategy are forced to use only two lanes. The GP speeds are slightly higher in the HOV-10% strategy compared to the HOV-0% strategy consistent with the shift in the mode shares to car-pooling in the HOV-10% strategy.

8.1.2 Impact on the Throughput

Although, the traffic speed on the HOV lanes improved, it occurred at the cost of the GP lanes. Therefore the overall vehicle throughput of the HOV lane and GP lane is lower compared to the before HOV implementation scenario. However, the purpose of HOV lanes is to improve the overall person throughput and not the vehicle throughput. Comparison of the person throughput before and after the implementation of the HOV lane strategy, presented in Figure 8.4 for one of the scenarios, indicated that the HOV lanes are instrumental in improving the person throughput. These trends were consistently seen in other scenarios corresponding to future years.

8.1.3 Impact on Travel Time Savings

As expected, the increased person throughput due to HOV implementation also translated into higher overall travel time savings in the NB direction as can be noticed from the Figure 8.5. These trends are consistent for the other scenarios corresponding to future years.

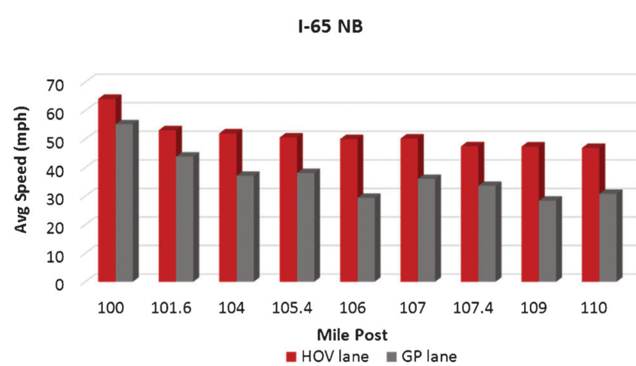

Figure 8.1 Comparison of average speed on HOV lane and GP lane in NB direction of I-65.

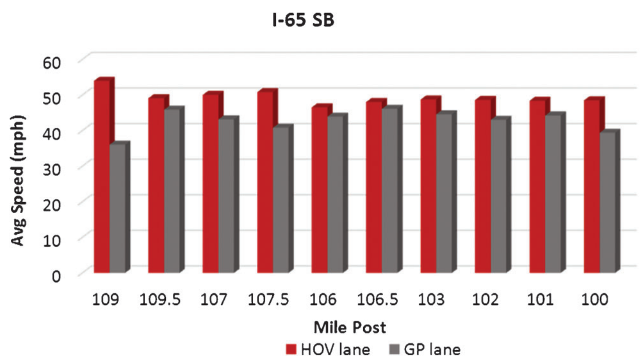

Figure 8.2 Comparison of average speed on HOV lane and GP lane in SB direction of I-65.

These results are consistent with the higher average HOV lane speeds and increasing demand over time (resulting in increasing HOV lane traffic over time). However, the rate of negative savings on GP lanes is higher than the rate of positive savings on HOV lanes and more significantly so in the SB direction (Figures 8.6 and 8.7). This is because of the fact that the speed on the GP lanes decreased more drastically with the increasing demand over time than the improvement of speed on the HOV lanes over time.

8.2 Economic Evaluation

This section presents the economic evaluation of the HOV lane strategy with 0%, i.e., with the assumption that there is not additional car-pooling due to implementation of HOV lanes.

8.2.1 Travel Time Savings

For estimation of travel time savings during the morning peak duration, it is assumed that the trip purpose for all the automobiles is work related trips. The corresponding value of travel time (VOT) for a single occupant vehicle (SOV) is assumed to $30/hour, while the VOT for automobiles with higher occupancy is equal to occupancy multiplied by $30/hour (NCHRP, 2012).

Figure 8.5 presents the net travel time savings from the HOV lane strategy in NB and SB directions. The monetary value of travel time savings is obtained by multiplying the savings by VOT corresponding to the occupancy of the vehicles. The net travel time savings after considering the travel time accrual on the GP lanes indicate that the HOV lane strategy offers significant savings only along the NB direction. Thus, the analysis in this study recommends implementation of HOV lanes only in the NB direction but not in the SB direction. Similar trends were observed with HOV-10% scenario as well with the only difference being that the magnitude of savings is higher than those in the HOV-0% scenario.

