Traffic Analysis Toolbox Volume XII:
Work Zone Traffic Analysis – Applications and Decision Framework

APRIL 2012

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U.S.Department of Transportation

Federal Highway Administration

FOREWORD

Work zones have significant impacts on the mobility and safety of transportation network. It is important to analyze and understand the anticipated extent and severity of work zone impacts associated with various project alternatives before implementing them. A work zone traffic analysis also enables practitioners to include appropriate mitigation strategies during project planning, design, and in the development of effective transportation management plans (TMP).

This document is the third volume in the *FHWA Traffic Analysis Toolbox: Work Zone Analysis* series. The first volume provides guidance to decision-makers at agencies and jurisdictions considering the role of analytical tools in work zone planning and management, and the second volume provides specific guidance to the analyst, researcher, or manager in charge of conducting a specific work zone analysis project. This document, the third volume in the *Work Zone Analysis* series, focuses on key considerations when applying various modeling tools for work zone traffic analysis and provides a decision framework on how to select the best alternatives based on a set of performance measures. It serves as a useful resource for practitioners, researchers, or managers in understanding the analytical methods and decision framework involved in conducting a work zone traffic analysis. It contains step-by-step guidance on determining the most suitable tools to perform the work zone analysis. It also presents the essential components of a work zone traffic analysis report. To illustrate the process and decision framework contained in this document, a variety of case studies are presented to demonstrate a diverse set of work zone traffic analysis applications.

This document serves as Volume XII in the FHWA Traffic Analysis Toolbox. Preceding volumes in the toolbox include: *Volume I: Traffic Analysis Tools Primer*, *Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools*, *Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, *Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software*, *Volume V: Traffic Analysis Tools Case Studies – Benefits and Best Practices*, *Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness*, *Volume VII: Predicting Performance with Traffic Analysis Tools: Case Studies*, *Volume VIII: Work Zone Modeling and Simulation – A Guide for Decision-Makers*, *Volume IX: Work Zone Modeling and Simulation – A Guide for Analysis*, *Volume X: Localized Bottleneck Congestion Analysis Focusing on What Analysis Tools Are Available, Necessary and Productive for Localized Congestion Remediation*, and *Volume XI: Weather and Traffic Analysis, Modeling and Simulation*.

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Director
Office of Transportation Operations

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1.0 BACKGROUND AND OBJECTIVES OF THIS GUIDEBOOK

1.1 OVERVIEW OF WORK ZONE TRAFFIC ANALYSIS GUIDANCE

Work Zone Traffic Analysis (WZTA) is the process of evaluating and determining the mobility and safety impacts within a transportation construction, maintenance, or rehabilitation project. Establishing a procedure for analyzing work zone mobility and safety impacts aids agencies in the planning, decision-making, design, and financial aspects of the project. In order to establish an effective and comprehensive process, the **work zone traffic analysis plan should address broader considerations of mobility and safety impacts** that go beyond the work zone itself. An agency's WZTA procedure should, therefore, include the following considerations:

- Impacts on mobility and safety of the project at corridor, network, and regional levels;
- Impacts on nearby facilities;
- Impacts on emergency management/incident management;
- Impacts on neighborhoods;
- Impacts on public property and services;
- Impacts on affected businesses and developments;
- Impacts on the environment; and
- Impacts of concurrent projects located near project.

Components of a Work Zone Traffic Analysis

The structure of a WZTA procedure will vary depending on the agency performing the analysis, as well as the size and complexity of the project. A WZTA plan will typically include the components listed below. More detailed guidance on developing a methodology for analyzing work zone traffic impacts is provided in Chapter 2 of this document.

- Goals and objectives of the Analysis Plan.
- Identification of construction design, staging, and phasing plans and alternatives.
- Analysis of work zone impacts. This section of the WZTA plan defines how the mobility and safety impacts of the alternatives will be calculated. This section will, therefore, define the analysis outputs, performance measures, and thresholds used for the analysis.
- Impact mitigation strategies that will address or minimize mobility and safety impacts of alternatives. These strategies can include public information, traffic control devices, travel demand management, and traffic operations measures.
- Decision framework for choosing a recommended alternative. The criterion or process of choosing the recommended alternative or combination of alternatives using data and information from the traffic impact analysis results and mitigation strategies assessment.

Role of Work Zone Traffic Analysis

As previously mentioned, the development of a WZTA can have multiple benefits for agency staff as they proceed through the planning, development, and implementation of a project. It

enables agencies to understand the potential mobility and safety impacts of the project and identify the optimal alternative or combination of alternatives that will minimize impacts while keeping cost low and construction process efficient. The following details other benefits and uses of the WZTA process:

- Assisting agency staff in allocating resources more effectively and gaining the best value for the money.
- Improving construction management and scheduling. WZTA has the potential to improve the coordination and management of multiple projects and construction schedules to minimize overall impacts.
- Developing ways of monitoring and managing work zone impacts during construction.
- Conducting performance assessment pre- and post-construction. Evaluating the performance measures of a work zone prior to, during, and post – implementation helps provide data and information that aids agency staff in improving and updating work zone policies, procedures, and practices in the future.

Purpose of the Work Zone Traffic Analysis Guide

The purpose of this document is to provide a WZTA applications manual. This guide will be a useful resource for practitioners in understanding the analytical methods involved in conducting and developing a WZTA. The prior Federal Highway Administration (FHWA) work zone guidance, *Traffic Analysis Tools Volume VIII* and *Traffic Analysis Toolbox Volume IX*, provided guidance on the appropriate consideration of analytical tools in work zone planning and management, and the selection of a modeling approach based on these tools.[1,2] This particular guide will focus on the work zone applications of these tools. It will provide a step-by-step guide customized to the selected tool and type of work zone project.

1.2 ROLE OF TRAFFIC ANALYSIS TOOLS FOR WORK ZONE APPLICATIONS

Work zone project types can span from simple flagging to complex corridor reconstruction projects. Additionally, work zones are temporal and can often take different forms over the project duration, depending on the construction staging plans. **Measuring mobility and safety impacts may be dynamic**, depending on these factors, therefore, making calculations and analyses more complex. There are a variety of different analysis tools that vary in complexity of features and functions. The sophistication of the analysis should be matched to the complexity of the road projects and the potential impacts. There is no one tool that can fit all work zone types. Traffic analysis tools can provide work zone mobility performance measures, such as duration and severity of congestion, queue lengths, and estimated volumes, which can be used to further analyze safety, economic, environmental impacts.

The FHWA's work zone analysis framework is presented in Chapter 3 of the *Traffic Analysis Tools Volume VIII*.[1] **The components of the framework are reflective of the program delivery process: 1) System Planning; 2) Preliminary Engineering (PE)/Design; and 3) Construction**; however, the types of decisions that need to be made are more important than specifically where in the program delivery process it is. These decisions are represented by three

interrelated decision types that drive the overall work zone decision-making process as a decision-making engine:

1. **Scheduling Decisions** – Decisions impacting when work zone activity will occur, ranging from the selection of time of day to days of week to time of year. Analysis tools can be used to determine the optimal construction phasing/staging plan that will be cost-effective and time efficient.
2. **Application Decisions** – Decisions pertaining to the construction technique to be used within the work zone (e.g., a decision to use cast-in-place techniques rather than a precast approach). Analysis tools can play a role in determining which construction design strategies can minimize both mobility and safety impacts while improving construction time efficiency and cost-effectiveness. Analysis tools also can provide insight on impacts to road users, neighboring developments, and nearby projects.
3. **Transportation Management Plan Decisions** – Decisions that determine how traffic will be managed while work zones are in place. This includes issues of temporary traffic control, public information, and transportation operations. Analysis tools can determine how to best manage traffic in work zones by aiding agencies in identifying the optimal use and combinations of transportation management strategies.

The decision-making engine concept is visually represented in Figure 1, with each decision type represented by one of the three circles.[1] All of the three circles are connected, indicating each decision type does not operate in isolation, but is influenced by decisions made in other areas. Thus, a decision made about the application (e.g., cast-in-place concrete) may dictate the scheduling of the work (e.g., to work in warmer weather months), which, in turn, impacts the Transportation Management Plan (TMP) that could be implemented.

S – Scheduling; A – Application, and TMP – Transportation Management Plan. Adjacent to each circle is a smaller circle used to indicate a relative level of finality regarding the decisions within each category.
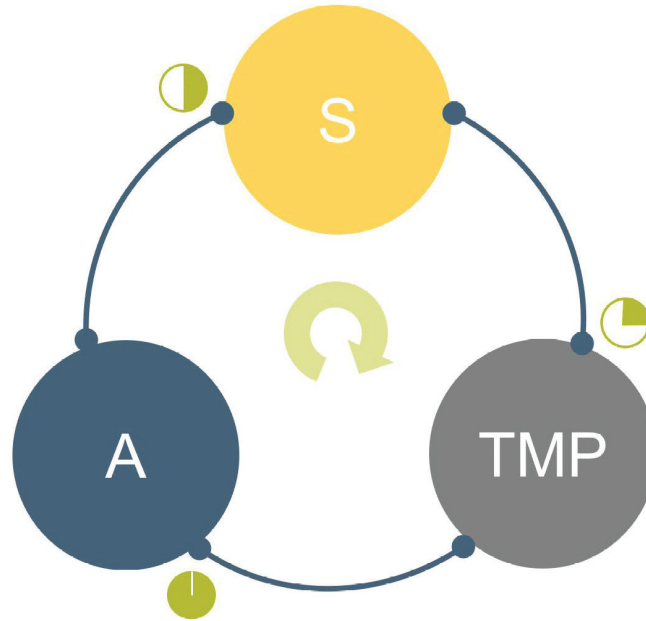
Figure 1. Work Zone Analysis Strategies Decision-Making Engine

(Source: Hardy and Wunderlich, 2008.)

1.3 ORGANIZATION OF THIS REPORT

The purpose of this guide is to provide a useful resource for practitioners in understanding the analytical methods involved in conducting and developing a work zone traffic analysis. This document is organized as follows:

- Chapter 1 provides background and objectives of this guidebook and introduces the rest of the document;
- Chapter 2 describes the methodology for developing and implementing a work zone traffic analysis;
- Chapter 3 presents a process on how to select the appropriate type of traffic analysis tool to determine the impacts of a work zone;
- Chapter 4 presents key considerations when applying various modeling tools for work zone traffic analysis;
- Chapter 5 provides guidance on developing and applying a Maintenance of Traffic Alternatives Analysis (MOTAA) decision framework;
- Chapter 6 presents guidance on how to reconcile inconsistencies and conduct sensitivity analysis;
- Chapter 7 presents a mix of quantitative and qualitative factors that may be considered in an MOTAA process;
- Chapter 8 presents the essential components of a MOTAA Report; and
- Chapter 9 presents case studies to demonstrate the MOTAA process.

2.0 ESTABLISHING A METHODOLOGY FOR WORK ZONE TRAFFIC ANALYSIS

A WZTA can serve as a critical tool for work zone management and decision-making. This type of analysis provides a valuable resource for understanding the various impacts of particular work zone strategies. Evaluation of these impacts aids an agency in creating the optimal combination of work zone strategies and construction project management decisions that can optimize the efficiency of the construction work and minimize costs to the agency, road user, and society.

This chapter describes the methodology for developing and implementing a WZTA. The sections provide a sequential order for approaching WZTA, including the following:

1. The first section defines the WZTA's goals and objectives;
2. The second section defines or sets performance targets that serve as a measure of the work zone strategies' effectiveness towards achieving the established goals and objectives;
3. The third section provides some suggested work zone alternatives or strategies that are commonly used to mitigate work zone impacts on safety, mobility, and constructability of a project;
4. The fourth section provides a methodology for narrowing down alternatives that will best serve the goals and objectives of the project;
5. The fifth section provides project coordination for work zone traffic management; and
6. The last section discusses typical steps in an MOTAA and decision framework.

2.1 IDENTIFYING WORK ZONE ANALYSIS GOALS AND OBJECTIVES

One of the main components of developing a work zone traffic analysis plan is to define the goals and objectives of the analysis. Setting goals and objectives serves several purposes. By establishing a set of goals and objectives, an agency is forced to evaluate the traffic impacts, benefits, and costs of their work zone project. Using these results, they can direct their resources to those strategies that will help them minimize costs or maximize benefits, mitigate traffic impacts, and improve safety within the work zones. Second, it provides a direction to guide the analysis and the decisions made towards a set of expected and desired results. Third, it sets an established target to determine the effectiveness of potential work zone strategies.

Vision

Typically, an agency will have an overall mission statement or policy in regards to work zone traffic management, which explains the agency's vision with respect to maintaining the safety, mobility, and quality of work within the work zones. An agency's goals and objectives will typically be guided by this vision statement. Safety, mobility, and constructability are often at the core of an agency's vision statement.

- **Safety** – An agency's work zone policy or vision statement for safety will include considerations for both users and workers within and around the work zone. Examples of safety goals can include reducing crashes and/or reducing worker fatalities and injuries at the construction site.

- **Mobility** – This pertains to facilitating efficient travel conditions through or around a work zone area with a minimum delay compared to baseline travel (preconstruction) conditions, while maintaining optimal construction duration/timeframe and not compromising safety.
- **Constructability** – This refers to efficient and effective planning, designing, and building of projects while minimizing impacts on mobility and safety. For agencies, such goals may include optimizing construction duration, minimizing construction costs, or reducing negative economic impacts on the surrounding community.

Examples of Agency Vision Statements

Wisconsin DOT

Creating a work zone traffic impact mitigation strategy requires finding the most cost-effective strategy.

New York State DOT

- To provide a high level of safety;
- To minimize congestion and community impacts by maintaining levels of service close to or at preconstruction levels; and
- To provide contractors with adequate access to the roadway to complete the work efficiently while meeting quality requirements of the contract.

Maryland DOT

The Maryland State Highway Administration (SHA) is committed to maintaining optimum worker safety while having traffic traveling smoothly and safely through and around work areas at all times.[3] Careful consideration of work zone impacts should begin during planning and continue through design, construction, and post-construction review.

Figure 2. Maryland Strategic Emphasis Areas for Work Zone Safety and Mobility

(Source: Maryland State Highway Administration, 2012.)

Developing Project Goals and Objectives

Strategic goals and performance objectives should be established in accordance with the work zone vision. The goals should directly correlate to the work zone safety, mobility, and constructability concerns and needs of the agency. The performance objectives then drive the selection of work zone alternatives or strategies that are designed to meet the established goals.

Before setting the specific goals and performance objectives, the agency should review project details, such as the design, plans, scope, and environmental documents for important safety, mobility, and constructability constraints and considerations that help form the basis of the goals and objectives. Examples of safety, mobility, and constructability considerations include:

- Safety:
  - Worker and road user safety;
  - Impacts to emergency response; and
  - Injury/fatality crash rates.

- Mobility:
  - Road user costs;
  - Average Daily Traffic (ADT);
  - Delay or queue length;
  - Truck percentages;
  - Lane closure hours;
  - Transit operational impacts;
  - Bike/pedestrian access; and
  - Detour availability and impacts.

- Constructability:
  - Duration of construction;
  - Number of construction stages;
  - Maintenance considerations;
  - Environmental constraints; and
  - Business and residential impacts.

The goals and objectives can be qualitative and/or quantitative. A qualitative goal may be to promote public awareness and motorist travel information of work zone traffic conditions. A quantitative goal may be to reduce work zone delays by X percent within a certain time period. If quantitative, it also may be necessary for an agency to conduct data collection efforts and a preliminary analysis to identify the specific areas of concern that may potentially need mitigation. There may be several areas of concern the agency may like to analyze or mitigate. However, the number of concerns may exceed the agency's monetary and time resources, thus it may be necessary for the agency to prioritize which specific project design or work zone strategies should be analyzed. The agency also can qualitatively evaluate the impacts of the project's particular work zone characteristics as a way of prioritizing. For instance, the New Jersey DOT Traffic Mitigation Guidelines for Work Zone Safety and Mobility rate project characteristics based on if they will have high, medium, or low impacts. The impact rating helps New Jersey DOT determine the particular mitigation strategies needed to achieve their goals of maintaining work zone mobility and safety. Figure 3 shows a sample impact matrix developed by the agency.[4]

Project	Overall Impact Assessment	
Project Characteristic	Project Data (Qualitative)	Project Impact Level
Primary Project Characteristics		
Road User Cost		
Retail Business Disruption		
Neighborhood Disruption		
Disruption to Employers/Activity		
Political Sensitivity		
Impacts of Local/Developer Projects		
Secondary Project Characteristics		
Duration of Contract		
Number of Construction		
Capacity Reduction (Percent)		
Roadway Type		
ADT		
Seasonal Traffic Increase		
Expected Delay		
Project Length		
Urbanization		
Truck Volume		
Public/Media Attention		

Figure 3. New Jersey DOT Project Impact Matrix

(Source: New Jersey Department of Transportation, 2008.)

Example Goals and Objectives

Once the project details and plans have been reviewed and any preliminary analysis has been completed, the particular goals and associated performance objectives should be established. **Goals and performance objectives will vary depending on project characteristics, agency policies, and resources**. The following serves as example goals and corresponding performance objectives:

- **Goal 1 –** Keep work zone congestion at preconstruction levels.
  - **Objective 1 –** Optimize lane closure strategies; evaluate impact of detours; alternative work schedules (i.e., nighttime, weekend work).
- **Goal 2 –** Reduce work zone-related crashes by X percent.
  - **Objective 2 –** Determine impacts of traffic incident management strategies, intelligent transportation systems (ITS) strategies, enhanced monitoring on crash rate.
- **Goal 3 –** Promote public awareness.
  - **Objective 3 –** Keep the public apprised of Maintenance of Traffic (MOT) plans and their projected impacts.

New Jersey identified a potential list of work zone goals and objectives:[4]

- Provide work zone speed reductions of 10 mph compared to preconstruction speed limit;
- Reduce traffic volumes by X percent;

- Decrease average daily traffic by Y vehicles during peak period;
- Maintain level of service (LOS) D or better;
- Reduce expected delay by Z percent;
- Keep average delay per vehicle to less than X minutes during the peak period;
- Maintain vehicle or person throughput by increasing auto occupancy and transit ridership;
- Promote public awareness;
- Keep congestion no worse during construction than before;
- Mitigate community impact;
- Maximize safety of workers and the traveling public; and
- Keep road user costs below X dollars per day.

Concurrent with setting goals and objectives is selecting the appropriate analysis tool, discussed in Chapter 3. The type of analysis tool can vary from simple to complex and also will depend on the type of project, the goals, and available data and resources.

2.2 SELECTING MEASURES OF EFFECTIVENESS (MOE) AND THRESHOLDS

Once goals and objectives have been established, measures of effectiveness (MOE) or thresholds should be set to determine the performance standards for the safety, mobility, and constructability of the work zone. The MOEs or thresholds selected should be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the objectives must meet or exceed. They also will help in evaluating the different objectives or alternatives as a way of determining which strategies best fit the goals of the project. For instance, for Goal 1 listed in the Example Goals and Objectives from Section 2.1, "keep work zone congestion at preconstruction levels," an MOE could be LOS, delay, travel time, or road user costs. Based on the MOE(s) selected, the agency will select an analysis tool to determine the LOS, delays, travel time, or road user costs of the work zone area prior to construction. Then, each of the proposed alternatives can be analyzed using the selected analysis tool and compared against the results of the preconstruction scenario.

Selecting an MOE will depend on the goals, project characteristics, and agency resources. However, determining an appropriate MOE or threshold also will require some analysis of the existing conditions within the work zone area. For instance, the agency should have some data supported knowledge regarding the transportation facility's average daily traffic (or hourly volumes), applicable intersection counts, ramp metering and signal control timings, travel times, delays/queue lengths, bottleneck locations and severity and roadway capacity. These provide background information regarding the current performance of the roadway facility. It also provides a way of determining the performance standards the agency may want to meet or improve upon prior to construction.

The FHWA recently released a primer on work zone safety and mobility performance measurement.[5] It describes various work zone MOEs, and provides guidance to help agencies select and implement measures that make sense for their own work zone programs.

Example MOEs and/or Thresholds

The following provides some examples of performance measures used to determine the appropriate traffic mitigation strategies to use in work zone projects.

Maryland State Highway Administration (MD SHA)

MD SHA uses mobility thresholds that are calculated according to their *Work Zone Lane Closure Analysis Guide*. MOEs, according to the guide, include LOS, intersection control delay, and arterial travel time based on the type of facility being analyzed.

Ohio DOT

The Ohio DOT has two levels of MOEs that particular strategies are measured against. The first is defined by lane closure duration and the other uses queue thresholds.

- **Permitted Lane Closure Map (PLCM)** – Each Ohio district is required to prepare a permitted lane closure map (PLCM) that specifies the allowable times a lane may be closed on a freeway within that district. The predefined times are determined based on work zone capacity. For any proposed lane closures that do not meet the PLCM, the district must analyze the impacts on motorists.
- **Queue Thresholds Analysis** – A quantitative queue analysis should be performed for those lane closures proposed outside of PLCM allowable times. This analysis compares existing queues with expected queues caused by the lane closure. A vehicle will be considered part of a queue if its average operating speed is approximately 10 mph or less. The district may use analysis tools, such as QUEWZ-92, Synchro/SimTraffic, CORSIM or similar programs to model the expected queues. The allowable queue thresholds are defined below:
  - For queues less than 0.75 mile, the work zone impacts are acceptable.
  - For queues greater than 0.75 mile and less than 1.5 miles, the work zone impacts are acceptable if the queue exceeds 0.75 mile for 2 hours or less. Where queues are expected to exceed 0.75 mile for any period of time, additional advanced work zone warning signing should be specified.
  - For queues longer than 0.75 mile for more than 2 hours or longer than 1.5 miles for any period of time, the work zone impacts are unacceptable.

Wisconsin DOT

For any individual project, the most cost-effective mitigation strategy (or combination of strategies) should be selected. To determine the most cost-effective mitigation strategy, Wisconsin DOT uses Road User Costs (RUC) as the MOE. The agency also sets a particular RUC threshold that the project's cost for mitigations strategies must meet. For any individual project, the agency costs for mitigation should be less than 10 percent of the monetary value of the RUC associated with the construction. This is equivalent to a benefit/cost ratio of 10 or higher for mitigation activities.

2.3 IDENTIFYING MOT ALTERNATIVE STRATEGIES

MOT alternative strategies can be evaluated and fit several categories, including the following:

- **Construction Approach** – These strategies minimize traffic disruption by optimizing construction duration or by ensuring that the road has sufficient capacity during peak travel periods. Strategies within this category include:
  - Staging/sequencing of construction phases;
  - Lane closure and ramp closure alternatives;
  - Alternative work schedules, such as night work or weekend work; and
  - Innovative contracting.
- **Traffic Control Operations** – These strategies increase safety and capacity. Strategies within this category include:
  - Speed limit reductions;
  - Truck restrictions;
  - Signal timing, coordination, and phasing improvements;
  - Reversible lanes; and
  - Physical barriers.
- **Public Information** – These strategies can include public outreach efforts to inform the community about the project, as well as the provision of traveler information regarding travel conditions at the work zone. Strategies within this category include:
  - Public outreach efforts through community meetings, newsletters/pamphlets, and project web sites;
  - Dynamic message signs;
  - Highway advisory radio;
  - Telephone hotlines (i.e., 511); and
  - Closed-circuit television (CCTV).
- **Incident Management and Enforcement** – These strategies work to efficiently plan for, detect, respond, and clear incidents that can occur within the work zone area. These strategies can include:
  - Incident management plans;
  - Traffic management centers and the use of ITS technologies for advanced detection and response technologies;
  - Emergency service patrols; and
  - Enhanced police enforcement.
- **Travel Demand Management (TDM)** – This includes strategies that shift motorists from driving alone to multi-occupant modes in order to reduce congestion along the work zone, especially during critical travel periods. TDM strategies for work zones include:
  - Rideshare incentives;
  - Transit incentives and improvements;
  - High-occupancy vehicle (HOV) facility provisions and improvements; and
  - Park-and-ride provisions.

The selected MOE and related threshold(s) can be used to filter out MOT alternatives that do not meet certain criteria, will not minimize traffic impacts, or will make traffic conditions worse.

2.4 CONDUCTING FATAL FLAW ANALYSIS

Fatal flaw analysis determines if an individual alternative has one or more defects that prevent it from being successfully implemented. One of the key inputs to a fatal flaw analysis is the establishment of clear goals and objectives for the work zone project. Using these as a guide, a multidisciplinary team reviews the proposed alternatives and performs an initial screening of the identified alternatives. This screening identifies those alternatives that deviate from the stated goals in a significant manner, and determines if that deviation is substantial enough to remove the alternative from further consideration before more detailed analyses are completed. While this review may result in the elimination of alternatives, it also can result in refinement of the proposed alternatives. However, care must be taken not to cut too deeply with the fatal flaw analysis process, as some of the more innovative strategies that may utilize unconventional approaches could be lost in this manner.

2.5 IDENTIFYING NEEDED COORDINATION BETWEEN PROJECTS

An important step that should be considered during the planning and design stages of the project development process is the identification of coordination between projects, other infrastructure improvements or maintenance activities, and agencies. **Project coordination strategies are a critical part of the work zone traffic analysis process**, as they can contribute to the reduction of traffic impacts and project duration. Project coordination can begin with discussions with other transportation and public works agencies and other stakeholders that may be impacted by the work zone. While coordination makes intuitive sense, the reality of work zone projects often involves a number of different agencies, contractors, funding sources, stakeholders, etc. that may pose logistical challenges for coordination efforts. In creating a work zone traffic analysis plan or a transportation management plan for a particular highway maintenance, reconstruction, and/or rehabilitation project, the following coordination strategies and considerations may be employed:

- **Coordination between Construction Projects** – This coordination strategy involves considerations for nearby state, local, and regional projects that may be occurring concurrently. This strategy involves coordinating, phasing, and scheduling these multiple projects in a way that will minimize delays and impacts on motorists, businesses, and neighborhoods, while reducing potential construction delays for all projects. This coordination effort also may involve assessing the potential combined impacts of the multiple projects at the corridor level in order to identify potential conflicts between projects and other coordination opportunities.
- **Coordination with Special Events and Major Traffic Generators** – Considerations for special events and major traffic generators that may be impacted by or could impact the project under consideration also are essential for reducing mobility and safety impacts. Construction schedules and sequencing, alternate routes, and other work zone strategies can be structured and coordinated with these events and traffic generators in mind in order to minimize disruption to motorists, businesses, and neighborhoods.
- **Utilities Coordination** – Coordinating and scheduling utility work within and around the work zone project is critical in minimizing disruptions to utility work and the overall construction duration. Coordinating the construction work with utility work also can

identify additional utility improvements, roadway work and utility and traffic device installations (i.e., detectors, cameras, metering) that can be done concurrently with the work zone project. Consolidating the various improvements can reduce the need for future work zones and minimize road user disruptions.

- **Right-of-Way and Permit Coordination** – This type of coordination strategy involves considerations for right-of-way needs and issues that may impact construction duration.
- **Coordination with Other Transportation Infrastructure Improvements and Maintenance Activities** – This involves coordination with non-highway transportation facilities and associated agencies. Such facilities would include transit, railroads and intermodal facilities. As with other coordination efforts, this also will help to minimize mobility and safety impacts network- or regionwide.

2.6 STEPS IN THE MAINTENANCE OF TRAFFIC ALTERNATIVES ANALYSIS (MOTAA) AND DECISION FRAMEWORK PROCESS

Figure 4 presents the steps involved in the application of a maintenance of traffic alternatives analysis (MOTAA) and decision framework. They vary depending on the agency work zone policies and resources. While work zone traffic analysis can vary in complexity, there are common components applied by various agencies in their work zone alternatives analysis and decision-making procedures. These common elements are described below. The common components or steps in an MOTAA and decision framework have been categorized into the various project stages that may occur in project planning and data collection, impact analysis, decision-making criteria, impact mitigation, and monitoring and post-implementation.
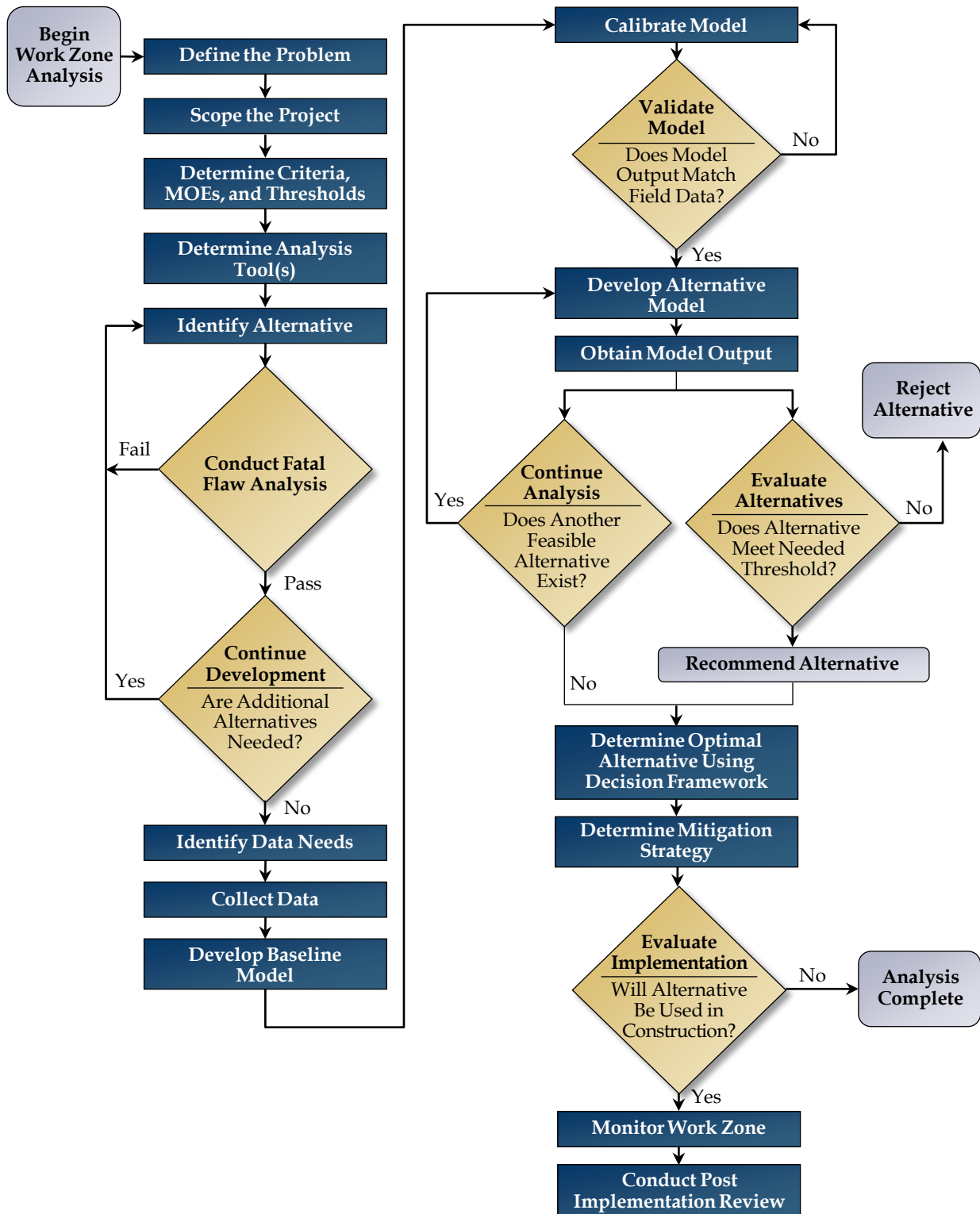
Figure 4. MOTAA and Decision Framework Flowchart

Planning and Data Collection

During this stage of the alternatives analysis, agency staff develops an analysis approach using existing conditions information, project characteristics, and traffic and/or economic data within and around the work zone. Considerations involved in this stage could include:

- **Determination of Goals and Objectives** – This step answers questions such as what is the purpose of the analysis or what are the priority impacts that need to be mitigated? Section 2.1 provides examples and further information on setting work zone goals and objectives.
- **Project Scoping** – This step involves reviewing the project characteristics and work zone strategies in order to gain a better understanding of the potential mobility and safety impacts within the work zone, as well as impacts on nearby projects, businesses, and neighborhoods.
- **Determine Criteria, Thresholds, or Measures of Effectiveness** – This step involves determining performance measures by which to compare proposed alternatives against. The selected thresholds vary based on the goals and objectives of the agency. Section 2.2 provides further information and examples of how to select and develop the thresholds or measures.
- **Determine appropriate analysis tool(s)** – Using the information gathered from the data collection efforts and existing conditions data, an appropriate analysis tool that matches the level of complexity of the project could be selected at this stage of the project. Chapter 3 of this guide provides detailed information on how to select the appropriate analysis tool based on the work zone's characteristics.

