Integrating Planning and Operations Models to Predict Work Zone Traffic

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ABSTRACT

The impetus of this research is to meet the growing need for accurate and practical methods to support traffic analysis in work zones. Road construction and maintenance activities have become a common feature for the majority of U.S. roads over the last few years as a result of an aging infrastructure and increased funding in the last two highway bills. At the same time, traffic levels across the United States continue to surge, especially along urban corridors. Therefore, it is no surprise that concerns over traffic safety and delays in work zones continue to top national transportation priorities [8]. Recent transportation legislation has addressed work zone safety and mobility concerns by requiring states to develop a systematic process that starts early in project development and continues through project completion. In addition, every significant project must include a transportation management plan [14].

This research examines the application of two classes of traffic analysis models, macroscopic sketch analysis and microscopic traffic simulation, to work zones. The Excel-based QuickZone developed by the Federal Highway Administration provides a relatively easy to use macro-level analysis tool. Citilabs' Dynasim and PTV America's VISSIM are the two microscopic traffic simulation models used in this study. The research will evaluate the application of these tools to an urban interstate work zone. Specifically, this research will examine the following: 1) how the use of traffic analysis models relates to federal requirements about considering traffic impacts of major construction projects, 2) the accuracy of model results in comparison to real-world conditions, and 3) modeling effort and data requirements of these models.

The primary objectives of this research are as follows: 1) determining the feasibility of applying a traffic-analysis model to a work-zone environment, 2) calibrating and validating the simulation models based on data collected in the work zone, 3) using the calibrated model to apply various work zone management strategies, and 4) documenting the research findings and lessons learned from the model applications.

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1.   INTRODUCTION

Over the last few years, road construction projects have become more frequent due to the aging infrastructure and an increase in federal funding designated for roadway construction and maintenance. With this increase in construction projects, highway work zones have become a common occurrence for drivers. There are several issues involved with the introduction of work zones to roadways, primarily concerning safety and mobility, especially with the increasing traffic volumes on most roads [11]. This combination of an increasing number of drivers with an increasing number of work zones poses a challenge to effectively manage an infrastructure that is at the limits of its capacity while reducing impacts on road users.

The Federal Highway Administration (FHWA) has been actively involved in addressing the issues of work zone safety and mobility since 1999 when the Work Zone Mobility and Safety Program was developed [8]. In September of 2004, the FHWA published the Work Zone Safety and Mobility Rule in the Federal Register. The importance of this rule was that it required all state and local governments that receive federal funding to consider work zone traffic impacts prior to finalizing construction projects. The rule provides requirements on issues such as work zone impact assessment and management, transportation management plans for work zones, and public information and outreach strategies.

In light of these requirements, it has become imperative that transportation agencies utilize the proper tools to ensure compliance with the Work Zone Safety and Mobility Rule. This research will compare two types of traffic analysis models to determine their suitability to model an urban work zone.

1.1   Study Objectives

This research will examine the application of two classes of traffic analysis models, macroscopic sketch analysis and microscopic traffic simulation, to work zones. QuickZone, an Excel-based estimation tool developed by the FHWA, provides a relatively straightforward and simple approach to a macro-level work zone analysis. The microscopic simulation models examined in this study are Dynasim, which is a simulation tool developed by Citilabs; and VISSIM, which is a simulation model developed by Planung Transport Verkehr AG (PTV).

The research will evaluate the performance of the aforementioned models in an urban interstate work zone. Specifically, the research will examine the following: 1) how their use relates to federal requirements on considering traffic impacts of major construction projects; 2) the accuracy of model results in comparison to real-world conditions; and 3) modeling effort and data requirements of each model. The primary objectives of this research are as follows:
1)   Determine the feasibility of applying a traffic analysis model to a work zone environment.
2)   Calibrate and validate the simulation models based on data collected in the work zone.
3)   Use the calibrated models to apply various work zone management strategies.
4)   Document the research findings and lessons learned from the model applications.

1.2   Problem Statement

The overarching issue addressed by this research is the ability of a traffic analysis tool to accurately represent work zone conditions given data availability and requirements specified by the Work Zone Safety and Mobility Rule. Considering the wide range of traffic analysis tools, it is important for agencies to select the most cost-effective and practical tool to estimate work zone impacts on traffic flow. To determine the feasibility of applying a traffic analysis model to a work zone, several factors must be

considered. These factors include the size and type of work zone in consideration and the characteristics of the traffic that will be traveling through the work zone. The work zone characteristics that must be known are the size, geometry, type of work being done, and location. Having an understanding of the traffic characteristics in the work zone and the surrounding areas plays a key role in the modeling process. Examples of these data include traffic volume, speeds, composition of the traffic, and temporal distribution of traffic (i.e., peak periods). Data requirements vary greatly depending on the traffic analysis tool of choice, but are most demanding for simulation-based tools. Data requirements are often a crucial factor in not only selecting an analysis tool, but also the success of its application to model a particular work zone or other scenario. Another important aspect of assessing the feasibility of using a traffic analysis model is the user effort required for the construction and calibration of the model, and the computing requirements for running the analysis.

The calibration and validation of a traffic analysis tool is an important step in the modeling process. However, to properly calibrate a model, the user must have an adequate understanding of each model's specific constraints and parameters. Each model has unique parameters which are used in algorithms to represent the traffic based on the input data. Traffic analysis models also have specific data requirements that must be understood by the user in order to be matched with available data.

The evaluation of work zone management strategies using a calibrated model will provide the basis for analysis tool comparisons for this research. Through the use of analysis tools, the overall impact on users can be quantified by implementing work zone staging plans based on estimated traffic impacts, temporal construction work restrictions based on traffic patterns, and type of work being done. Other strategies include evaluating the effectiveness of variable message signs and sign placements (merge areas, lane closures, speed limits, etc.), identifying areas with potential for speeding, and variable speed limit applications. The information provided by these strategies will be extremely valuable to transportation agencies, and will help with compliance of the new federal requirements of implementing a traffic management plan for work zones.

1.3   Report Organization

This section provides an outline of the document organization. This first section is intended to provide a general background for the study, and states the objective and problem statement of the research. Chapter 2 includes a literature review and overview of the models used. Chapter 3 outlines the methodology of the research and will give a detailed description of the modeling process. Chapter 4 discusses the results of the research, the output of the various analysis tools, as well as the lessons learned and future research.

2.   LITERATURE REVIEW

This chapter summarizes some of the relevant works reviewed in the literature and provides supporting information to this research. It starts by explaining the main components of the federal work zone rule. It introduces the various types of traffic analysis tools, with special attention to work zone applications. Three analysis tools selected for this research are introduced in greater detail. The section concludes with a brief summary.

## 2.1   Federal Requirements

This section outlines the specific requirements of the new rule, particularly the work zone impact assessment and management, traffic management plans for work zones, and public information and outreach strategies. The Work Zone Safety and Mobility Rule mandated several requirements on state and local agencies with respect to work zone planning and management strategies. The rule stresses a focus on institutionalizing work zone policies and procedures on an agency level, a systematical approach to addressing work zone impacts from planning and design through the implementation, and addressing the overall impacts of work zones such as network performance and traffic safety [14].

There are three primary elements addressed by the rule. The first is a requirement of agencies to develop standard processes and procedures to support the implementation of a work zone safety and mobility policy. The second requires agencies to develop procedures to support the implementation of the developed policy. The third requirement is the implementation of project-level procedures to assess the impacts of individual projects [10].

2.1.1 Work Zone Impact Assessment and Management

Although many agencies already perform work zone impact assessments, it is now a requirement for all federal aid projects. In addition, agencies are encouraged to apply the same procedures and principles for all projects to better facilitate work zone operations and mitigate potential traffic impacts. The rule serves as a guide to both emphasize the importance of assessing a work zone's impact, and to introduce new concepts and procedures.

The policies and procedures outlined in the rule are applied to all phases of the project, from the initial development through the design and implementation of the work zone. With the required project assessments, the agencies can document how various procedures impacted the work zone operations, and refinements can be made for future projects. This approach allows agencies to consciously make an effort to improve work zone management and recognize the impacts that work zones have on the transportation system. The systematic process of assessing work zone impacts can be seen in Figure 2.1.
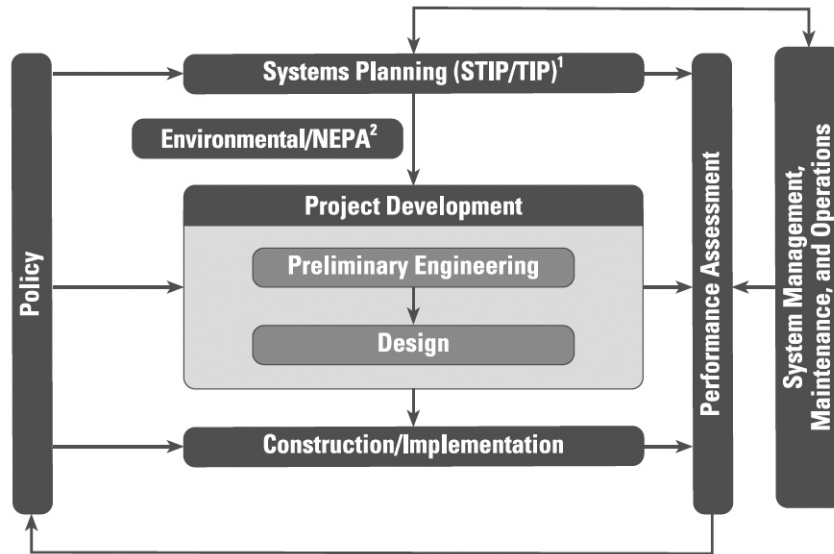
Figure 2.1 Work Zone Impact Assessment Process [10]

From this process developed by the FHWA, the importance of having adequate analysis tools is evident. The tools must be flexible enough to use during each phase of the project, from inception to assessment, and must be robust enough to provide detailed summaries of how traffic is impacted. Guidance on the type and use of analysis tools is one type of policy-level procedure that can be developed by agencies [10]. Therefore, it is imperative that agencies have a clear understanding of the various analysis methodologies and tools available.

2.1.2 Traffic Management Plans for Work Zones

Traffic management plans (TMPs) are an essential aspect of work zone operations. A TMP as defined by the FHWA is "a set of coordinated transportation management strategies which will be used to manage the impacts of a work zone on a road project" [4]. Specific transportation management plans must be developed for each type of project based on the level of anticipated impacts to the transportation network. Transportation management plans are developed from the work zone impact assessment and are meant to serve as a dynamic guide that can be changed based on the actual impacts observed during the project implementation.

The three main areas addressed by a transportation management plan are temporary traffic control, public information, and transportation operations [4]. Clearly, each of these areas relies on accurate and thorough analysis of the work zone. Therefore, developing and maintaining the analysis throughout the project duration is necessary for the proper implementation of the TMP.

2.2   Range and Application of Traffic Analysis Tools

The use of traffic analysis tools is paramount to the planning, operation, and assessment of work zone management. This section will discuss the importance of analysis tools in light of the new federal requirements, the use of analysis tools in various projects, and the types of analysis tools available. In addition, the analysis tools used for this research will be discussed along with a detailed description of their characteristics.