SB direction of I65 is not considered for further evaluation of economic feasibility due to the net negative travel time savings. It is therefore economically infeasible to implement HOV lanes in SB direction during the morning peak.

8.2.2 VOC Savings

The vehicle operating cost savings are estimated as described previously for the reversible lanes in the Chapter 7. The values of VOC are listed in Table 8.1. The VOC savings are found to be negative because the negative VOC savings due to congestion on GP lanes is higher than the rate of positive savings on HOV lanes.

8.2.3 Emissions Savings

Emission savings are estimated as described previously in the Chapter 7. The values of VOC are listed in Table 8.1. An interesting observation from these results is that the emission savings, although small, are positive (except for the first year) unlike the expectation that they should have been negative due to congested conditions on the GP lanes. This phenomena is thought to be because of the lower vehicle throughput in the before HOV implementation scenario. Emission sav-

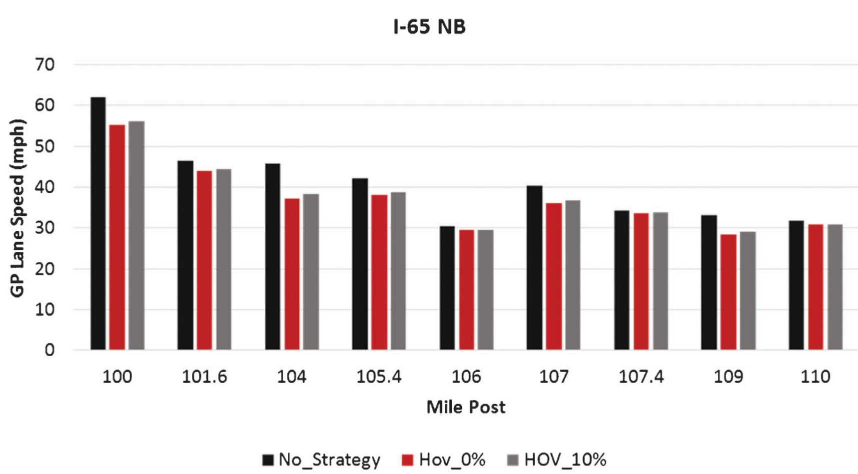

Figure 8.3 Comparison of average GP lane speed for different scenarios in NB direction of I-65.

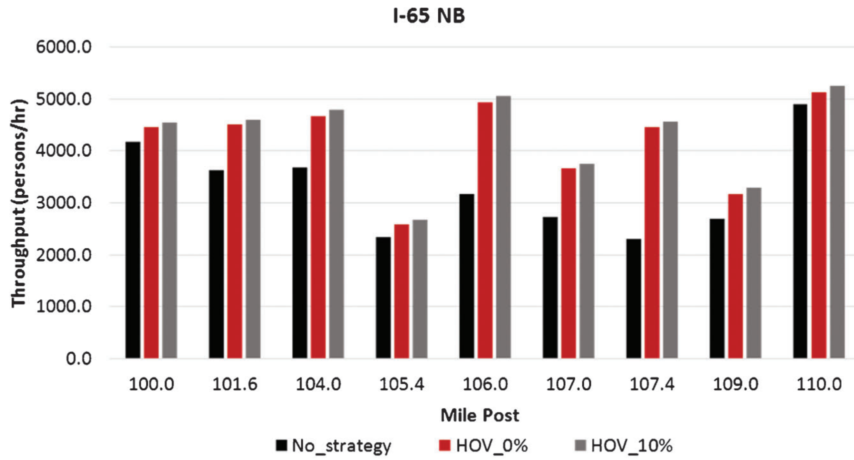

Figure 8.4 Comparison of average person throughput for different scenarios in NB direction of I-65.

ings are positive probably because the savings are estimated based on the total VMT, and because the total VMT is lower in the after HOV implementation scenario compared to the before HOV implementation scenario.

8.2.4 HOV Lane Costs

The overall cost of HOV lanes is significantly influenced by the components included in the analysis. Typical components of HOV lane cost estimation include right of way acquisition cost, HOV lane construction cost, sign and pavement markings costs, construction of access ramps and park-ride facilities, and dedicated enforcement area construction costs. In this study, one (leftmost lane) of the three existing lanes in each direction is converted to HOV lane giving rise to one HOV lane and two general purpose (GP) lanes in each direction. Therefore, the cost of right of way acquisition and HOV lane construction cost is equal to zero. Furthermore, the costs of constructing park and ride facilities along with dedicated enforcement areas were not considered. Hence, signing and pavement marking costs are the only components the associated with HOV lane cost analysis.