Impact Analysis

Most highway projects go through some type of impact analysis to determine any negative impacts the project may have on the mobility, safety, and environmental conditions of the study area, as well as the surrounding community, corridor, or region. At this stage of the project, the various work zone alternatives also can be analyzed for their mobility, safety, environmental, and financial impacts within and beyond the work zone area. This analysis will contribute to selecting the appropriate set of work zone alternatives or strategies that will minimize impacts while maintaining or reducing the project duration and costs. The steps involved in the impact analysis may vary depending on the selected analysis tool. Common components may be as follows:

- **Perform Analysis** – How the analysis is performed will depend on the type of tool utilized. Chapter 4 of this document provides further information on performing the analysis.
- **Calibration and Validation of Model** – If the selected analysis tool requires modeling, an existing condition or preconstruction model is typically created. This preconstruction model, often called the "no-build" model, provides the baseline for the mobility and safety performance of the roadway facility. The calibration and validation process

ensures that this baseline model accurately reflects the existing travel conditions and patterns on the ground.

- **Obtaining Model Outputs** – The model outputs also will vary depending on the type of tools and analysis selected. For instance, simulation tools may produce outputs, such as delay, travel time, and volumes. Sketch-planning tools may include measures, such as LOS or a benefit/cost ratio.

Decision-Making Criteria

The decision-making criteria an agency may choose to apply in determining the recommended alternative (or combination of alternatives) may be greatly influenced by the goals and objectives, the data collection efforts, and the level and complexity of their impact analysis. The typical steps involved in this stage of the project often include the following:

- Determining whether the alternative(s) meets the thresholds or decision framework criteria; and
- Selecting the alternative(s) with the least impacts or the best fit for the criteria established.

For further information on developing a decision-making framework, refer to Chapter 5 of this document.

Impact Mitigation

This stage of the project and the alternatives analysis depends on the results of the impact analysis and the decision-making criteria stage. The alternatives analysis indicates the types of impacts to expect from the recommended alternative or combination of strategies. The impact mitigation stage identifies the potential mitigation strategies that can aid in further reducing the impacts. Further analysis may be conducted to determine which combination of mitigation strategies may prove to be most efficient and cost-effective. Types of mitigation strategies can include public information, traffic control devices, travel demand management, and traffic operations measures.

Monitoring and Post-Implementation

The monitoring and post-implementation efforts include monitoring the performance of the work zone and the effectiveness of the recommended alternatives and/or mitigation strategies during the duration of the construction period and after. Developing a monitoring plan can serve as a way to determine the effectiveness of the work zone traffic analysis and the alternatives analysis process by determining impacts and mitigating mobility and safety issues. The results of the monitoring efforts and post-implementation analyses also can serve as feedback to improve the agency's current analyses and decision-making methodologies.

3.0 SELECTING THE APPROPRIATE TYPE OF TRAFFIC ANALYSIS TOOL

For the purpose of assessing work zone impacts, different transportation agencies have used a variety of transportation analysis tools. Each tool is unique and has its own set of capabilities and limitations. After an overview of the various categories of traffic analysis tools, this chapter discusses the key factors, challenges, strengths, and limitations to consider before selecting a suitable analysis tool to determine the impacts of a work zone. The following presents these considerations through a step by step approach that is adapted from the tool selection procedures described in the *Traffic Analysis Toolbox Volume IX: Work Zone Modeling and Simulation – A Guide for Analysts*[2] and *Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools.*[7]

3.1 ANALYSIS TOOL CATEGORIES

This section provides an overview of the various categories of traffic analysis tools in order to provide guidance to users in selecting the appropriate analysis tool for their project. The section below will describe the typical features of each tool category as well as each tool class's strengths and limitations. Guidance on what inputs to consider adjusting and how to make tools function better for work zone traffic analysis projects are provided in Chapter 4.

As outlined in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer and Volume VIII: Work Zone Modeling and Simulation – A Guide for Decision-Makers*, numerous traffic analysis methodologies and tools have been developed by public agencies, vendors, research organizations, and consultants.[1,8] These traffic analysis tools can be categorized into seven types, in order of increasing complexity:

1. Sketch-planning tools;
2. Analytical/deterministic tools (HCM-based);
3. Travel demand models;
4. Traffic signal optimization tools;
5. Macroscopic simulation models;
6. Mesoscopic simulation models; and
7. Microscopic simulation models.

For the purpose of the guidance following this chapter, sketch-planning and analytical/ deterministic tools will be combined into a single category referred to as sketch-planning and analytical/deterministic tools.

There are many factors that go into determining which tool is right for the job, and there is no "one-size-fits-all" approach. More than one tool might be needed to address the analysis needs, particularly as the project progresses from planning to design to construction. As shown in Figure 5, the higher the level of detail needed from the analysis, the higher the level of resources are required to make successful use of a particular tool.[2]
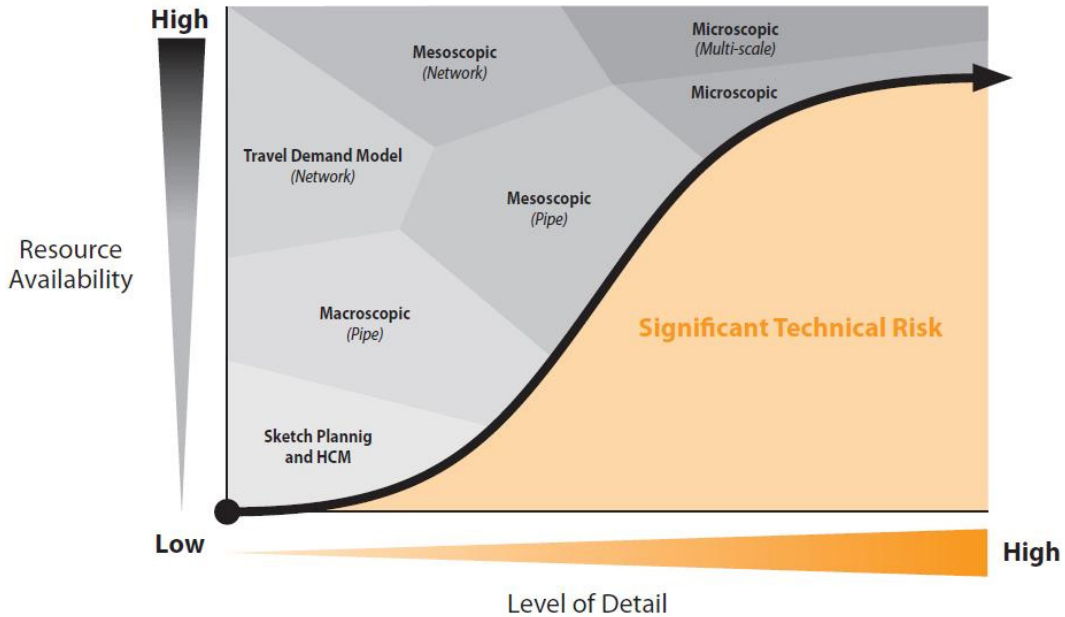
Figure 5. Analytical Work Zone Decision Framework – Modeling Approaches

(Source: Hardy and Wunderlich, 2009.)

Sketch-Planning Tools

Sketch-planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation changes. Often, sketch-planning tools are based upon simple queuing techniques or volume-to-capacity relationships from the Highway Capacity Manual (HCM). Sketch-planning tools perform some or all of the functions of other analytical tool types, using simplified analyses techniques and highly aggregated data. They typically are the simplest and least costly of the traffic analysis tools.

The strength of sketch-planning tools rests upon their relative **ease of use and ability to facilitate a rapid analysis**. Typically, a sketch-planning tool requires fewer resources and less staff training to deploy than a mesoscopic or microscopic simulation model, since they are simpler in terms of data requirements, calibration, and interpretation of the results. Regarding work zones, an analysis using a sketch-planning tool is normally quite rapid, including both the input of the data and the model run time. This is important in cases where a decision needs to be made quickly; or the agency desires a less resource-intensive analysis (e.g., for a project with a modest level of expected work zone impacts).

The weaknesses of sketch-planning tools are their limited network complexity and inability to generate potential network impacts, inability to consider vehicle interactions, and high-level analysis. For example, QUEWZ-98 only allows simple "pipeline" analysis without the ability to model cross-streets and detour routes. However, some of the more complex sketch-planning tools (e.g., QuickZone) do include the ability to model a detour route. In the end, the **results from any sketch-planning tool will be relatively high-level** (e.g., average or maximum queue).

Table 1 lists some general pros and cons of using sketch-planning tools for work zone traffic analysis.

Table 1. Pros and Cons of Sketch-Planning Tools for WZTA

Pros	Cons
• Easy to use • Low cost • Quick results • Low complexity • Less data intensive • Reduced technical skill set • Easy interpretation of results	• Order-of-magnitude output • Limited network complexity • Limited presentation capabilities • Low-analytical robustness • Traffic diversion typically not modeled explicitly

A list of sketch-planning tools can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Sketch Planning in Work Zone Traffic Analysis – QuickZone

Maryland/Virginia Woodrow Wilson Bridge: I-95[9]
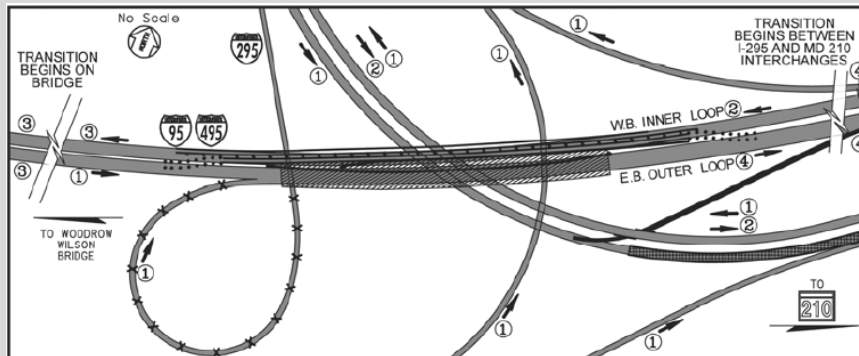
(Source: Mitretek Systems, 2004.)

The Woodrow Wilson Bridge Project involved the replacement of the existing six-lane bridge with a dual-span bridge that increases the number of traffic lanes. The original construction staging plan included lane closures during overnight hours (12:00 a.m.-4:00 a.m.) and two temporary openings in the median barrier to divert traffic around the construction area. This work zone plan would result in a construction duration of four to six months. However, the contractor noted that this original closure duration was insufficient. The contractors requested a larger construction time window for set-up, as well as production time. Therefore, alternative staging plans were evaluated.

QuickZone was used to analyze various construction staging scenarios to choose an optimal alternative that could take place without causing severe mobility impacts. QuickZone was chosen because: 1) it could analyze multiple scenarios quickly; 2) MD SHA already had their own customized version of the tool; and 3) it generates the exact performance measures the agency needed for the analysis. The results of the analysis showed that time for lane closures can be extended to hours between 9:00 p.m. and 5:00 a.m. without significant impacts to motorists.

Woodrow Wilson Bridge QuickZone Network
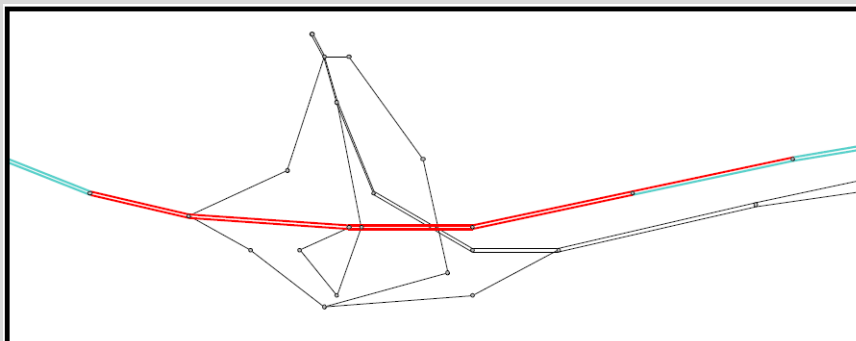
(Source: Mitretek Systems, 2004.)

Analytical/Deterministic Tools (HCM-Based)

HCM procedures are capable of analyzing facility performance (capacity, density, speed, delay, and queuing) as a function of demand, geometry, and traffic controls. These methods and tools usually provide quick results. They are reliable for predicting whether a facility will be operating above or below capacity and they have been well tested through significant field-validation efforts. HCM procedures are generally limited in their ability to evaluate system

effects and vehicle interactions. Most of the HCM methods and models assume that the operation of one intersection or road segment is not adversely affected by conditions on the adjacent roadway. Therefore, HCM procedures are of limited value in analyzing the effects of queuing.

Table 2 lists some general pros and cons of using analytical/deterministic tools for work zone traffic analysis.

Table 2. Pros and Cons of Analytical/Deterministic Tools for WZTA

Pros	Cons
• Widely used and trusted • Typically can be performed by in-house staff • Quick analysis time • Reduced technical skill set • Reduced analysis costs	• Cannot assess systemwide impacts • Not well suited for high levels of congestion • Unable to reflect atypical roadway geometries • Unable to analyze transitions in operations between one system state and another (e.g., unable to analyze transition from noncongested to congested conditions)

Analytical/Deterministic Tools in Work Zone Traffic Analysis – FREEVAL

I-40, Wake County, North Carolina[10]

FREEVAL was the selected tool used in the I-40 project in Wake County, North Carolina. This project evaluated the impacts of a work zone where a lane was added in each direction along four miles of the Interstate between State Road 1728 and the interchange with I-440/U.S. I-64. In planning for this project, two work zone configurations were considered: 1) a two-lane pattern representing day-time operations during the work zone construction where work will be completed behind barriers while maintaining all travel lanes open for traffic; and 2) an off-peak lane closure with nighttime construction that would require full closure of several travel lanes, leaving only one lane open to traffic. A total of six scenarios were modeled using these two work zone configurations in conjunction with other strategies.

FREEVAL was used to evaluate the mobility impacts of the scenarios. FREEVAL was chosen due to its ability to measure the impacts of freeway ramps and weaving segments, ease of use and accessibility, and its ability to generate performance measures, as well as graphical outputs helpful for analysis. The analysis measures reported were average travel time, mainline travel speed, total system delay, maximum queue length, and number of un-served vehicles left on the facility after the analysis time period. The FREEVAL analysis showed the impacts of work zone speed reductions, barriers, and nighttime lane closures on speeds, travel times, and vehicle queues.

FREEVAL (HCM 2000) Network
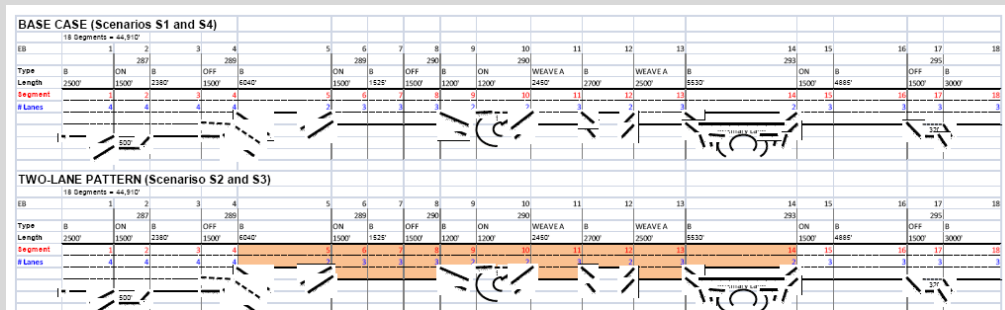
(Source: Schroeder and Rouphail, 2010.)

A list of HCM methodologies can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Travel Demand Models

Travel demand models have specific analytical capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, and route choice. These are mathematical models that forecast future travel demand based on current conditions, and future projections of household and employment characteristics. Traditionally, they are large regional planning models used by metropolitan planning organizations (MPO) and were originally developed to determine the benefits and impacts of major highway improvements in metropolitan areas. A distinguishing feature of travel demand models is their geographic coverage, which generally includes an entire metropolitan area: a city, its suburbs, and the adjacent counties.

For work zone analysis, a strength offered by travel demand models is their **ability to predict areawide traffic redistribution**. For example, if an agency is considering closing an important urban, freeway-to-freeway interchange for several months while it is rebuilt, a travel demand model could help evaluate the overall changes in total daily traffic volumes on various roadways throughout the region. Another important consideration is that most major metropolitan areas already have an established travel demand model, which could be used either as the sole analysis tool, or as a foundation for developing a transportation network for another model type.

However, travel demand models have limited capabilities to estimate accurate changes in operational characteristics (such as speed, delay, and queuing), resulting from the implementation of operational strategies and changes (including the effects associated with roadwork construction). Because these models are prepared at a broad regional scale, they **lack detail that may be critical to the analysis objective**. For example, they may model only one or two time periods (such as the AM peak hour or the daily average), which may not be sufficient for analyzing time-specific work zone traffic management strategies.

Table 3 lists some general pros and cons of using travel demand models for work zone traffic analysis.

Table 3. Pros and Cons of Travel Demand Models for WZTA

Pros	Cons
• Low cost (assuming readily available regional model) • Able to predict areawide traffic redistribution • Able to predict mode choice, destination choice, time-of-day travel choice, route choice, trip generation • Useful for large-scale, long-term projects	• Only accounts for recurring congestion conditions • Unable to accurately evaluate operational strategies such as ITS • Less useful for small-scale, short-term work zones • Limited accuracy for intersection turning movements • Not suitable for time-specific work zone analysis • High-technical skill set • Assumes network is operating in equilibrium

Travel Demand Modeling in Work Zone Traffic Analysis – TRANPLAN

Cleveland Innerbelt Project

The Cleveland Innerbelt Project was a rehabilitation and reconstruction project of the Innerbelt Freeway system, which includes Interstates 71 and 90. A maintenance of traffic alternatives analysis was conducted in order to evaluate traffic detour routes and a full closure work zone configuration during the rehabilitation/reconstruction effort. Several alternatives were analyzed such as reduction in the capacity of travel lanes along various segments of the Innerbelt, as well as the full closure of the Central Viaduct Bridge.

TRANPLAN, the regional travel demand model was used to simulate and measure the impacts of the traffic assignments and diversion that would take place as a result of the various work zone alternatives considered. TRANPLAN was used for a variety of reasons including its ease of use, accessibility (the model was already developed) and ability to generate the required performance measures needed for the analysis.

Portion of Cleveland Innerbelt TRANPLAN Network
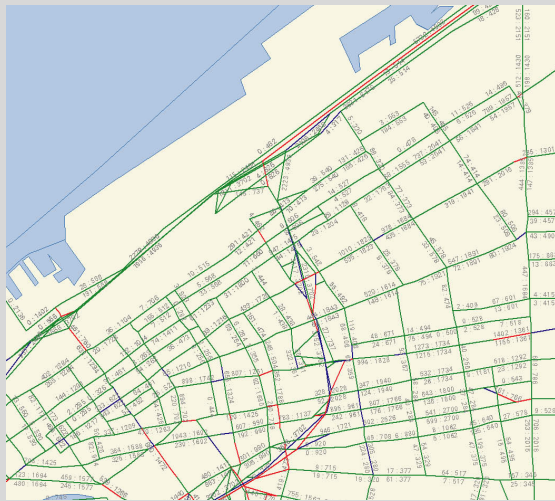
A list of travel demand models can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Traffic Signal Optimization Tools

Traffic signal optimization tools are primarily designed to develop optimal signal phasing and timing plans for signalized intersections, arterial streets, or signal networks. This may include capacity calculations; cycle length; splits optimization, including left turns; and coordination/offset plans. With respect to work zones, traffic signal optimization tools are useful when developing a signal plan for a temporary traffic signal, or analyzing signal plans when a detour route directs traffic to an existing signalized arterial roadway.

The primary **limitation of traffic signal optimization tools is their single focus**. Traffic signal optimization tools are typically used to provide supplementary analysis when analyzing the overall mobility impacts of a work zone.

Table 4 lists some general pros and cons of using traffic signal optimization tools for work zone traffic analysis.

Table 4. Pros and Cons of Traffic Signal Optimization Tools for WZTA

Pros	Cons
• Useful for temporary and permanent traffic signal design • Relatively quick analysis • Widely used and trusted • Capable of signal optimization	• Requires detailed traffic signal design expertise • Not well suited for freeway operations • Not well suited to analyze oversaturated conditions

Traffic Signal Optimization Tools in Work Zone Traffic Analysis – Synchro/SimTraffic

Eastern Avenue Bridge Reconstruction over Kenilworth Avenue[11]

Synchro/SimTraffic was used to evaluate various detour options for the reconstruction of the Eastern Avenue Bridge over Kenilworth Avenue, N.E. in Washington, D.C. The bridge needed to be rebuilt in order to provide additional clearance height for trucks and to provide a safer travel route for all vehicles.

Initially, the Maryland State Highway Administration's Lane Closure Analysis Program (LCAP) was used to evaluate the queues of the lane closures along Kenilworth Avenue. However, the tool could not capture the impacts of diversions/detours to other routes. Therefore, Synchro/SimTraffic was used in order to incorporate the potential for diversion when assessing the mobility impacts of the work zone. The preferred alternative in this project was to detour one of the three Kenilworth Avenue mainline lanes in each direction onto the service road and keep two shifted lanes in each direction. This alternative required closing the bridge. The bridge closures required detours via the "local" lanes of the service roads via Nannie Helen Burroughs Avenue and via the U.S. 50 interchange. A U-turn lane and special signal timing schemes were evaluated for the Nannie Helen Burroughs Avenue interchange using Synchro and SimTraffic. Using the results from the analysis, each alternative was compared economically for construction and user costs.

Diversion Routes on Kenilworth Avenue
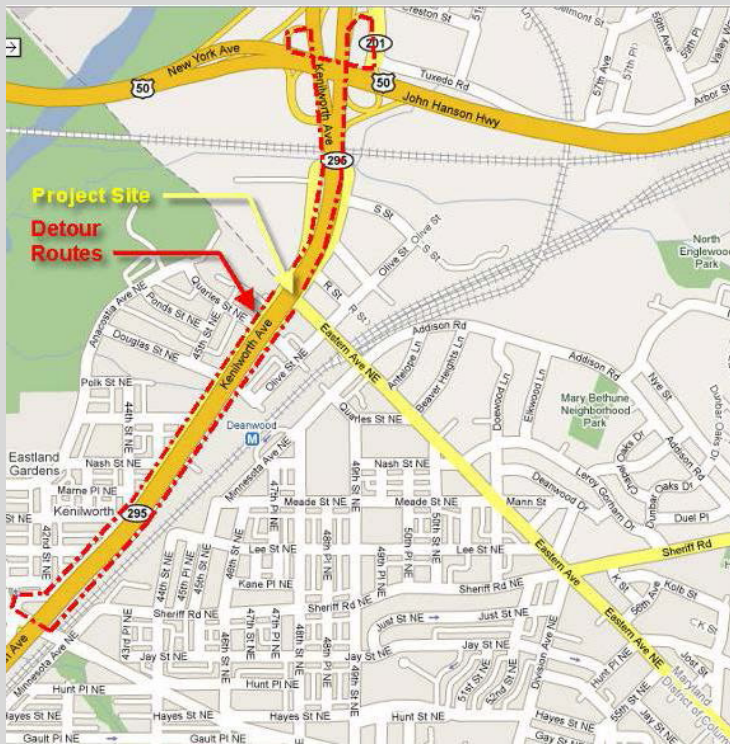
(Source: Bhajandas, Mallela, and Littleton, 2011.)

A list of traffic signal optimization tools can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Macroscopic Simulation Models

Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis, meaning they treat traffic flows as an aggregated quantity; they do not model the movement of individual vehicles on a network.

Similar to travel demand models, macroscopic models have the **ability to model a large geographic area**. This is particularly useful when the work zone impacts may affect a larger corridor or region, such as in the case of a full closure. They also can be set up and run fairly quickly due to the fact that they simulate aggregate flows. The primary limitation of macroscopic models is their simple representation of traffic movement, which limits the fidelity of the results.

Table 5 lists some general pros and cons of using macroscopic simulation models for work zone traffic analysis.

Table 5. Pros and Cons of Macroscopic Simulation Models for WZTA

Pros	Cons
• Able to model large geographic areas • Short simulation runtime • Easier to calibrate than mesoscopic and microscopic models • Medium technical skill set	• Simple representation of traffic movement • Limited network complexity • Traffic diversion not modeled explicitly • Unable to accurately evaluate operational strategies like ITS

Macroscopic Simulation in Work Zone Traffic Analysis – NetZone

SR 41 Fresno Corridor Construction Work Zone Traffic Impact Study[12]

NetZone was used on a case study along SR 41 in Fresno, California. This project involved weekend, daytime construction where two of the three lanes along the highway and one on-ramp upstream of the work zone would be closed to traffic. The work zone length was about four miles and the construction duration would last from 3:35 to 4:35 p.m. when construction efforts were active. The impacts of three scenarios were evaluated. The first scenario was the precondition or base case scenario. The second assessed the mobility impacts of the work zone if there were no traffic management plans. The third scenario assessed the impacts when pre-trip information and a media campaign were implemented as part of the work zone.

NetZone was used to evaluate measures such as travel time, delay, queues, and traffic diversion. The advantages of NetZone includes its user-friendliness, versatility to account for various factors and strategies (including demand changes, route diversions, ITS strategies, and traveler information), and detailed statistics. Because it is a macroscopic simulation tool, it requires less computation time and resources than more complex tools such as microsimulation, while still providing a dynamic modeling option to capture peak spreading and queuing within the network.

SR 41 Network
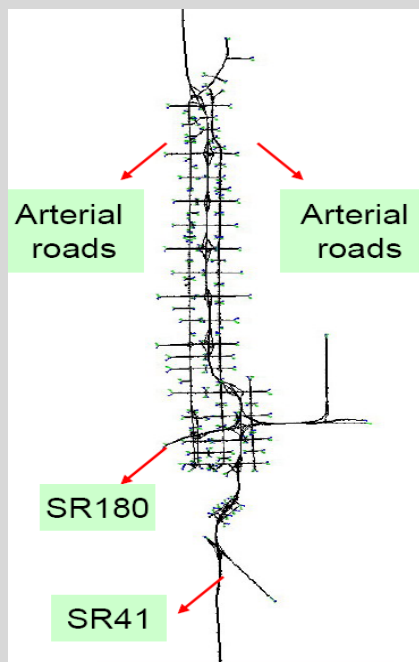
(Source: Zhang, 2007.)

A list of macroscopic simulation models can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Mesoscopic Simulation Models

Mesoscopic simulation models combine the **properties of both microscopic and macroscopic simulation models**. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is typically governed by the average speed on the travel link. Mesoscopic model

travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques. The primary strength of mesoscopic simulation models, when analyzing work zones, includes the **ability to model both large geographic areas and corridors**. In addition, they are capable of dynamic traffic assignment (DTA) and can readily be used to predict route diversions, temporal demand shifts, and even modal shifts in some cases.

Mesoscopic simulation models do have a number of weaknesses. One is their limited ability to model detailed operational strategies, such as complex signal control. Thus, if a work zone includes a number of signalized intersections, a different type of model (such as a microscopic simulation model or traffic signal optimization tool) may be a better choice. Another drawback is the overall model complexity and data requirements necessary for accurate results. Mesoscopic models are an **order of magnitude more complex** than the most sophisticated sketch-planning tools; require similar amounts of data (albeit at a more granular level) as regional planning models; and similar resources (time, money, and knowledge) as travel demand models and microscopic simulation models.