2.2.1 Role of Traffic Analysis Tools

Traffic analysis tools assist transportation professionals in evaluating strategies that best address the transportation needs in their jurisdiction [2]. These tools have several possible applications, including: 1) improving the decision-making process through providing a consistent approach in comparing potential improvements or alternatives; 2) projecting potential future traffic conditions; 3) evaluating and prioritizing planning/operational alternatives; 4) improving design and evaluation time and costs; 5) reducing disruptions to traffic; 6) presenting and marketing strategies to the public and stakeholders; 7) operating and managing existing roadway capacity; and 8) monitoring the performance of transportation facilities. [2]

2.2.2. Types of Analysis Tools Available

Traffic analysis tools can be categorized according to their capabilities and the methodology used by the individual model. This section outlines the various types of traffic analysis tools available that are applicable to work zone analyses. For the purposes of this discussion, traffic analysis tools may be categorized into the following classes: sketch-planning, analytical, and simulation-based tools.

Sketch-Planning models provide general estimates of travel demand and traffic operations to specific road construction projects. Typically, they are the simplest and most cost-effective means of analysis and can be done in a relatively short period of time. However, they lack the features and capabilities found in more detailed and complex modeling tools [5].

Analytical analysis tools are generally associated with software programs that utilize the Highway Capacity Manual (HCM) methodologies. This type of static analysis uses a sequential and logical approach based on a series of values input by the user. The analysis done by this type of tool is best suited to isolated facilities, as it is unable to account for network performance [5].

The most detailed types of analysis are done using simulation analysis tools. These tools generally try to capture traffic dynamics with a greater level of detail than their analytical counterparts. Microscopic traffic simulation models offer the highest level of detail that captures dynamic and stochastic behavior of individual vehicle movements to simulate each vehicle on the transportation network. They take into account specific vehicle characteristics (acceleration rate, size, classification) and driver behavior (car-following, lane changing). The stochastic aspect of microscopic simulation models accounts for random occurrences within the model, and uses a random seed to determine the variables within the model [3]. The use of microscopic analysis tools requires a significant amount of computational effort, and requires several simulation runs to obtain a statistical convergence. These models also require extensive data for calibration to properly replicate real-world conditions.

Mesoscopic analysis tools are generally defined as a combination of microscopic and macroscopic models. Although they account for characteristics of individual vehicles and drivers similar to microscopic simulation models, they look at average flows on the links. The travel prediction of mesoscopic models does not consider speed/volume relationships [5].

Macroscopic models use the characteristics of flow, speed, and density of the traffic stream to model sections of a transportation network [5]. Vehicle movements are measured in platoons rather than individually. These types of models use aggregated speed/volume and demand/capacity relationships for the analysis [5].

2.2.3 Strengths and Weaknesses of Analysis Tools

Traffic analysis tools have several uses ranging from intersection and corridor analyses to system-wide performance evaluations. Depending on the type of analysis required, agencies have many different types of tools at their disposal. Each analysis tool has specific strengths and must be used in an application to which it will provide the most accurate results.

In 2006, Edara conducted research for the Virginia Department of Transportation on the state of the practice of estimating traffic impacts on work zones [12]. The purpose of this study was to help VDOT determine the most appropriate analysis tool for estimating traffic impacts at work zones. The basic premise of this study is a literature review of tools available for estimating work zone impacts and a survey of state DOTs in regard to how they conduct work zone impact estimates. This study does not conduct a quantitative comparison of analysis tools but provides insight into what various agencies are using for work zone analyses. The analysis tools identified through the literature review and survey were summarized according to their documented strengths and weaknesses.

Research done by Skabardonis, et al. documents a methodology for selecting traffic analysis tools based on several variables such as available data, type of application, and staff/computing resources. Although the document provides a relatively detailed selection process on what type of analysis tool is best suited for a particular function, there is little discussion of tools other than HCM-based and microscopic simulation. The authors provide some insight into the strengths and limitations of these two types of analysis tools, although some of the documented limitations of microscopic simulation tools are no longer valid due to software upgrades and improvements. The strengths of microscopic simulation models, according to the authors, are the "effective evaluation of the dynamic evolution of traffic congestion on transportation systems." Through the evaluation of a system of facilities, microscopic simulation models can evaluate the interference that occurs when congestion builds up at one location on the network and impacts the capacity at another location [2]. The main limitations recognized from this research are the amount of input data and error checking required, potential calibration of the model to represent actual field conditions, and the overall time required for building and calibrating the model [2].

2.3 Evaluating Traffic Analysis Tools in a Work Zone

Several studies compare various traffic analysis tools in a work zone. However, few of the studies compare high-end microscopic simulation models. The majority of the traffic analysis tools that have been compared are sketch-planning or analytical tools. This section will provide a discussion on the research that has been done in comparing various traffic analysis tools.

Research done by Schell, Mohror, and Aktan (2002), compares the Highway Capacity Software (HCS), Synchro, CORSIM, NetSim, QueWZ92, and a spreadsheet developed by the Ohio Department of Transportation (ODOT) [9]. This research was conducted for the ODOT to determine the most accurate commercially available tool for modeling work zones. The objective of this study was to determine if the available models could be calibrated to predict accurate queue length and delay time for freeway work zones. This study analyzed four separate work zones and found that the most accurate tool for estimating capacity was QUEWZ-92. The best tool for estimating maximum queue lengths was the ODOT spreadsheet when provided with an adequate capacity estimate from QUEWZ-92. This study concluded that the microscopic simulation programs could not be calibrated to the oversaturated conditions of the work zones, and they generally underestimated the queue lengths [9].

In 2003, research done by Kaja-Mohideen, Chitturi, and Benekohal, examined QUEWZ-98, FRESIM, and QuickZone to estimate queue lengths and delays at work zones [1]. This research used field data

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gathered from eleven interstate work zones to determine which program gave the most accurate estimate. This research found that QUEWZ overestimated speeds due to an outdated speed-flow relationship, and underestimated queue lengths. FRESIM was found to overestimate speeds in the work zone, and the queue lengths were overestimated in some cases, while underestimated in others. QuickZone underestimated both the queue lengths and delay. The reason QuickZone was found to underestimate the delay was that it did not consider delay due to lower speed limits in the work zone even for under saturated conditions. The conclusion of this research was that none of the analysis tools gave a reasonable and consistent representation of the observed field data [1]. During the course of this research, a survey was sent to all state DOTs. Within this survey, questions were asked about analysis tools used for work zone impact estimates and the satisfaction with those programs. It was found that the most common analysis programs for capacity estimation were the HCM, HCS, and QUEWZ. The most common tools used for estimating queue length and delay were QUEWZ, QuickZone, and the HCS. It should be noted that the survey respondents were generally not satisfied with the analysis tools they used [1].

In 2004, research was done by Harvey, Lee, and Mun, which evaluated the impact of construction work on a high volume urban freeway [7]. One of the objectives of this study was to utilize microscopic simulation programs to model construction closure scenarios and compare the simulation results with data collected in the field. Traffic simulation models used in this study were PARAMICS and MITSIM. This study found that the overall results of the simulation programs were consistent with the observed traffic data. Due to the large size of the network, there was some difficulty encountered in the calibration of the model. However, it was determined that using microscopic simulation programs with an increased skill in calibration and modeling effort would provide useful information in developing efficient TMPs in the future [7].

2.4 Selected Analysis Tools

Three traffic analysis tools were used for this research. Two microscopic simulation models, Dynasim and VISSIM, were analyzed and compared with QuickZone, which is a sketch-analysis tool. This section will provide discussion about the tools used in this research, and will give a description of each.

2.4.1 QuickZone

QuickZone was developed by the FHWA to address the need for an analysis tool capable of estimating the delays in work zones. QuickZone uses a Microsoft Excel program to quantify queue lengths, delays, and user costs associated with a work zone. Because QuickZone operates within Microsoft Excel, the computing requirements are relatively minimal.

QuickZone Version 2.0, the most recent version of the program, is used in this research. The program has four major categories: Input Data, Program Controls, Output Data, and Save/Open [13]. A separate program contains a graphical user interface that allows users to draw the network. This feature allows a much faster data entry process since each separate node and link attribute is automatically entered from the constructed network. There is a size limitation for QuickZone, however, as the maximum number of nodes that can be used is 100, with a maximum number of 200 links [13].

Four main data components must be considered for a QuickZone analysis. These components, along with a brief description are listed at follows: 1) network data; 2) project data; 3) travel demand data; 4) corridor management data [13]. The network data required are essentially the node and link attributes of the network. The nodes in QuickZone represent either the intersection of two or more links or the end of a link. The links within QuickZone represent sections of roadway, characterized by mainline, work zone, detour, or ramp; which have various attributes such as length, number of lanes, capacity, free-flow speed,

and jam density. The project data required by QuickZone entails a description of the work being done such as the starting date, duration, project phasing, and capacity reduction as a result of the work zone. Travel demand data is essentially the AADT, seasonal variations, and time-of-day variations in traffic flow. The corridor management data required for QuickZone involves congestion mitigation strategies and the resulting capacity changes.

The results available from QuickZone are queue lengths, delay, travel behavior, and user costs. QuickZone operates using a simple deterministic queuing model [13], so performing the analysis of a work zone is relatively quick, as there is no simulation that must be run. All the results are generated within the program and are displayed as Excel workbooks.

2.4.2 Dynasim

Dynasim is a microscopic traffic simulation program developed by Citilabs. It is the microsimulation component of the Cube traffic analysis suite, which consists primarily of travel demand forecasting software programs. The unique features of Dynasim are its integration with Cube and the scenario-based simulation capabilities. Dynasim is a relatively new microscopic simulation program, in comparison with other models such as VISSIM. The most recent version, which was used for this research is 2.0.13.

Dynasim operates as a microscopic, stochastic, and event-based simulation model [6]. The stochastic and event-based characteristics are due to the statistical distribution of the model's parameters and the effect of the modeled environment on the vehicles. Dynasim uses a combination of scenarios and layers to create a network model. The layers allow for changes to be made to the network without having to re-code the entire model. Dynasim scenarios are a subset of the available layers within the network and are classified into vehicle flow scenarios, signal scenarios, public transport scenarios, and network scenarios [6].

A Dynasim network model is constructed using layer-based trajectories (links). The links are drawn using a background map or aerial photo as a reference. Each link has specific attributes and must be assigned to a particular layer. There are two modes to consider when constructing a Dynasim network, geometric and logical. The links and attributes are added in the geometric mode, which then must be modified in the logical mode to specify link connections, origins, and destinations. If a link is added or deleted in the geometric mode, the user must also reflect that change in the logical mode of the program.

The vehicle movement through the network is a product of the origin/destination matrix and the vehicle/driver characteristics. There are several vehicle categories available for the user to choose, each having its own specific adjustable parameters, such as speed and minimum/maximum acceleration/deceleration. Dynasim's parameters governing driver behavior fall into two main categories, lane-changing parameters and car-following parameters. The lane-changing parameters within Dynasim depend on the type of link on which a vehicle is traveling. Multilane weaving sections are the only type of link that allows lane-change movements. The lane-change maneuver depends on a user-defined distance in which a vehicle must change lanes. As a vehicle approaches the end of the allowed lane-change distance, the urgency of the lane-change is increased until the driver must come to a stop and force a lane-change. Car-following behavior is also a driver characteristic defined primarily by gap-acceptance and headway parameters. These parameters largely determine the difference between "passive" and "aggressive" drivers. In addition, the intersections and merge areas within Dynasim are governed by priority rules. Priority rules establish a hierarchy of vehicle movements based on right-of-way.