The cost of HOV lane signing is assumed to be approximately equal to \$26,000 per lane mile. Cost of lane signs is estimated based on the HOV only signs and guide signs at regular locations (every two miles) along the I-65 corridor. Furthermore, the cost of pavement markings is assumed to be equal to two percent of lane construction cost (Bhargava et al., 2006). Therefore one-time fixed costs of the new lane signs and pavement markings are calculated as \$260,000 each.

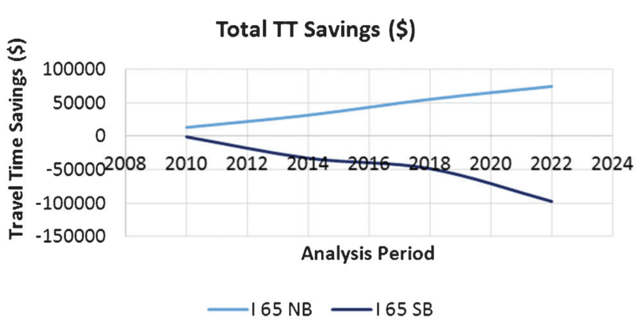

Figure 8.5 Total vehicle travel time savings (in \$) from HOV implementation in NB and SB directions.

8.2.5 Benefit-Cost Ratio (B/C) and Net Present Value (NPV)

Economic evaluation of HOV lanes is performed for the NB and SB directions separately. The yearly

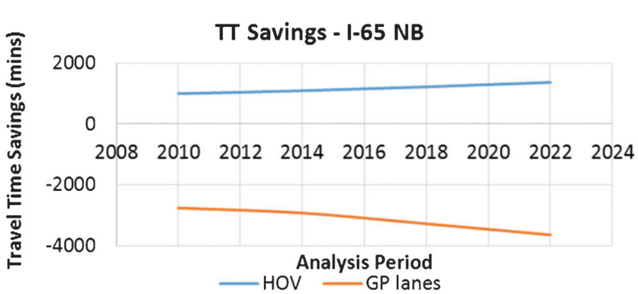

Figure 8.6 Total vehicle travel time savings (in minutes) from HOV implementation in NB directions.

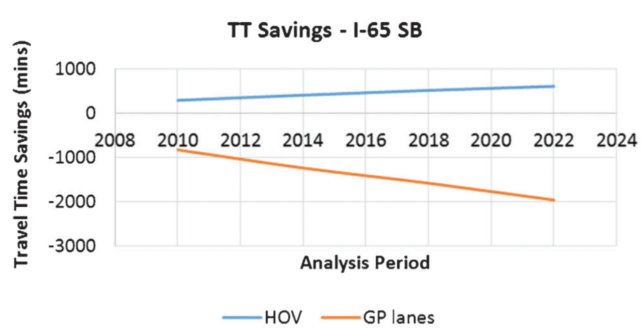

Figure 8.7 Total vehicle travel time savings (in minutes) from HOV implementation in SB directions.

TABLE 8.1
Annual costs and benefits of implementation of HOV lane strategy on I-65 in the NB direction

Year	VOC Savings ($)	Emission Savings ($)	Travel Time Savings ($)	Total Benefits (B) ($)	PVB	Initial Fixed Cost ($)	Maint. Cost ($)	Total Cost (C) ($)	PVC ($)	NPV ($)
0	0	0	0	0	0	520,000		520,000	520,000	−520,000
1	−375,499	−17	49,733	−325,783	−310,270	0	0	0	0	−310,270
2	−374,091	7,159	70,488	−296,444	−268,884	0	0	0	0	−268,884
3	−376,429	12,457	91,243	−272,729	−235,594	0	0	0	0	−235,594
4	−381,959	16,109	111,998	−253,852	−208,845	0	0	0	0	−208,845
5	−390,127	18,347	132,753	−239,027	−187,284	0	0	0	0	−187,284
6	−400,382	19,404	153,508	−227,470	−169,741	0	0	0	0	−169,741
7	−412,168	19,512	174,263	−218,394	−155,208	0	0	0	0	−155,208
8	−424,935	18,902	195,018	−211,014	−142,823	0	0	0	0	−142,823
9	−438,127	17,808	215,773	−204,546	−131,852	0	0	0	0	−131,852
10	−451,192	16,462	236,528	−198,202	−121,679	0	0	0	0	−121,679
					Net Present Value					**−2,452,179**