Table 6 lists some general pros and cons of using mesoscopic simulation analysis for work zone traffic analysis.

Table 6. Pros and Cons of Mesoscopic Simulation Models for WZTA

Pros	Cons
• Capable of measuring corridor or areawide impacts • Capable of dynamic routing • Detailed temporal analysis • Captures nonrecurring and operational strategies • Less intensive than micro, and more refined than macro	• Resource intensive (data, cost, expertise, analysis time) • Typically link, not lane-based impacts • Not all are capable of reflecting detailed traffic signal parameters • High-technical skill set

Mesoscopic Simulation in Work Zone Traffic Analysis – DynusT

Dynamic Traffic Assignment Application: I-10 Corridor Study, Tucson Arizona[13]

The I-10 Corridor Project provides freeway and interchange improvement along a five-mile segment of I-10. Improvements associated with the project include road widening and reconstruction of four interchanges along I-10, converting them from overpasses to underpasses. During the planning stages of the project, DTA modeling was used in order to develop a design concept and preliminary plans for the project. Using mesoscopic simulation software, DynusT, DTA modeling was performed for three phases of the project development process – capacity analysis, construction sequencing, and evaluation of work zone traffic control. It will also be used to evaluate work zone strategies during the final design in 2012.

The DynusT model was created using a regional TransCAD travel demand model. Signal data and intersection geometry were imported into the DynusT model from a regional Synchro model. These two steps were automated with conversion tools. Manual fine-tuning was also conducted to correct signal phasing/timing, geometry, posted speed limit, etc. as necessary. The measures of effectiveness (MOE) used in ranking alternatives included travel time, volume-to-capacity (v/c) ratio, and average speed.

DynusT was chosen for the following reasons:

- A preliminary model was already available from local agency;
- DTA modeling in DynusT allows for greater accuracy, more realistic results, and capabilities for analysis at the corridor and regional level; and
- Capabilities for evaluating various work zone alternatives.

DynusT Network of I-10 Project
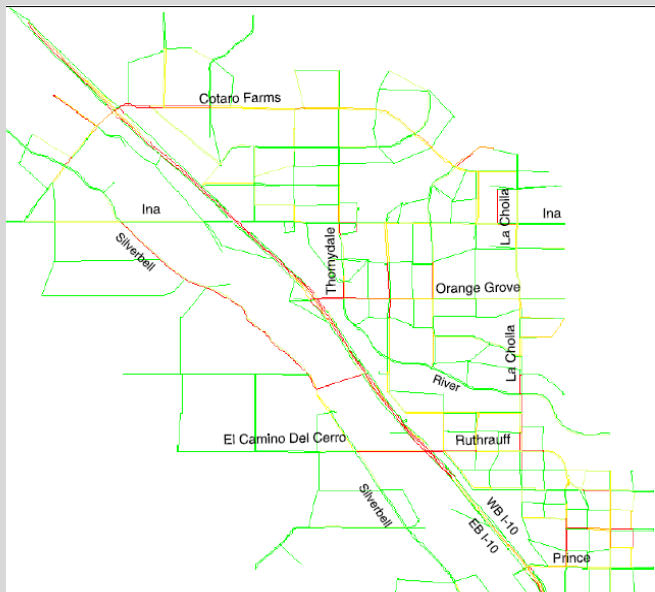
(Source: Zou, Nguyen, and Schoen, 2010.)

A list of mesoscopic simulation models can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

Microscopic Simulation Models

Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., one second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed.

Microscopic simulation models were developed to **represent transportation systems accurately at the individual vehicle level**. They simulate the movement of individual vehicles based on car-following and lane-changing theories and other parameters. Microscopic simulation models update the positions and intentions of individual vehicles every second (or fraction of a second) as they move through a network. To account for the diversity of vehicles and driving styles that are encountered in real-world traffic, each vehicle is assigned a set of characteristics that influence the way it responds to the presence of other vehicles and to traffic control devices. Many transportation agencies currently use microscopic models, in conjunction with travel demand models, to better understand the impact of roadway geometry modifications on LOS and carrying capacity.

Microscopic simulation models are effective in evaluating a wide range of scenarios, including heavily congested conditions, complex geometric configurations, and system-level impacts of proposed transportation improvements that are beyond the limitations of other model types. While practical considerations may limit the geographic coverage of a microscopic simulation model, these models are useful in analyzing key bottlenecks on roadway segments and corridors, where the movement of each individual vehicle needs to be represented to better understand the impact on roadway conditions.

The primary limitation of microscopic simulation models is the substantial amount of roadway geometry, traffic control, and traffic pattern data they require. Specialized training for staff is needed and the model development time is often lengthy, particularly when performing calibration of oversaturated conditions. In addition, microsimulation models **do not directly calculate LOS and delay consistent with the HCM** control delay definition, which can be difficult for decision-makers who have relied on this information in the past.

Table 7 lists some general pros and cons of using microscopic simulation analysis for work zone traffic analysis.

Table 7. Pros and Cons of Microscopic Simulation Models for WZTA

Pros	Cons
• Detailed design level • Complex geometric configurations • Operational impacts • Static or dynamic • Able to model oversaturated conditions • Able to model key bottlenecks • Good visualization capability (for both technical and lay persons) • Wide range of performance measures • Local and systemwide impacts	• Resource intensive (data, cost, expertise, analysis time) • Restricted to corridor or smaller study areas • Unfamiliar to decision-makers (produces different performance measures different from traditional HCM-based tools) • Requires "tricks" to mimic work zone conditions • High-technical skill set

Microscopic Simulation in Work Zone Traffic Analysis – CORSIM

I-80 Reconstruction Project, Iowa County, Iowa[14]

The Interstate 80 project in Iowa County, Iowa included a six-mile pavement reconstruction of four traffic lanes along I-80. The construction lasted from May 31, 1997 until September 13, 1997, where the Interstate was modified into a two-lane, two-way operation configuration. Using CORSIM, the impacts of four work zone alternatives were analyzed:

- Do-nothing alternative;
- Non-stop work alternative (chosen alternative);
- Four traffic lanes throughout the work zone; and
- Diversion route alternative.

Microscopic simulation was used to determine the amount of motorist delay associated with each alternative. Microscopic simulation Traffic Software Integrated System (TSIS-CORSIM) was chosen for the analysis because of its ability to simulate a work environment and provide the measures of effectiveness needed to effectively compare alternative traffic management plans. It also provided data required for benefit/cost analyses that would be difficult to obtain from other sources. Monetary values of delays were used to evaluate and compare alternatives.

I-80 Work Zone Location and Diversion Routes
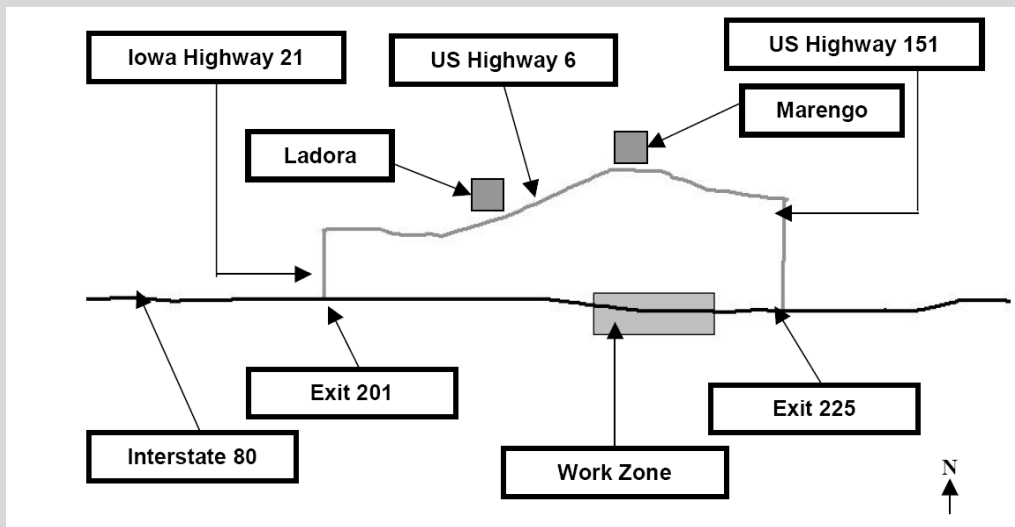
(Source: Schrock and Maze, 2000.)

A list of microscopic simulation models can be found in the *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

3.2 KEY FACTORS FOR SELECTING THE ANALYSIS TOOL(S)

Work zone impacts analysis may involve a high-level, qualitative review for some projects; or a detailed, quantitative analysis using modeling and/or simulation tools for other projects. **Tool selection is critical in ensuring the most appropriate analysis results** for decision-makers to make an informed judgment. The key to successful work zone analysis does not depend only on selecting the suitable transportation modeling approach, but also on successful integration of data and tools to provide a meaningful assessment of work zone impacts relevant to one or more key project decisions. One of the first and most critical steps in selecting a work zone traffic analysis tool is to identify the objectives of the analysis and the desired outcome(s). In order to achieve those objectives and make an informed decision, it is critical for a work zone analyst to consider a number of key factors before selecting a traffic analysis tool. As described in both *Traffic Analysis Toolbox Volume IX: Work Zone Modeling and Simulation – A Guide for Analysts*[2] and *Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools,*[7] the key factors in determining the appropriate tool can be broadly categorized into seven major areas: 1) project stages; 2) facility types; 3) tool features; 4) agency resources; 5) work zone characteristics; 6) transportation management plan; and 7) performance measures.

Within each of the key factors are important questions that the analyst should consider when identifying the appropriate tool for the project. A **scoping work sheet** such as the one featured in *Traffic Analysis Toolbox Volume IX*[2] and Figure 6, organizes these key questions and considerations by each key factor.

A similar work sheet can be developed with the recommended key factors aforementioned to use as a **tool for documenting the various components of a work zone project** that needs to be analyzed using a transportation analysis tool. These work sheets are intended to be used as a supplemental guide for tool selection. They should be used in conjunction with other important considerations that may be specific to the agency or the project when choosing a specific modeling approach(es)/tool(s).

This chapter discusses the strategic framework to identify an appropriate transportation modeling approach and analysis tool(s). The chapter provides step-by-step guidance to assist the analyst in determining the suitable tool(s) to perform work zone analysis. A hypothetical case study also is provided in order to demonstrate the application of each step. Figure 7 illustrates the steps involved to assist the analyst identify the most appropriate modeling approaches. In total, seven criteria are necessary to help identify the analytical tools that are most appropriate for a particular project. Depending on the analytical context and the project's goals and objectives, the relevance of each criterion may differ. The criteria include:

1. **Project Stages –** Ability to perform analysis under the specific project stage, including planning, preliminary engineering/design (PE/Design), and construction stages.
2. **Facility Types –** Capability of modeling various facility types, such as freeways, ramps, arterials, intersections, high-occupancy vehicle (HOV) lanes, toll plazas, etc.
3. **Tool Features –** Ability to provide features such as mode split estimation and animation. Other features include ease of use and whether the tool is popular and well trusted.

4. **Agency Resources –** Ability to meet agency resources that are required for analysis, including technical skills, tool capital cost, schedule/time, hardware, and data requirements.
5. **Work Zone Characteristics –** Ability to analyze the appropriate work zone type, work zone network configuration, work zone size, and work zone analysis area (study area).
6. **Transportation Management Plan (TMP) –** Ability to analyze various traffic management strategies and applications, such as temporary traffic control, motorist information, corridor management, and incident management.
7. **Performance Measures –** Ability to produce and output performance measures, such as travel time, delay, queue length, speed, volume, level of service (LOS), vehicle hours of travel (VHT), emissions, and fuel consumption.

> The tool relevance to each of the seven criteria presented in this section is for the general tool type, not individual tools. Certain tools within a tool type may have advanced features or capabilities that majority of the others within the same tool type do not have. The analyst may revise the tool relevance when justified.

Work Zone Analysis Scoping Worksheet

What key decision are you supporting?

Work Zone Characteristics
Select One for Each Category

Type	I / II / III / IV	Institutional	culture / leadership / data / contracting
Network Configuration	isolated / pipe / grid	Technical Staff	consultant / in-house
Size	small / medium / large	Funding	$ $ $ $ $ $ $ $ $ $ $ $
Analysis Area Dimension	site / local / metropolitan	Time to Analyze	short / medium / long

Agency Resources

Performance Measures
●= Key Performance Measure; ◔= Secondary; ○= Not Important

In the space adjacent to the circle, note any key policy requirements associated with the performance measure.

Travel Time	○	Volume	○
Delay	○	User Cost	○
Queue Length	○	Incidents	○
Speed	○	Cumulative Impacts	○

Precision of Results

rough estimation ●————————————● detailed assessment

Data

		Availability	Notes
Type	Roadway Characteristics		
	Travel Demand Characteristics		
	Cost Attributes		
Source	Primary		
	Archived		
Quality	Collection Frequency		
	Geographic Coverage		
	Archive Length		
	Accuracy		

Transportation Management Plan Strategies
■ Key TMP Strategy; ☑ Minor TMP Strategy; □ TMP Strategy Not Considered

Temporary Traffic Control			Public Info.	Transportation Operations			
Control Strategies	Traffic Control Devices	Project Innovation	Motorist Information	Demand Mgmt Strategies	Corridor/Network Mgmt Strategies	Work Zone Safety Mgmt	Traffic/Incident Management
□ Construction phasing/ staging	□ Changeable message signs	□ Project Coordination	□ Changeable message signs	□ Transit service improvements	□ Signal timing/ coordination	□ Speed limit reduction/ variable speed limits	□ ITS for traffic Monitoring
□ Full roadway closure	□ Flaggers and uniformed traffic control officers	□ Contracting Strategies	□ Dynamic speed message sign	□ High-occupancy vehicle lanes	□ Temp. traffic signals	□ Temporary traffic signals	□ Transportation management center
□ Lane shifts or closures	□ Temporary traffic signals	□ Innovative construction techniques	□ Highway advisory radio	□ Toll/congestion pricing	□ Street/intersection improvements		□ Tow/freeway service patrol
□ One-lane, two way operations			□ 511 traveler information systems	□ Ramp metering	□ Bus turnouts		□ Local detour routes
□ Two-way traffic on one side of divided facility					□ Turn restrictions		
□ Reversible lanes					□ Separate truck lanes		
□ Ramp closures/ relocation					□ Reversible lanes		
□ Freeway-to-freeway interchange closures					□ Ramp metering		
□ Night work					□ Temporary suspension of ramp metering		
□ Weekend work					□ Ramp closures		
□ Work hour restrictions for peak travel					□ Coordination with adjacent construction sites		
□ Off-site detours/use of alternate routes							

Figure 6. Work Zone Analysis Scoping Work Sheet

(Source: Hardy and Wunderlich, 2009.)
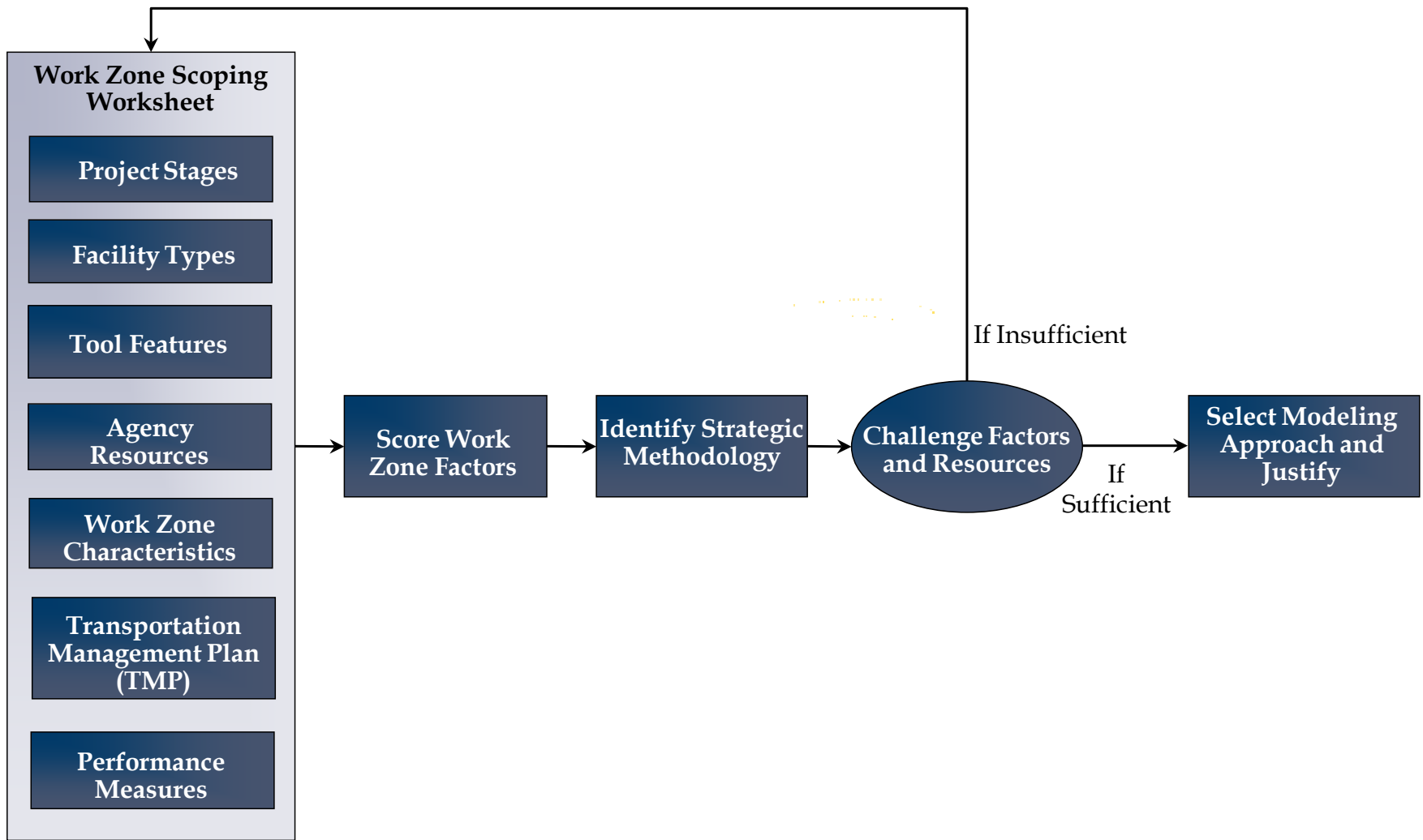
Figure 7. Framework for Identifying Appropriate Modeling Approach for Work Zones

The figure shows a flowchart. On the left is a container labeled "Work Zone Scoping Worksheet" containing stacked boxes: "Project Stages", "Facility Types", "Tool Features", "Agency Resources", "Work Zone Characteristics", "Transportation Management Plan (TMP)", and "Performance Measures". An arrow leads from this container to "Score Work Zone Factors", then to "Identify Strategic Methodology", then to an ellipse labeled "Challenge Factors and Resources". From the ellipse, "If Insufficient" loops back up to the Work Zone Scoping Worksheet, and "If Sufficient" leads to "Select Modeling Approach and Justify".

Project Stages

One of the initial steps in selecting a transportation analysis tool and modeling approach will be to identify the key decisions that need to be supported during the analysis. These key decisions should include scheduling decisions (time of day, time of year, duration, etc.); application decisions; and transportation management plan decisions. Additionally, the analyst also should consider how these key decisions would differ based upon the project stage (planning, design, or construction) of the project or decision-making process. The three stages of the decision-making process are shown in Figure 8. Further information about these three stages in the decision-making process is provided in the FHWA's *Traffic Analysis Toolbox Volume VIII: Work Zone Modeling and Simulation – A Guide for Decision-Makers*.[1] The decision-making process evolves over time, and the decisions made in the initial stage will have a direct impact on forthcoming stages. For example, while making decisions at the planning stage, careful considerations should be made taking into account the preliminary engineering/design (PE/Design) and construction stages. Because these may change depending on where the project is in the process, certain tool classes may be better suited for certain key decisions involved in a particular stage than others. Table 8 presents the relevance of each tool class to the different project stages.
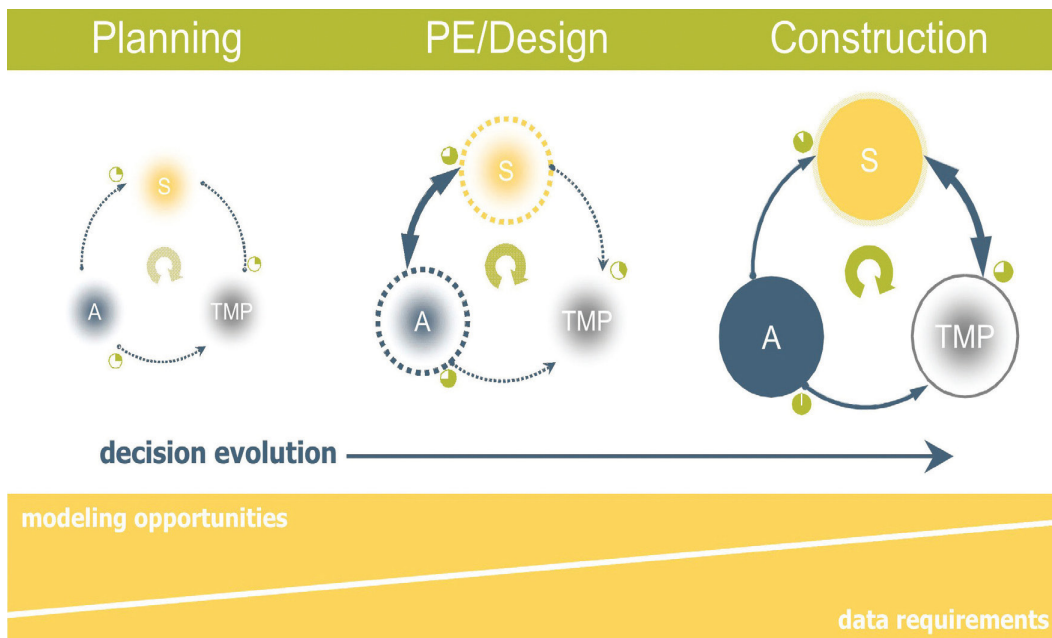
Figure 8. Work Zone Decision-Making Process

(Source: Hardy and Wunderlich, 2008.)

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Table 8. Project Stages

Factors – PROJECT STAGES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Planning	●	●	○	⊘	⊘	○
PE/Design	⊘	⊘	●	●	●	●
Operations/Construction	⊘	○	●	●	●	●

Notes:
●   Specific context is generally addressed by tools in this category.
⊘   Some of tools in this category address the specific context but some do not.
○   Tools within this category do not generally address the specific context.

Facility Types

This factor includes the various facility types that will be included in the analysis area. An analysis can include a multitude of facility types such as freeways, arterials, ramps, and auxiliary lanes, among others. A full list and description of each facility type is provided in Table 9.

Tool Features

This factor includes various tool features such as mode split estimation and animation. Certain tool classes may offer additional capabilities or features that would allow the agency to optimize their modeling process. Some of these tool features that may be considered include:

- **Mode Split –** It evaluates whether the tool provides estimation on percentage of travelers using each travel mode (SOV, HOV, transit, bicycle, pedestrian, etc.).
- **Ease of Use –** It evaluates whether the tool is generally user-friendly.
- **Popular/Well Trusted** – It evaluates whether the tool is popular and well regarded by current users.
- **Animation/Presentation –** This factor evaluates whether the tool has animation/ presentation features such as colorful three-dimensional views and simulation video clips.

Table 10 provides a summary of these tool features for each specific modeling approach.

Table 9. Facility Types

Factors – FACILITY TYPES	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Isolated Intersection	Single crossing point between two or more roadway facilities.	⊘	⊘	●	⊘	●	●
Roundabout	Unsignalized intersection with a circulatory roadway with entering vehicles yielding to traffic.	⊘	○	○	⊘	⊘	●
Arterial	Signalized street that may serve through traffic and/or provide access to abutting properties.	⊘	●	●	●	●	●
Highway	High-speed roadway connecting major areas or arterials, with little to no traffic signal operations.	●	●	⊘	●	●	●
Freeway	Multilane, divided highway with a minimum of two lanes in each direction, no traffic signal interruption.	●	●	⊘	●	●	●
HOV Lane	Exclusive lane for vehicles with a defined minimum number of occupants (more than one), including buses, taxis, or carpools.	⊘	●	○	●	●	●
Ramp	Segment of roadway connecting two roadway facilities.	⊘	●	⊘	●	●	●
Auxiliary Lane	Additional lane on a freeway connecting an on-ramp and an off-ramp.	⊘	○	⊘	⊘	●	●
Truck Lane	Designated lane for commercial vehicles, but not for public transit vehicles.	⊘	●	⊘	⊘	●	●
Bus Lane	Designated lane for buses during specified periods.	○	●	○	⊘	⊘	●
Toll Plaza	Facility where a payment transaction for certain use of the roadway is required.	⊘	⊘	○	○	⊘	●

Notes:
●   Specific context is generally addressed by tools in this category.
⊘   Some of tools in this category address the specific context but some do not.
○   Tools within this category do not generally address the specific context.

Table 10. Tool Features

Factors – TOOL FEATURES	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Mode Split	This factor evaluates whether the tool provides percentage of travelers using each travel mode (SOV, HOV, transit, bicycle, pedestrian, etc.).	⊘	●	⊘	⊘	⊘	⊘
Easy to Use	This factor evaluates whether the tool is generally user-friendly.	●	○	⊘	⊘	○	○
Popular/Well Trusted	This factor evaluates whether the tool is popular and well regarded by current users.	●	⊘	●	○	⊘	●
Animation/Presentation	This factor describes whether the tool provides capabilities for animation and/or other presentation features.	○	⊘	○	⊘	⊘	●

Notes:
●   Specific context is generally addressed by tools in this category.
⊘   Some of tools in this category address the specific context but some do not.
○   Tools within this category do not generally address the specific context.

Agency Resources

The extent to which the impacts of a work zone can be analyzed is strongly dependent upon availability of agency resources. It is critical for an analyst to consider the following five factors while determining the suitable analysis approach.

1. **Technical Skill Requirements** – This factor describes the amount of technical knowledge required in order to use the tool. For instance, this factor addresses how much training may be involved in order for agency staff to utilize the tool effectively for the work zone traffic analysis. On Table 11 tools that do not require extensive technical skill requirements or training are indicated by a ●. Tools requiring a moderate amount of training are noted by ⊘   and those requiring an extensive amount of training or technical skill set is indicated by ○.

2. **Tool Capital Cost** – This factor evaluates the average capital cost to acquire the tool. Tools with an average cost less than $1,000 are considered inexpensive. Those tools within the $1,000-$5,000 range can be considered as mid-range and those with average costs greater than $5,000 are considered to be expensive. On Table 11 tools considered inexpensive are depicted by ●. Tools with average costs falling in the medium range are rated ⊘   and those classified as expensive are indicated by ○.

3. **Time/Schedule Requirements for Analysis** – The time or schedule requirements associated with a tool can include how much coding and/or data inputs are required in order to use the tool. It also can include how much computer run time is needed in order to obtain the necessary model output or performance measures using a particular tool. On Table 11 tools that do not have extensive time requirements for model network preparation and/or computer run time are depicted by ●. Tools with mid-range time requirements are rated ⊘   and those requiring a significant amount of time for model network coding and preparation as well as computer run time for post-processing outputs are indicated by ○.

4. **Hardware Requirements** – The amount of computer power or processing capabilities required in order to run the analysis can influence which tool is best suited for the project. On Table 11 tools that do not have extensive hardware (computer power and memory storage) requirements for the analysis are depicted by ●. Tools with mid-range requirements are rated ⊘   and those requiring a significant amount of resources are depicted by ○.

5. **Data Requirements** – The amount of input data required in order to perform the analysis also can influence what tool is suitable for the project. Input data typically fall under two categories: roadway characteristics and travel demand characteristics. Roadway characteristics data provides information regarding the physical design and operational characteristics of the roadway. Data inputs in this category can include intersection, lane, and road geometric characteristics, traffic control locations, and meter and traffic signal timing plans. Travel demand characteristics describes the vehicle and traffic demand of the system being analyzed and can include data inputs such as Origin-Destination trip tables, trip classifications, traffic volume counts and forecasts. On Table 11 tools that do not have extensive data requirements for the analysis are depicted by ●. Tools with mid-range requirements are rated ⊘   and those requiring a significant amount of data inputs and resources are depicted by ○.

Table 11. Agency Resources Required for Analysis

Factors – AGENCY RESOURCES REQUIRED FOR ANALYSIS	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Technical Skill Requirements	Tools without extensive technical skill or training requirements are shown with ●; moderate amount of training is marked ⊘ and extensive technical skill/training requirement is indicated by ○.	●	○	⊘	⊘	○	○
Tool Capital Cost	Inexpensive tools are marked by ●. Tools with average costs falling in the medium range are rated ⊘ and those classified as expensive are indicated by ○.	●	⊘	⊘	⊘	⊘	○
Schedule/Time Requirements	Tools that do not require much time for model network preparation and/or computer run time are depicted by ●. Tools with mid-range time requirements are rated ⊘ and those requiring significant time requirements are marked with ○.	●	⊘	⊘	⊘	○	○
Hardware Requirements	Tools that do not have extensive hardware (computer power and memory storage) requirements for the analysis are depicted by ●. Tools with mid-range requirements are rated ⊘ and those requiring a significant amount of resources are depicted by ○.	●	○	●	⊘	○	○
Data Requirements	Tools that do not have extensive data requirements for the analysis are depicted by ●. Tools with mid-range requirements are rated ⊘ and those requiring a significant amount of data inputs and resources are depicted by ○.	●	⊘	⊘	⊘	○	○

Notes:
●   Tools that do not have extensive requirements for the analysis.
⊘   Tools that have mid-range requirements for the analysis.
○   Tools that have extensive requirements for the analysis.