The data are collected within the network during the simulation at user-defined locations. The data are compiled after the simulation is completed and is available within Dynasim without any post-processing requirements. In addition, Dynasim has a feature that allows multiple simulation runs, which may be

necessary to obtain a statistical convergence of the results. This feature accounts for the randomness of the simulation and allows for greater accuracy.

2.4.3 VISSIM

VISSIM is a stochastic, dynamic, microscopic simulation program developed by PTV [15]. A VISSIM network is constructed using link-connector logic, which simplifies the coding process. The simulation within VISSIM operates on a user-defined time-step, which can be up to one tenth of a second. This allows simulations to run faster than real-time.

The computing requirements for VISSIM are relatively high, especially for large networks. VISSIM has the capability to import networks from other traffic analysis programs like Synchro, which makes it much easier to model an existing network. In addition, the VISSIM program has been in existence for a relatively long time, and has been continually updated with new features. The current version of VISSIM used for this research was version 4.30. The 3-D modeling features of VISSIM are extremely sophisticated and allow for an export to a graphics software package, which allow users to add a greater level of detail to the model.

The modeling of intersection control in VISSIM can be done using various types of signal control logic, which is built into the software program [15]. The intersection areas in VISSIM can be controlled by either priority rules, which determine the vehicle movements based on right-of-way, or by defining conflict areas, which allows the drivers to determine when to move through the intersection or merge area by observing other vehicles in their proximity [15].

A VISSIM network is created by drawing links and connectors and assigning the corresponding attributes such as speed, number of lanes, lane width, etc. All the network attributes necessary for the model are then added to the links and connectors, such as vehicle detectors, signal stop lines, priority rules, and vehicle inputs. VISSIM also requires the assignment of driver behavior parameters to obtain accurate simulation.

VISSIM contains several driving behavior parameters that dictate the movement of vehicles through the network. The four main categories of driver behavior are car-following, lane changing, lateral, and signal control. Car-following behavior is defined by two models, Wiedemann-74 for urban traffic simulation and Wiedemann-99 for freeway traffic simulation [15]. The Wiedemann-99 model was the primary model for this research. The parameters within the Wiedemann-99 model is listed as follows: [15]
1) CC0 – standstill distance, which is the desired distance between stopped cars
2) CC1 – headway time, which is the desired time that a driver wants to keep from the preceding vehicle
3) CC2 – following variation, the additional distance from the desired safety distance that a driver allows before intentionally moving closer to the preceding vehicle
4) CC3 – threshold for entering 'following,' which controls the start of the deceleration process
5) CC4 and CC5 – following thresholds, which define the sensitivity of reactions to the acceleration and deceleration of preceding vehicles
6) CC6 – speed dependency of oscillation, which define the distance of a vehicles speed oscillation while following another vehicle
7) CC7 – oscillation acceleration, which defines the acceleration of a vehicle during the oscillation process
8) CC8 – standstill acceleration, which defines a driver's desired acceleration when starting from a stop
9) CC9 – acceleration at 80 km/h, which is a driver's desired acceleration when traveling at 80 km/h

The lane-changing parameters used by VISSIM are functions of the deceleration, distance, and headway of the vehicles in proximity to each other. The lateral driving behavior depends on parameters such as vehicle position at free flow and vehicle class. The signal control parameters define the driver's reaction to a yellow light, and are a function of the driver's 'awareness.'

There are several vehicle characteristics that can be defined within the model, and the vehicles in the network are a result of a statistical distribution of the selected vehicle types. The combination of the various driver behavior parameters and vehicle characteristics produce a highly complex model. However, due to the number of parameters that can be changed within the model, a significant amount of time is required for an accurate calibration.

To account for the stochastic nature of the microsimulation program, it may be necessary to run several simulations before the convergence of results is achieved. To address this issue, VISSIM has a feature that allows multiple runs to be conducted. Before the simulation is run, the user can select the data needed from the model.

2.5   Summary

The literature review done for this research highlights the need for accurate and practical traffic analysis tools. In light of the requirements of the Work Zone Safety and Mobility Rule, the use of traffic analysis tools is paramount for implementing transportation management plans and conducting work zone assessments. However, care must be taken to insure that the traffic analysis tool used has the capability to provide accurate results. This depends primarily on the user's understanding of the methodology of how traffic analysis tools operate.

3. METHODOLOGY

This chapter describes the methodology followed in this research in order to accomplish the research objectives. The first section provides a detailed description of the work zone, and uses a case study to illustrate the methodology. The second section outlines the data collection process, including data collection systems, data collection points, and data collection periods. The third section explains the development of the case study network consistent with the requirements of the three modeling tools used, i.e., Quickzone, Dynasim, and VISSIM. The fourth section illustrates the calibration of each model to reflect local conditions. The fifth section outlines the analysis scenarios included in the methodology. Figure 3.1 illustrates the overall methodology followed during the course of this research.
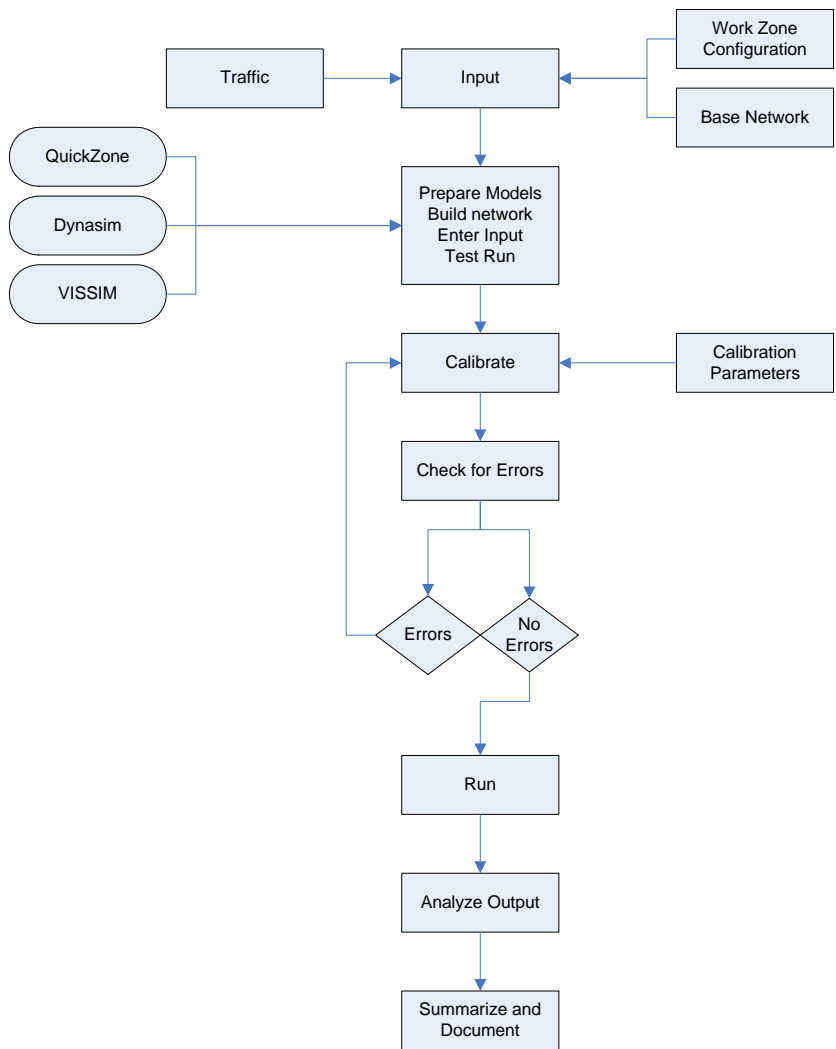
Figure 3.1 Research Methodology

3.1 Case Study Description

The case study utilized in this research consists of a major work zone located along Interstate Highway 29 through Fargo, ND. A 3.7-mile section of I-29 was under construction from March 13 to September 18, 2006. The work involved the demolition and re-construction of the northbound direction of the interstate, along with the addition of a third lane. The work zone stretched from Main Avenue to County Road 20, north of Fargo.

An additional lane was constructed from Main Avenue to 12th Ave. N. The construction work also involved demolishing a major overpass at 19th Ave. N. and re-constructing the bridge with the addition of new access ramps. The access ramps at the interchange of 12th Ave. N. and I-29 were also re-constructed, and a new northbound on-ramp was added at this location. Figure 3.2 shows an aerial photo of the study area, including the work zone location.

3.1.1 Location Characteristics

Traffic on I-29 was impacted by several areas in close proximity to the work zone. The campus of North Dakota State University is located on 12th Ave. N., approximately one-mile east of the interstate. When classes are in session, traffic increases at the interchange of 12th Ave. N. and I-29. The university also has several large venues, such as the Fargodome and Newman Outdoor Field. Event traffic for these locations has a significant impact on interstate traffic.

Another traffic generator on 12th Ave. N. is the Stamart Truck Stop located in the southeast quadrant of the interchange of I-29 and 12th Ave. N. The volume of large trucks that use this truck stop has a major impact on traffic flow, especially at the signalized intersection of 12th Ave. N. and 35th St., which is just east of the I-29 interchange. In addition, a large industrial park with several significant traffic generators lies to the west of I-29 and also impacts traffic on the interstate. The 2005 average daily traffic (ADT) for 12th Ave. N. at I-29 was 19,300 vehicles. Main Avenue, which is located on the south end of the work zone, is a major east-west arterial in Fargo. The 2005 ADT for Main Ave. near I-29 was approximately 21,700 vehicles. The ADT for I-29 in 2005 was approximately 41,000.

Figure 3.2 Work Zone Overview

3.1.2 Work Zone Description

Three major interchanges were affected by the work zone, which include the interchanges at Main Avenue, 12th Ave. N., and 19th Ave. N. The 19th Ave. interchange was closed for a considerable period during the construction process. The overpass was demolished and re-constructed, and new ramps were added to the interchange. This had a major effect on traffic in north Fargo, as detour routes had to be utilized during this time period. The 12th Ave. N. interchange was also under construction, with the addition of a northbound loop ramp from 12th Ave. N., but the interchange remained open for the duration of the construction. The Main Avenue interchange located at the south end of the work zone did not have any construction work but was impacted by the reduced capacity of the interstate.

Traffic was head-to-head on the southbound side of I-29 during construction. Traffic utilizing the interchange ramps was serviced via crossovers that were constructed in 2005. There was only one northbound lane through the work zone, and one southbound lane from County Road 20 to 12th Ave. N. The southbound on-ramp at 12th Ave. N. provided an auxiliary lane to Main Avenue to help alleviate congestion at this location.

Three major construction phases were identified for this project. The first phase lasted from March 15, 2006 until April 15, 2006. The duration of phase two was from April 15, 2006, until June 16, 2006. Phase three was from June 16 until September 18, 2006, which was the completion date for construction. The phase descriptions are listed as follows:

- 1A) No northbound closures ─ right southbound lane closed for striping
- 1B) Traffic reduced to one lane in each direction ─ two southbound lanes from 12th Ave. N. onramp
- 2) Traffic operates head-to-head via crossovers ─ Two southbound lanes from 12th Ave. N. on-ramp
- 3A) Traffic reduced to 2 lanes NB and SB ─ One SB lane from CR 20 to 12th Ave. N. and one NB lane from 19th Ave. N. to CR 20
- 3B) One SB lane from CR 20 to 12th Ave. N.

3.2   Data Collection

Field data for this study were collected using radar and video traffic data collection technologies. Five Wavetronix SmartSensor radar sensors were placed at strategic locations throughout the work zone. The Advanced Traffic Analysis Center (ATAC) Traffic Data Collection System (TDCS) using Autoscope video detection was placed at merge areas in the work zone. This section will provide details about the specifications and operational characteristics of the two data collection technologies used for this research.