benefits and costs associated with implementation of HOV lane strategy in NB direction are listed in the Table 8.1. Total benefits (B) are calculated as the sum of VOC, emission and travel time savings. Similarly, total costs are determined as the sum of total initial fixed costs and the annual operation and maintenance costs. Present value of benefits (PVB) and costs (PVC) are estimated using a discount rate equal to 5%. From the above economic evaluation for 10 year analysis period, it is found that the NPV of HOV lane implementation in the NB is negative and equal to -$2,452,179 and the B/C ratio is 0.79. This indicates the implementation of reversible lanes is economically infeasible.

9. RAMP METERING

The objective of ramp metering is to regulate the flow from ramps into the freeway so as to minimize congestion on the freeway. If the freeway segment upstream of the ramp location is already congested, then the benefits due to ramp metering are minimal as the vehicles from ramp entering the freeway has longer waiting times (Bhargava et al., 2006). Also, benefits of metering are not significant when the ramp volume is below a threshold value. One of the warrants, discussed previously, require that the freeway and ramp volume should be at least a minimum threshold value to consider metering at a ramp location.

The ramp at I-65 and I-465 is a freeway-to-freeway type of ramp connector which requires special considerations (Bhargava et al., 2006). One of the warrants, discussed previously, require a minimum of two ramp lanes to implement freeway-freeway ramp metering. However, the existing infrastructure is such that only one ramp lane exists connecting the I-465 and the I-65 in the NB direction. Since objective of this study is to maximize the lane use by managing the existing infrastructure, ramp metering at this location is not considered for further study. Results of microsimulation analysis along with the economic evaluation of the traffic predictive ramp metering implemented separately at the Raymond and I-65 ramp location are presented in this study. This is selected because it is the only location which has ramp and freeway volumes greater than the minimum threshold value of 4250 vph.

9.1 Microsimulation Analysis Results

Table 9.1 presents the vehicle hours spent on the freeway and the ramp before and after ramp metering at the Raymond Street between 2010 and 2022. It is observed that the ramp metering improved the freeway travel conditions. And the average increase in the travel time on the ramp increased by 34%in the base (2010) year. This is due to additional delay on the ramps due to the ramp metering. The net travel time savings after subtracting the additional time spent by all the vehicles along the ramps is the metric of interest and is presented in Table 9.1. Overall, the results suggest that ramp metering offers significant travel time savings

TABLE 9.1
Results of microsimulation analysis of ramp metering at Raymond ramp location

	With Ramp Metering				Without Ramp Metering		
Analysis Year	Avg. Travel Time on I-65 NB (sec)	Avg. Travel Time on Ramp (sec)	Flow on I-65 at Ramp (Veh/hr)	Flow on Ramp (Veh/hr)	Avg. Travel Time on I-65 NB (sec)	Avg. Travel Time on Ramp (sec)	Total Net Travel Time Savings (VHT)
2010	792.55	40.7	3137	1061	809.83	26.88	10.98
2014	826.38	41.75	3216	1080	844.73	27.33	12.07
2018	842.28	42.7	3311	1116	861.41	28.2	13.10
2022	898.31	45.85	3467	1266	916.15	34.85	13.31

during the analysis period although the rate of increase in the savings was found to decrease with time. This is because the traffic along freeway increases every year regardless of the traffic along the ramp and delay at ramp meters increases at a higher rate compared to the travel time savings along the freeway.

9.2 Economic Evaluation

This section presents the economic evaluation of implementing ramp meter strategy at the I-65 and Raymond interchange. A discount rate of 5% is used to estimate the present value of various annual benefits and annual costs.

The annual travel time savings in monetary terms are obtained by multiplying the annual travel time savings, expressed as vehicle hours travelled (VHT), by the value of travel time and a factor equal to 780 ($=3 \times 5 \times 52$) which accounts for conversion of hourly savings to annual savings.

Similarly, the vehicle operating cost savings and the emission savings are estimated as described previously for the reversible lanes. However, the emission savings due to implementation of reversible lanes are very small compared to the travel time savings. This is because of the lower differences the total VMT before and after implementing ramp metering. Therefore, emissions savings are assumed to be equal to zero. The values of VOC, emission and travel time savings are listed in Table 9.2.