Work Zone Characteristics

This subsection discusses how the physical attributes of a work zone impacts the type of tool that should be selected for the analysis. The work zone characteristics include the type, the network configuration, size, and the analysis area dimension of the work zone analysis project included in the analysis area, as shown in Table 12. Detailed definitions of these attributes are provided in *Traffic Analysis Toolbox Volume IX: Work Zone Modeling and Simulation – A Guide for Analysts*[2] and *Traffic Analysis Toolbox Volume II*.[7] Work zone characteristics used in the tool selection methodology include:

- **Work Zone Type –** As defined in the FHWA's *Work Zone Self Assessment Guide*, Work Zone Types I, II, III and IV are indicative of the level of impact a work zone will have on travelers. Agencies may choose their own categories based on level of impact, but typically Type I is more complex and attracts greater public interest than Type II and so on.
- **Network Configuration –** The network configuration determines the overall complexity of the work zone that will be evaluated. It is composed of the following three general categories:
  - Isolated – Single work zone with limited interaction of surrounding infrastructure;
  - Pipe – Roadway segment with multiple, interacting work zones; and
  - Grid – Connected, interdependent network structure with multiple access points and alternate routes.
- **Work Zone Size –** This factor includes the actual size of the work zone itself and the immediate area that will be impacted. Work zones are divided into three sizes:
  - Small – A work zone implemented on a short segment of an individual roadway or a single intersection;
  - Medium – One or more work zones on longer stretches of a single facility and/or portions of adjacent facilities; and
  - Large – Interacting work zones implemented on significant elements of a larger roadway network.
- **Analysis Area Dimension** – Analysis area dimension determines the entire area impacted by the work zone. It is divided into three categories:
  - Site – Restricted to the immediate area surrounding the work zone;
  - Local – Includes surrounding area beyond the work zone to account for detour routes or other localized impacts; and
  - Metropolitan – Includes multiple jurisdictions (counties, cities, etc.) or facilities.

Table 12. Work Zone Characteristics

Factors – WORK ZONE CHARACTERISTICS	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Work Zone Type							
Type I	Affects a large number of traveler at the regional scale, with high public interest, significant user cost impacts and a long duration.	⊘	●	⊘	⊘	●	○
Type II	Similar to Type I but moderate impact.	⊘	⊘	⊘	⊘	●	⊘
Type III	Similar to Type I but low impact.	●	○	●	○	⊘	●
Type IV	Short-duration work zone with low visibility and public interest.	●	○	●	○	○	●
Work Zone Network Configuration							
Isolated	Single work zone with limited interaction of surrounding infrastructure.	●	○	⊘	⊘	⊘	⊘
Pipe	Roadway segment with multiple, interacting work zones.	●	○	⊘	⊘	●	●
Grid	Connected, interdependent network structure with multiple access points and alternate routes.	○	⊘	⊘	⊘	●	●
Work Zone Size							
Small	A work zone implemented on a short segment of an individual roadway or a single intersection.	●	○	●	○	⊘	⊘
Medium	One or more work zones on longer stretches of a single facility and/or portions of adjacent facilities.	●	⊘	⊘	⊘	●	●
Large	Interacting work zones implemented on significant elements of a larger roadway network.	●	●	⊘	●	●	●
Work Zone Analysis Area Dimension							
Site	Analysis area is restricted to the immediate area surrounding the work zone.	●	○	●	○	⊘	⊘
Local	Analysis area includes surrounding area beyond the work zone to account for detour routes or other localized impacts.	●	⊘	⊘	⊘	●	●
Metropolitan	Analysis area includes multiple jurisdictions (counties, cities, etc.) or facilities.	⊘	●	⊘	●	●	⊘

(Source: Hardy and Wunderlich, 2009.)

Notes:

● Specific context is generally addressed by tools in this category.

⊘ Some of tools in this category address the specific context but some do not.

○ Tools within this category do not generally address the specific context.

Transportation Management Plan (TMP)

A TMP describes the management strategies that will be used to manage the impacts of a work zone. The work zone analysis tool must be capable of modeling the impacts of the type of strategy to be evaluated. As described in the FHWA's *Developing and Implementing Transportation Management Plans for Work Zones*, TMP strategies are broadly grouped into the following categories:

- **Temporary Traffic Control (TTC) –** These strategies include conceptual decisions on possible construction approaches, traffic control and management approaches, and time of construction. These include the following:
  - Control strategies;
  - Traffic control devices; and
  - Project innovation.
- **Public Information –** For projects that will have a significant impact on the traveling public, the analyst should consider, including motorist information strategies. Information dissemination to the public can be delivered a number of ways, such as general public awareness campaigns and motorist information strategies (e.g., pre-trip and en route traveler information).
- **Transportation Operations –** Operational strategies are wide ranging and can be classified into four major categories:
  - Demand management strategies;
  - Corridor/network management strategies; and
  - Traffic incident management and enforcement strategies.

Table 13 presents the relevance of each tool class to the different TMP strategies.

Table 13. TMP Strategies

Factors – TMP STRATEGIES	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Temporary Traffic Control	Traffic control approaches used to accommodate road users within the work zone and adjoining corridor in an efficient and safe manner (e.g., construction phasing/staging, lane closures, ramp closures/relocation, temporary traffic signals).	●	⊘	●	⊘	●	●
Motorist Information	Provision of current/real-time information to road users regarding the project work zone.	●	⊘	●	⊘	●	●
Demand Management	Strategies intended to reduce the volume of traffic traveling through the work zone. Examples include diverting motorists to alternate modes of travel, shifting motorists to alternate routes, and encouraging off-peak travel trips.	●	●	⊘	⊘	●	⊘
Corridor/Network Management (traffic operations)	Strategies used to optimize traffic flow through work zone using traffic operations strategies and technologies.	⊘	⊘	⊘	⊘	●	●
Traffic/Incident Management and Enforcement Strategies	Strategies to manage work zone traffic operations.	⊘	○	○	⊘	●	●

Notes:
●   Specific context is generally addressed by tools in this category.
⊘   Some of tools in this category address the specific context but some do not.
○   Tools within this category do not generally address the specific context.

Performance Measures

Once the agency determines the work zone traffic analysis objectives at the onset of the project, a list of the most desired and appropriate performance measures should be identified to allow for informed decision-making. Both the type of measure and the precision of the results (rough estimated or a detailed assessment) are important. A comprehensive list of performance measures are compiled in the FHWA's *Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects* and *A Primer on Work Zone Safety and Mobility Performance Measurement*.[5,6] Some of the most common measures include:

- Travel time;
- Delay;
- Queue length;
- Speed;
- Volume;
- Density;
- LOS; and
- VMT/VHT.

The stage of the project's life cycle often determines the overall precision of the results. For example, as the project moves from Planning to PE/Design to Construction, the level of precision needed increases. Table 14 provides a summary of the relevance of each tool class to various performance measures.

Table 14. Performance Measures

Factors – PERFORMANCE MEASURES	Summary	Transportation Modeling Approach					
		Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Travel Time	Average time spent by vehicles traversing a facility, typically in minutes per vehicle.	⊘	●	●	●	●	●
Delay	Additional travel time experienced by travelers at speeds less than the free-flow speed.	●	●	●	●	●	●
Queue Length	Length of queued vehicles waiting to be served by the system (expressed in distance or number of vehicles).	●	○	●	●	●	●
Speed	Rate of motion (expressed in distance per unit of time).	●	●	●	●	●	●
Volume	Number of persons or vehicles passing a point on a roadway during some time interval.	●	●	●	●	●	●
V/C Ratio	Ratio of flow rate to capacity for a transportation facility.	⊘	●	⊘	⊘	⊘	⊘
Density	Number of vehicles on a roadway segment averaged over space (usually expressed in vehicles per mile or vehicles per mile per lane).	⊘	○	●	●	●	●
LOS	Qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Ranges from LOS A (best) to LOS F (worst).	⊘	⊘	●	⊘	⊘	⊘
VMT/PMT	Total distance traveled by all vehicles or persons on a transportation facility or network during a specified time period (expressed in miles).	⊘	●	⊘	●	●	●
VHT/PHT	Total travel time spent by all vehicles or persons on a transportation facility or network during a specified time period (expressed in hours).	⊘	●	⊘	●	●	●
Emissions	Predicted emissions for each pollutant type on a transportation facility or network.	⊘	○	○	○	⊘	⊘
Fuel Consumption	Fuel consumption rate associated with the use of a transportation facility or network.	⊘	○	○	⊘	●	●

Notes:
● Specific context is generally addressed by tools in this category.
⊘ Some of tools in this category address the specific context but some do not.
○ Tools within this category do not generally address the specific context.

3.3 SELECTING THE ANALYSIS TOOL(S)

The purpose of this section is to provide users guidance regarding how to use the criteria and factors described in Section 3.2 to select the appropriate analysis tool types. This section also uses a hypothetical example in order to demonstrate the steps of this approach.

Assign Criteria Relevance Weight

In most cases, the most appropriate tool category or tool depends on the type of project and the level of detail required by each project. In this step, the criteria relevance weight is assigned to each of the criteria, depending on the type of study. The weight ranges from 0 (not relevant) to 5 (most relevant). For instance, if the project is a long-range plan, the project stage weight should be 5 for "Planning" and 0s for "PE/Design" and "Construction," as shown in Table 15.

Table 15. Example Criteria Relevance Weight

Factors – PROJECT STAGES	Criteria Relevance
Planning	5
PE/Design	0
Construction	0

Assign Tool Relevance Values

The tool relevance values are assigned as follows:

   a. For every solid circle (●), assign a value of 10.
   b. For every null symbol (⊘), assign a value of 5.
   c. For every empty circle (○), assign a value of 0.

Tables 16 through 22 present the tool relevance values for each of the seven criteria presented in Tables 8 through 14.

> The tool relevance to each of the seven criteria presented in this section is for the general tool type, not individual tools. Certain tools within a tool type may have advanced features or capabilities that majority of the others within the same tool type do not have. The analyst may revise the tool relevance values when justified. Also, the analyst may adopt a different set of values than the ones provided herein (0-10).

Table 16. Tool Relevance Values – Project Stages

Factors – PROJECT STAGES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Planning	10	10	0	5	5	0
PE/Design	5	5	10	10	10	10
Operations/Construction	5	0	10	10	10	10

Table 17. Tool Relevance Values – Facility Types

Factors – FACILITY TYPES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Isolated Intersection	5	5	10	5	10	10
Roundabout	5	0	0	5	5	10
Arterial	5	10	10	10	10	10
Highway	10	10	5	10	10	10
Freeway	10	10	5	10	10	10
HOV Lane	5	10	0	10	10	10
Ramp	5	10	5	10	10	10
Auxiliary Lane	5	0	5	5	10	10
Truck Lane	5	10	5	5	10	10
Bus Lane	0	10	0	5	5	10
Toll Plaza	5	5	0	0	5	10

Table 18. Tool Relevance Values – Tool Features

Factors – TOOL FEATURES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Mode Split	5	10	5	5	5	5
Easy to Use	10	0	5	5	0	0
Popular/Well Trusted	10	5	10	0	5	10
Animation/Presentation	0	5	0	5	5	10

Table 19. Tool Relevance Values – Agency Resources Required for Analysis

Factors – AGENCY RESOURCES REQUIRED FOR ANALYSIS	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Technical Skill Requirements	10	0	5	5	0	0
Tool Capital Cost	10	5	5	5	5	0
Schedule/Time Requirements	10	5	5	5	0	0
Hardware Requirements	10	0	10	5	0	0
Data Requirements	10	5	5	5	0	0

Table 20. Tool Relevance Values – Work Zone Characteristics

Factors – WORK ZONE CHARACTERISTICS	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Work Zone Type						
Type I	5	10	5	5	10	0
Type II	5	5	5	5	10	5
Type III	10	0	10	0	5	10
Type IV	10	0	10	0	0	10
Work Zone Network Configuration						
Isolated	10	0	5	5	5	5
Pipe	10	0	5	5	10	10
Grid	0	5	5	5	10	10
Work Zone Size						
Small	10	0	10	0	5	5
Medium	10	5	5	5	10	10
Large	10	10	5	10	10	10
Work Zone Analysis Area Dimension						
Site	10	0	10	0	5	5
Local	10	5	5	5	10	10
Metropolitan	5	10	5	10	10	5

Table 21. Tool Relevance Values – TMP Strategies

Factors – TMP STRATEGIES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Temporary Traffic Control	10	5	10	5	10	10
Motorist Information	5	0	0	5	10	10
Demand Management	10	10	5	5	10	5
Corridor/Network Management (Traffic Operations)	5	5	5	5	10	10
Traffic/Incident Management and Enforcement Strategies	5	0	0	5	10	10

Table 22. Tool Relevance Values – Performance Measures

Factors – PERFORMANCE MEASURES	Transportation Modeling Approach					
	Sketch-Planning and HCM	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Travel Time	5	10	10	10	10	10
Delay	10	10	10	10	10	10
Queue Length	10	0	10	10	10	10
Speed	10	10	10	10	10	10
Volume	10	10	10	10	10	10
V/C Ratio	5	10	5	5	5	5
Density	5	0	10	10	10	10
LOS	5	5	10	5	5	5
VMT/PMT	5	10	5	10	10	10
VHT/PHT	5	10	5	10	10	10
Emissions	5	0	0	0	5	5
Fuel Consumption	5	0	0	5	10	10

Calculate Criteria Score

After assigning the tool relevance values and criteria relevance weights, the next step is to calculate the criteria score. The criteria score is calculated by multiplying the criteria relevance weight by the tool relevance value. For instance, if the project involves arterials, highways, freeways, ramps, and auxiliary lanes, the criteria scores can be calculated accordingly, as shown in Table 23.

Calculate Total Score

After the criteria score is calculated for each criterion, add up the scores for each tool type. The tool types with the highest totals are the most appropriate tools for the work zone project. Table 24 shows an example total score calculation for a project. For this project, the sketch-planning and HCM-based models have the highest score and they are the most appropriate tools.

The work zone analysis scoring work sheet, as shown in Table 25, can be utilized to assist in selecting the analysis tools using the methodology described above.

Table 23. Example Criteria Score Calculation

Factors – FACILITY TYPES	Criteria Relevance	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim
Isolated Intersection	0	5	5	10	5	10	10	0	0	0	0	0	0
Roundabout	0	5	0	0	5	5	10	0	0	0	0	0	0
Arterial	5	5	10	10	10	10	10	25	50	50	50	50	50
Highway	5	10	10	5	10	10	10	50	50	25	50	50	50
Freeway	5	10	10	5	10	10	10	50	50	25	50	50	50
HOV Lane	0	5	10	0	10	10	10	0	0	0	0	0	0
Ramp	5	5	10	5	10	10	10	25	50	25	50	50	50
Auxiliary Lane	5	5	0	5	5	10	10	25	0	25	25	50	50
Truck Lane	0	5	10	5	5	10	10	0	0	0	0	0	0
Bus Lane	0	0	10	0	5	5	10	0	0	0	0	0	0
Toll Plaza	0	5	5	0	0	5	10	0	0	0	0	0	0
							Subtotal	175	200	150	225	250	250

Table 24. Example Total Score Calculation

Criteria	Sketch-Planning and HCM-Based Models	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
1. Project Stage	50	50	0	25	25	0
2. Facility Types	100	100	50	100	100	100
3. Tool Features	50	25	50	0	25	50
4. Agency Resources	250	75	150	125	25	0
5. Work Zone Characteristics	200	25	125	50	125	150
6. Transportation Management Plan (TMP) Strategies	100	75	75	50	100	75
7. Performance Measures	225	200	250	250	250	250
Total	**975**	**550**	**700**	**600**	**650**	**625**

Table 25. Work Zone Analysis Scoring Sheet

Factors	Criteria Relevance	Relevance Value						Score					
		Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim
Project Stage													
Planning		10	10	0	5	5	0						
PE/Design		5	5	10	10	10	10						
Construction		5	0	10	10	10	10						
Facility Types													
Isolated Intersection		5	5	10	5	10	10						
Roundabout		5	0	0	5	5	10						
Arterial		5	10	10	10	10	10						
Highway		10	10	5	10	10	10						
Freeway		10	10	5	10	10	10						
HOV Lane		5	10	0	10	10	10						
Ramp		5	10	5	10	10	10						
Auxiliary Lane		5	0	5	5	10	10						
Truck Lane		5	10	5	5	10	10						
Bus Lane		0	10	0	5	5	10						
Toll Plaza		5	5	0	0	5	10						
Tool Features													
Mode Split		5	10	5	5	5	5						
Easy to Use		10	0	5	5	0	0						
Popular/Well Trusted		10	5	10	0	5	10						
Animation/Presentation		0	5	0	5	5	10						
Agency Resources													
Technical Skill Requirements		10	0	5	5	0	0						
Tool Capital Cost		10	5	5	5	5	0						
Schedule/Time Requirements		10	5	5	5	0	0						
Hardware Requirements		10	0	10	5	0	0						
Data Requirements		10	5	5	5	0	0						
Work Zone Characteristics													
Work Zone Type													
Type I		5	10	5	5	10	0						
Type II		5	5	5	5	10	5						
Type III		10	0	10	0	5	10						
Type IV		10	0	10	0	0	10						

Factors	Criteria Relevance	Relevance Value						Score					
		Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim
Work Zone Network Configuration													
Isolated		10	0	5	5	5	5						
Pipe		10	0	5	5	10	10						
Grid		0	5	5	5	10	10						
Work Zone Size													
Small		10	0	10	0	5	5						
Medium		10	5	5	5	10	10						
Large		10	10	5	10	10	10						
Work Zone Analysis Area													
Site		10	0	10	0	5	5						
Local		10	5	5	5	10	10						
Metropolitan		5	10	5	10	10	5						
Transportation Management Plan (TMP) Strategies													
Temporary Traffic Control		10	5	10	5	10	10						
Motorist Information		5	0	0	5	10	10						
Demand Management		10	10	5	5	10	5						
Corridor/Network Management		5	5	5	5	10	10						
Traffic/Incident Management and Enforcement Strategies		5	0	0	5	10	10						
Performance Measures													
Travel Time		5	10	10	10	10	10						
Delay		10	10	10	10	10	10						
Queue Length		10	0	10	10	10	10						
Speed		10	10	10	10	10	10						
Volume		10	10	10	10	10	10						
V/C Ratio		5	10	5	5	5	5						
Density		5	0	10	10	10	10						
LOS		5	5	10	5	5	5						
VMT/PMT		5	10	5	10	10	10						
VHT/PHT		5	10	5	10	10	10						
Emissions		5	0	0	0	5	5						
Fuel Consumption		5	0	0	5	10	10						
Total Score													

Analysis Tool Selection Example: I-123 Corridor Reconstruction Project

The following hypothetical example serves as an example to illustrate the analysis tool selection methodology featured in this chapter using the given project background information. The information presented in this example is intended for illustrative purposes only. While the following example can be used to select or justify the use of a particular analysis tool, there may be additional questions that the analyst should consider, such as those shown on the example scoping work sheets, when determining the overall analysis approach.

Project Background

A six-mile corridor reconstruction project is in the design stage for Interstate 123 (I-123). Figure 9 depicts the location of the reconstruction project, with the work zone area highlighted in a box (in red color). As shown on the figure, I-123 is an urban freeway located within the central business district (CBD) of Coast City. The reconstruction will include freeway connectors between Interstate 123 and SR 456. Interstate 123 includes four to six lanes in each direction with an AADT of 150,000 vehicles and 12 percent truck traffic. The I-123 project will include reconstruction of three interchanges and two auxiliary lanes, pavement rehabilitation, and lane widening. The estimated duration to complete the entire project is 10 months. Because the project will require lane and ramp closures, parallel facilities, Frontage Road, Shell Avenue, Palm Boulevard, and Coastal Highway, have been identified as potential detour routes. The alternative routes are shown in blue on Figure 9.

At this design stage, the agency has identified several work zone alternatives for completing the project. Various alternatives considered include alternative construction work schedules (i.e., weekend work and night work) and various construction phasing/staging options. The agency will, therefore, need an analysis approach that applies a well-trusted tool in order to determine which of the alternatives should be implemented. For stakeholder and public meetings, the agency prefers that the selected tools have good animation and presentation features.

The agency has collected plenty of data and has enough resources to meet technical, cost, schedule, and hardware requirements of all levels of analysis tools. The work zone project will involve temporary traffic controls, motorist information, demand management, corridor management, and traffic incident management strategies. The desired performance measures from the analysis include travel time, delay, queue length, speed, volume, VMT, and VHT.
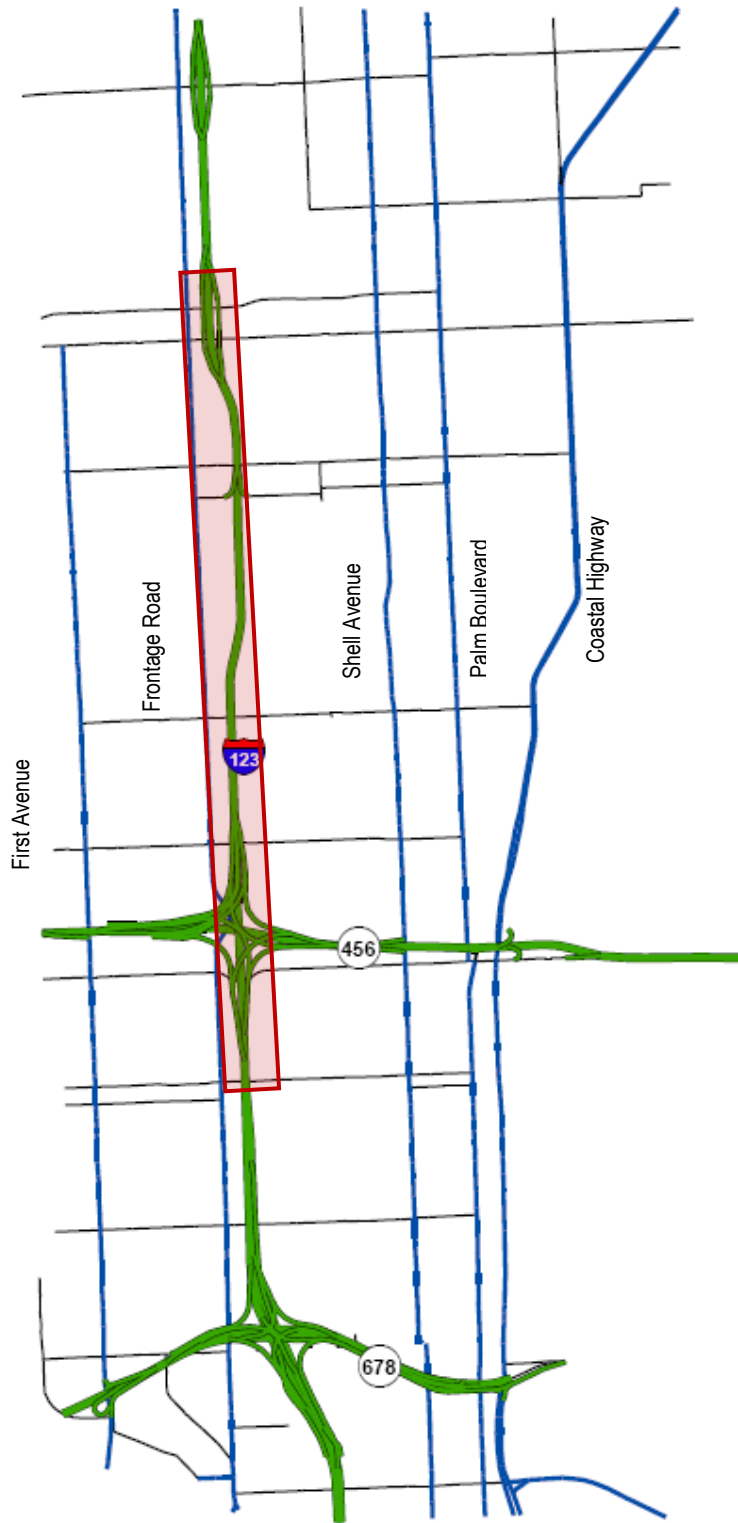
Figure 9. Analysis Tool Selection Example: I-123 Reconstruction Project

Select the Analysis Tool

The detailed steps on how to select the appropriate tool types for this hypothetical example are presented below.

Step 1: Project Stages

The analysis is in the design stage. Therefore, a criteria relevance weight of 5 is assigned to *PE/Design,* as shown in Table 26.

Step 2: Facility Types

This project will include reconstruction of three interchanges and two auxiliary lanes, pavement rehabilitation, and lane widening. It also will require lane and ramp closures. Major detour routes include Frontage Road, Shell Avenue, Palm Boulevard, and Coastal Highway. Therefore, the following facility types are involved in this project: arterial, highway, freeway, ramp, and auxiliary lane, as shown in Table 26.

Step 3: Tool Features

The agency wants an analysis approach that applies a well-trusted tool in order to determine which of the alternatives should be implemented. Also, the agency prefers that the selected tools have good animation and presentation features for the stakeholder and public meetings. Therefore, criteria relevance weights of 5 are assigned to both *Popular/Well Trusted* and *Animation/Presentation*, as shown in Table 26.

Step 4: Agency Resources

In order to determine the appropriate analysis methodology and tool that best fits the project, the resources that the agency can dedicate to the analysis should be considered. For the I-123 reconstruction project, the agency has collected plenty of data and has enough resources to meet technical, cost, schedule, and hardware requirements of all levels of analysis tools. In other words, there is least concern on agency resources. Therefore, criteria relevance weights of 1, for instance, are assigned to all five major key factors related to agency resources, as shown in Table 26.

Step 5: Work Zone Characteristics

The analysis area includes a six-mile segment in both directions of I-123. The analysis area also includes the diversion routes comprised of Frontage Road, Shell Avenue, Palm Boulevard, and Coastal Highway.

- **Work Zone Type** – The project can be classified as a *Type II* for the following reasons:
  - The project is located on an urban freeway near the city core and also includes access to two major highway facilities; and
  - Because the work zone project takes up to 10 months to build, its impacts can be classified as moderate to high.

- **Work Zone Network Configuration** – The six-mile work zone can be classified as a *Pipe* network.
- **Work Zone Size** – The project can be classified as *Medium* size as it is on a longer stretch of a single facility with impacts that extend to adjacent facilities.
- **Analysis Area** – As previously mentioned the analysis area dimension identifies the full area impacted by the work zone. Because the impact of this work zone project extends to the multiple facilities, this project's analysis area can be classified as a *Local*.

Step 6: Transportation Management Plan (TMP) Strategies

The work zone project will involve temporary traffic controls, motorist information, demand management, corridor management, and traffic incident management strategies. Criteria relevance weights of 5 are assigned to them*,* as shown in Table 26.

Step 7: Performance Measures

The agency wants to collect the following performance measures from the analysis: travel time, delay, queue length, speed, volume, VMT, and VHT, as shown in Table 26.

Step 8: Criteria Score Calculation

After assigning the criteria relevance weights, the next step is to calculate the criteria score. As shown in Table 26, the criteria score is calculated by multiplying the criteria relevance weight by the tool relevance value.

Step 9: Total Score Calculation and Final Recommendation

After the criteria score is calculated for each criterion, add up the scores for each tool type. As shown in Table 26, the two analysis methods that scored the highest are mesoscopic and microscopic simulation tools. For this project, either mesoscopic or microscopic simulation tools are appropriate for the analysis. Between them, mesoscopic simulation provides better detour analysis, while microscopic simulation provides better animation features (e.g., 3-D vehicle animation).

Table 26. Example Work Zone Analysis Scoring Sheet:
I-123 Corridor Reconstruction Project

Factors	Criteria Relevance	Relevance Value						Score					
		Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim
Project Stage													
Planning	*0*	10	10	0	5	5	0	0	0	0	0	0	0
PE/Design	*5*	5	5	10	10	10	10	25	25	50	50	50	50
Construction	*0*	5	0	10	10	10	10	0	0	0	0	0	0
Facility Types													
Isolated Intersection	*0*	5	5	10	5	10	10	0	0	0	0	0	0
Roundabout	*0*	5	0	0	5	5	10	0	0	0	0	0	0
Arterial	*5*	5	10	10	10	10	10	25	50	50	50	50	50
Highway	*5*	10	10	5	10	10	10	50	50	25	50	50	50
Freeway	*5*	10	10	5	10	10	10	50	50	25	50	50	50
HOV Lane	*0*	5	10	0	10	10	10	0	0	0	0	0	0
Ramp	*5*	5	10	5	10	10	10	25	50	25	50	50	50
Auxiliary Lane	*5*	5	0	5	5	10	10	25	0	25	25	50	50
Truck Lane	*0*	5	10	5	5	10	10	0	0	0	0	0	0
Bus Lane	*0*	0	10	0	5	5	10	0	0	0	0	0	0
Toll Plaza	*0*	5	5	0	0	5	10	0	0	0	0	0	0
Tool Features													
Mode Split	*0*	5	10	5	5	5	5	0	0	0	0	0	0
Easy to Use	*0*	10	0	5	5	0	0	0	0	0	0	0	0
Popular/Well Trusted	*5*	10	5	10	0	5	10	50	25	50	0	25	50
Animation/Presentation	*5*	0	5	0	5	5	10	0	25	0	25	25	50
Agency Resources													
Technical Skill Requirements	*1*	10	0	5	5	0	0	10	0	5	5	0	0
Tool Capital Cost	*1*	10	5	5	5	5	0	10	5	5	5	5	0
Schedule/Time Requirements	*1*	10	5	5	5	0	0	10	5	5	5	0	0
Hardware Requirements	*1*	10	0	10	5	0	0	10	0	10	5	0	0
Data Requirements	*1*	10	5	5	5	0	0	10	5	5	5	0	0
Work Zone Characteristics													
Work Zone Type													
Type I	*0*	5	10	5	5	10	0	0	0	0	0	0	0
Type II	*5*	5	5	5	5	10	5	25	25	25	25	50	25
Type III	*0*	10	0	10	0	5	10	0	0	0	0	0	0
Type IV	*0*	10	0	10	0	0	10	0	0	0	0	0	0

Factors	Criteria Relevance	Relevance Value						Score					
		Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim	Sketch Plan	TDM	Signal Opt.	Macro Sim	Meso Sim	Micro Sim
Work Zone Network Configuration													
Isolated	*0*	10	0	5	5	5	5	0	0	0	0	0	0
Pipe	*5*	10	0	5	5	10	10	50	0	25	25	50	50
Grid	*0*	0	5	5	5	10	10	0	0	0	0	0	0
Work Zone Size													
Small	*0*	10	0	10	0	5	5	0	0	0	0	0	0
Medium	*5*	10	5	5	5	10	10	50	25	25	25	50	50
Large	*0*	10	10	5	10	10	10	0	0	0	0	0	0
Work Zone Analysis Area													
Site	*0*	10	0	10	0	5	5	0	0	0	0	0	0
Local	*5*	10	5	5	5	10	10	50	25	25	25	50	50
Metropolitan	*0*	5	10	5	10	10	5	0	0	0	0	0	0
Transportation Management Plan (TMP) Strategies													
Temporary Traffic Control	*5*	10	5	10	5	10	10	50	25	50	25	50	50
Motorist Information	*5*	5	0	0	5	10	10	25	0	0	25	50	50
Demand Management	*5*	10	10	5	5	10	5	50	50	25	25	50	25
Corridor/Network Management	*5*	5	5	5	5	10	10	25	25	25	25	50	50
Traffic/Incident Management and Enforcement Strategies	*5*	5	0	0	5	10	10	25	0	0	25	50	50
Performance Measures													
Travel Time	*5*	5	10	10	10	10	10	25	50	50	50	50	50
Delay	*5*	10	10	10	10	10	10	50	50	50	50	50	50
Queue Length	*5*	10	0	10	10	10	10	50	0	50	50	50	50
Speed	*5*	10	10	10	10	10	10	50	50	50	50	50	50
Volume	*5*	10	10	10	10	10	10	50	50	50	50	50	50
V/C Ratio	*0*	5	10	5	5	5	5	0	0	0	0	0	0
Density	*0*	5	0	10	10	10	10	0	0	0	0	0	0
LOS	*0*	5	5	10	5	5	5	0	0	0	0	0	0
VMT/PMT	*5*	5	10	5	10	10	10	25	50	25	50	50	50
VHT/PHT	*5*	5	10	5	10	10	10	25	50	25	50	50	50
Emissions	*0*	5	0	0	0	5	5	0	0	0	0	0	0
Fuel Consumption	*0*	5	0	0	5	10	10	0	0	0	0	0	0
Total Score								925	765	780	900	1,155	1,150

3.4 CHALLENGES IN SELECTING TRAFFIC ANALYSIS TOOLS FOR WORK ZONE APPLICATIONS

In addition to identifying the objectives and available resources/requirements for a work zone traffic analysis, there are technical challenges and limitations to consider when determining which tool to use.