3.2.1. Data Description

Data collected for this research consisted of lane-by-lane vehicle volumes, speeds, and classification. These types of data are among standard traffic data collected by most transportation agencies using commonly available data collection technologies. Vehicle classification data consisted of three length classes: small (0 – 30ft.), medium (30ft. – 40ft.), and large (greater than 40ft. in length). For simplicity, the medium and large vehicles were combined for the truck classification. This simplification was motivated by the capabilities of the radar-based sensors used in the study.

3.2.2 Data Collection Devices

Gathering the required data was an important aspect of this research. Due to the lack of previous data for I-29, it was necessary to collect data for both normal traffic conditions prior to construction, as well as for traffic conditions during construction. The data provide a baseline for comparisons with the analysis tools, as well as providing validation for the models.

The primary data collection device used for this research was the Wavetronix SmartSensor 105, a non-intrusive traffic detector that uses digital-wave radar to detect vehicles passing through its radar beam. The SmartSensor has a range of 200 feet and collects traffic volume, speed, occupancy, and classification for up to eight lanes of traffic [16]. Vehicle classification is user-defined and can be divided into three length-based classes. Speed data collected by the SmartSensor is a running average of 16 vehicles, independent of the time period. The speeds are recorded at the end of each data interval and are stored accordingly. The SmartSensor is capable of collecting data on a lane-by-lane basis, providing directional volumes, classifications, and speeds.

The SmartSensor can be operated from a side-fire position, which allows for a safe and relatively quick deployment. One unique feature of the sensor is "auto-calibration" in which the sensor detects passing cars and assigns the respective lanes. Although the SmartSensor has an auto-calibration feature, fine-tuning was required to improve the accuracy of the sensor. The SmartSensor has an internal data storage capacity of 2,976 time intervals, with a minimum time interval of five seconds. The sensors were powered by 12-volt marine deep-cycle batteries, which were changed every time the sensor's data were downloaded (every three days).

Portable mounting towers were designed and built by ATAC staff to allow for field deployment of the SmartSensor. Five towers were built that can be completely disassembled for storage and transport in a 6'x10' cargo trailer. Each tower is adjustable for height and terrain variation, depending on the sensor's height/offset requirements. The structures also have storage compartments, which were used for protecting the batteries.

The secondary data collection system used in the study was ATAC's TDCS. The TDCS uses a 6'x10' cargo trailer, which houses a 42-foot extendable pneumatic mast. Two pan-tilt-zoom (PTZ) cameras can be mounted on the mast for surveillance and data collection. The entire system is self contained and is powered by a gas generator. The TDCS uses Autoscope machine-vision video detection technology, which processes the video signal sent from both cameras. The system is used primarily for data collection via video recording at various sites.

3.2.3 Location of Data Collection

The SmartSensor radars were placed at both the entrance and exit of the I-29 work zone, and between every interchange within the work zone. This was done to monitor the changes in traffic volumes and speeds throughout the work zone. The sensor locations were as follows:
1) Sensor 1 – 3500-ft north of CR 20 off ramp
2) Sensor 2 – Between 19th Ave. N. and CR 20
3) Sensor 3 – Between 12th Ave. N. and 19th Ave. N.
4) Sensor 4 – Between Main Ave. and 12th Ave. N.
5) Sensor 5 – Between 13th Ave. S. and Main Ave.

Each sensor was placed on the west side of the interstate, with a 50-foot offset from the shoulder of the roadway. The offset was provided to ensure that the sensors remained out of the clear zone. The sensors were mounted at a height of 30 feet, as specified in the installation manual for the selected offset. Figure 3.2 illustrates the location of the work zone in relation to the Fargo-Moorhead area, and the location of the sensors that were used for data collection.

3.2.4 Data Collection Period

Data collection for this project began one week prior to the start of construction (March 6, 2006), as soon as weather allowed, in order to capture a snapshot of normal traffic patterns. The data collection continued through each phase of construction and was completed on October 31, 2006. This allowed for over a month of data to be collected after the construction was completed.

The data for each sensor were stored in Five-minute intervals, equivalent to three days worth of storage. These intervals allowed for a relatively high data resolution, which was necessary to monitor changes in vehicle speeds and densities. Data from the sensors were downloaded every Monday, Wednesday, and Friday to maximize the battery life of each sensor. Because some of the construction phases required a shift in traffic, the sensors were re-calibrated accordingly. All the sensor data were stored in a Microsoft Access database and organized according to each sensor and the month in which the data was collected.

3.3 Model Network Construction

The case study network used in this research consisted of an eight-mile by three-mile section of North Fargo along I-29. The network is bound by I-94 in the south, County Rd. 20 in the north, 45th St in the west, to 25th St. in the east. There are 41 intersections in the network (29 signalized and 11 unsignalized). Only the major routes were used in the network to minimize the complexity of running the various models. The VISSIM network contains approximately 1,400 links and connectors while the Dynasim network contains approximately 3,000 links and connectors. The difference in the number is due to how the networks were constructed and the inherent difference between the two models. The QuickZone network contains 29 nodes and 64 links.

Each analysis tool used in this research had specific requirements for building the model network. To maintain analogous characteristics between the two microscopic simulation models, an existing Synchro network was used as the basis for the network construction within each model. The Synchro network contained the existing geometry and signal timing information, which was then exported to the microscopic simulation models. This section will provide a description of the network construction process for each analysis tool.

3.3.1 QuickZone

Because it is a sketch-analysis tool, QuickZone is relatively simple to use. The construction of the network was straightforward, and it only took a few hours to complete. There were two main steps for creating the QuickZone network. The first step was to draw the links and nodes in reference to a background image. The second step was to enter all the information required by the program for the analysis. Six link types can be used in QuickZone: mainline, work zone, detour 1, detour 2, ramp, or blank. [13]

QuickZone includes a graphical user interface, called network editor, which allows the user to place nodes and links on a background image [13]. When the nodes and links are placed in the network editor, they are assigned x-y coordinates based on where they are drawn. After all the nodes and links were

placed in the network editor, attributes were then added for each link, which included the number of lanes, capacity, length, free-flow speed, jam density, direction, and type of link [13].

After the network was constructed, the information regarding traffic patterns and flows was entered. The inbound and outbound average daily traffic (ADT) used for the network was taken from the SmartSensor data, which were 32,000 vehicles at the location of the work zone. Additional data, such as the project description and user costs, were also entered into QuickZone. The user cost data entered into QuickZone were taken from the socioeconomic data used for the Fargo-Moorhead transportation planning model.

3.3.2 Dynasim

The Dynasim network construction process was the most difficult of the three analysis tools since the version of Dynasim used did not support a direct Synchro network import. The only available import capability was for Cube, Citilabs' transportation planning software. To make use of the Synchro network, it was imported into Cube and then exported to Dynasim.

Once the Dynasim model was successfully imported from Cube, several parameters within Dynasim had to be adjusted. The signal control plans for each signalized intersection were inspected and adjusted to reflect the corresponding Synchro network. Additional network parameters (data collectors, priority rules, lane-change distributions, etc.) were also examined. All the necessary modifications were then made to the network according to the Dynasim reference manual.

Dynasim operates using two types of input, geometric mode and the logic mode, which can be thought of as layers in the network [6]. The first "layer" to which a majority of the attributes are added is the geometric mode. This view shows the links and connectors along with their associated attributes, such as intersection control, priority rules (give-ways), data collection points, lane-change distribution points, etc. The second "layer" is called the logic mode. The logic mode tells the simulation how vehicles move through the network by connecting vehicle entry points to links and connectors in the network, which are then connected to the exit points. Every major change within the Dynasim network (i.e. modifying links) had to also be replicated in the logic mode. For example, if a link was deleted in the network using the geometric mode, it was then necessary to switch to the logic mode and re-connect the links that were broken.

Eventually the major errors were corrected, and the model ran successfully using test vehicle volumes. The test volumes were used to determine if there were any errors present within the model. After a simulation was run, the error file was observed and each error was fixed in the network. When the errors were addressed, the simulation was run again. This iterative process was very time consuming, considering a one-hour simulation took approximately 24-hours to complete.

3.3.3 VISSIM

Construction of the VISSIM model was done in a similar fashion to the Dynasim network. However, VISSIM has the capability to directly import a network from Synchro [15]. Once the network was imported, it was adjusted to represent existing conditions. This was done by importing a background image to which the network elements could be referenced. The network adjustments in VISSIM involved the inspection and modification (when necessary) of the links/connectors, signal timing plans, vehicle detectors, speed decision areas, reduced speed areas, priority rules, etc. [15].

Once all the modifications were made within the VISSIM network, test vehicle volumes were entered and data collection points were added on each entering link, to major arterial routes in the network, and along I-29 where the sensors had been deployed. After the network construction was complete, the simulation

was run. The error file was checked after each simulation, and the errors were addressed. This process was repeated until the simulation ran without any significant errors. Figure 3.3 shows the completed VISSIM network that was used for this research. The Dynasim network that was created looked similar to the VISSIM network.

Because Dynasim operates dynamically using an origin-destination (O-D) matrix, the VISSIM network was constructed in a similar fashion. Instead of using vehicle entry points and routing decisions to move the vehicles through the network, the network in VISSIM was modeled to run in a Dynamic Traffic Assignment mode. This allows VISSIM to use an O-D matrix to allow vehicles to choose the best route through the network based on congestion, travel time, and costs associated with each link. The O-D matrix for both Dynasim and VISSIM was obtained from the Fargo-Moorhead transportation planning model.

Figure 3.3 VISSIM Network

3.4   Model Calibration

The calibration of the analysis tools used in this research is a critical aspect of the comparison. Each tool has different characteristics that had to be examined. The calibration of the models was accomplished using two distinct data sets: baseline data and work zone data. The microscopic simulation models were calibrated to the SmartSensor data for the interstate sections in the work zone. Then the data for work zone scenarios modeled by both VISSIM and Dynasim were compared with the data collected during construction to validate the models. This section will discuss the calibration procedures for each of the three analysis tools.