9.2.1 Ramp Metering Costs

The cost components of traffic predictive ramp metering include ramp meter installation cost, cost to enable communication between detectors and meters, detector and series processor cost and annual operating and maintenance costs. The corresponding costs of various components were obtained from (Bhargava et al., 2006) and are listed in the Table 9.3. A total of five detectors are required to implement ramp metering—three for the freeway and two for the ramp. One ramp detector is placed at the ramp meter signal to detect vehicles while the other detector is placed near the ramp entry to detect threshold queuing condition. The three detectors on freeway are to be placed on each of the three lanes upstream of the ramp meter to determine the metering rate of the ramp signal.

9.2.2 Benefit-Cost Ratio (B/C) and Net Present Value (NPV)

The annual benefits and costs associated with implementation of ramp metering strategy at Raymond

TABLE 9.2
Annual costs and benefits of implementation of ramp metering strategy Raymond and I-65 ramp location

Year	VOC Savings ($)	Emission Savings ($)	Travel Time Savings ($)	Total Benefits ($)	PVB	Initial Fixed Cost ($)	Mnt. Cost ($)	Total Cost ($)	PVC ($)	NPV ($)
0	0	0	0	0	0	164,200		164,200	164,200	−164,200
1	81,621	0	256,137	412,465	392,824	0	18,000	16,700	15,905	305,770
2	84,229	0	264,322	425,644	386,072	0	18,000	16,700	15,147	300,999
3	86,635	0	271,870	437,800	378,188	0	18,000	16,700	14,426	295,264
4	88,838	0	278,784	448,933	369,339	0	18,000	16,700	13,739	288,704
5	90,839	0	285,062	459,043	359,672	0	18,000	16,700	13,085	281,443
6	92,637	0	290,704	468,130	349,326	0	18,000	16,700	12,462	273,593
7	94,233	0	295,712	476,194	338,422	0	18,000	16,700	11,868	265,258
8	95,626	0	300,084	483,234	327,072	0	18,000	16,700	11,303	256,529
9	96,817	0	303,821	489,251	315,376	0	18,000	16,700	10,765	247,489
10	97,805	0	306,922	494,246	303,424	0	18,000	16,700	10,252	238,215
				Net Present Value ($)						**2,586,265**
				Benefit Cost Ratio						**9.74**

TABLE 9.3
Cost components for implementation of ramp metering

Component	Unit Cost ($)	Quantity	Total Cost ($)
Ramp meter installation cost	45,000	1	45,000
Communication from detectors to meters (twisted pair wire)	100,000	1	100,000
Detector cost	2,800	5	14,000
Series processor	8,000	1	8,000
Total fixed installation costs			**167,000**
Annual operating and maintenance costs	10% of installation costs		16,700

and I-65 ramp location are listed in the Table 9.2. Total benefits (B) are calculated as the sum of VOC, emission and travel time savings. Similarly, total costs are determined as the sum of total initial fixed costs and the annual operation and maintenance costs. Present value of benefits (PVB) and costs (PVC) are estimated using a discount rate equal to 5%. From the above economic evaluation for 10 year analysis period, it is found that the NPV is positive and equal to $2,586,265, while the B/C ratio is 9.74. This indicates the implementation of ramp metering strategy is economically viable. Although the implementation of this strategy is economically feasible, it may be criticized for the increasing congested conditions on the ramp due to ramp metering.

10. SUMMARY AND CONCLUSIONS

Increasing demand and funding deficit pose a substantial challenge for the transportation systems. In the United States and worldwide, various cost-effective lane use management strategies have been implemented to address these challenges. Some of these strategies can be adopted seamlessly, while others require additional infrastructure/operational changes. Therefore, a simulation based analysis should be performed to evaluate various lane use manage strategies. In order to evaluate the effectiveness of different strategies using microsimulation modeling, an organized framework is required to the model should be calibrated to replicate field conditions.

In this context, the objective of this study was to develop a systematic simulation-based methodology to evaluate lane use management strategies and presents a case study of VISSIM microsimulation. The I-65 corridor stretch was selected to demonstrate the procedure used in this study.

The study focuses on all the stages of the VISSIM modeling. This includes the analysis performed to identify a congested corridor in Indiana, followed by demand estimation analysis for the study area, along with calibration and validation of the microsimulation model. Furthermore, operational and economic evaluations of reversible lanes, HOV lanes and ramp metering lane use management strategies are performed.