Figure 10 depicts a continuum of traffic analysis tools from simple to complex. Simpler tools include the categories of HCM and sketch planning, while the more complex tools include macro-, meso-, and microscopic simulation software.[2] The spectrum includes seven of the many commonly used transportation analysis tools for assessing the impacts of roadway construction projects. As the diagram shows, the resources needed increase as the complexity of the tool increase.
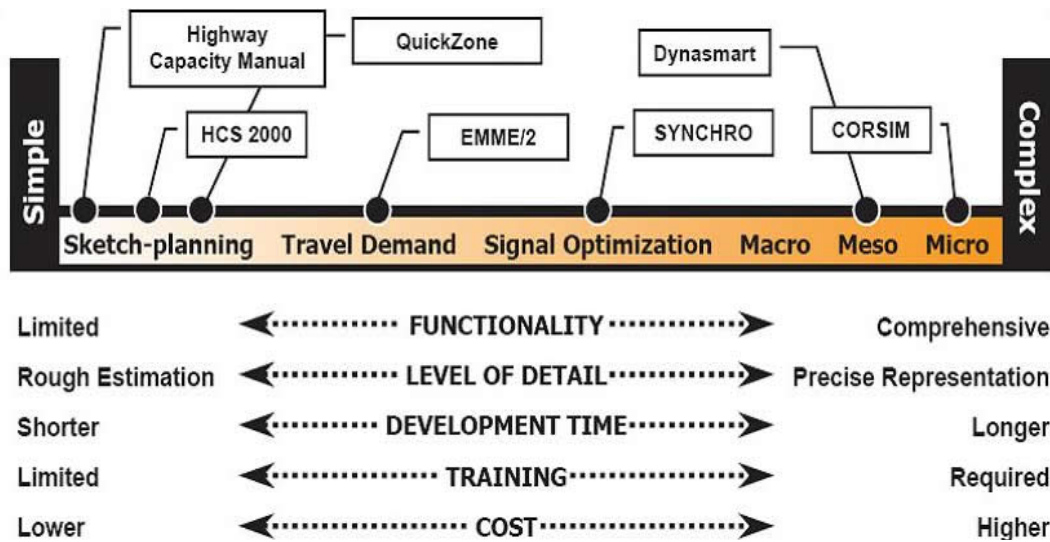
Figure 10. Work Zone Modeling Spectrum

(Source: Hardy and Wunderlich, 2009.)

Common technical challenges and limitations are presented in Chapter 5 of the *Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools*, and are briefly summarized below.[7]

A significant technical challenge is the **availability of data** in the formats and quality required to effectively apply a particular tool. After weighing the key factors described in Section 3.2, an analyst may desire a detailed analysis tool, such as microsimulation. However, this type of modeling tool is data intensive and requires robust information about volumes (15-minute intervals or less), speeds, queues, etc. for calibration. It may later be discovered that the available peak hour traffic data is in one-hour blocks and/or it may be of poor quality. If financial and time resources are not available to collect what is needed, a simpler tool should be considered.

The **availability and expertise of staff** is another technical challenge. Because of lack of resources, past experience, or lack of familiarity with other available tools, many agencies use one of the tools currently in their possession, even if it is not the most appropriate tool for the project. In addition, simpler tools can be effectively applied by experienced technicians; whereas the complex tools require analysts with specialized training.

The **availability of project funding** is an important consideration, as traffic analysis tools require a significant capital investment. Costs associated with a work zone traffic analysis can include software licenses, training, running analytical scenarios, etc. When faced with funding limitations, analysts should focus on the project's goals and objectives and try to identify the point of diminishing returns for the investment.

The **development time and computer run time** typically increase with the complexity of the tool. The implementation of many traffic analysis tools can be a resource-intensive process, especially in the model coding and calibration (front-end) phases for simulation analyses. Depending on the computer hardware and the scope of the study (e.g., area size, data requirements, duration, analytical time periods, etc.), an analytical model run may range from a few seconds to several hours. The most effective approaches to addressing this issue involves using the most robust computer equipment available and/or carefully limiting the scope of the study to conform to the analytical needs. Careful scheduling and pre-agreed upon acceptance criteria are necessary to keep the project focused and on target.

The **output measures produced by each tool vary**, so the process of matching the project's desired performance measures with the tool's output is important. In addition, some of the more complex projects require the use of more than one tool or analysis method. Keep in mind that the definition of a particular performance measure can vary from tool to tool. For example, LOS is calculated differently in a traditional HCM demand-based analysis versus an operations-based simulation model.

Analytical tools have functional limitations. Some analytical tools are not designed to evaluate the specific strategies that users would like to implement. Common limitations for each tool category are outlined in Section 3.1. Key considerations for each tool type are provided in Chapter 4.

A considerable amount of research has been conducted in the area of **work zone capacity determination**. Although it is widely accepted that capacity is reduced in work zone situations, estimating that reduction is not a straightforward process. Different transportation agencies around the country use varying methodologies, and work zone capacity values are often estimated differently depending on the roadway type (e.g., arterial versus freeway); duration of the work zone; intensity of the work activity (number of workers, types of machinery, and proximity of travel lanes to work under way); truck presence; and proximity of ramps, among other factors.

Some traffic analysis tools are unable to directly account for this reduced capacity. For example, reduced capacity can be directly specified in FREEVAL, an HCM-based deterministic analysis

tool. In contrast, there is no direct "capacity" input in VISSIM, a microsimulation tool. In order to account for the reduced capacity, the analyst needs to adjust a set of parameters that affect capacity, such as standstill distance, headway time, and following variation. For some tools, it is possible to adjust variables other than capacity itself to, in turn, reflect reduced capacity conditions. Those variables may include driver and vehicle characteristics (e.g., headways, etc.). The variables are different depending on the tool. This may not be an issue in every analysis, particularly if all the alternatives are being compared under the same assumptions. Work zone capacity determination is addressed for each tool category in Chapter 4.

Finally, **do not lose sight of the big picture**, and be careful not to get lost in the technical details of the analysis. Keep focused on the identified project objectives, and let them guide your decisions as technical challenges are encountered along the way.

4.0 KEY CONSIDERATIONS FOR MODELING APPROACH

4.1 INTRODUCTION

After a suitable analysis tool is selected, the next step is to use the tool to determine the impacts of a work zone. This chapter describes the key considerations when applying the modeling tools for work zone traffic analysis.

Before proceeding to discuss each category of the modeling tools, it is important to have an understanding of the following key items, as they play a significant role in work zone analysis when using any of the modeling tools.

- Study Network;
- Work Zone Capacity;
- Capacity versus Discharge Rate;
- Variability of Capacity and Time-of-Day Models;
- Analysis Period;
- Change in Traffic Pattern;
- Common Data Collection;
- Model Development Application Process;
- Error Checking; and
- Level of Effort.

Study Network

In preparation for the data collection required for work zone analysis, it is necessary to determine the limits of the network to be studied. The study network should consider both the work zone boundaries and the surrounding area where the traffic is affected by the work zone. Specifically, the following should be considered:

- The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions;
- Include all detour routes, if possible;
- For freeways and highways, include on- and off-ramps, and other routes to which traffic is diverted; and
- For arterials, consider the following:
  - Include, at a minimum, the adjacent intersections both upstream and downstream of the work zone;
  - Include all intersections outside of the work zone that are impacted by queues from intersections within the work zone;
  - Consider the limits of the coordinated signal system; and
  - Consider including any side streets that are expected to be impacted by work zone queues.

For instance, to obtain an initial estimation of the queue length caused by the work zone at signalized intersections, the following equation may be used:[15]

$$L = max \left\{ \frac{V}{N} - \left(\frac{G}{C} * s \right) + \frac{V*C}{3,600*N}, \frac{V*C}{3,600*N} \right\}$$ (1)

Where:

L = The approach queue length (in number of vehicles);
V = The through traffic volume for the approach;
G = The duration of the green interval for the through movement;
C = The cycle length;
N = The number of open through lanes; and
s = The saturation flow rate (in vehicles per hour per lane (vphpl)). Local data at work zones shall be used. In the absence of better local data, the analyst may use 1,400 vphpl (1,200 to 1,600 vphpl) as the starting point and make modifications accordingly to reflect local work zone conditions.

If the work zone will directly impact more than one intersection, the queue length at the critical intersection, and at the first intersection that motorists will encounter while traveling through the work zone should be evaluated. The critical intersection is defined as the intersection where one or more of its approaches impacted by the work zone have the highest existing volume per through lane. Figure 11 illustrates how to determine where the queue length should be evaluated.[15]
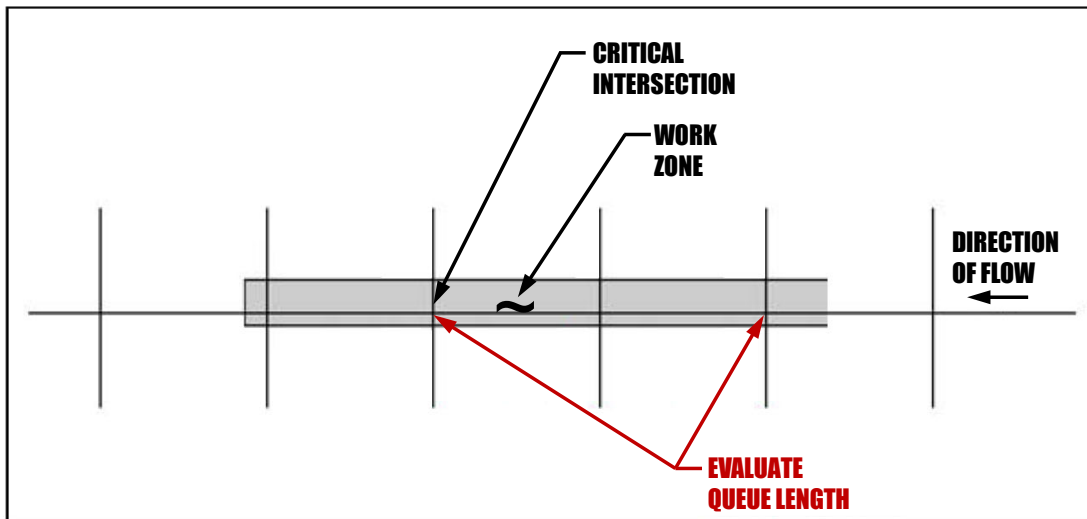
Figure 11. Locations of Queue Length Evaluation

(Source: Maryland State Highway Administration, 2008.)

Work Zone Capacity

The *Highway Capacity Manual 2010 (HCM 2010)* defines capacity as "the maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform segment of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions."[16] **Roadway capacity in a work zone is reduced due to a variety of factors**, including:

- Work zone speed;
- Work intensity (work zone type);
- Percentages of trucks;
- Number of lanes;
- Number of lane closures;
- Lane width;
- Lateral clearance;
- Work zone layout (lane merging, lane shifting, and crossover);
- Length of closure;
- Presence of ramps;
- Work zone location (urban or rural);
- Work zone duration (long-term or short-term);
- Work time (daytime or nighttime);
- Work day (weekday or weekend);
- Type of control devices and their placement;
- Weather conditions (sunny, rainy, or snowy);
- Pavement conditions (dry, wet, or icy);
- Pavement grade; and
- Driver composition (commuters or non-commuters, such as tourists).

Tables 27 and 28 list work zone lane capacity defaults for use (in passenger cars per hour per lane or pcphpl) based on previous studies, with Table 27 for short-term work zones and Table 28 for long-term ones.[16,17,18] **It is strongly recommended, though, that local data at work zones are collected and used instead. In the absence of better local data, the analyst may use these defaults as the starting point and make modifications accordingly to reflect local work zone conditions.** Also, some state DOTs and other agencies may have their own guidelines on work zone capacity and related defaults.

Table 27. Table Work Zone Lane Capacity Defaults that Can Be Used in the Absence of Better Data: Short-Term Work Zones

Short-Term Work Zone Capacity[17,18] (pcphpl)		
	Arterial	
Freeway/Highway[2]	Urban	Rural
1,200-1,600	600[*]	400[*]

(Source: Transportation Research Board, 2011. Weng and Meng, 2011. WSDOT Work Zone Safety and Mobility, 2009.)

* These are average capacity values. The actual values would be dependent on several factors, which include the existing number of lanes, number of lanes closed, traffic speed, truck percentage, interchanges/intersections, type of work, type of traffic control, and seasonal factors (among others).

**Table 28. Work Zone Lane Capacity Defaults that Can Be Used in the
Absence of Better Data: Long-Term Work Zones**

Default Type	Long-Term Work Zone Capacity (pcphpl)[16] Normal Lanes to Reduced Lanes (Freeways)					
	2-1	3-2	3-1	4-3	4-2	4-1
Range	1,200-1,800	1,300-1,600	1,200-1,800	1,300-1,600	1,300-1,600	1,200-1,600
Single Value	1,400	1,450	1,450	1,500	1,450	1,350

(Source: Transportation Research Board, 2011. Weng and Meng, 2011. WSDOT Work Zone Safety and Mobility, 2009.)

Note: Capacities through long-term construction zones are highly variable and depend upon many site-specific characteristics. It is, therefore, better to base this adjustment on local data and experience. If such data do not exist, and cannot be reasonably acquired, the range above may be used to provide a very approximate estimate of construction zone capacity.

Capacity versus Discharge Rate

Queue discharge flow rate represents traffic flow that has just passed through a bottleneck and is accelerating back to the free-flow speed (FFS). Queue discharge flow is relatively stable as long as there is not another nearby bottleneck downstream. The *Highway Capacity Manual 2010* suggests that the queue discharge flow rate is lower than the maximum flows observed before breakdown (capacity). Two methods have been widely used in previous studies to define work zone capacity:

- **Work Zone Capacity – Method 1 –** The observable maximum throughput under relatively free-flow conditions before the formation of a traffic queue; and
- **Work Zone Capacity – Method 2 –** The discharge flow rate under the queued conditions.

Method 1 is particularly relevant to traffic mitigation efforts to avoid queue formation and Method 2 is particularly relevant to manage queues, estimate the length of queues, and understand the amount of delay when upstream flow rates are consistently above the capacity of the work zone.

Since traffic conditions vary between pre-queuing and queuing conditions at work zone locations, a more precise work zone analysis may consider using both of the above work zone capacity values: one for pre-queuing conditions, and the other for queuing conditions. However, if resources or schedules do not allow for the development of separate models using different capacity values for pre-queuing and queuing conditions, select one of the above methods using engineering judgment and previous experience. The analyst may concentrate on other more important factors that have bigger impacts on model calibration and alternatives analysis.

Variability of Capacity and Time-of-Day Models

Roadway capacity within a work zone may vary due to the following factors:

- **Driver Characteristics –** This may vary from hour to hour, from day to day, and from one region to another. This variation is mainly due to the ability of the driver population

to adapt to the changing conditions. For instance, Al-Kaisy et al. suggested that commuter drivers are expected to be more familiar with the route and the work zone configuration.[19] Therefore, they can proceed through the work zone with shorter headways and higher flows. Similarly, Al-Kaisy and Hall examined the effect of driver population at freeway reconstruction zones.[20] **Based on a factor of 1.0 for commuter traffic, a driver population factor of 0.93 was estimated for the afternoon peak period and a driver population factor of 0.84 was estimated for weekends.** The driver population factor was responsible for more of a capacity reduction on weekends compared with the capacity on weekdays. It should be noted that the reduction factor varies and it depends on local conditions.

- **Nonrecurrent Events –** Nonrecurrent events such as inclement weather and traffic accidents further reduce capacity within a work zone. For instance, in the HCM 2010 (Exhibit 10-15), inclement weather may reduce the capacity of freeways by 1 percent to 22 percent, depending on the intensity of the weather condition.

- **Work zone Duration –** The duration of the work zone has an impact on driver behavior; after a period of time, drivers adjust to the changed conditions and capacity and speeds may go up. According to Kim, Lovell, and Paracha, the average capacity at long-term work zones was noticeably greater than that at short-term ones, as drivers became more familiar with the work zones. **Based on this study, long-term work zones may have capacities as much as 150 pcphpl higher than short-term ones.**[21] It should be noted that the capacity difference between long-term and short-term work zones varies and it depends on local conditions.

- **Random Effect –** Even when all prevailing conditions are held constant, capacity was found to be a random variable, because of stochastic variations in vehicle mix, lane distribution, and driver behavior.[22]

As discussed above, work zone capacity is influenced by many factors. Therefore, sensitivity analysis may be deemed necessary when resources allow.

Analysis Period

Work zone capacity is influenced by many factors; it may be specific to different times of the day, different demographic groups (age/experience), and different populations reflecting regional or local tendencies. Therefore, if **different time-of-day analysis is considered critical and resources are available**, it is recommended to create different time-of-day models, such as a.m. peak, off-peak, p.m. peak, weekend peak, and weekend off-peak, to reflect the variable capacity, as well as the variable demand in analysis tools. Also, for longer duration work zones, it is recommended that **interim analysis be performed to better reflect varying capacities, if resources and data are available**.

> For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available.

In addition, different analysis tools may accommodate various time periods; some can analyze longer time periods, while others cannot. For instance, some sketch-planning analysis tools can analyze longer time periods, such as multiple days, months, or even years, which is typically beyond the capability of other analysis tools such as macro-, meso-, and microscopic simulation models.

> The analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.

Changes in Traffic Pattern

Drivers obtain roadway information through various means to select their preferred route(s). These means include dynamic message signs (DMS), highway advisory radio (HAR), public information and outreach, incident management systems or other traveler information systems, etc. Some tools, such as DynusT, have the ability to directly model roadway information system, such as DMS. In DynusT, DMS can be set to provide multiple types of messages, such as speed advisory, mandatory detour, and congestion warning. DynusT permits users to specify a percentage of vehicles that respond to the DMS and make detour decisions.

According to Horowitz et al., many drivers are responsive to warnings that they might encounter excessive delays along their current route.[23] However, a much larger percentage of drivers would not divert, even though it is to their advantage to do so. This study suggested that a 10 percent alternative route selection rate during peak periods is achievable when accurate, up-to-the-minute information about delay through a work zone is provided and there is an attractive set of alternative routes. This study was conducted on a rural freeway. For drivers using lower classification or urban highways with attractive alternative routes, the diversion rate could be higher.

The FHWA conducted a study that examined the use of ITS for work zone traffic management with a purpose to highlight "before and after" or "with and without" analyses that quantify the mobility and safety benefits.[24] According to this study, significant traffic diversion was observed in response to appropriate messages displayed during congested conditions. In Texas, an average of 10 percent diversion (range of 1 to 28 percent) was observed, while in the District of Columbia (D.C.) an average of 52 percent (range of 3 to 90 percent) lower mainline volume (combination of diversion, demand reduction, and congestion) was observed. The study noted that in Texas, during major incidents or high construction impact periods combined with high demand, the system diverted an average of 10 percent of mainline traffic to alternate routes and traffic diversion was as high as 28 percent.

When congestion occurs on the mainline due to a work zone, motorists may choose alternate routes to bypass the congested segment. Subsequently, travel time on the alternate routes will increase, and the route choice between the mainline and an alternate route may vary over time. Dynamic traffic assignment (DTA)-based tools can take this into account. In the case of long-term work zones, generally traffic reaches equilibrium after a few weeks, especially in urban areas with commuter traffic. Travelers typically choose the available route having the least

travel time between their origin and destination (O-D). Due to congestion effects, the travel time of a route between an origin and destination also depends on the choices made by other travelers, who are themselves also trying to choose the least travel time route between their own origin and destination. When every traveler succeeds in finding such a route, every used route has the minimum time or cost between its origin and destination. This condition is known as equilibrium. **The collection of local data is encouraged in order to create a more robust analysis network that captures the effects of changes in traffic pattern.**

Besides finding alternate routes, some motorists may change their trip departure times or even cancel their trips, especially in the case of long-term work zones with heavy congestion.

Common Data Collection

Once the size of the study network has been determined, it is necessary to collect data that will be needed to model work zone operations. The data collection effort may be considerably reduced by obtaining information using aerial imagery, or by downloading the traffic signal plans from agency web sites, and/or by obtaining the roadway design plans (if available). If needed, these data should be confirmed with a field visit.

It should be noted that the required data accuracy may vary during different project stages (e.g., project planning, preliminary engineering, and final design). **It is not appropriate to use planning-level data to make engineering design decisions.**

Included in Table 29 are the common data that should be collected for all work zone traffic analysis, no matter which method or tool is selected. Additional data for specific modeling tools will be discussed in each tool category. Depending on the complexity of the study network and of the analysis needed, different types of data may be required and may broadly be classified into four categories: general, geometric, traffic, and construction.

Table 29. Work Zone Data Collection – Common Data

Category	Data
General	• Location of work zone • Weather conditions • Police presence • Flagger presence • Crash/incident information • Traffic impact mitigation strategies
Geometry	• Lane width • Number of lanes in each direction • Number of open lanes • Presence of ramps • Length of lane closure • Position of closed lane • Length of work activity • Turn bay lengths • Mid-block intersections
Traffic	• Volume of traffic • Heavy vehicle percentage • Volume of pedestrians • Speed limits • Speed of vehicles in work zone • Locations of traffic control devices • Signal detection type and location • Signal phasing and timing • Queue lengths • Presence of congestion (bottlenecks) – location and time of day • Length and duration of congestion • Driver behavior • Travel time • Delay • Saturation flow rate • Growth factor • Seasonal variation factor
Construction	• Type of construction activity • Number of workers present • Number and size of construction equipment • Proximity of work activity to the travel lanes in use • Traffic control devices used

Origin-Destination Data

Origin-destination (O-D) data is often needed for work zone traffic analysis. **This data can be used to serve as a basis for trip assignment in the existing conditions models and trip redistribution between alternate routes in the analysis models**. O-D data may be estimated based on a select link analysis using a regional travel demand model, field observations/studies, and data from the private sector such as INRIX® and TomTom®. The preferred method of obtaining origin-destination data is a field study, such as a post card survey or license plate study, as the travel demand model may not have the fidelity to generate an accurate estimate for detailed traffic operations analysis. For less complex projects, origin-destination data may not

need to be collected. Instead, assumptions may be made based on engineering judgment as to reasonable traffic distribution and traffic trends. Additionally, the appropriate agency may be consulted for assistance with traffic distribution and diversion assumptions. More information on performing O-D studies can be found in the Institute of Transportation Engineers' (ITE) *Manual of Transportation Engineering Studies*.

Origin-Destination Matrix Estimation (ODME)

The use of an Origin-Destination matrix is fundamental to the application of a travel demand model. However, the development of that O-D matrix can be both difficult and costly due to the need for extensive traveler survey data. An O-D matrix may be available or easily made available from the local MPO or other transportation planning agency. In addition, by using traffic counts and other available data, it may be possible to estimate a "reasonable" O-D matrix. This process is called ODME.

Many estimation techniques exist for developing a reliable O-D matrix, including Least Squares (constrained or not), statistical methods such as Likelihood methods and Kalman filtering, Bayesian estimator or combined estimators and Moving Horizon Estimation (MHE) methods.

Model Development and Application Process

In order to evaluate the impacts of a proposed work zone, it is necessary to build models for both existing and work zone conditions. The existing conditions or preconstruction model can be built using data collected for existing conditions of the study network. This may include the existing lane configurations, existing traffic volumes, and existing signal timings and phasing. The model is then calibrated to represent field observed conditions through the adjustment of parameters in the analysis tool. This calibrated existing conditions model, often called the "no-build" model, provides the baseline for the performance of the roadway facility. The existing conditions model can then be modified to represent work zone conditions.

The basic principles of work zone traffic analysis tools vary from one type to the next. The overall procedure of developing and applying models to work zone analysis consists of the following major tasks. A flowchart, complementing the overall process, is presented in Figure 12. It should be noted that the existing conditions ("no-build") model development and calibration may be skipped if there already is a calibrated model available. The available existing conditions model could be generated by a project leading to the work zone analysis or from other independent studies.

1. **Identification of Project Scope and Data Collection** – The project scope needs to be identified to define the study objectives, breadth (geographic and temporal boundaries), approach, tools, resources, and time schedule for the study. Once the project scope is determined, data should be collected for model development and calibration, such as roadway geometry, traffic demands, capacities, traffic controls, travel times, and queues.
2. **Existing Conditions Model Development** – Once data are collected, the next step is to develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Coding errors can distort the subsequent model calibration

process and cause the analyst to adopt incorrect values for the calibration parameters. Therefore, error checking, as described in the next section, should be performed to identify and correct those model coding errors. If a calibrated existing conditions model already is available from other resources, this step and the following existing conditions model calibration step can be skipped.

3. **Existing Conditions Model Calibration** – Each analysis tool has a set of user-adjustable parameters that enable the analyst to calibrate the tool to better match specific local conditions. This calibration process involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. The calibration process can be time-consuming. It should be well documented so that later reviewers of the model can understand the rationale for the various parameter changes made during calibration.

4. **Work Zone Base Conditions Model Development** – The next step is to develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions. These modifications may include geometry, traffic demands, capacities, and traffic controls. Roadway geometry and traffic controls can usually be collected from construction drawings or field surveys. Traffic demands for the work zone base scenario are usually generated from travel demand models, traffic counts, or O-D surveys. The preferred method of obtaining traffic demand data is a field study, as the travel demand model may not have the fidelity to generate an accurate estimate for detailed traffic operations analysis.

5. **Work Zone Base Conditions Model Calibration** – Work zone model calibration may include the calibration of both work zone capacity and performance measures. The work zone capacity calibration process is tool-dependent; some tools allow direct changes to capacity, while others do not have a "capacity" input and require adjusting a set of parameters in the tool that affect capacity. The performance measures collected either from the field or based on prior experience and engineering judgment, such as queue lengths, travel times, delays, and speeds, also must be calibrated in the model. Typically, work zone analysis is performed to gain insight into the potential impact of the proposed work zones. Therefore, collecting field data for the work zone to be implemented will likely not be possible. Under this case, the analyst should analyze similar work zone types in the project area to better understand local driving behaviors and implement those in the model.