3.4.1 QuickZone

Due to its nature, the QuickZone network did not require a calibration in the traditional sense. However, the network was simplified from its original construction to concentrate on the analysis of the interstate section. The QuickZone analysis process required the input of specific data (volumes, capacity, user costs, etc.) to produce results. This straightforward approach eliminates the need for any type of calibration. The network used in this research can be seen in Figure 3.4.
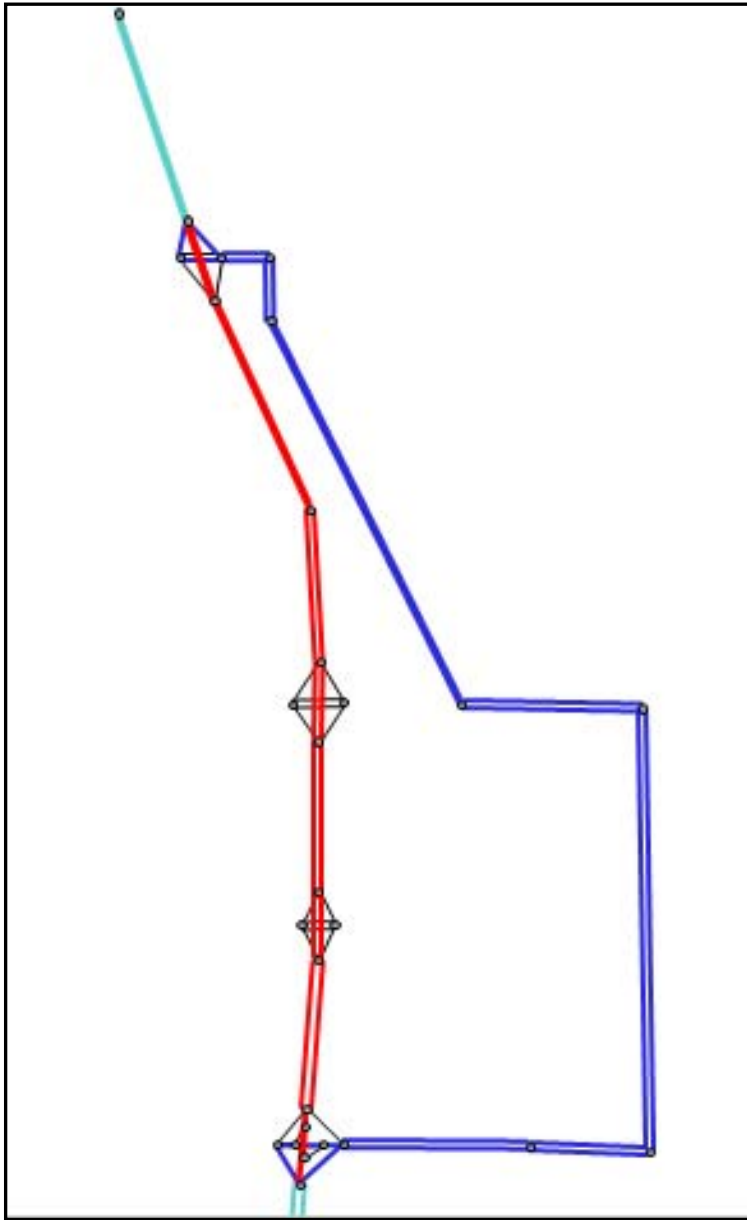
Figure 3.4 QuickZone Network

3.4.2 Dynasim

The calibration of Dynasim involves the adjustment of several parameters to obtain realistic vehicle movements within the network. Potential parameter adjustments include car-following, free-flow acceleration, headway threshold, reaction time, and lane-change behavior. These parameters are adjusted so the volumes on the interstate section resemble the ADT calculated by the F-M transportation planning model.

During the course of this research, Dynasim proved impractical for analyzing the network with the proposed methodology. Due to the limited literature on Dynasim and its capabilities, it was not known exactly what the limits to Dynasim were. The main reasons why Dynasim was incapable of completing the analysis of this network were due to its lack of dynamic assignment capabilities and lack of sufficient data output files. The details regarding why Dynasim could not be used for this study will be discussed in Section 4, but it should be noted that an operational network was constructed.

3.4.3 VISSIM

Calibrating the VISSIM network, particularly using dynamic traffic assignment, was a fairly complex process. The initial calibration of VISSIM involved calibrating the network to the base-case (pre-construction) scenario. After the base-case network scenario was calibrated, it was used as a baseline to calibrate the work zone scenario.

Due to the size of the network, it was required to use the model's dynamic traffic assignment capabilities. As stated previously, dynamic assignment is a function that allows the model to find the best paths from each origin to destination taking into account several factors such as congestion, travel time, and distance. Because the focus of this research was on the analysis of the interstate, the first step in calibrating the base case was to look at the north-south flows in the network, which consisted of I-29, 45th St. W., and 25th St. W. This was done by creating a screen line just south of Main Ave. The screen line created two super zones (north of Main Ave. and south of Main Ave.). The O-D matrix could then be looked at in four distinct areas: super zone 1 flows (vehicles staying north of Main Ave.), super zone 2 (vehicles staying south of Main Ave.), southbound flows (vehicles travelling from super zone 1 to super zone 2), and northbound flows (vehicles traveling from super zone 2 to super zone 1).

The base case scenario began with the original O-D matrix, which was adjusted incrementally and included several steps outlined as follows:
1) Determine the total entering volume at each zone (rows of the O-D matrix) and compare them to the required volumes for that link, which were based off the ADT.
2) Decrease or increase row volumes by a weighted percentage according to the target volumes.
3) Run a dynamic assignment and evaluate the results of the converged network.
4) Determine the volumes to be increased or decreased in each super zone.
5) Decrease/increase volumes in each super zone and distribute them (northbound or southbound) according to a weighted percentage.
6) Run a dynamic assignment and evaluate the results of the converged network.
7) Manually adjust the O-D matrix based on the results of the converged network as well as the simulation's animation.

The method of adjusting the O-D matrix began by adding up each row (the entering volume at that zone) and comparing the sum to the required volume (based off the ADT for that link). Once all the rows were added up, the percentage difference from their respective target volumes were calculated. Volumes were then added or subtracted to the northbound and southbound flows according to a weighted percentage of the volumes in each respective O-D pair for that row. Figure 3.5 illustrates the O-D matrix that was used in the calibrated simulations and the sections that identify movements in the network.

		west of I-29						west of I-29						east of I-29				east of I-29				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0	53	53	0	0	0	0	16	5	2	1	3	28	31	75	469	8	87	0	0	52	102
2	13	0	25	0	0	1	2	5	1	1	1	1	1	1	1	2	1	1	0	0	3	8
3	6	10	0	2	0	1	1	2	1	1	1	1	1	1	1	1	1	0	0	0	1	2
4	0	0	2	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	15	0
5	0	0	0	0	0	0	0	1	1	1	1	1	2	109	1	8	2	8	34	57	0	0
6	0	0	8	0	0	0	0	2	0	5	9	7	55	2	2	166	3	9	63	0	7	4
7	0	0	9	0	0	0	0	1	0	5	9	6	371	129	202	1	233	90	50	0	6	4
8	10	1	24	1	1	1	1	0	0	8	20	20	142	17	20	221	472	85	48	64	203	7
9	1	1	1	1	34	1	1	0	0	0	0	0	0	36	54	469	36	799	7	233	116	1
10	1	1	1	1	1	1	1	0	0	0	1	8	0	1	25	5	0	1	1	1	1	1
11	3	1	365	1	1	8	90	16	0	26	0	0	0	0	9	178	13	42	1	28	2	1
12	3	1	1	1	1	4	12	11	0	92	0	0	0	0	21	160	6	11	8	10	3	1
13	128	4	1	1	13	4	283	15	0	9	0	0	0	0	81	169	47	79	117	28	26	18
14	11	1	1	1	8	1	121	12	81	13	0	0	0	0	176	137	63	133	41	4	23	1
15	44	2	1	1	14	2	42	13	136	136	10	34	80	240	0	0	40	13	27	1	4	1
16	796	10	3	3	49	11	427	126	1474	73	60	91	275	134	0	0	1	244	109	1	1	1
17	16	2	1	1	11	2	54	83	0	0	0	0	1	3	0	0	0	445	9	1	1	1
18	102	12	4	3	14	5	608	1	15	16	20	36	32	175	7	1	387	0	20	0	43	5
19	8	1	11	8	10	10	10	438	24	5	2	9	16	160	18	5	158	3	0	0	11	0
20	2	0	0	0	20	1	15	55	166	31	39	36	29	50	50	50	200	0	0	0	0	0
21	47	30	14	46	0	5	10	112	25	13	1	5	31	18	5	450	1	50	31	0	0	121
22	45	81	61	0	0	1	2	27	7	1	1	1	16	1	1	7	1	2	0	0	7	0

Northbound
Southbound
Superzone 1
Superzone 2

Figure 3.5 O-D Matrix

After each change to the network or O-D matrix, a multi-run simulation had to be conducted for the network to reach a convergence. After the network reached convergence, which took an average of about seven hours, the output files were extracted and compared with the target data. Because any changes to the O-D matrix had a global effect, only one simulation iteration could be run at a time. All changes to the O-D matrix were based off the previous simulation in order to track the changes to the network output.

After the north-south flows in the network were adjusted row by row, the final step was to adjust individual O-D pairs to influence vehicle movements on 45th St. W., 25th St. W., and the interstate. This 'fine-tuning' of the network was the most time consuming part of the calibration process. Because of the dynamic nature of the traffic assignment in the network, one change to the network, whether it was a change in the geometry at one intersection or a change in volume of one O-D pair, had a ripple effect that could be seen throughout the network. An example of this would be increasing the southbound volume on 45th St. in the O-D matrix by 100 vehicles (in a single O-D pair), and seeing an increase of 139 vehicles in northbound volumes on 25th St.

Several model-specific calibration parameters in VISSIM were used during the course of calibrating the dynamic assignment simulations for this research. The main parameters used during the dynamic assignment phase of the calibration were the Kirchhoff exponent, the 'search new paths' parameter, the 'avoid long detours' factor, and adjustment of the evaluation interval for the simulation period [15]. Each of these parameters will be discussed in the following paragraphs.

The Kirchhoff exponent governs the attractiveness of the best path found during the dynamic assignment. According to PTV America, a Kirchhoff exponent value of four or higher will inhibit vehicles from using alternate paths between an O-D pair. In other words, more vehicles will stay on the best path found through the network. This is a critical parameter considering the size of the network in this study. Early on in the calibration process, before the parameter was adjusted, there would be several paths between origins and destinations, most of which did not seem practical. The initial value used was a 3.5, which was changed to a 4.5 for the final simulation iterations. After adjusting the Kirchhoff exponent, only the best paths (paths with the lowest cost) were used.

The parameter regarding the search for new paths in a dynamic assignment has four criteria, which can be selected by the user. The default option used for this network allowed the user to reject paths in the network with a total cost higher by a defined percent than the total cost of the best path. For this network,

a value of 10% was used as the cut-off value. This meant that any path with a cost higher than 10% of the best path found through the network would be disregarded. It should be noted that the link cost calculated by VISSIM during a dynamic assignment is a weighted sum of the travel time, distance, and financial cost of a link in the network [15].

The parameter that references the avoiding of long detours was also used to force vehicles to use the best paths through the network. The default value for this parameter is 2.5, which means that any detour or alternate route between an origin and destination in the network greater than a factor of 2.5 would be rejected. This value was initially changed to lower values to observe the effect, and it was determined that the default value was sufficient.

The evaluation interval in VISSIM's dynamic assignment defines how frequently the simulation searches for paths through the network. Due to the dynamic nature of the simulation, the demand and capacity continues to change throughout the simulation time period. Because of the constant fluctuations, it becomes necessary for the simulation to frequently monitor the availability of feasible paths through the network [15]. During the initial calibration iterations, the evaluation interval was set to the same duration as the simulation period, which resulted in the simulation reaching a convergence before the best paths could be found. The reason for this was due to the number of vehicles on each path between an origin and destination and the simulation being unable to look for alternate paths before the convergence criteria was met. The evaluation interval was eventually changed to 900 seconds, which allowed the simulation to evaluate the condition of the paths and look for acceptable alternatives several times during each simulation.

Three global factors govern the convergence of VISSIM's dynamic assignment: Travel Time on Paths, Travel Time on Edges (links), and Volume on Edges (links) [15]. It is recommended in the VISSIM manual that only one of the three parameters be used, and it is suggested that the 'Travel Time on Paths' option be used [15]. The default value for the Travel Time on Paths is 15%, which means that between successive iterations during a Dynamic Assignment, if the travel times on all paths in the network are lower than 15%, the network will reach convergence. For this study, a value of 10% was used to increase the validity of the converged network.