Based on the analysis of the traffic data, I-65 corridor is identified as the congested corridor and therefore selected as the study corridor. The demand volumes for the study area are estimated using subarea analysis along with the results of calibration and validation of the VISSIM model are presented.

Assessment of the impact of reversible lane strategy implementation on the I-65 corridor indicated that this strategy improved traffic flow conditions. Average travel speed in the major flow direction (NB I-65 stretch during the morning peak) is higher under the reversible lane scenario when compared to the base case scenario (representing existing conditions). While the minor flow direction (SB I-65 stretch during morning peak) experienced lower flow speeds and higher congestion compared to the base case, comprehensive economic evaluation indicated that this strategy is an effective and viable option.

Microsimulation analysis of high occupancy vehicle (HOV) lane strategy indicated travel speed improvement on the HOV lanes but resulted in reduced speeds on the general purpose (GP) lanes when compared to the base case scenario. Also, the person throughput increased due to the implementation of HOV lanes compared to the base case scenario. Furthermore, the travel time savings (expressed in monetary terms) in the major flow direction were positive due to the improved person throughput. However, economic analysis of the HOV lanes indicated that this strategy is not feasible for implementation.

Microsimulation analysis of traffic predictive ramp metering strategy implemented for I-65 at the Raymond ramp location indicated improved flow speeds on the I-65 corridor. However, the average travel time on the ramp increased due to the ramp signal. The NPV was positive implying the economic feasibility of this strategy.

A comparison of the three lane use management strategies with respect to NPV is presented in the Table 10.1. It illustrated that reversible lane and ramp metering strategies are found to be economically feasible with positive NPVs. However, the NPV for reversible lane strategy is found to be the highest and therefore is the preferred lane use management strategy for the I-65 corridor stretch analyzed. HOV lane

TABLE 10.1
Comparison of the three lane use management strategies

Strategy	Reversible Lanes	HOV Lanes	Ramp Metering
NPV ($)	3,273341	−2,452,179	2,586,265

strategy was found to be economically infeasible due to low HOV volume on these lanes.

In summary, the study provides a simulation-based methodological framework to evaluate various strategies. As future congestion bottleneck areas arise in Indiana, the associated corridors could be analyzed for the effectiveness of lane use management strategies.

11. RECOMMENDATIONS

This chapter presents the recommendations developed based on the simulation-based analysis and the literature review of the three lane use management strategies: reversible lanes, HOV lanes and ramp metering. These recommendations can be used during the preliminary decision-making process involved in selecting potential lane use management strategies. However, the simulation-based analysis of the strategies under consideration should be performed using the methodology presented in this study when future congestion bottleneck areas arise in Indiana.

11.1 Reversible Lanes

Following are the recommendations for the implementation of reversible lanes on freeways:

- The minor flow direction should have no fewer than two lanes.
- Implementation of reversible lanes is justified on freeways with highly directional congestion. Ratio of major to minor flow (vph) during peak hour should be greater than a threshold value.
- Although literature review suggested that the ratio of major to minor flow during the peak hours should always stay between 2:1 and 3:1, in this study flow ratio of 1.7:1 yielded positive results.
- Presence of structures like bridges and tunnels warrant reversible lanes since expansion and addition of lanes is difficult.
- Finally, reversible lane implementation should be economically feasible.

11.2 HOV Lanes

Following are the recommendations for implementation of HOV lanes on freeways:

- In cases where one or more of the existing GP lanes are converted to HOV lanes, there should be at least two GP lanes apart from the HOV lane.
- A minimum occupancy level (at least 600–800vphpl) of HOV lanes is required to justify HOV lane implementation and also to avoid "empty lane syndrome".
- Planning agencies should consider policies such as those encouraging car-pooling to improve the vehicle occupancy and HOV lane usage.

11.3 Ramp Metering

The three significant factors to be considered before implementation of ramp metering are: ramp volume, freeway volume and ramp geometry. The following are recommendations for the implementation of ramp metering:

TABLE 11.1
Threshold volumes required for ramp metering (Bhargava et al., 2006)

No. of Freeway Lanes Including Auxiliary Lanes	Threshold Freeway + Ramp Volume Downstream of Ramp
2	2650
3	4250
4	5850
5	7450

- Single lane ramp metering should be adopted if the ramp volume is between 1200–1400 vph and dual lane metering for ramp volume greater than 1400 vph.
- Also, the combined volume of the ramp and the freeway should be greater than a minimum threshold value for effectiveness of ramp metering. The threshold volumes for ramp metering are listed the Table 11.1.
- Metering on ramps connecting freeway to freeway requires at least two ramp lanes.
- Existing ramp geometry must permit safe metering by providing adequate merging distance with the freeway.
- Finally, implementation of ramp metering should be economically feasible.