6. **Alternatives Analysis** – Significant efforts have been made on developing and calibrating the model. Now it is time to put the model to work by analyzing various project alternatives. The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any mobility requirements, extract relevant statistics, and perform various analyses of the results. Some agencies may have their own mobility criteria. For instance, MD SHA uses LOS, control delay, and travel time as mobility requirements and the thresholds for arterials.[15]

7. **Final Report/Technical Documentation** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document. This task also may include presentation of study results to technical supervisors, elected officials, and the general public.
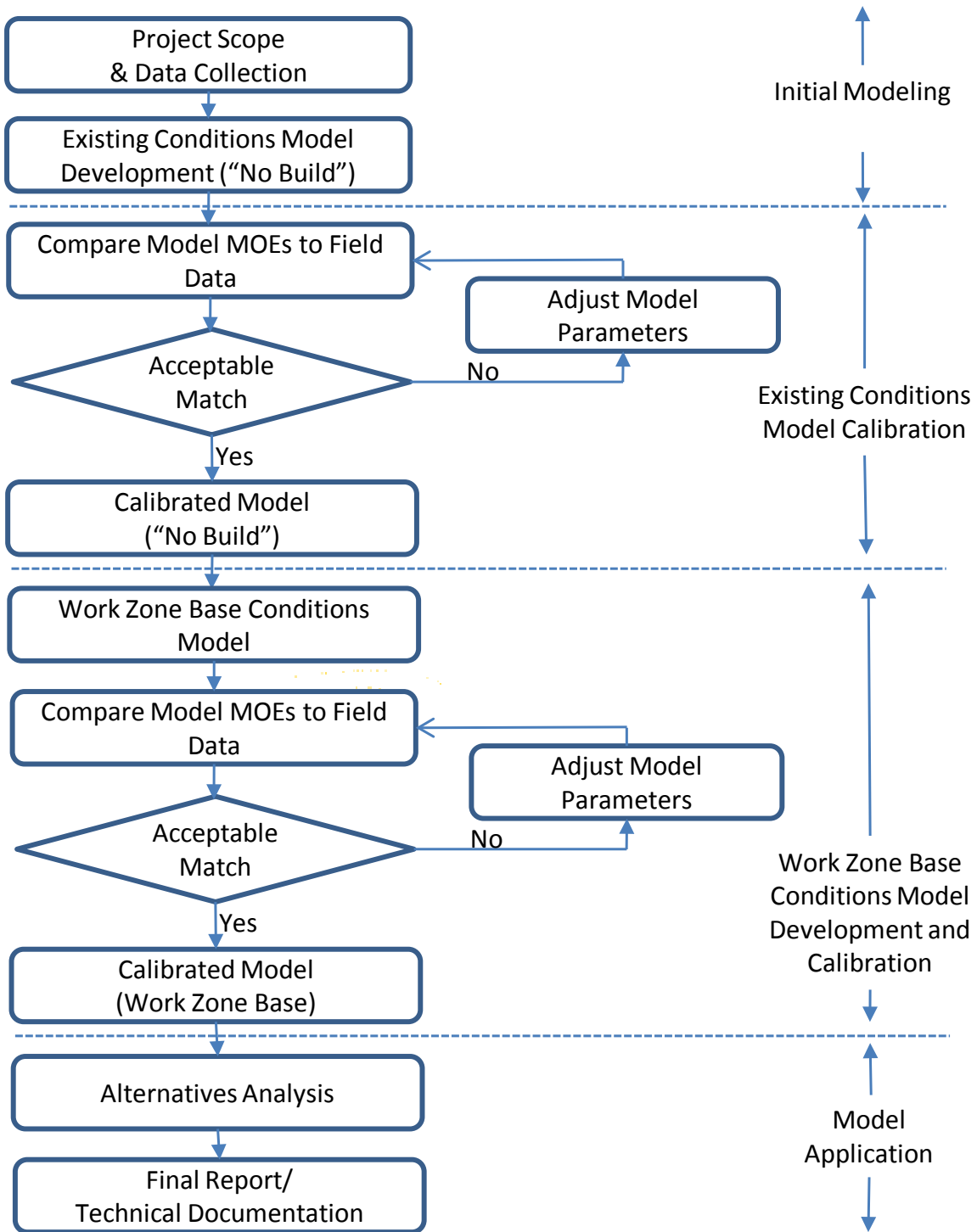
Figure 12. Typical Model Development and Application Process for Work Zone Analysis

Error Checking

The error-checking step is necessary to identify and correct model coding errors so that they do not interfere with the model calibration task. Coding errors can distort the model calibration process and cause the analyst to adopt incorrect values for the calibration parameters. Error checking involves various tests of the coded network and the demand data to identify input coding errors. The goal of the error-checking step is to eliminate all major errors in network coding and demand before model calibration.

Error checking involves various reviews of the coded network and coded demands. Error checking proceeds in the following basic stages:

1. **Review Software Errors** – The analyst should review the software and user group web sites to ensure that he or she is aware of the latest known "bugs" and user workarounds for the software. The analyst should ensure that he or she is using the latest "patch" of the software.
2. **Review Coded Network** – The analyst should review the coded network, including:
   a. Check network connectivity.
   b. Check geometry, including lengths, number of lanes, free-flow speed, facility type, etc. Overlaying the coded network over aerial photographs of the study area is a quick way to verify the accuracy of the coded network geometry. In addition, color codes may be used to help identify network links with different attributes.
   c. Check intersection controls, including control type and control data, if there are intersections in the network.
   d. Check lane closures or restrictions.
3. **Review Demand Data** – The analyst should review the demand data, including:
   a. Check vehicle inputs or O-Ds;
   b. Check vehicle mix proportions; and
   c. Verify output volumes against traffic counts.
4. **Other Reviews** – There are some other review items that are tool-specific. For instance, microsimulation models require animation review to spot less obvious input errors. Animation output enables the analyst to see the vehicle behavior that is being modeled and assess the reasonableness of the microsimulation model itself. Running the simulation model and reviewing the animation, even with artificial demands, can be useful to identify input coding errors.

Level of Effort (LOE)

The level of effort on conducting work zone traffic analysis varies with analysis tool types. In general, sketch-planning tools require the lowest level of effort, while microscopic simulation tools demand the highest level of effort.

The level of effort determination typically provides labor-hour estimates for project tasks. These estimates assist project managers and program leaders in developing budget and schedule

estimates, as well as the scope of the project. Project tasks typically incorporated into the level of effort labor-hour estimates of a traffic analysis project include:

- Data collection;
- Base model and calibration;
- Alternatives analysis;
- Documentation/presentations; and
- Project management.

For additional information regarding the development of a level of effort especially for a traffic analysis project using microsimulation, please refer to the FHWA sponsored *Guidance on the Level of Effort Required to Conduct Traffic Analysis Using Microsimulation*.[25]

In the subsequent sections, some of the commonly used software packages are mentioned in each tool category, and parameters are suggested to adjust for work zone analysis. Please note that these are associated with the current software versions, and future software updates may result in different parameters. Please refer to the latest documentation of the software for the most up-to-date interpretation of those parameters.

4.2 USING SKETCH-PLANNING AND ANALYTICAL/DETERMINISTIC ANALYSIS

Sketch-planning and analytical/deterministic analysis tools (HCM-based) are typically specialized models designed for a specific application, such as work zone analysis. These types of tools are in contrast to other general-purpose tools, such as travel demand models and microscopic simulation models, which are targeted towards a much wider range of application, not just work zone analysis. Sketch-planning and analytical/deterministic analysis tools include a wide range of software, including spreadsheet models developed by individuals or state DOTs for specific projects or conditions, to more generalized delay estimation tools such as QuickZone and QUEWZ-98. They vary in complexity from analyzing only individual roadway segments to network-based analyses. Often, they are based on simple queuing techniques or volume-to-capacity relationships from the HCM.

The key strength of sketch-planning and analytical/deterministic analysis tools is their relative ease of use and ability to facilitate a rapid analysis. Typically, a sketch-planning or analytical/deterministic tool requires fewer resources and less staff training since they are simpler in terms of data requirements, calibration, and interpretation of the results. An analysis using a sketch-planning or analytical/deterministic tool is usually quite rapid. This is important in cases where a decision needs to be made quickly or the agency desires a less resource-intensive analysis. In addition, some sketch-planning analysis tools can analyze longer time periods, such as multiple days, months, or even years, which is typically beyond the capability of other analysis tools such as macro-, meso-, and microscopic simulation models.

Some of the challenges of sketch-planning and analytical/deterministic analysis tools include limited network complexity and presentation capabilities, and the high level of the analysis techniques. For example, QUEWZ-98 only allows simple "pipeline" analysis without the ability to model cross-streets and detour routes. The results from sketch-planning and

analytical/deterministic analysis tool are relatively high-level (e.g., average queue and maximum queue) and the results are constrained by the quality of the input data and analysis methodology. Sketch-planning and analytical/deterministic analysis tools are primarily used in the planning stages of a project, and are not considered to be a substitute for the detailed engineering analysis often needed later in the project implementation process.

Some examples of sketch-planning and analytical/deterministic analysis tools are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **FREEVAL –** http://www.hcm2010.org/;
- **HCS (Highway Capacity Software) –** http://www.mctrans.ce.ufl.edu/hcs/;
- **IDAS (ITS Deployment Analysis System) –** http:/www./idas.camsys.com/;
- **QUEWZ-98 –** http://www.tti.tamu.edu/publications/catalog/record/?id=2920; and
- **QuickZone –** http://www.fhwa.dot.gov/research/topics/operations/travelanalysis/ quickzone/.

The computational engine, FREEVAL (FREeway EVALuation) 2010 as shown in Figure 13, is a computerized, work sheet-based environment designed to implement the operational analysis computations for undersaturated and oversaturated directional freeway facilities.[26] It incorporates entire freeway segment procedures outlined in Chapters 11, 12, and 13 in HCM2010 for basic freeway segments, weaving segments, and merge and diverge segments, respectively. FREEVAL-2010 is executed in Microsoft Excel, with most computations embedded in Visual Basic modules. It allows the user to analyze a freeway facility of up to 70 analysis segments and for up to 24, 15-minute time intervals (six hours). The engine can generally handle any facility that falls within these temporal and spatial constraints. It provides clean outputs, such as summary work sheets with segment performance (e.g., speed, density, volume, volume-to-capacity ratio (v/c), demand-to-capacity ratio (d/c), and LOS, and 3-D contour plots. FREEVAL-2010 can handle both undersaturated (d/c $\leq$ 1.0) and oversaturated traffic conditions (d/c > 1.0). When the facility is considered to be "oversaturated," an additional output, i.e., demand-based LOS, is generated.

FREEVAL-2010 is not a commercial software product; instead, it is made available freely to all HCM users in HCM2010s on-line Volume 4. FREEVAL-2010 allows the user to make changes to geometry, segment capacity, demand patterns, and free-flow speeds to analyze the operational effects of work zones.
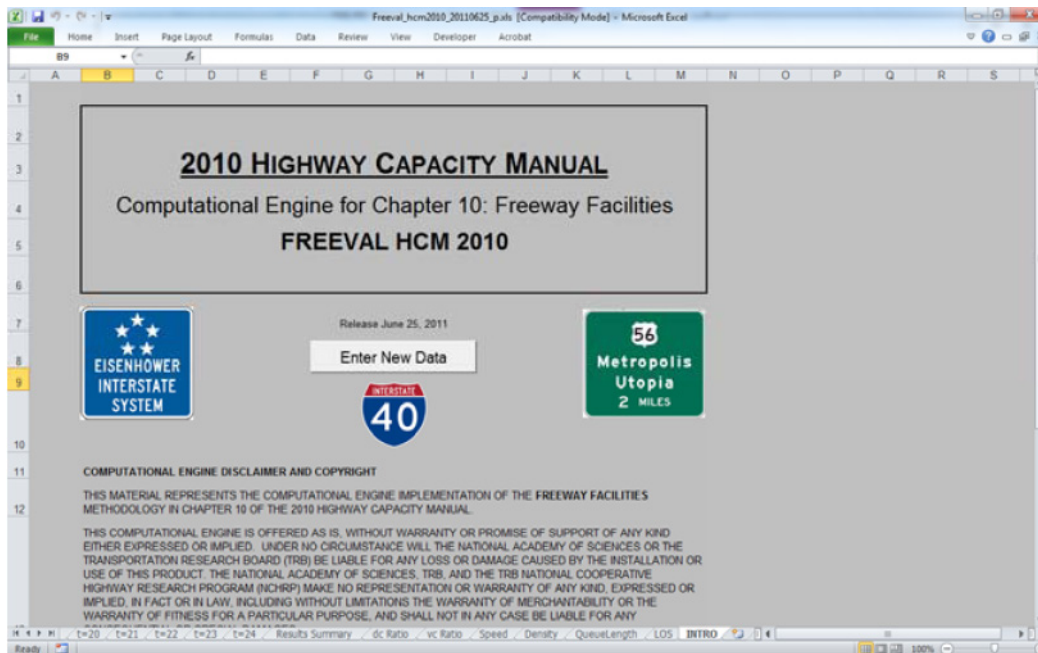
Figure 13. FREEVAL-2010

(Source: Rouphail, Schroeder, and Eads, 2011.)

Data Collection

The precise input data required by a sketch-planning or analytical/deterministic analysis tool will vary by software and the specific modeling application as defined by the study objectives and scope. Most sketch-planning and analytical/deterministic analysis tools require the following types of input data, besides the general data identified at the beginning of this chapter.

Existing Models

Check if the agency maintains a database of sketch-planning and analytical/deterministic analysis model files. A field visit may need to be performed to verify the accuracy of the model input data.

Traffic Volumes

Most sketch-planning and analytical/deterministic analysis tools require traffic volumes as input data. Traffic volumes can be either collected in the field, be extracted from existing detectors (if available), or exported from other analysis tools. Also, procedures exist in many demand models to generate O-D tables for the study area, which can be easily converted to traffic volumes.

Calibration Data

Calibration data consist of measures of traffic counts and system performance such as speeds and queues.

Other Data

Some sketch-planning and analytical/deterministic analysis tools such as QuickZone require detailed work zone project data, such as project start date, project duration, and construction phases.

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. **It is strongly recommended that local data at work zones be collected and used**, as driver characteristics vary from region to region and capacity may vary from location to location. In the absence of better local data, the analyst may use the capacity defaults as the starting point and make modifications accordingly to reflect local work zone conditions.

Capacity can be directly specified in most sketch-planning and analytical/deterministic analysis tools. Typically, the user can adjust the capacity for any type of link in the network, if needed. In addition, the free-flow speed (if appropriate) can be modified as well for capacity calibration. Table 30 lists major parameters that the analyst may adjust for work zone analysis in several commonly used sketch-planning and analytical/deterministic analysis tools.

Table 30. Parameters to Adjust for Work Zone Analysis in Common Sketch-Planning and Analytical/Deterministic Analysis Tools

Sketch-Planning and Analytical/Deterministic Analysis Tools	Primary Parameters	Secondary Parameters
FREEVAL	• Capacity Adjustment Factors • Free-Flow Speed • Number of Lanes	• Traffic Composition (Percent Trucks)
HCS	• Capacity • Free-Flow Speed • Number of Lanes	• Traffic Composition
IDAS	• Lane Capacity • Free-Flow Speed • Number of Lanes	• N/A
QUEWZ-98	• Work Zone Capacity • Number of Lanes Closed • Length of Lane Closure • Schedule of Work Activity	• Percentage of Trucks • Speed-Volume Relationship • Definition of Excessive Queuing
QuickZone	• Capacity • Number of Lanes • Free-Flow Speed • Percent of Local Traffic Traveling on Detours (Percent)	• Truck Percentage • Yearly Capacity Decrease (Percent) • Yearly Demand Increase (Percent, for Large Projects that Extend over Several Years) • Mode Shift Change (Percent) • Cancel Trip (Percent)

Key Considerations Regarding Use for Analysis

The key strengths of sketch-planning and analytical/deterministic analysis tools are their relative ease of use and ability to facilitate a rapid analysis. This is important in cases where a decision needs to be made quickly or the agency desires a less resource-intensive analysis. Some sketch-planning tools can analyze a longer time span in one model, such as multiple days, months, or even years of work zones, which is typically beyond the capability of other analysis tools such as macro-, meso-, and microscopic simulation models. Discussed below is the model development and application process when using analytical/deterministic analysis tools.

Model Development and Application Process

The typical model development and application process, which was discussed at the beginning of this chapter, applies to sketch-planning and analytical/deterministic analysis tools as well. Compared to other types of tools, the model calibration of sketch-planning and analytical/deterministic analysis tools is more high-level and less time-consuming.

Sketch-Planning Model Development and Application – Check List

This subsection provides a high-level synthesis combining the concepts presented above on model development and application. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives** – The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks** – Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.
- **Determine Study Network** – Determine the limits of the study network. The network boundary should be able to accommodate queue lengths under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned.
- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peaks. For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.

- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.
- **Select Measures of Effectiveness and Thresholds** – The MOEs or thresholds selected will be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.
- **Collect and Analyze Data** – Collect data that is needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.
- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.
- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.
- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones be collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.
- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Error checking should be performed to identify and correct the model coding errors.
- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions.
- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.
- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.
- **Conduct Alternative Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.
- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

4.3 USING TRAVEL DEMAND MODEL ANALYSIS

Travel demand models are analytical models that forecast future travel demand based on current conditions, and future projections of household and employment characteristics. Traditionally,

they are large regional planning models used by metropolitan planning organizations (MPO), and were originally developed to determine the benefits and impacts of major highway improvements in metropolitan areas. A distinguishing feature of travel demand models is their geographic coverage, which generally includes an entire metropolitan area: a city, its suburbs, and the adjacent counties.

For work zone analysis, a key strength in using travel demand models is their ability to predict areawide traffic redistribution. For example, if an agency is considering closing an important urban freeway-to-freeway interchange for several months while it is rebuilt, a travel demand model could help evaluate the overall changes in total daily traffic volumes on various roadways throughout the region. In general, travel demand models can handle larger networks more efficiently than mesoscopic and microscopic simulation models. Another important consideration is that most major metropolitan areas already have a travel demand model available that could be used either as the sole analysis tool or as a foundation for developing a transportation network or forecasting travel demand for another model type (e.g., mesoscopic and microscopic simulation models).

However, **travel demand models have limited capabilities to accurately estimate changes in operational characteristics** (such as speed, delay, and queuing) resulting from the implementation of operational strategies and changes. This includes the effects associated with roadwork construction. Because these models are prepared at a broad regional scale, they lack detail that may be critical to the analysis objective. For example, they may model only one or two time periods (such as the a.m. peak hour or the daily average), which may not be sufficient for analyzing time-specific work zone traffic management strategies.

Some examples of travel demand models are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **CUBE –** http://www.citilabs.com/products/cube;
- **EMME –** http://www.inro.ca/en/products/emme/index.php;
- **TransCAD –** http://www.caliper.com/tcovu.htm; and
- **VISUM –** http://www.ptvamerica.com/.

Data Collection

Besides the general data identified at the beginning of this chapter, travel demand models require the following types of input data.

Existing Models

Check if the MPO or other local transportation planning agency maintains a regional travel demand model. A field visit may need to be performed to verify the accuracy of the model input data. Additionally, since the regional travel demand model maintained by an agency typically covers a significant area, it may be necessary to have a subarea model created for use in work zone analysis (see Subarea Modeling in Key Considerations Regarding Use for Analysis).

Calibration Data (Traffic Counts and Speed/Travel Time)

For work zone analysis, calibration data typically consist of measures of traffic counts and speed/travel time.

Model Refinement Data (Traffic Analysis Zone Splitting)

Often the physical changes to the roadway associated with a work zone are localized in nature and, thus, only impact the physical characteristics of the corridor where the work zone is present. For larger projects, work zone mitigation strategies may result in physical changes to detour routes in addition to changes to the subject corridor.

Utilizing a travel demand model to capture the impact of a work zone requires the analysis of the localized corridor(s) where the work zone is occurring or has a significant impact, as opposed to regional travel patterns. As such, **it may be necessary to increase the fidelity of the model by improving the network details surrounding the corridor(s) being studied**. In addition, it may be necessary to improve details for parallel corridors if there are significant anticipated operational impacts or if potential mitigation strategies make significant changes to the physical or operational characteristics of these detour corridors.

A travel demand model typically represents travel in a region by generating trips from an origin to a destination, determining the mode split for these trips and then assigning these trips to the transportation network. The origin and destinations for these modeled trips are represented by Traffic Analysis Zones (TAZ). The size and complexity of these TAZs can vary by location in the model. Often, TAZs near the center (often the downtown area of a model) of the model are smaller in size and can represent a single city block or several city blocks combined. This TAZ will connect to the transportation network with several centroid connectors to allow modeled trips to be transferred from the TAZ to the represented transportation network. Further out toward the edges of the modeled area, TAZs often become larger and can represent several square miles of development with more limited number of centroid connectors. **The size of TAZs represented near the corridor being studied should be examined to determine if they need to be split into smaller TAZs or if additional centroid connectors need to be added to the network to accurately represent travel near the corridor.**

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. It is strongly recommended that local data at work zones are collected and used, as driver characteristics vary from region to region and capacity may vary from location to location. In the absence of better local data, the analyst may use the capacity defaults as the starting point and make modifications accordingly to reflect local work zone conditions.

Capacity can be directly specified in travel demand models. Typically, the user can adjust the lane capacity for any link type in the network to reflect any capacity reduction due to the work zone.

The major parameters that the analyst may adjust for work zone analysis using travel demand models include:

- Number of lanes;
- Free-flow speed; and
- Capacity (vehicles per hour per lane).

Key Considerations Regarding Use for Analysis

The main strengths of using travel demand models for work zone analysis are their ability to model large geographic areas and predict areawide traffic redistribution. Travel demand models, however, have limited capabilities to accurately estimate changes in detailed operational strategies (such as optimized signal operations). Therefore, it is important that the tool selection process detailed in Chapter 3 has been undertaken to ensure that travel demand models are the appropriate tool for the specific work zone analyzed. Discussed below are key considerations when using travel demand models, including:

- Subarea modeling;
- Link length change to match work zone area; and
- Model development and application process.

Subarea Modeling

Travel demand models generally cover large regional areas and are maintained by MPOs. Travel demand models do not have to be cut to smaller subareas for work zone modeling. However, sometimes it is necessary to do so for faster modeling and better focus on the work zone and its immediate vicinity. If a subarea model is created for a particular analysis, care should be taken to ensure that any potential detour or alternate routes be contained within the subarea so that impacts from the changes associated with a work zone can be accurately captured.

The subarea models are typically validated using observed hourly count data. An Origin Destination Matrix Estimation (ODME) process is typically applied to improve the match between model volumes and observed counts in the subarea.

Creating subarea models is necessary when travel demand models are used to generate Origin-Destination (O-D) tables for other tools such as microscopic simulation analysis which do not capture traffic diversion directly. The subarea selected corresponds to the area to be modeled in the microscopic simulation analysis. Often, the subarea model created from the travel demand model can be utilized as a basis for generating the roadway network to be simulated in the microsimulation. However, because the roadway networks generally utilized for travel demand

modeling are developed for conventional static planning applications, they often lack several key features. Some of these missing or deficient data include:

- **Time-Dependent Component for the O-D Demand** – Commonly, the O-D demand is associated with a full 24-hour period or broken down into an a.m. peak, p.m. peak, and off-peak component. This fidelity may not be sufficient for detailed work zone analysis.
- **Explicit Roadway Network Representation** – Most travel demand applications only need the roadway network to represent the connections possible between links. Consequently, the actual roadway geometry may be approximated. For example, a highway interchange loop ramp may only be represented as a link connecting the freeway link to the arterial link and not represent the actual curving or loop geometry of the ramp.
- **Signal Control Information** – Signal controls are not typically explicitly modeled in a travel demand model. As such, signal timing and phasing data are not typically included.

The inclusion of this data often represents the differentiation between a travel demand model and a mesoscopic model.

The use of a travel demand model subarea as a starting place for the development of another simulation tool, such as microsimulation, calls for careful integration of several different data sources. When utilizing a travel demand model to support analysis from another simulation tool, the interface between the outputs of the travel demand model and the necessary inputs to the other simulation tool can vary widely. Depending on the models utilized, this link can vary from being nearly automated to very labor intensive. For example, the output of travel demand data from a VISUM travel demand model to a microsimulation of VISSIM is accomplished via a series of automated scripts that come as part of the PTV Simulation Suite. On the other extreme, the use of travel demand data for use in the microsimulation model CORSIM requires each input volume and turning assignment to be either manually input or a script must be written to accomplish this.

Link Length Change to Match Work Zone Area

Some links in travel demand models can be very long; it is not unusual to see links with a length of several miles. The work zone analyzed may be shorter than the corresponding link in the travel demand model. In this case, the link in the travel demand model has to be broken into shorter ones so that different link attributes (such as free-flow speed and capacity) can be assigned properly.

Model Development and Application Process

The typical model development and application process, which has been discussed at the beginning of this chapter, applies to travel demand models as well.

Travel demand models do not explicitly represent signal control at intersections. Less sophisticated travel demand models may utilize a simple volume-delay curve to represent the impedance of the signalized intersection on the approach links. The more sophisticated travel demand models utilize a "capacity calculator" to approximate the impact of signal control on the

upstream links to the intersection. This capacity calculator applies HCM style intersection analysis to the turning movements calculated for each intersection. The results of this analysis are used to generate penalties for each movement, which are applied during the next iteration of the travel demand model.

1. Travel demand models have a set of user-adjustable parameters that enable the analyst to calibrate the software to better match local conditions. This calibration process involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. The calibration process can be time-consuming. It should be well documented so that later reviewers of the model can understand the rationale for the various parameter changes made during calibration. For details on the calibration and validation process, please refer to the *Model Validation and Reasonableness Checking Manual*.[27]

2. In most instances, it is beyond the scope of most work zone projects to undertake recalibration and validation of the regional travel demand model. There are typically strict calibration and validation guidelines associated with these models, which must be documented and verified by an independent agency. As such, this step is often skipped.

Travel Demand Model Development and Application – Checklist

This subsection provides a high-level synthesis combining the concepts presented above on model development and application for travel demand model use for work zone analysis. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives** – The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks** – Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.
- **Determine Study Network** – Determine the limits of the study network. The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned. For faster modeling and better focus on the work zone and its immediate vicinity areas, a subarea modeling may be necessary.
- **Conduct Subarea Modeling** – Determine whether a subarea model is necessary. Travel demand models do not have to be cut to smaller subareas for work zone modeling. However, sometimes, it is necessary to do so for faster modeling, better focus on the work zone and its immediate vicinity areas, and integration with other tools such as microsimulation analysis. Care should be taken to ensure that potential detour or alternate routes are contained within the subarea so that impacts from the changes associated with a work zone can be accurately captured.
- **Split TAZs** – The size of TAZs represented near the corridor being studied should be examined to determine if they need to be split into smaller TAZs or if additional centroid

connectors need to be added to the network to accurately represent travel near the corridor.

- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peak. For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.

- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.

- **Select Measures of Effectiveness and Thresholds** – The MOEs or thresholds selected will be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.

- **Collect and Analyze Data** – Collect data that are needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.

- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.

- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.

- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones be collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.

- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Error checking should be performed to identify and correct the model coding errors.

- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions.

- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.

- **Change Link Length** – The work zone analyzed may be shorter than the corresponding link in the travel demand model. In this case, the link in the travel demand model needs to be broken to shorter ones so that different link attributes (such as free-flow speed and capacity) can be assigned properly.

- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.

- **Conduct Alternative Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare

against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.
- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

4.4 USING TRAFFIC SIGNAL OPTIMIZATION ANALYSIS

Traffic signal optimization tools are designed to develop optimal signal phasing and timing plans for isolated signalized intersections, arterial streets, or signalized networks. The more advanced traffic optimization tools are capable of modeling actuated and semi-actuated traffic signals, with or without signal coordination.

With respect to work zones, traffic signal optimization tools are useful when developing a signal plan for temporary traffic signal controls or analyzing signal plans when a detour route directs traffic to an existing signalized arterial roadway. The primary limitation of these tools is their single focus. Therefore, traffic signal optimization tools are typically used to provide supplementary analysis when analyzing the overall mobility impacts of a work zone. Signal optimization tools are sometimes combined with simulation tools to have a better understanding of traffic operations (both calibration of existing conditions models, as well as future alternatives analysis). Examples of this combination are Synchro/SimTraffic and TRANSYT-7F/VISSIM.

Some examples of traffic signal optimization tools are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **PASSER IV-96** – http://ttisoftware.tamu.edu/fraPasserIV_96.htm;
- **Synchro** – http://www.trafficware.com;
- **TEAPAC/SIGNAL2000** – http://www.strongconcepts.com/Products.htm; and
- **TRANSYT-7F** – http://www.mctrans.ce.ufl.edu/store/description.asp?itemID=437.

Data Collection

The precise input data required by a signal optimization model will vary by software and the specific modeling application as defined by the study objectives and scope. Besides the common data discussed at the beginning of this chapter, most signal optimization analytical work zone studies require the following types of input data.

Existing Models

Check if any of the local agencies maintain a database of traffic signal optimization model files. A field visit may need to be performed to verify the accuracy of the model input data.

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. It is strongly recommended that local data at work zones are collected and used, as driver characteristics vary from region to region and capacity may vary from location to location. **In the absence of better local data, the analyst may use the capacity defaults as the starting point and make modifications accordingly to reflect local work zone conditions.**

Once the work zone capacity is determined, the next step is to implement it in the signal optimization model. Among other things, the base saturation flow rate (SFR) is typically adjusted to represent the reduced capacity due to work zone operations. This can be accomplished either by reducing the lane widths/number of lanes through the work zone, or by changing the base saturation flow rate directly.

Table 31 lists some major parameters that the analyst may adjust for work zone analysis in several commonly used signal optimization software programs, including Synchro, Passer, and TRANSYT-7F.

Table 31. Parameters to Adjust for Work Zone Analysis in Common Signal Optimization Software

Signal Optimization Software	Primary Parameters	Secondary Parameters
SYNCHRO	• Number of lanes • Ideal saturation flow rate • Speed limit • Lane inputs, including turn bays and U-turns • Peak hour factor	• Heavy vehicle percentage
PASSER	• Number of lanes • Ideal saturation flow rate • Speed limit • Lane inputs, including turn bays • Peak hour factor	• Heavy vehicle percentage
TRANSYT-7F	• Number of lanes • Base saturation flow rate • Lane inputs, including turn bays • Peak hour factor	• Heavy vehicle percentage • Grade percentage

Key Considerations Regarding Use for Analysis

Signal optimization tools have a variety of applications for work zone analysis, especially in urban and suburban environments. Broadly speaking, these applications can be grouped in four categories:

1. Preparing timing plans for temporary signals used to manage traffic within a work zone;
2. Preparing timing plans for flagger or portable signals used to manage traffic within a work zone;
3. Adjusting signal timing on corridors that are directly impacted by work zone; and

4. Adjusting signal timing to improve progression on corridors that serve as alternate routes or detours around a work zone.

Model Development and Application Process

Signal optimization tools can be used to identify the need for temporary traffic signals and to revise the signal timing plans for existing signals where volumes are expected to increase or decrease as a result of the construction.

The typical model development and application process, which was discussed at the beginning of this chapter, applies to signal optimization tools as well. It should be noted that model calibration might not be required for some projects. If the analyst is unsure as to whether calibration will be required, consult with the contracting agency for a determination for the specific project.

For example, the Work Zone Analysis Guide by the MD SHA recommends the following guidelines be used to calibrate a Synchro model:[15]

- Synchro queue lengths should match field-measured queues on the critical movements within an 85 percent error (for field-measured queues shorter than 10 vehicles, a 2-vehicle error may be acceptable).
- Synchro travel times should match field-measured travel times within 85 percent. Note that the travel times should be compared for the overall length of the arterial, and not on a link-by-link basis.
- The SimTraffic simulations, a microsimulation tool coupled with Synchro, should match field-observed bottlenecks to the analysts' satisfaction.