The second phase of calibration required the adjustment of headway factors. VISSIM contains two types of car-following parameters that govern driver behavior in the network. These car-following parameters are the Wiedemann-74 and Wiedemann-99 behavior models [15]. The VISISM manual states that the Wiedemann-74 car-following model is recommended for use in urban settings, while the Wiedemann-99 car-following model is recommended for use on freeways. Since the focus of this research deals with work zones in an urban freeway section, only the Wiedemann-99 parameters were changed during the calibration process.

The Wiedemann-99 car-following model is defined by ten parameters that can be adjusted by the user. These parameters and their respective default values are listed as follows: standstill distance (1.5 meters), headway time (0.9 seconds), following variation (4 meters), threshold for entering 'following' (-8), negative 'following' threshold (-.35), positive 'following' threshold (.35), speed dependency of oscillation (11.44), oscillation acceleration (.25 meters per second-squared), standstill acceleration (3.5 meters per second-squared), and acceleration at 80 kilometers per hour (1.5 meters per second-squared). Each of these parameters can be adjusted to calibrate the simulation throughput [15].

The most effective parameter within the Wiedemann-99 car-following model was found to be the headway factor. Once the work zone scenario was created in the network, the headways for links within the work zone were adjusted incrementally until the modeled volumes on the interstate were close to the sensor data obtained from the actual work zone in the field. The headway that was used for the first

simulation was the default value of 0.9 seconds. Initial volumes in the work zone were 27% higher than the target volumes, which meant that the headways needed to be increased on those links, thereby decreasing the capacity of the work zone. Sequential dynamic assignment simulations were run with values of 1.5 seconds, 2.0 seconds, 2.5 seconds, and 3.0 seconds. After all the simulations were completed with the varying headway factors, the results were plotted, and it was observed that the target headway fell between a value of 2.0 seconds and 2.5 seconds, which are realistic values for headways. The process was then repeated using values of 2.1, 2.2, 2.3, and 2.4 seconds until the correct headway was found.

3.5   Analysis Scenarios

This section will provide a discussion of the analysis scenarios that were evaluated for this research. The analysis scenarios for this research used the PM peak period for both pre-construction conditions as well as the work zone conditions. The two main scenarios are the baseline or pre-construction scenario, in which the baseline calibration was conducted. The data obtained from the baseline scenario was then used as input into the work zone scenario. Comparisons were then done for the output of QuickZone and VISSIM using various measures of effectiveness (MOE). The measures of effectiveness that were used for this research consist of the vehicle throughput in the work zone, and the estimated queue length at the entrance to the work zone.

The QuickZone analysis was done using pre-construction data and evaluated the change in capacity when a work zone was created. The evaluation was fairly straightforward, and did not require calibration or the use of various scenarios. The evaluation and output depended primarily on the data that was entered into the network.

Three analysis scenarios were used for the VISSIM network. The first scenario was the baseline network, in which a majority of the calibration took place. This scenario was dependent on the existing (pre-construction) conditions, and the resulting calibrated path and volumes were used in the work zone scenarios. Figure 3.6 illustrates the methodology involved in the VISSIM modeling process.

Two work zone scenarios were used in this research. The first used a static traffic assignment to quantify the impact of the work zone on the network. Using the calibrated path and volume data from the baseline scenario, the only change made to the network was the reduction in capacity of the links within the work zone (representing the lane closure) and the associated speed reductions. This scenario was able to show how queue lengths, travel times, and delays differed from the baseline scenario assuming that no vehicles changed their route due to the presence of the work zone.

The final scenario used a dynamic assignment to evaluate how VISSIM rerouted traffic in the network as a result of the reduction in capacity because of the work zone. This scenario was created to observe and quantify how vehicles changed their path through the network (still using the same O-D data). Intuitively, it would make sense for the results to show a decrease in queuing at the work zone, a decrease in travel times and delay in the work zone, and an increase in overall network delay due to vehicles using detours around the work zone.
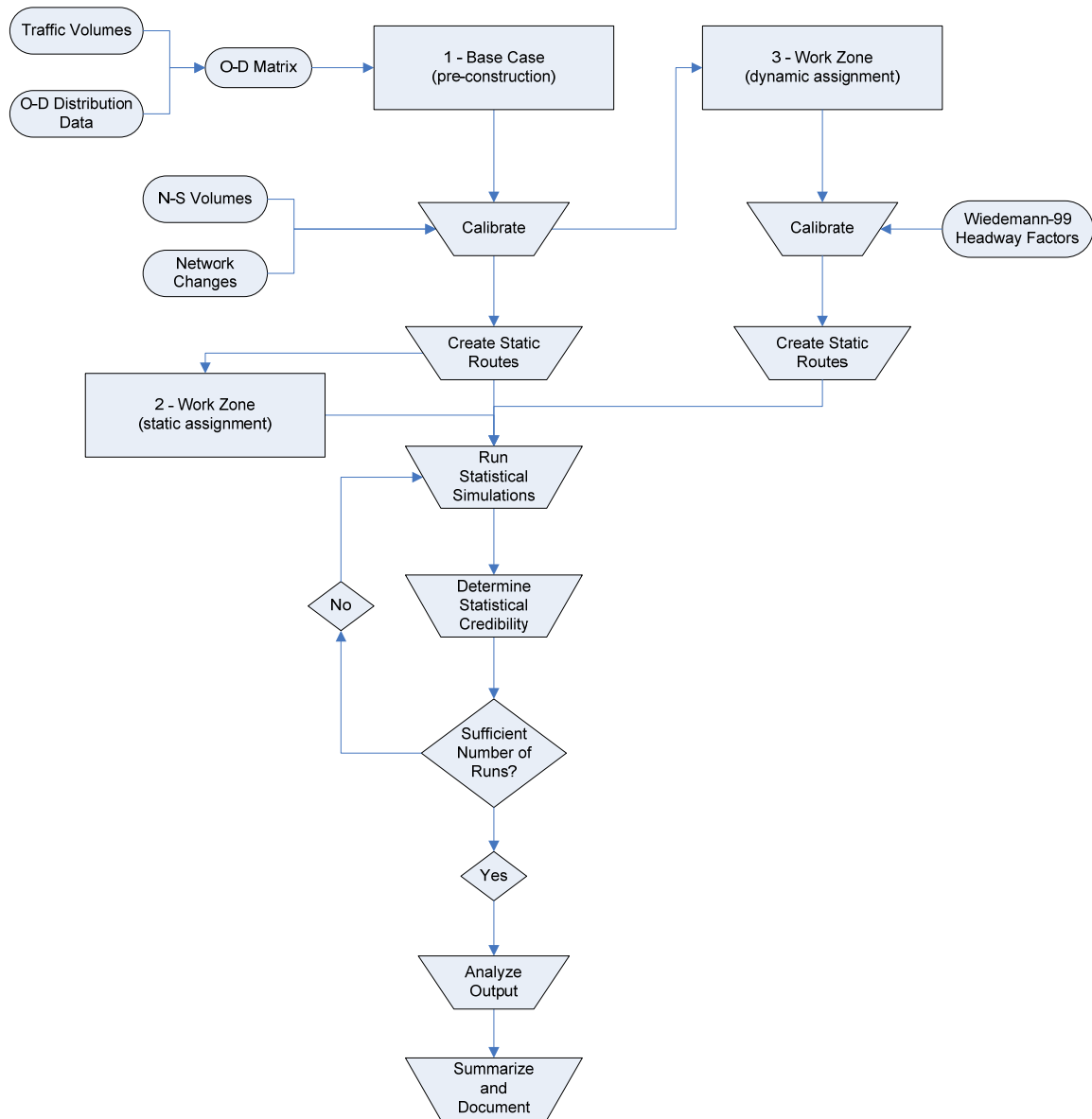
Figure 3.6 Microscopic Simulation Methodology

3.6   Analysis of Model Results

The MOEs for the microscopic simulation model were compared with the QuickZone analysis results. The results were not necessarily analyzed for accuracy, but were examined for the amount of variance between the tools. Other issues that are discussed in the results will be the compatibility of the software with other programs, computational requirements, user effort, and data requirements.

The analysis of the output, particularly for VISSIM, required the evaluation of the data's statistical significance. After each simulation analysis scenario was completed, static simulations had to be run to collect the output files corresponding to delays, queue lengths, travel times, and volumes. Due to the stochastic nature of VISSIM, running a static assignment will produce variances in the output. This is due to several factors that were previously discussed, but to obtain accurate data, several simulations had to be run.

For each VISSIM analysis scenario, 60 static simulations were done before the output was analyzed. After the simulations were completed, the output files were extracted and imported into Microsoft Excel. Once the data were organized according to output type, a statistical equation was used to determine if the number of simulation runs was sufficient. The statistical analysis was fairly straightforward and involved finding the sample size based on the average and standard deviation of the output as well as a specified confidence interval. The equation used for the analysis can be seen as follows:

$$n = \left\{ \frac{z_{\alpha/2} \times \sigma}{E \times \mu} \right\}^2 ,$$

where n = the required sample size, or number of runs needed, and

      $E = 10\%$, which corresponds to a 95% confidence interval.

4. RESULTS

This chapter summarizes the findings from the case study and evaluates the three analysis tools that were used. The first section discusses the issues regarding data requirements, modeling effort, and the comparison of the output of the software programs. The second section provides an overview of the contributions of this research. The final section in this chapter discusses the recommendations and future research.

4.1 Summary of Results

There were several findings from this study, which include not only the numerical output from the software tools, but also qualitative aspects such as data requirements of the analysis tools, modeling effort required, computational requirements, etc. As mentioned previously, the goal of the study was not to quantify the accuracy of various analysis tools, but to look at issues regarding the feasibility of their use.

4.1.1 Model Applications

Obtaining sufficient data is vital to conducting an accurate analysis of a transportation facility. The data requirements varied significantly among the three tools used in this research. QuickZone, which is a sketch-analysis tool, required basic data such as the ADT, daily demand factor (K-Value), capacity of the links in the network, proposed detour routes, speed limits, etc. Data requirements for VISSIM and Dynasim were considerably more extensive. Because of the nature of microscopic simulation models and their inherent complexity, they require more detailed data. Aside from the common types of data such as traffic volumes, speed limits, and lane/intersection geometry, they also require more detailed data such as signal timing information, priority rules, driving behavior, and vehicle path data. Modeling effort is also something that needs to be considered when determining what type of analysis tool to be used. The modeling effort is a result of the network coding, calibration, and computational requirements.

QuickZone was by far the easiest software program with which to work. The entire network was constructed, along with the data input, in a few hours. However, there are several drawbacks to using QuickZone for an urban interstate evaluation. The size of a QuickZone network is limited to 100 links and 200 nodes, which may be inadequate for certain work zone scenarios. In addition, QuickZone requires that the detour routes be specified. In an urban freeway setting, particularly where there are several interchanges within the work zone, modeling a static detour route may be insufficient, as drivers may chose several alternative routes around the work zone. Because QuickZone is essentially a macro embedded into Microsoft Excel, there was only one major software issue encountered during the course of this study. All the information in QuickZone needs to be saved within the program through the main menu. However, there are some modules which allow the user to save the file as an Excel worksheet. When this occurs, the macro changes and the network must be started over. This instance occurred a couple times during the data entry as a habit from using Excel.