REFERENCES

Barceló, J. (Ed.). (2010). *Fundamentals of traffic simulation (Vol. 145)*. New York, NY: Springer.

Bhargava, A., Oware, E. A., Labi, S., & Sinha, K. C. (2006). *Ramp metering and high occupancy vehicle facilities: a synthesis study* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2006/02). West Lafayette, IN: Purdue University. http://dx.doi.org.10.5703/1288284313404

Boyle, D. K. (1986). Proposed warrants for high-occupancy-vehicle treatments in New York State. *Transportation Research Record*, *1081*, 8–18.

Cambridge Systematics, Inc. (2001). *Twin cities ramp meter evaluation* (Report prepared for Minnesota Department of Transportation). Oakland, CA: Author. Retrieved from http://www.camsys.com/pubs/ramp_meter_final_report.pdf

Cambridge Systematics, Inc. (2002). *Twin Cities HOV study, Vol. 1* (Report prepared for Minnesota Department of Transportation). Oakland, CA: Author. Retrieved from http://www.dot.state.mn.us/information/hov/pdfs/full_study.pdf

Cambridge Systematics. (2004). *Traffic congestion and reliability linking solutions to problems* (Report prepared for Federal Highway Administration). Cambridge, MA: Author. Retrieved from http://ops.fhwa.dot.gov/congestion_report_04/congestion_report.pdf

Central Midlands Council of Governments. (2009). Congestion management. In *Midlands tomorrow 2035 long range transportation plan* (pp. 135–147). Columbia, SC: Author. Retrieved from http://www.centralmidlands.org/COATS_2035_pdf/COATS_FinalPlan_Rev_5-11-10.pdf

Collier, T., & Goodin, G. D. (2002). *Marketing the managed lanes concept*. College Station: Texas Transportation Institute, Texas A&M University System.

Dowling, R., Skabardonis, A., & Alexiadis, V. (2004). *Traffic analysis toolbox volume III: Guidelines for applying traffic microsimulation modelling software* (Publication No. FHWA-HRT-04-040). Washington, DC: U.S. Department of Transportation, Federal Highway Administration. Retrieved from http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/vol3_guidelines.pdf

Eisele, B., Schrank, D., & Lomax, T. (2011). *2011 Congested corridors report*. College Station: Texas Transportation Institute, Texas A&M University System. Retrieved from http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/corridors-report-2011.pdf

Federal Highway Administration (FHWA). (2010). Synthesis of active traffic management experiences in Europe and the United States. Retrieved in February 2011 from http://www.ops.fhwa.dot.gov/publications/fhwahop10031/listcont.htm

Felsburg Holt & Ullevig. (2010). *NFR MPO congestion management process* [Report prepared for North Front Range MPO]. Centennial, CO: Author. Retrieved from http://www.nfrmpo.org/Files/Congestion%20Management%20Process%20-%20Approved%20September%202010.pdf

Grant, M., Beverly, B., Day, M., Winick, R., Bauer, J., Chavis, A., & Trainor, S. (2011). *Congestion management process: A guidebook*. Washington, DC: U.S. Department of Transportation, Federal Highway Administration. Retrieved from http://www.fhwa.dot.gov/planning/congestion_management_process/cmp_guidebook/

Gunawardena, N. R., & Sinha, K. C. (1994). *The development of a prototype congestion management system for the State of Indiana: Phase 1* (Joint Highway Research Project Publication No. FHWA/IN/JHRP-94/02). West Lafayette, IN: Purdue University. http://dx.doi.org.10.5703/1288284313336

Highways. (1989). Contra flow safety: Where the real problems lie. *Highways*, 57(1946), 27–29.

Huizinga-Barton, L. (2013). *Flexible positive protection to minimize work zone congestion, increase safety & save time & money*. Retrieved from http://www.teamconference.org/2013/Moveable_Concrete_Barrier.pdf.pdf

Kim, K., & Cassidy, M. J. (2010). *On-ramp metering and commuter delay: A before and after study* (PATH Research Report). Berkeley: University of California, Berkeley.