A work zone base conditions model is then developed by modifying the calibrated existing conditions model to represent work zone conditions. Adjustment to the base model to create the work zone base conditions model may include:

- Lane Configurations:
  - Lane reductions on arterial segments can be modeled explicitly in most signal optimization tools. For instance, Synchro uses bend nodes and TRANSYT-7F uses dummy nodes to model lane reductions. Using Synchro as an example, bend nodes can be created on either end of the proposed work zone, overriding the number of lanes on one or both directions of the roadway. Take into consideration the required taper and buffer lengths approaching the work zone and adjust the model accordingly.
  - When lane reductions occur through an intersection, take into consideration any impacts that this may have on the turning lanes from the side street(s).
  - When lane and/or shoulder widths are reduced, the work zone capacity should be reduced accordingly.
- Traffic Volumes:
  - When a detour route is being proposed, it will be necessary to redistribute the traffic volumes in the network based on O-D data and engineering judgment.

- If work zone demand management strategies are being employed, it may be necessary to reduce the traffic volumes by the estimated reduction in vehicle demand through the work zone.
- Saturation Flow Rate:
  - Where there are no lane reductions, but where work would occur adjacent to the roadway, it may be necessary to adjust the saturation flow rate to represent the reduced capacity due to work zone operations. This can be accomplished either by reducing the lane widths through the work zone, or by changing the saturation flow rate directly.

For alternatives analysis, the analyst needs to run the model for each alternative, review the output, compare against any mobility requirements, extract relevant statistics, and perform various analyses of the results. Some agencies may have signal-related mobility criteria. For instance, MD SHA uses LOS, control delay, and travel time as mobility requirements, as listed in Table 32.[15]

Table 32. Mobility Thresholds for Arterials (MD SHA)

Signalized Intersections	
Existing LOS	**Mobility Threshold**
A, B, or C	Maximum LOS D, control delay ≤ 45 seconds
D	Maximum increase in control delay of 30%
E	Maximum increase in control delay of 30%, or control delay ≤ 80 seconds
F	No increase in control delay
Arterials	
TT	Travel time cannot increase more than 15 minutes (maximum of TT+15)

(Source: Maryland State Highway Administration, 2008.)

Traffic Signal Optimization Model Development and Application – Checklist

This subsection provides a high-level synthesis combining the concepts presented above on model development and application for work zone analysis involving signal optimization tools. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives –** The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks –** Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.
- **Determine Study Network –** Determine the limits of the study network. The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned.

- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peak. For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.
- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.
- **Select Measures of Effectiveness and Thresholds** – The MOEs or thresholds selected will be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.
- **Collect and Analyze Data** – Collect data that is needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.
- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.
- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.
- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones are collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.
- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Error checking should be performed to identify and correct the model coding errors.
- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions.
- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.
- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.
- **Conduct Alternative Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.
- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

4.5 USING MACROSCOPIC ANALYSIS

Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis, meaning they treat traffic flows as an aggregated quantity; they do not model the movement of individual vehicles on a network.

Similar to travel demand models, a key feature of macroscopic models is their ability to model large geographic areas. This ability is particularly useful when the work zone impacts may affect a larger corridor or region, where large geographic impacts need to be better understood based upon a certain work zone design such as a full closure. Macroscopic simulation models also can be set up and run fairly quickly due to the fact that they simulate aggregate flows, speeds, and density measures on each section of the network (rather than individual vehicles).

However, the simple representation of traffic movement (e.g., no car-following/lane-changing algorithms) in macroscopic simulation models may limit the fidelity of the results. Also, macroscopic simulation models may provide limited detail in simulating real-world traffic conditions. They do not have the ability to analyze transportation improvements in as much detail as the mesoscopic and microscopic models.

Some examples of macroscopic models are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **FREQ** – http://its.berkeley.edu/systems/research; and
- **NetZone** – http://www.dot.ca.gov/researchconn/past_speakers/DrZhang/ michael_zhang_pres_april_26.pdf.

Data Collection

The precise input data required by a macroscopic model will vary by software and the specific modeling application as defined by the study objectives and scope. Most macroscopic studies require the following types of input data besides the general data identified at the beginning of this chapter.

Existing Models

Check if a local agency maintains a database of macroscopic model files. A field visit may need to be performed to verify the accuracy of the model input data.

Travel Demand

Most macroscopic models require O-D tables as input data. Procedures exist in many demand models to generate O-D tables for the study area. Certain macroscopic models, such as FREQ, have the capability to derive O-D tables based on traffic counts.

Calibration Data

Calibration data consist of measures of traffic counts and system performance such as travel times, speeds, delays, and queues.

Other Data

Some macroscopic models (e.g., KRONOS) require a flow-speed-density (q-v-k) relationship for each roadway type (e.g., freeway and arterial). The q-v-k relationship can be acquired using typical tube counter data, in which the average speed and counts are reported per user-defined interval. First, the counts can be converted to flow rates (q). If the reported speed is the space-mean-speed (total distance divided by total time that the speed trap is occupied), then the density can be calculated by taking $k = q/v$. If the average is the time-mean-speed (e.g., the average speed is the arithmetic mean of the individual speed measures), then three percent to five percent reduction from the time-mean-speed can be used to approximate the space-mean-speed.

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. It is strongly recommended that local data at work zones be collected and used, as driver characteristics vary from region to region and capacity may vary from location to location. In the absence of better local data, the analyst may use the capacity defaults as the starting point, and make modifications accordingly to reflect local work zone conditions.

Capacity can be directly specified in most macroscopic models. Typically, the user can adjust the capacity for any type of link in the network, if needed. In addition, the jam density and speed limit (if appropriate) can be modified as well for capacity calibration. Table 33 lists major parameters that the analyst may adjust for several commonly used macroscopic simulation software.

Table 33. Parameters to Adjust for Work Zone Analysis in Common Macroscopic Simulation Software

Signal Optimization Software	Primary Parameters	Secondary Parameters
FREQ	• Capacity • Speed • Speed curves (volume-speed relationship)	• Traffic composition (percent trucks)
KRONOS	• Capacity • Minimum delay speed • Jam density • Critical density	• Traffic composition (vehicle types)
NetZone	• Capacity • Capacity reduction (Percent) • Free-flow speed • Jam density • Critical density • Queue storage (vehicle/mile)	• Pre-trip traveler information factor

Key Considerations Regarding Use for Analysis

The strength of macroscopic simulation models is their ability to model large geographic areas. This ability is particularly useful when the work zone impacts may affect a larger corridor or region. Macroscopic simulation models can be set up and run fairly quickly due to the fact that they simulate aggregate flows, rather than individual vehicles.

Discussed below is the model development and application process when using macroscopic simulation tools.

Model Development and Application Process

The typical model development and application process, which has been discussed at the beginning of this chapter, applies to macroscopic simulation as well.

The calibration of macroscopic simulation models typically involves replication of observed congestion patterns. Freeway validation is based on travel time run information and speed contour diagrams constructed for the analysis periods, which are then aggregated to provide a "typical" congestion pattern. Surface-street calibration is based on speed, queue, delay, and capacity information. Macroscopic models have considerably less demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as mesoscopic or microscopic models; and do not consider trip generation, trip distribution, and mode choice in their evaluation of changes in transportation systems.

Macroscopic Simulation Model Development and Application – Checklist

This subsection provides a high-level synthesis combining the concepts presented above on model development and application for macroscopic tool work zone analysis. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives** – The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks** – Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.
- **Determine Study Network** – Determine the limits of the study network. The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned.
- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peak. For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.
- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.
- **Select MOEs and Thresholds** – The MOEs or thresholds selected will be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.
- **Collect and Analyze Data** – Collect data that is needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.
- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.
- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.
- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones be collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.

- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Error checking should be performed to identify and correct the model coding errors.
- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions.
- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.
- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.
- **Conduct Alternative Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.
- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

4.6 USING MESOSCOPIC ANALYSIS

As discussed above, macroscopic models can only provide limited detail in simulating real-world traffic conditions. In certain cases, more in-depth simulation results are required. This is where mesoscopic models come into play.

Mesoscopic simulation models combine the properties of both macroscopic and microscopic simulation models (discussed in the next section). As in microscopic models, the mesoscopic model's unit of traffic flow is the individual vehicle. Their movement, however, follows the macroscopic properties of traffic flows (such as average speed, density, and flow rates) without having to examine the interaction of individual vehicles in detail. Therefore, the mesoscopic model provides greater computational efficiency that allows a much faster simulation of larger networks than microscopic models, while providing users with more detailed information than macroscopic models. For instance, the lane-change maneuver could be represented for individual vehicles as an instantaneous event with the decision based on relative lane densities, rather than detailed vehicle interactions. Another example is that users have the capability to model diversion routes from major roadways (e.g., freeways and highways) to other road types (e.g., signalized arterial).

In short, mesoscopic simulation strikes a balance between the macroscopic and microscopic models. Mesoscopic models provide users with higher accuracy in simulating real-world traffic behavior than macroscopic models, but less accuracy than microscopic models. Mesoscopic analysis has the ability to analyze larger geographic areas than microscopic analysis, while still providing some of the detailed data that macroscopic analysis cannot provide.

If agency policy stipulates a need to measure lane-by-lane queue lengths, the most accurate results will most likely be generated by a microscopic model, since it provides results at the vehicle and lane level. However, microscopic tools are particularly complex and costly to deploy when modeling large corridors and regions. In these cases, a mesoscopic model or sketch-planning model could be used to predict queue lengths when lane-level results are not critical. It is important to select the approach that best provides the needed measures relative to the available data, resources, and work zone attributes.

Some examples of mesoscopic traffic simulation models are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **Aimsun –** http://www.aimsun.com/wp/;
- **Dynameq –** http://www.inro.ca/en/products/dynameq/index.php;
- **DYNASMART-P –** http://www.fhwa.dot.gov/research/deployment/dynasmart.cfm;
- **DynusT –** http://dynust.net/; and
- **TransModeler/Meso –** http://www.caliper.com/transmodeler/Simulation.htm.

Data Collection

The precise input data required by a mesoscopic model will vary by software and the specific modeling application, as defined by the study objectives and scope. Most mesoscopic analysis work zone studies require the following types of input data besides the general data identified at the beginning of this chapter.

Existing Models

Check if a local agency maintains a database of mesoscopic model files. A field visit may need to be performed to verify the accuracy of the model input data.

Travel Demand (O-D Table)

Mesoscopic models require O-D tables as input data. Procedures exist in many demand modeling software packages to generate O-D tables for the study area.

Calibration Data (Traffic Counts and Performance Data, Such As Speed and Queues)

Calibration data consist of measures of traffic counts and system performance such as travel times, speeds, delays, and queues.

In addition to the above basic input data, speed and density data for each roadway type (e.g., freeway and arterial) are required as most mesoscopic models move vehicles according to the speed-density (v-k) relationship. The v-k relationship can be acquired using typical tube counter data in which the average speed and counts are reported per user-defined interval. First, the counts can be converted to flow rates (q). If the reported speed is the space-mean-speed (total distance divided by total time that the speed trap is occupied), then the density can be calculated

by taking k = q/v. If the average is the time-mean-speed (e.g., the average speed is the arithmetic mean of the individual speed measures), then three percent to five percent reduction from the time-mean-speed can be used to approximate the space-mean-speed.

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. It is strongly recommended that local data at work zones be collected and used, as driver characteristics vary from region to region and capacity may vary from location to location. In the absence of better local data, the analyst may use the capacity defaults as the starting point and make modifications accordingly to reflect local work zone conditions.

Capacity can be directly specified in most mesoscopic models. Typically, the user can adjust the capacity for any link in the network, if needed. In addition, the jam density and speed limit (if appropriate) can be modified as well for capacity calibration. Table 34 lists major parameters that the analyst may adjust for several commonly used mesoscopic simulation models.

Table 34. Parameters to Adjust for Work Zone Analysis in Common Mesoscopic Simulation Software

Mesoscopic Simulation Software	Parameters
AIMSUN/Meso	- Maximum speed - Jam density - Curvature geometries - Intersection geometries - Reaction time factor - Look ahead distance
DynaMIT/DYNASMART	- Density - Saturation flow rate - Maximum service flow rate - Travel/route guidance - Weaving sections
DYNAMEQ	- Free-flow speed - Mandatory lane changes - VMS
DynusT	- Service flow rate - Saturation flow rate - Jam density - Speed limit
TRANSMODELER/Meso	- Lane width factor - Speed limit - Saturation flow rates - Look ahead

Key Considerations Regarding Use for Analysis

The strength of mesoscopic simulation models is the ability to model both large geographic areas and corridors. In addition, diversion routes and signalized intersections can be modeled. In the case of a corridor with a freeway and a signalized arterial road running through it, the diversion

route onto the arterial could be more readily modeled using a mesoscopic simulation model. Mesoscopic traffic simulation models can provide knowledge of route choice behavior and are ideal for prediction applications, where the detailed modeling of route choice and other strategic driver choices are essential, but where the detailed modeling of driver interaction with the road network and other drivers is not needed.

Mesoscopic simulation models are useful for simulating existing and work zone traffic conditions for complex work zone scenarios. Discussed below are key considerations when using mesoscopic simulation tools, including:

- DTA;
- Network convergence; and
- Model development and application process.

Dynamic Traffic Assignment (DTA)

DTA models are well suited for work zone analysis due to their capability of assigning traffic dynamically.[28] DTA models are more responsive to operational factors (e.g., queuing) than traditional travel demand models. Also, DTA models can dynamically assign traffic over a much larger network than microscopic models. It helps to assess impacts of different work zone management strategies at the network level, not just at the corridor level.

DTA models have become a viable modeling option recently. DTA models supplement existing travel demand models and microscopic simulation models. Travel demand models represent the static regional travel demand analysis capability, whereas microscopic simulation models are superior for dynamic travel analysis at the corridor level. DTA models fill in the gap by enabling dynamic traffic to be modeled at a range of scales from the corridor level to the regional with expanded and unique functional capabilities enabled by the DTA methodology.

The static traffic assignment used in travel demand models determines network traffic flows and conditions resulting from demand/supply interactions via route choices from travelers. Route choice behavior is based upon the assumption that all travelers are aimed at traveling from their origin to their destination with the least travel time. When each traveler succeeds in finding such a route, every used route has the minimum time or cost between its origin and destination; moreover, for each O-D pair, every route used has the same travel time. This condition is known as user equilibrium. Therefore, in travel demand models, trips are instantaneously on all links between origins to destinations (not time-dependent). In addition, static traffic assignment does not take into consideration congestion spillback (i.e., where congested traffic spans a sequence of two or more links due to downstream bottleneck).

Unlike the static traffic assignment, DTA considers **time variations** in traffic flows and conditions, thus, attempting to reflect the reality of that traffic network. To represent these time-varying conditions in the context of user equilibrium, two concepts must be recognized: 1) in a dynamic approach, the user equilibrium condition of equal travel times on used routes applies only to travelers who are assumed to depart at the same time between the same O-D pair, which means the equilibrium condition is **disaggregated** to consecutive departure times instead of the

entire analysis period; and 2) travel times on network links **vary over time** based on preceding experienced travel times, as this will depend on when travelers arrive at the various links along a route.

DTA models seek to provide a more detailed means to represent the interaction between travel choices, traffic flows, and time and cost measures in a temporally coherent manner (e.g., further improve upon the existing time-of-day static assignment approach). More specifically, DTA models aim to describe such **time-varying network** and demand interaction using a behaviorally sound approach. The DTA model analysis results can be used to evaluate more meaningful performance measures related to individual travel time and cost, as well as systemwide network measures for regional planning purposes.

DTA in Microscopic Simulation Models

Currently, many microscopic models are route-based, meaning vehicles select a route at departure and follow that route with or without further update along the journey during simulation. The "one-shot" (non-iterative) assignment-simulation approach is commonly used in microscopic simulation models, in which vehicles departing at different times are given a route that is periodically updated in simulation based on **instantaneous travel times**, not **experienced travel time**.

- **Instantaneous Travel Time –** It is a snapshot travel time measured at the time that the routes are generated without considering congestion during subsequent time periods. Such an assignment can be regarded as if travelers strictly follow some type of "pre-trip" route guidance.
- **Experienced Travel Time –** Experienced travel time is used in DTA models instead. The experienced travel time needs to be evaluated "after the fact," at which point the traffic condition along the entire journey is revealed and experienced. In other words, choosing a minimal experienced travel time route at departure involves anticipation of future traffic condition along the journey. This anticipation is usually formed by learning from prior experience (e.g., try different routes). To account for this "learning" process, an **iterative** algorithmic process is needed. Such an iterative process reflects the learning and adjustment in route choice from one iteration to the next until the traveler cannot find a route with a shorter experienced travel time. In reality, the majority of travelers choose a route that leads to the minimal **experienced travel time** instead of minimal instantaneous travel time.

The difference between experienced and instantaneous travel times can be better illustrated by using Figure 14, which is a simple one-way network with four nodes and three links.[28] The stack of values represents the different times to traverse a link when departing from the upstream node (and entering the link) at different times. Time-varying link travel time is common during peak hours due to congestion buildups. As an example, the time needed to traverse link 1 is 1 time unit when departing the upstream node at time 1, and 3 time units when departing the upstream node at time 5. Similarly, the travel time for link 2 is 1 and 4 time units when departing the link 2 upstream node at times 1 and 5, respectively.

- The **instantaneous travel time** for the entire route at each different departure time is calculated by summing up the link travel time corresponding to that same departure time for all links comprising the route. As an example, for vehicles departing at time 1, the travel time is 1+1+1=3 time units; for vehicle departing at time 2, the travel time is 1+2+3=6 time units.
- The **experienced travel time** calculation accounts for the time needed for traversing one link, and looks up the downstream link travel time based on the time of entering that downstream link (assuming that traversing a node takes no time). Based on this approach, the travel time for the route when starting at departure time 1 should be 1 + 2 (vehicle entering link 2 at time 2, so the link 2 travel time is 2 time units), plus 6 (vehicle arriving at link 3 at time 4, so the link 3 travel time is 6 time units). The experienced travel time is 1+2+6=9 time units.

Clearly, these two methods produce different route travel times and, likewise, differing results for the shortest routes. The shortest route obtained based on the instantaneous travel time calculation has the minimum travel time based on the "snapshot" of the link travel times prevailing at departure. However, because link travel times change dynamically (due to congestion), that route does not necessarily result in minimal experienced travel time, because there is no provision in this procedure to reflect the anticipation of congestion that is to occur at a later time down the road (e.g., congestion caused by vehicles departing later but entering the same link, one which the vehicle being modeled is still traversing).

Assigning vehicles with an instantaneous travel time route is not necessarily "incorrect." The route choice associated with instantaneous travel time may be interpreted as: 1) travelers know what the shortest route is at departure through pre-trip information (e.g., 511, news or web site) or en-route in-vehicle information system (if the traveler is to take another route when en-route); or 2) from day to day, travelers do not assess the route travel time from the experience standpoint, but rely instead on the traveler information. In contrast, the shortest route obtained based on the experienced travel time calculation method will yield a time-dependent shortest route with minimal experienced travel time. This assumes that travelers are willing to seek routes that minimize their experienced travel time instead of the route that appears to be the best only at the departure.
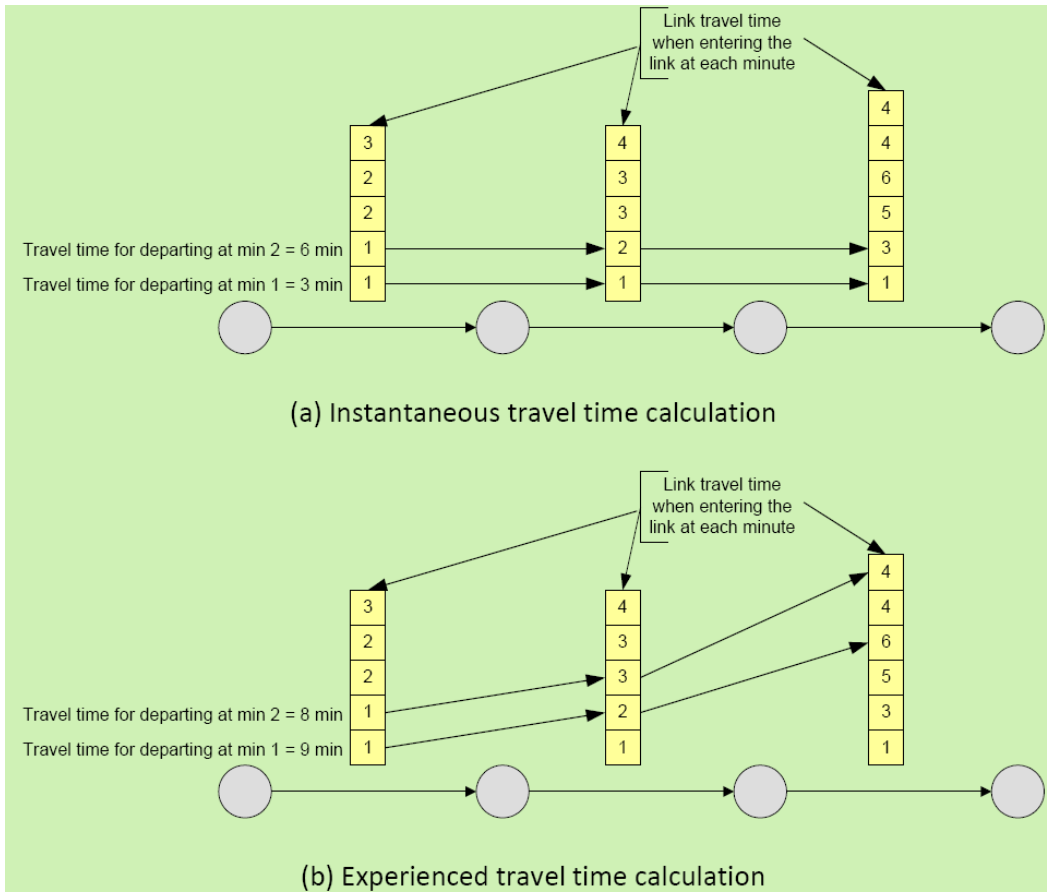
Figure 14. Experienced Travel Time versus Instantaneous Travel Time

(Source: Transportation Research Board, 2010.)

Network Convergence

Almost all DTA models apply an iterative algorithm to compute an approximation to dynamic user equilibrium. From one iteration to the next, time-dependent route choices and link flows and times change as the algorithm progresses towards an equilibrium solution. At some point, the **convergence criteria** are satisfied and the algorithm terminates.

A poorly converged network may have the problem of "nonlocal impacts" – a minor change in the network has large impacts on flows or conditions far from the location of the change. For example, a minor change, such as a speed limit change on a particular link, would not be expected to significantly affect flows and conditions far from the link in question. DTA model outputs that showed such effects should be closely examined. When an apparent nonlocal impact exists, it is best to verify the quality of the computed convergence solution, for example, by resolving the DTA model with more stringent convergence criteria.

However, stricter convergence criteria lead to increased computational time. Therefore, a tradeoff between convergence and computational time must be made when choosing the appropriate convergence criteria.

Model Development and Application Process

The typical model development and application process, which was discussed at the beginning of this chapter, applies to mesoscopic models as well.

1. For mesoscopic models, typically two forms of calibration are required; they are:
    - **Capacity Calibration –** Factors that influence capacity calibration typically include maximum speeds, jam densities, number of lanes, curvature geometries, intersection geometries, and other minor characteristics.
    - **O-D Matrix Calibration –** This is a more time-consuming effort as numerous iterations are often required to produce an O-D matrix that results in realistically modeled traffic. This involves utilizing an existing demand matrix and then make some adjustments to refine the accuracy of simulated flow compared with observed traffic flow.

2. The O-D matrix calibration process is illustrated in Figure 15. The mesoscopic model is run with the estimated time-dependent O-D matrices. With the difference between the simulated link counts and the field counts, an optimization tool is typically used to calibrate the O-D matrices, resulting in new O-D matrices. The iterations continue until the total deviation between the simulated and field counts is less than a user-defined threshold, or when the maximum number of iterations is reached.
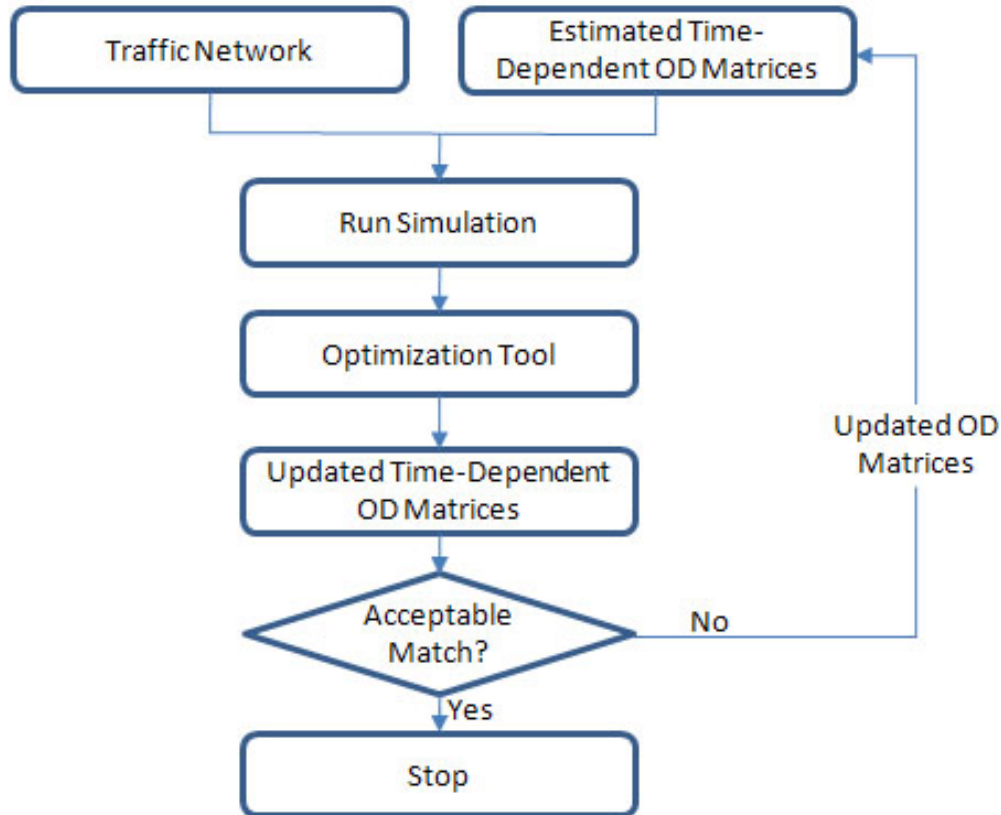
Figure 15. O-D Matrix Calibration in Mesoscopic Models

Mesoscopic Simulation Model Development and Application – Checklist

This subsection provides a high-level synthesis combining the concepts presented above on model development and application for mesoscopic simulation work zone analysis. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives** – The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks** – Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.
- **Determine Study Network** – Determine the limits of the study network. The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned.
- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peak. For

longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.

- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.
- **Select MOEs and Thresholds** – The MOEs or thresholds selected should be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.
- **Collect and Analyze Data** – Collect data that is needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.
- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.
- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.
- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones be collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.
- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls. Error checking should be performed to identify and correct the model coding errors.
- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions. For mesoscopic models, typically two forms of calibration are required, including capacity calibration and O-D matrix calibration.
- **Verify Network Convergence** – The majority of mesoscopic simulation tools use DTA to compute an approximation to dynamic user equilibrium. Once done, verify the quality of the computed convergence solution to see if it meets the appropriate convergence criteria.
- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.
- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.
- **Conduct Alternative Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.

- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

4.7 USING MICROSCOPIC ANALYSIS

Microscopic simulation tools simulate the movement of individual vehicles based on car-following and lane-changing models. Vehicles enter a transportation network using a statistical distribution of arrivals and are tracked through the network over brief time intervals (e.g., one second or a fraction of a second).

Microscopic simulation models are extensively used in a wide range of applications, including evacuation planning and work zone impact analysis. They are **effective in evaluating a wide range of scenarios, including heavily congested conditions, complex geometric configurations, and system-level impacts** of proposed transportation improvements that are beyond the limitations of other model types. They also are useful in analyzing key bottlenecks on roadway segments and corridors where the movement of each individual vehicle needs to be represented to better understand the impact on roadway conditions. Many transportation agencies currently use microscopic models in conjunction with other analysis tools such as travel demand models and mesoscopic models to better understand the impact of roadway geometry modifications on carrying capacity and level of service.

Some examples of microscopic traffic simulation models are listed below. For a complete list, please refer to *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*.[8]

- **AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Nonurban Networks)** – http://www.tss-bcn.com/aimsun.html;
- **CORSIM/TSIS (Traffic Software Integrated System)** – http://www.mctrans.ce.ufl.edu/featured/tsis/version5/corsim.htm;
- **PARAMICS** – http://www.paramics-online.com;
- **TRANSMODELER** – http://www.caliper.com/transmodeler/default.htm; and
- **VISSIM** – http://www.ptvamerica.com/support/vissim/.

Level of Effort (LOE)

The *Guidance on the Level of Effort Required to Conduct Traffic Analysis Using Microsimulation* evaluates four case studies of microsimulation projects of various sizes and their level of effort estimates.[25] Table 35 summarizes the labor-hour estimates expected for these case studies. Additionally, Figure 16 shows the typical percentage of labor hours required for various project tasks. These examples are meant to provide analysts and modeling managers with a frame of reference on the level of effort required to complete a microsimulation analysis. These estimates serve as a point of reference, not as absolute estimates that should be applied to all projects.