The VISSIM network was imported from an existing Synchro network, and each link and intersection had to be evaluated and modified to replicate the existing conditions. Due to the size of the network and the need for a dynamic traffic assignment, the calibration process required an intricate knowledge of the software program. The learning curve for VISSIM, particularly for the dynamic traffic assignment, would make its use daunting for a novice user. The entire network construction, calibration, and simulation took approximately 960 hours. However, depending on the expertise of the user and type of network being analyzed, the time required could be reduced considerably. There are several reasons why VISSIM would

be ideal for use in analyzing an urban freeway work zone. Once the network is properly calibrated, the network can be easily modified to illustrate various alternatives. If various construction alternatives are being explored for a project using VISSIM, it would be fairly simple to model the actual work zone conditions as well. Once the initial network is constructed, it can be stored and updated, so when future construction projects are proposed, the work zone(s) can be easily added. The animation and graphic capabilities of VISSIM would also be useful in illustrating to the public and decision makers what to expect for a proposed road construction project. The animation provides a visual alternative to the quantitative output of expected delays, queue lengths, travel times, etc.

Dynasim was another microscopic simulation tool which was analyzed for this research. After constructing the network, it was discovered that Dynasim did not have the capability of running a dynamic traffic simulation. Although the traffic inputs required the use of an O-D matrix, the paths had to be defined through the network. After contacting a few individuals at Citilabs, information was obtained that clarified how the algorithms within Dynasim work. For each O-D pair, only one path can be defined. The process of defining a path through a large network can be fairly tedious, and involves prohibiting vehicles from using any link not on the pre-defined path. This is similar to routing decisions in VISSIM, except that when defining routing decisions, the user simply selects a start and end point at each junction that forces vehicles to use that route. The size of the network used in this study required a 22 x 22 O-D matrix, so it was not feasible to use static traffic assignment. Data output from Dynasim is limited to six output files (instant flow, maximum number, mean number, mean travel time, maximum speed, and mean speed). There were two issues observed with the Dynasim output files. First of all, they are in French, so a translation was needed to determine what the output files contained. The second issue was the lack of any text in the output files to explain what the numbers meant. There was a brief explanation of the output files in the manual, but there was no text that offered a translation of the output file names. There is currently no output available for measuring queue length in Dynasim, and there is no direct output for delay. Although Dynasim can operate as a stand-alone microscopic simulation program, it is not compatible with other analysis tools other than Cube, which is the planning model software program developed by Citilabs. This was an issue when trying to import a Synchro network. The Synchro network had to be first imported into Cube. This process generated several issues ranging from errors with the coordinate system, sensitivity of the text files generated by Synchro, and errors with reading the signal timing plans in a .CSV format. Eventually the network was imported to Cube and then exported to Dynasim.

This process caused additional errors ranging from signal timing plan errors to basic translation errors between Cube and Dynasim. There are, however, potential benefits to using Dynasim. If there is an existing Cube planning model, the network and corresponding path data can be exported to Cube. This would make the network construction much simpler, but static routes would still be used in the model. If the network is small enough so dynamic assignment wouldn't be required, Dynasim could be used for the evaluation. It was also discovered through correspondence with Citilabs technical support that a newer version of Dynasim is being produced that will have several upgrades, particularly additional output files such as delay and queue length.

4.1.2 Discussion of Results

This section will discuss and compare the output from the analysis tools used for this research. In addition, the results of the VISSIM calibration will be discussed. The MOEs that were compared were queue lengths, travel times, and delay.

The calibration of the VISSIM network was performed in two phases. The baseline network calibration involved adjusting the O-D matrix and making modifications (such as speeds) to the network. The calibration of the work zone scenario was done by adjusting the headways for vehicles within the work

zone. Figure 4.1 shows a graphical representation of the calibrated baseline network. The two calibration criteria discussed previously are highlighted. The primary calibration criteria were the northbound and southbound volumes from sensor 4 and sensor 5. This data represented the traffic volumes on the interstate. The secondary calibration criteria were traffic volumes at 25th St. W. and 45th St. W. These three locations comprised the north-south links in the network. After the network link volumes were sorted, they were plotted against the target volumes to determine how close they were. The calibrated network had traffic volumes within 2% of the northbound sensor 4 volumes, 13% of the southbound sensor 4 volumes, 6% of the northbound sensor 5 volumes, and 8% of the southbound sensor 5 volumes. The numerical results of the calibrated network can be seen in Figure 4.2. The calibrated network is denoted as Iteration 15. The following two iterations (16 and 17) illustrate how small changes to the O-D matrix have global effects on the network, as discussed in the methodology.
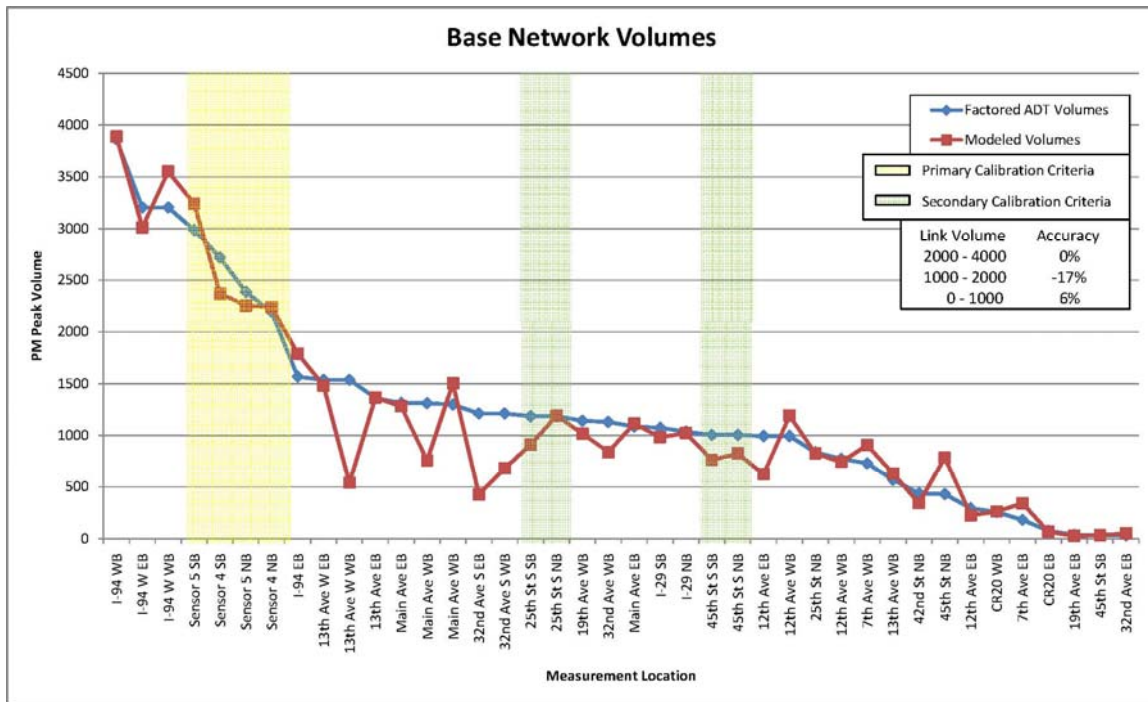

Figure 4.1 Baseline Network Calibrated Volumes

		Location	Target Volume	Iteration 15			Iteration 16			Iteration 17		
				Modeled	Difference	% Difference	Modeled	Difference	% Difference	Modeled	Difference	% Difference
Sensor Data (Primary)		Sensor 4 NB	2190	2237	47	2%	2215	25	1%	1960	-230	-11%
		Sensor 4 SB	2718	2371	-347	-13%	2369	-349	-13%	2374	-344	-13%
		Sensor 5 NB	2384	2252	-132	-6%	2187	-197	-8%	2075	-309	-13%
		Sensor 5 SB	2988	3242	254	8%	3364	376	13%	3301	313	10%
N-S Arterials (Secondary)		45th St S SB	1006	764	-242	-24%	888	-118	-12%	840	-166	-17%
		45th St S NB	1006	825	-181	-18%	874	-132	-13%	1007	1	0%
		25th St S SB	1187	913	-274	-23%	867	-320	-27%	875	-312	-26%
		25th St S NB	1187	1191	4	0%	1241	54	5%	1330	143	12%
				Best Results			Increased SB 45th St by 200 veh. from Iteration 15 (one O-D pair).			Increased SB 45th St by 100 veh. from Iteration 15 (one O-D pair).		

**Figure 4.2** Baseline Network Calibration Results

The results from the calibration of the work zone scenario in VISSIM can be seen in Figures 4.3 – 4.5. Figure 4.3 illustrates the modeled volume comparison with the target volumes for sensors 4 and 5. The primary criterion for this calibration process was the northbound sensor 4 volumes. It can be seen from Figure 4.4 that the optimal headway for volumes closest to the volumes at sensor 4 and 5 is 2.2 seconds. It should be noted that the southbound volumes at sensor 4 and 5 are largely unaffected by the variation in headways. Figure 4.5 illustrates the volume change according to the increasing modeled vehicle headways. The volumes at sensor 5 show a negligible deviation from the target volumes because vehicles are exiting the work zone at that location. One explanation for southbound volumes being high at sensor 4 could be due to congestion on alternate routes, which would make the interstate links more attractive regardless of the increased headways.
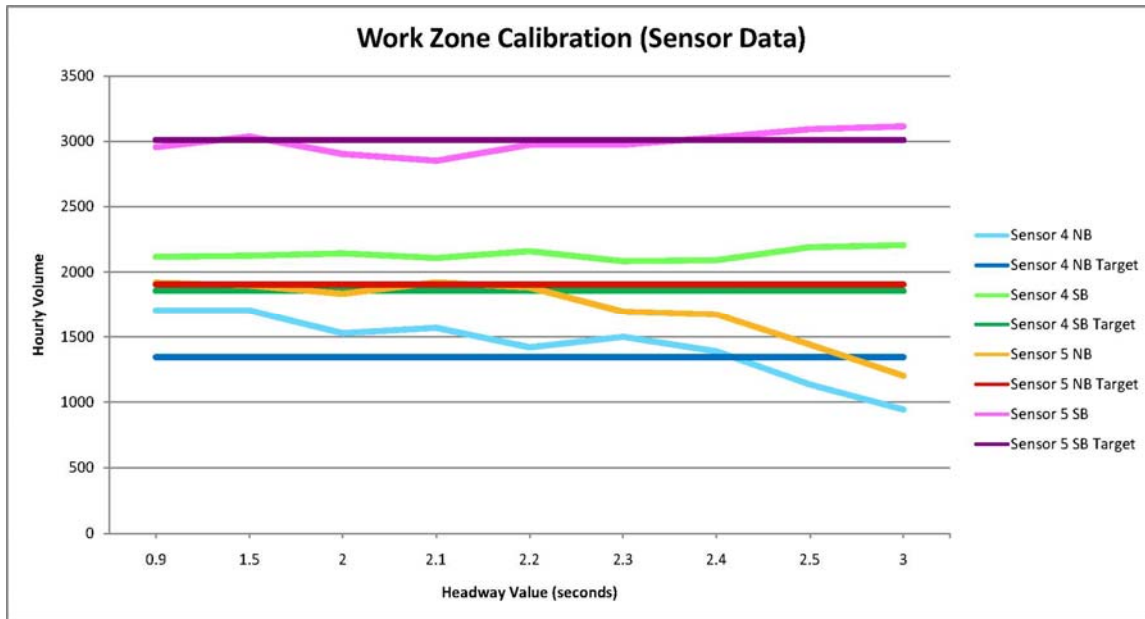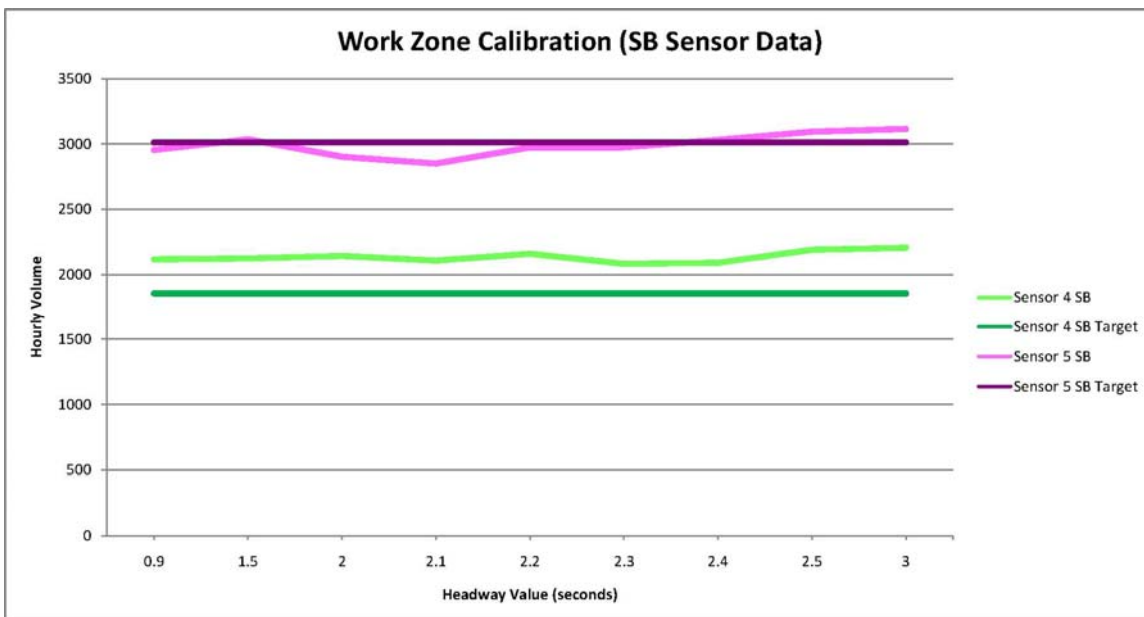