Martchouk, M., & Fricker, J. D. (2009). Through-trip matrices using discrete choice models: Planning tool for smaller cities. In *TRB 88th annual meeting: Compendium of papers DVD* (Session 774). Washington, DC: Transportation Research Board.

Meyer, M. D., Saben, L., Shephard, W., & Drake, D. E. (2006). Feasibility assessment of metropolitan high-occupancy toll lane network in Atlanta, Georgia. *Transportation Research Record*, 1959, 159–167. http://dx.doi.org/10.3141/1959-18

Murray, C. (1995, April 2). Adding an extra lane all in a day's work for barrier machine. *Chicago Tribune*. Retrieved from http://articles.chicagotribune.com/1995-04-02/travel/9504020127_1_reversible-lanes-movable-barriers-traffic

National Cooperative Highway Research Program (NCHRP). (2012). *Assessing highway tolling and pricing options and impacts: Volume 2—Travel demand forecasting tools* (Report 722). Washington, DC: Transportation Research Board.

National Surface Transportation Policy and Revenue Study Commission (NSTPRSC). (2007). *Transportation for tomorrow: Report of the National Surface Transportation Policy and Revenue Study Commission—Volume II*. Washington, DC: Author. Retrieved from http://mtcfilehost.net/transportationfortomorrow/final_report/index.htm

Obenberger, J. (2004). Managed lanes. *Public Roads, 68*(3). [Publication No. FHWA-HRT-05-002.] Retrieved from http://www.fhwa.dot.gov/publications/publicroads/04nov/08.cfm

Oil Price Information Service (OPIS). (n.d.) Gasoline pricing and news. Retrieved November 2013 from http://www.opisnet.com/gasoline-prices.aspx

Park, B., & Qi, H. (2005). Development and evaluation of a procedure for the calibration of simulation models. *Transportation Research Record*, *1934*(1), 208–217.

Park, B., Won, J., and Yun, I. (2006). Application of microscopic simulation model calibration and validation procedure: Case study of coordinated actuated signal system. *Transportation Research Record*, *1978*(1), 113–122.

Qu, T. (2010). *Investigating the effect of freeway congestion thresholds on decision-making inputs* (Dissertation). College Station: Texas A&M University System. Retrieved from http://repository.tamu.edu/handle/1969.1/ETD-TAMU-2010-08-8191

Skowronek, D. A., Ranft, S. E., & Cothron, A. S. (2002). *An evaluation of Dallas area HOV lanes, year 2002*. College Station: Texas Transportation Institute, Texas A&M University System.

Sinha, K. C., & Labi, S. (2007). Transportation decision making: Principles of project evaluation and programming. Hoboken, NJ: John Wiley & Sons.

Stockton, W., Benz, R., Rilett, L., Skowronek, D. A., Vadali, S., & Daniels, G. (2000). *Investigating the general feasibility of high-occupancy/toll lanes in Texas* (Report No. 4915-1). College Station: Texas Transportation Institute, Texas A&M University System. Retrieved from http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4915-1.pd

Stockton, W. R., Grant, C. L., Hill, C. J., McFarland, F., Edmonson, N. R., and Ogden, M. A. (1997). *Feasibility of priority lane pricing on the Katy HOV lane: feasibility assessment*. College Station: Texas Transportation Institute, Texas A&M University System.

Stokes, R. W., & Benson, J. D. (1987). *Feasibility of validating the Shirley highway HOV lane demand model in Texas (Report No. 1103-1)*. College Station: Texas Transportation Institute, Texas A&M University System. Retrieved from http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1103-1.pdf

Swanson, D. A. (2008). Measuring uncertainty in population data generated by the cohort-component method: a report on research in progress. In S. H. Murdock & D. A. Swanson (Eds.), *Applied demography in the 21st century* (pp. 165–189). Amsterdam, Netherlands: Springer Netherlands. Available at http://link.springer.com/chapter/10.1007%2F978-1-4020-8329-7_10

Wolshon, P. B., & Lambert, L. (2004). *Convertible roadways and lanes* (NCHRP Synthesis 340). Washington, DC: Transportation Research Board.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Paleti, C., Peeta, S., & Sinha, K. C. (2014). *Identifying strategies to improve lane use management in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2014/09). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284315503