Figure 4.3 Work Zone Network Calibration (Sensor Data)

The output from QuickZone and VISSIM can be seen in Tables 4.1 – 4.5. The queue length output from the models can be seen in Table 4.1. The queue lengths generated by VISSIM's static assignment show a length of nearly two miles in the northbound direction. This length is reduced to 6,850 feet through the dynamic assignment. Queue lengths of this size would equate to a queue from Main Ave. down to the 17th Ave. S., overpass, which is a realistic length. Southbound queue lengths were relatively non-existent according to VISSIM. It should be noted that QuickZone did not estimate any queues for the PM peak period. However, queues were estimated for the AM peak period with average lengths of 3,380 feet in the northbound direction and 3,274 feet in the southbound direction (Table 4.2).
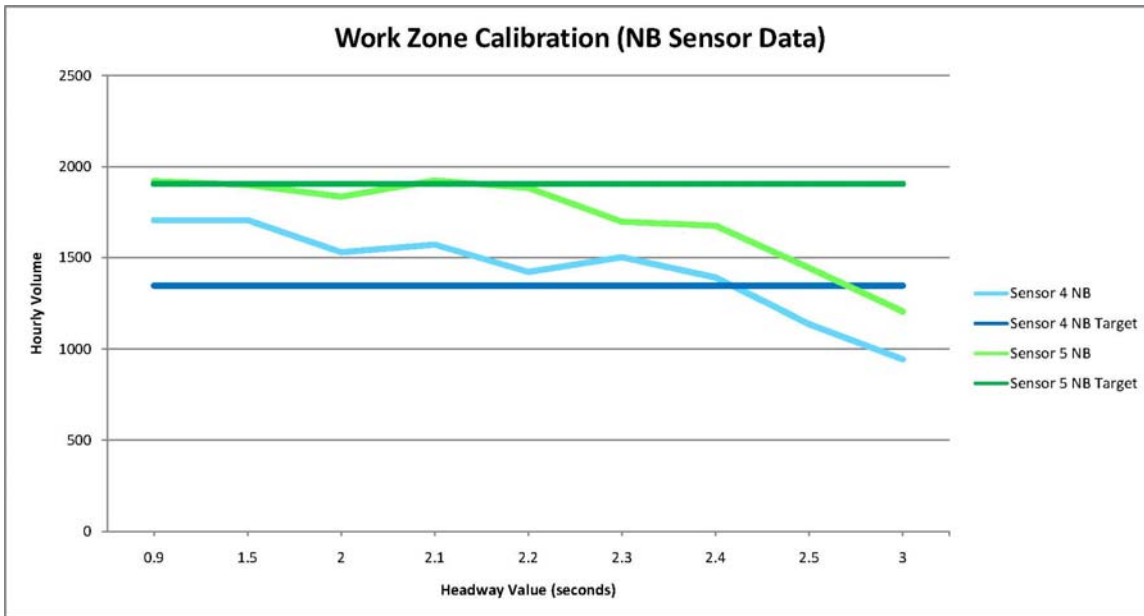
Figure 4.4 Work Zone Network Calibration (NB Sensor Data)

Figure 4.5 Work Zone Network Calibration (SB Sensor Data)

Table 4.1 PM Queue Length

PM Average Queue Length (ft)		
	NB	SB
QuickZone	0	0
VISSIM (static)	9,614	45
VISSIM (dynamic)	6,850	95

Table 4.2 AM Queue Length

AM Average Queue Length (ft)		
	NB	SB
QuickZone	3,380	3,274

The total travel times recorded for the work zone were similar between QuickZone and VISSIM. However, there was a discrepancy between the northbound travel times and the southbound travel times. QuickZone estimated northbound travel times of 9.6 minutes and southbound travel times of 15 minutes. The travel time was calculated for a span of approximately 6.5 miles, so a travel time of 10 minutes is equivalent to an average speed of 39 mph. Average speeds for the calibrated baseline network were approximately 59 mph, with an average northbound speed of 60 mph and an average southbound speed of 58 mph. It should be noted that the posted speed limit in the work zone was 40 mph from Main Ave. to approximately 0.5 miles north of 19th Ave. N., which then increased to 55 mph until the north end of the work zone.

Table 4.3 Work Zone Travel Times

PM Average Travel Time in Work Zone (min)			
	Total	NB	SB
QuickZone	24.6	9.6	15.0
VISSIM (baseline)	13.2	6.5	6.7
VISSIM (static)	19.4	9.2	10.3
VISSIM (dynamic)	18.0	9.5	8.5

There were two types of delays calculated from the analysis of the work zone. The first type of delay was calculated from the work zone section of Interstate 29, which can be seen in Table 4.4. QuickZone does not have the capability to calculate the delay within the work zone, but VISSIM calculated delays in the baseline case of 29 seconds per vehicle. VISSIM's static routing for the work zone scenario resulted in delays of approximately 92 seconds per vehicle, which was reduced to approximately 49 seconds per vehicle using dynamic assignment. This was a result of vehicles being re-routed in the network.

Table 4.4 Work Zone Delay

PM Average Delay in Work Zone (sec/veh)	
VISSIM (baseline)	29.0
VISSIM (static)	91.8
VISSIM (dynamic)	48.5

The overall network delay is a reflection of how vehicles are impacted on a global level. QuickZone estimated a network delay of 154 vehicle hours, which is due primarily to the southbound queuing of vehicles entering the work zone. Table 4.5 shows the results of the network delays for both analysis tools. The difference between the baseline network and the two work zone scenarios shows the effectiveness of dynamic assignment in minimizing the impacts of work zones on a network. There is approximately a ten-fold increase in network delay between the baseline scenario and the static-assigned work zone scenario. Using dynamic assignment, the network delay was decreased by approximately 29% from the static assignment scenario. This is a good illustration of how a microscopic simulation model could be useful in determining potential detour routes, and predicting driver behavior when a work zone is present in a network.

Table 4.5 Network Delay

PM Average Network Delay (veh-hr)	
QuickZone	154.0
VISSIM (baseline)	997.0
VISSIM (static)	9,614.0
VISSIM (dynamic)	6,850.0

4.2   Research Contributions

This research looked at the ability of a traffic analysis tool to accurately represent work zone conditions given data availability and requirements specified by the Work Zone Safety and Mobility Rule. Specifically, it examined the feasibility of applying a traffic analysis model to a work zone environment; calibrating a simulation model to data collected in the field; and the ability of a model to apply work zone management strategies.

This research also examined the capabilities of Dynasim for analyzing an urban work zone scenario. Several discoveries were made during the course of the research that ultimately led to excluding Dynasim from the overall comparison, but the experience was informative. There is definitely potential for Dynasim to be capable of conducting an evaluation of work zone impacts, but it depends on the size, location of the work zone, and the output required.

4.3   Recommendations and Future Research

There are several factors to consider when determining the type of analysis tool to use for evaluating a work zone. The size, location, and duration of the work zone are the most important criteria to consider. For rural work zones or small urban work zones, it may be sufficient to use a sketch-planning tool such as QuickZone. QuickZone offers the ability to quickly conduct an analysis and provide results.

Microscopic analysis tools such as VISSIM are ideal for conducting a thorough evaluation of a work zone and the surrounding network. For large work zones with several access points, such as interchanges, VISSIM would be ideal. It would also be beneficial in estimating the impacts on the surrounding routes and predicting the detours that would be most likely used by the drivers. Because of its potential in estimating impacts on detour routes, VISSIM could be used to mitigate congestion by providing the data necessary for adjusting traffic control plans at affected intersections. Being able to accurately predict impacts due to a work zone and having the necessary tools to make changes would be a valuable asset to transportation agencies.

Dynasim would not be recommended for a large network. According to Citilabs, the next version of Dynasim will have improved features and output capability. Two of the most important types of output when evaluating a work zone are the queue length and delay. With this in mind, the feasibility of using Dynasim may improve with the next version. A future research suggestion would be to evaluate the updated version Dynasim and to compare it with other microscopic simulation programs.

Further recommendations regarding microscopic simulation tools, such as VISSIM, include evaluating traffic management and Intelligent Transportation Systems (ITS) strategies. With regards to traffic management strategies, a simulation model has the ability to not only quantify, but provide visual feedback on how various construction strategies will affect traffic. An example of this is estimating how traffic is affected by construction during peak periods as opposed to off-peak periods (night construction) or the effect of staging a work zone during peak periods (beginning a lane closure at 7:30 AM as opposed to 10:30 AM).

There are several examples of how ITS strategies could be evaluated by a microscopic simulation model. One example is using a model to predict the effectiveness of variable speed limits in work zones. Another example is modeling the effects of providing information to drivers using changeable message signs on traffic volumes through and around work zones as well as travel speeds. In addition, the effectiveness of real-time traffic monitoring/vehicle navigation systems (in a work zone scenario) could be estimated.

As with any type of evaluation, the data collected for the analysis play a key role in the accuracy of the results. It is also imperative that the user knows exactly what data are required by a particular analysis tool before beginning the evaluation. The use of any type of analysis tool for the evaluation of work zone impacts requires an emphasis on accurate data collection.

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