Table 35. Level of Effort for Various Microsimulation Projects

Task	Model Size and Hours			
	Small	Medium 1	Medium 2	Large
Data Collection	40	262	80	2,000
Base Model and Calibration	140	597	560	2,500
Alternatives Analysis	280	1,056	640	2,520
Documentation/Presentations	40	62	240	1,850
Project Management	40	84	80	1,210
Total	**540**	**2,061**	**1,600**	**10,080**

(Source: Cambridge Systematics, Inc., 2012.)
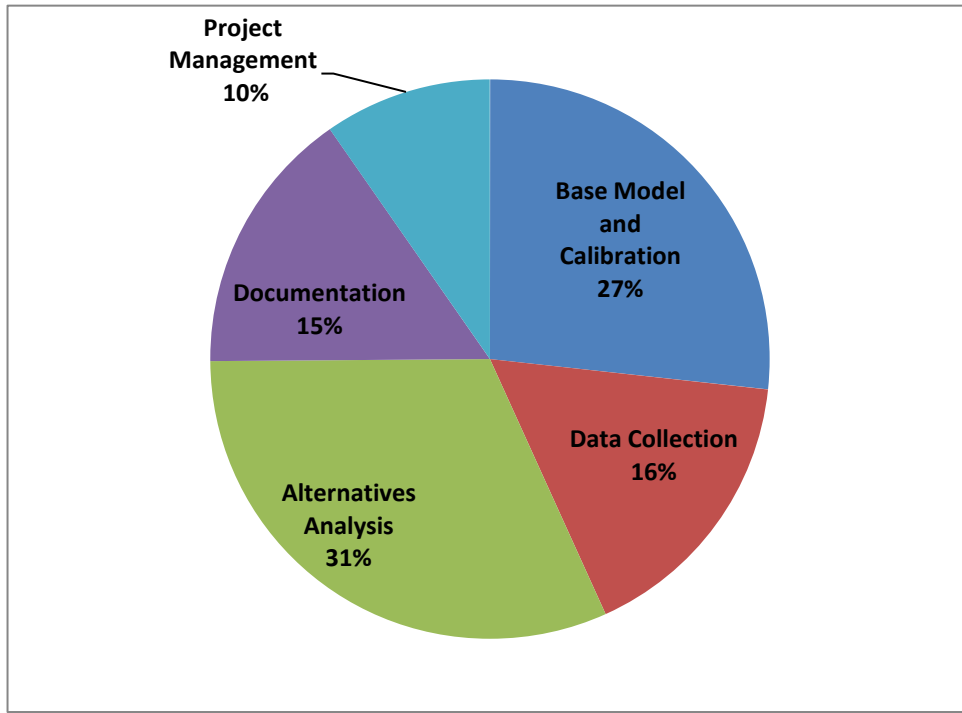
Figure 16. Expected Level of Effort by Project Tasks for Microsimulation Projects

(Source: Cambridge Systematics, Inc., 2012.)

Data Collection

The precise input data required by a microsimulation model will vary by software and the specific modeling application as defined by the study objectives and scope. Most microsimulation studies require the following types of input data besides the general data identified at the beginning of this chapter.

Existing Models

Check if the local agency maintains a database of microsimulation model files. A field visit may need to be performed to verify the accuracy of the model input data.

Demands (Entry Volumes, Turning Volumes, O-D Table)

The basic travel demand data required for most models consist of entry volumes (traffic entering the study area) and traffic at ramps within the study area. Some models require one or more vehicular O-D table(s), which enable the modeling of route diversions. Procedures exist in many demand modeling software and some microsimulation software for estimating O-D tables from traffic counts.

Calibration Data (Traffic Counts and Performance Data, such as Speed and Queues)

Calibration data consist of measures of capacity, traffic counts, and measures of system performance such as travel times, speeds, delays, and queues.

Other Data

In addition to the above basic input data, microsimulation models also require data on vehicle and driver characteristics (vehicle length, maximum acceleration rate, driver aggressiveness, etc.). Because these data can be difficult to measure in the field, it is often supplied with the software in the form of various default values.

Each microsimulation model also will require various control parameters that specify how the model conducts the simulation. The user's guide for the specific simulation software should be consulted for a complete list of input requirements.

Capacity in Modeling Tools

At the beginning of this chapter, details on work zone lane capacity were presented. It is strongly recommended that local data at work zones be collected and used, as driver characteristics vary from region to region and capacity may vary from location to location. **In the absence of better local data, the analyst may use the defaults as the starting point and make modifications accordingly to reflect local work zone conditions.**

Once the work zone capacity is determined, the next step is to implement it in the microsimulation model. For microsimulation tools, however, there is **no direct input for "capacity."** Instead, each microsimulation software program has its own set of parameters that affect capacity, depending on the specific car-following and lane-changing logic implemented in the software. Table 36 lists major parameters that the analyst may adjust for several commonly used microsimulation software programs.

Similar to the input, there is **no direct output in microsimulation models for "capacity."** Instead, the number of vehicles that pass a given point can be generated. Thus, the analyst must manipulate the input traffic demand as necessary to create a queue upstream of the target section to be calibrated so that the model will report the maximum flow rate (i.e., capacity) through the area. After the capacity is calibrated, the analyst will change the input traffic demand back.

Table 36. Parameters to Adjust for Work Zone Analysis in Common Microsimulation Software

Microsimulation Software	Parameters		
	Speed	Car-Following	Lane-Changing (Before Approaching Work Zone)
AIMSUN	• Maximum speed • Turn speed at intersections • Lane speed limit	• Reaction time factor • Minimum headways	• Maximum delay time to remove vehicles • Look ahead distance • Lane-changing model • Lane selection model • Global reaction time and local reaction time factor
CORSIM	• Speed limit	• Car-following sensitivity • Headway factor by vehicle type • Rubbernecking factor	• Time to complete lane-change maneuver • Percentage of drivers yielding the right-of-way to lane-changing vehicles • Gap acceptance
PARAMICS	• Speed limit • Roadway type	• Headway factor • Reaction factor	• Lane choice; Signposting
VISSIM	• Reduced speed area • Desired speed decision	• Standstill distance (CC0) • Headway time (CC1) • Following variation (CC2)	• Look-back distance • Safety distance reduction factor • Waiting time before diffusion • Maximum deceleration
TRANSMODELER	• Lane width factor • Tunnel factor • Max speed difference • Speed limit	• Desired speed model • Headway thresholds	• Look ahead • Critical distance

Key Considerations Regarding Use for Analysis

Microscopic simulation models are useful for simulating existing and work zone traffic conditions for complex work zone scenarios. Discussed below are key considerations when using microscopic simulation tools, including:

- Identifying the chokepoint;
- Work zone taper simulation;
- Model development and application process;
- Congested versus noncongested conditions;
- Initialization period;

- Number of runs; and
- Avoiding bias in the results.

Identifying the Chokepoint

For most work zones, the chokepoint will be the taper.[22] However, if there is an on-ramp near the taper, either upstream or downstream, the chokepoint could be within the on-ramp merge area. If the chokepoint is in an on-ramp merge area, specific care must be exercised in setting or proportioning on-ramp flow rates. Being able to identify a single chokepoint can simplify the analysis.

Work Zone Taper Simulation

A work zone taper is typically modeled as a "lane drop" in most microsimulation tools. A model can vary the amount of space ahead that drivers have to react to a lane drop, but the physical length of the taper cannot be specifically entered as a variable.

Model Development and Application Process

The typical model development and application process discussed at the beginning of this chapter applies to microscopic models as well.

Each microsimulation software package has a set of user-adjustable parameters that enable the analyst to calibrate the software to better match specific local conditions. For details on the microsimulation model calibration process, please refer to the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*.[29]

Congested versus Noncongested Conditions

The calibration of a congested network follows the same procedure as that of noncongested ones. However, the analyst may need to pay special attention to the following issues:

- **Network Boundary** – Ideally, the calibrated existing conditions model (preconstruction, or "no-build") should have its network boundary established to accommodate queues even under the worst scenario, including the work zone conditions. However, this may not be always the case. Thus, under the congested conditions, the analyst may need to extend the network further upstream so that the ends of all queues are within the simulation network.
- **Temporal Boundary** – The analyst also may consider expanding the temporal boundaries (i.e., the duration of the simulated time period), so that at the beginning and the end of the simulation, there are no significant queues within the network.
- **Merging/Weaving Segment** – Because of the lack of congestion, the microsimulation model under the noncongested conditions may be calibrated using the default driving parameters on merging/weaving segments. However, under-congested conditions, the segments with heavy merging or weaving activities may need special attention. Local

lane-changing behavior parameters may need to be adjusted to reflect realistic driving conditions in the field.

Initialization Period

Simulation model runs usually start with zero vehicles on the network. If the simulation output is being compared to field measurements (as in calibration), the artificial period where the simulation model starts out with zero vehicles (the warm-up period) must be excluded from the reported statistics for system performance. Some software programs will do this automatically. For others, the warm-up period must be computed offline by the analyst. For details on how to identify the warm-up period, please refer to the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*.[29]

Number of Runs

Random numbers are used in microsimulation models to generate vehicles, decide their behavior, and select their destination and route as they move through the network. A single simulation run cannot be expected to represent specific field conditions. It is necessary to run the model several times with different random number seeds to get the necessary output to determine mean, minimum, maximum values, and standard deviation. The multiple runs then need to be post-processed to obtain the necessary output statistics.

The determination of the number of simulation runs is an iterative process. For more information, please refer to the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*.[29]

Avoiding Bias in the Results

The simulation geographic and temporal limits should be sufficient to include all congestion related to the base case and all of the alternatives. Otherwise, the model will not measure all of the congestion associated with an alternative, thus potentially causing the analyst to underreport the benefits of an alternative.

Microscopic Simulation Model Development and Application – Checklist

This subsection provides a high-level synthesis combining the concepts presented above on model development and application for microsimulation model work zone traffic analysis. Please note that not all the items listed below are required for all work zone analysis.

- **Determine Study Objectives** – The goals should directly correlate to the work zone safety, mobility, constructability concerns, and needs of the agency. The performance objectives then determine the selection of work zone alternatives or strategies that are designed to meet the established goals.
- **Identify Needed Coordination Tasks** – Determine what coordination must occur between other projects, agencies, facilities, and events. This input may require additional

modeling to quantify impacts, such as when work is to occur on an arterial that contains mass transit.

- **Determine Study Network** – Determine the limits of the study network. The network boundary should be able to accommodate queues under the worst scenario, including the work zone conditions. The network also should include potential detour routes, both signed and unsigned.
- **Determine Analysis Time Period** – Determine the analysis time period. If needed, create different time-of-day models, such as a.m. peak, off-peak, and p.m. peak. For longer duration work zones, it is recommended that interim analysis be performed to better reflect varying capacities, if resources and data are available. Each analysis period should be long enough to include no queue at the beginning, queue buildup, and queue dissipation at the end of the analysis period.
- **Confirm Analysis Method** – Verify that the analysis tool(s) selected have sufficient capabilities to satisfy the analysis needs with regards to work zone characteristics, transportation management plan, data, resources, and performance measures.
- **Select MOEs and Thresholds** – The MOEs or thresholds selected will be customized to the agency's goals and project characteristics. The MOEs and thresholds set a minimum performance standard that the alternatives must meet or exceed.
- **Collect and Analyze Data** – Collect data that is needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required. Data may broadly be classified into four categories: general, geometric, traffic, and construction.
- **Identify Work Zone Alternatives** – Identify potential work zone alternatives for evaluation.
- **Conduct Fatal Flaw Analysis** – Perform a fatal flaw analysis on each selected alternative to determine the viability of the alternative for further analysis.
- **Determine Work Zone Capacity** – Roadway capacity in a work zone is reduced due to a variety of factors. It is strongly recommended that local data at work zones be collected and used. Check with the appropriate stakeholder agencies as some of them may have their own guidelines on work zone capacity and related defaults. In the absence of better local data, the analyst may use the proposed defaults as the starting point and make modifications accordingly to reflect local work zone conditions.
- **Determine Initialization Period** – Simulation model runs usually start with zero vehicles on the network. Therefore, an initialization period (warm-up period), where the simulation model starts out with zero vehicles needs to be determined and used in the simulation models.
- **Develop Existing Conditions Model** – Develop an existing conditions model with the correct geometry, traffic demands, capacities, and traffic controls.
- **Check Errors** – Error checking should be performed to identify and correct the model coding errors. The error checking involves the reviews of software errors, network coding, demand data, and simulation animation.
- **Calibrate Existing Conditions Model** – Calibrate the model by adjusting a set of user-adjustable parameters in the analysis tool to better match specific local conditions.
- **Verify Network Convergence** – If dynamic assignment is used, the network convergence needs to be verified to see if it meets the appropriate convergence criteria.

- **Determine the Number of Runs** – A single simulation run cannot be expected to represent specific field conditions. It is necessary to run the model several times with different random number seeds to get the necessary output to determine mean, minimum, maximum values, and standard deviation.
- **Develop Work Zone Base Conditions Model** – Develop a work zone base conditions model by modifying the calibrated existing conditions model to represent work zone conditions.
- **Simulate Work Zone Taper** – A work zone taper is typically modeled as a "lane drop" in most microsimulation tools. A model can vary the amount of space ahead that drivers have to react to a lane drop, but the physical length of the taper cannot be specifically entered as a variable.
- **Calibrate Work Zone Base Conditions Model** – Work zone model calibration includes the calibration of both work zone capacity and performance measures.
- **Conduct Alternatives Analysis** – The alternatives analysis may involve the forecasting of the future demand and the testing of various project alternatives against the base case. The analyst needs to run the model for each alternative, review the output, compare against any performance requirements, extract relevant statistics, and perform various analyses of the results.
- **Recommend Best Alternative** – Utilizing a decision framework, the best overall alternative is selected.
- **Document Findings** – The analytical results are summarized in a final report and the analytical approaches are documented in a technical document.

5.0 ESTABLISHING AN MOTAA DECISION FRAMEWORK

This chapter will provide guidance on developing and applying an Maintenance of Traffic Alternatives Analysis (MOTAA) decision framework. The chapter is organized as follows:

- The first section will provide an overview of the decision-making process within a work zone MOTAA. It also will describe the factors that shape the decision-making process, as well as the traditional decision-making frameworks often applied in work zone traffic analysis.
- The second section will highlight several analysis methodologies that can aid in the prioritization of criteria, and factors and/or thresholds used to evaluate and compare work zone alternatives.
- The third section will present evaluation methodologies that aid decision-makers in identifying the optimum alternative or combination of strategies that will best fit the project.
- The fourth section will highlight several decision-making tools that help automate the analysis needed to choose among different work zone alternatives.

5.1 OVERVIEW OF AN MOTAA DECISION FRAMEWORK

The Decision Framework within an MOTAA Process

The MOTAA decision-making methods and evaluation framework are typically applied after the agency has developed their set of potential work zone alternatives. The alternatives are generated during the planning process after the agency has established its set of goals and objectives. The list of alternatives is further refined once the agency has narrowed down the alternatives to only those feasible, either through a fatal flaw or other type of analysis. The decision-making process then occurs after the agency has evaluated the performance of the project, along with their potential alternatives using a selected analysis tool. After the modeling analysis, a set of performance measures and other factors, such as those described in Chapter 6, will be used to form the criteria that determine how well the alternative meets the goals and objectives of the project. How these criteria or measures are used in determining the recommended alternative will be a function of the selected decision framework.

Traditional Decision-Making Framework

While no standardized decision-making framework has been established in a typical MOTAA process, the most common decision-framework used to date typically follows rule-based reasoning. Rule-based reasoning uses **"if-then-else" rule** statements. For instance, in an MOTAA process, an "if" statement may evaluate whether an alternative meets a particular criterion. If the alternative does meet the criterion, the "then" statement may indicate that the alternative should be chosen. If the alternative does not meet the criterion, the "else" statement may specify to reject the alternative, suggest revising the alternative or choose the alternative with the least impact. An example of a typical rule-based reasoning for a hypothetical work zone scenario is illustrated in Figure 17.
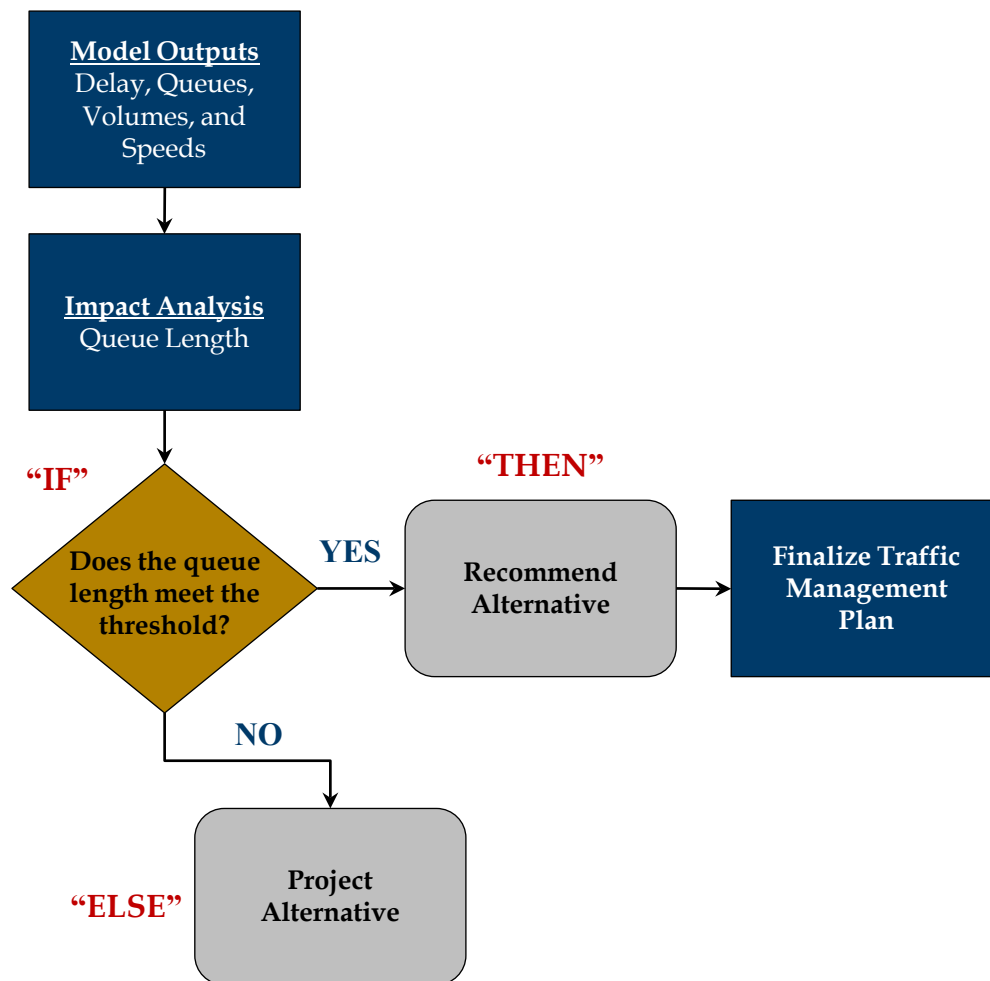
Figure 17. Example of a Traditional Decision-Framework

The traditional MOTAA decision-making process begins with the formulation of work zone alternatives – the development of different work zone configurations and strategies. Afterwards, these alternatives are analyzed based on performance measures or standards set by the agency. If the alternatives do not meet the standards, they will either be revised or replaced by other alternatives that comply with the set performance measures. The alternative that best meets the standard(s) or has the least negative impacts is selected.

Decision Methodologies

In the typical decision frameworks, the decision criterion used is often dependent upon one type of measure – a mobility, safety, or cost measure. While this method may address one of the objectives of the project, it does not account for a multidimensional way of comparing alternatives. The methodologies discussed in this section present additional analysis methods and tools that account for how multiple factors can form a criteria for evaluating and choosing among alternatives. The following decision-making frameworks serve as potential options for an

agency to consider. However, in some cases, an agency may be required to follow a standard approach established by their organization.

In these types of decision-making frameworks, there are often two levels of analysis. The first level typically applies **factor prioritization analysis methods**. These analysis methods can **prioritize and/or assign weights to the factors that are used to compare and evaluate potential work zone alternatives**. The second level of analysis typically employs **scoring and/or evaluation matrices** for recommending an alternative(s). These methodologies **provide the structure for the decision framework**. They determine how the prioritized and/or weighted criterion determined in the factor prioritization procedures can be used to evaluate and choose among the alternatives.

Below is an overview of the **factor prioritization methodologies** featured in this chapter. Further information, including example work zone applications of such methodologies, is provided in Section 5.2.

- **Delphi Method** – This method offers a methodology for identifying and prioritizing factors or criteria through surveying a panel of experts, who then works towards reaching a consensus on the priority of the factors based on their level of importance to the project.
- **Factor Analysis** – This analysis is a general scientific method for analyzing data by uncovering order, patterns, and regularity in the data.[30] The overview focuses on its use for prioritizing and weighting criteria.
- **Ranking Analysis** – The ranking method calculates normalized criteria weights based on how a panel of surveyed or polled participants ranks the factors based on their level of importance.
- **Ratio Analysis** – The analysis calculates normalized criteria weights based on surveyed participants' responses on how criteria elements measure up against each other.
- **Paired Comparison Analysis** – In a paired comparison analysis, criteria are compared against each other one pair at a time. A criterion's score or weight is based on the number of times it is preferred over others.
- **100-Point Distribution** – In a 100-point distribution, criteria weights are decided based on how an individual or group distributes 100 points amongst the factors/criteria.

An overview of the **work zone alternatives evaluation frameworks** featured in this chapter are listed below. The factor prioritization methodologies previously identified are often incorporated within these evaluation frameworks to guide how the factors or criteria are used in recommending an alternative(s). Further information on how to apply these methodologies within an MOTAA decision framework is provided in Section 5.3.

- **Multi-Criteria Decision-Making Models (MCDM)** – Mathematical methodologies that evaluate and compare the utility or relevancy of alternatives to the project goals and objectives. There are two MCDM techniques: **Simple Additive Weighting (SAW)** and **Analytical Hierarchy Process (AHP)**, which are featured in this chapter.

- **Kepner Tregoe (KT) Method** – Decision-making that features a step-by-step approach, evaluating each alternative by its impacts, risks, and opportunities.
- **Benefit/Cost Analysis** – This compares the sum of all costs with the sum of all benefits associated with an alternative. The benefit/cost ratio can be used to compare alternatives.

Choosing a Decision-Making Framework

There are several general considerations an agency should consider in determining the framework or analysis method best suited for choosing among different work zone alternatives. Sections 5.2 and 5.3 discuss these considerations in further details, as well as addressing many of the methodologies' limitations and strengths. Some of these considerations include the following:

- **Level of Data Collection Effort** – Several of the methodologies may require gathering data from case studies, extracting performance measures from the analysis tools, or polling/surveying people in order to develop the criteria for choosing amongst alternatives. The agency needs to be aware of the data collection effort needed to conduct a particular decision-making methodology.
- **The Complexity of the Analysis** – The analysis methodology may range from simple to more complex mathematical models. The agency must take into consideration whether or not they have the appropriate tools or expertise to perform a particular decision-making methodology.
- **Time** – Some of the methods are more time-consuming than others. An agency should choose the methodology that best fits their time line.
- **Project Complexity** – The complexity of the project may impact which methodology is best suited for the agency. Since some methodologies may be more resource intensive than others, it may not make sense to use highly complex decision-making frameworks for simple, short-term projects.

5.2 APPROACHES TO FACTOR PRIORITIZATION

This section provides further detail on the use of the factor prioritization methodologies for an MOTAA application. As previously mentioned, **analysis methods can aid agencies in prioritizing their selected factors by level of importance to the project, as well as in creating weighted criteria**. The weighted factors can then be integrated into a weighting/scoring method to choose among alternatives.

At this stage in the process, the agency should have a list of factors, both quantitative and qualitative, that have relevancy to the project characteristics, goals, and objectives. These factors should indicate how well the alternative can meet the goals and objectives established by the agency for the work zone project. Some example criteria include level of delay at the work zone, average speeds, accident rates, and the work zone alternative's impacts to operating and maintenance costs.

Various methodologies are described below and each is structured to contain the following:

- An overview of the approach;
- Pros and cons of the methodology; and
- An example application.

A summary table (Table 37) highlights the particular features and capabilities of these methodologies, their strengths, and weaknesses.

Table 37. Factor Prioritization Methodologies Summary

Methods/ Considerations	Project Complexity Suited For	Analysis Complexity	Level of Data Needs	Development Time	Analysis Time	Potential for Bias/ Conflict
Delphi	Medium-High ●	⊘	●	●	●	⊘
Factor Analysis	Medium-High ●	●	●	⊘	⊘	○
Ranking	Low-Medium ⊘	○	⊘	⊘	○	⊘
Ratio	Low-Medium ⊘	○	⊘	⊘	○	⊘
Paired Comparison Analysis	Low ○	○	⊘	○	○	●
100-Point Distribution	Low ○	○	○	○	○	●

○ Low　　⊘ Medium　　● High

The Delphi Method

Approach Overview

The Delphi Method offers a methodology for identifying the factors or criteria that can be used to screen alternatives. The steps for applying the Delphi Method are:

- **Step 1 –** The careful selection of panel experts from disciplines most relevant to the project and its goals and objectives.
- **Step 2 –** Distribute questionnaires that will narrow down the attributes, and determine the level of importance and average utility values of each of the attributes. A factor prioritization method can be used to determine the level of significance of each attribute using the survey results.
- **Step 3 –** Repeat Step 2 as necessary.
- **Step 4 –** After all rounds of the questionnaire have been completed, the end result is a set of weighted attributes to be used in ranking the alternatives.

The duration of this approach, including the number of questionnaire rounds and the number of experts comprising the panel, is dependent on available resources and other project characteristics. Table 38 lists some general pros and cons of the Delphi Method.

Table 38. Pros and Cons of the Delphi Method

Pros	Cons
• Finds consensus among differing opinions • Less biased • Allows participants to be anonymous • Well selected expert panel can provide broad analytical perspectives on impacts • Flexibility and applicability to various issues	• Judgments are still made by a select group and not necessarily representative • Technique can be time-consuming

Example Application

The following presents a hypothetical case study for the application of the Delphi Method in MOTAA. For ease of presentation of this technique, the example focuses on the analysis of two broad project goals – improvement of standard construction strategies/methodologies and minimizing traffic, environmental, and economic impacts.

The agency in this case has developed potential alternatives. Additionally, they have developed a list of potential factors, labeled "objectives" that can be used to screen the alternatives. In order to determine which factors have the most significance to the project goals, the agency applies the Delphi Method (see Table 39 for Delphi structure) through the following steps:

- **Step 1 –** The agency assembles an expert panel. The panel participants in this case should have experience in work zone management, traffic management, and/or work zone relevant research and have an understanding of the agency's goals.
- **Step 2 –** The agency assembles the first round of three questionnaires. This first round asks the panel to list five objectives that are of relevance to the project and its goals. After the results from the first round are turned in, the evaluator(s) can choose to reduce the list in preparation for the next round.
- **Step 3 –** In the second round of questionnaires, the panel is asked to rank the refined list of objectives by desirability and importance to the project. Table 40 lists the reference scale and definitions for desirability and importance. In this example, the higher the value, the more desirable or important the objective is to the project. After the panel responses for the second round have been turned in, the evaluator(s) can then average the group scores for both desirability and importance. Table 41 shows example results.
- **Step 4 –** The evaluator determines a threshold for narrowing down the list of objectives. In this example, objectives that scored lower than 3.0 for either importance or desirability was eliminated for the next round. Objective that are bold in Table 41 were eliminated in the third round.
- **Step 5 –** For the third round, the evaluator revises the motivations for the questionnaire. The panel participants are again asked to rank the objectives by level of desirability and importance. However, in this round they rank the objectives according to specified categories such as project management, safety, mobility, and environmental impacts as shown in Table 42.
- **Step 6 –** After the responses from the third round have been collected, the evaluator can then create a weighting scale based on the results. In Table 42, the evaluator determined the weights by calculating the objective's score as a percentage of the total score for that category.

Table 39. Delphi Technique Example

	Round 1 – Generating List of Objectives	Round 2 – Desirability and Importance Rating	Round 3 – Final Ratings
Goals: Improve standard construction strategies and methodologies; minimize traffic, environmental, and economic impacts			
Database for Questionnaire	Panel feedback	Panel feedback	Panel feedback
Duration	1-3 weeks	1-3 weeks	1-3 weeks
Number of Experts	5-30	5-30	5-30
Findings	Panel respondents list five objectives most relevant to project goals.	Rating the narrowed down objectives by desirability and importance.	Narrowed down objectives will be organized into specific categories.
Analysis of Findings	List of potential objectives. Evaluator may choose to reduce the number of objectives considered for the next round.	Determine average desirability and importance score by averaging panel response. Narrow down to highest scoring.	The refined list of objectives will be re-rated based on how they fit/address the specific categories.

Table 40. Delphi Example Scale Reference

Score	Importance	Definition	Desirability	Definition
1	Most Unimportant	No relevance; no priority	Highly undesirable	No benefit
2	Unimportant	Insignificantly relevant; low priority	Undesirable	Costs or negative effects outweigh benefits/positives
3	Moderately Important	May be relevant to project goals; third order priority	Neither desirable or undesirable	Equal benefits and costs
4	Important	Is relevant to the project goals; second order priority	Desirable	Positive effect with minimum negative effects or costs
5	Very important	Most relevant to project goals; first order priority	Highly desirable	Positive effect or little to no negative effects or costs

Table 41. Delphi Example – Round 2 Questionnaire

Objectives	Group Score Average	
	Desirability	Importance
Reduce construction duration	3.56	3.89
Improve standard construction operations	**2.71**	**2.66**
Optimal use of resources	4.23	3.98
Reduce capital costs	4.58	4.88
Reduce operations and maintenance cost over life of project	4.78	4.88
Reduction/improvement over typical work zone delay	4.88	4.93
Reduce incident rate	4.55	4.72
Improve travel information dissemination	**2.51**	**2.5**
Maintain peak-period congestion to preconstruction level	3.11	3.47
Reduce typical/expected work zone area queue length	3.9	3.82
Air Quality	**2.03**	**2.33**
Noise pollution reduction	3.78	3.81
Fuel consumption reduction	**1.43**	**1.23**
Reduce impacts to local businesses	3.67	3.61
Reduce impacts to neighborhoods	3.91	3.83
Lengthen life of structures	**2.87**	**2.65**
Reduce current work zone accident rate (construction workers)	**2.13**	**2.22**
Reduce accident severity	4.07	4.19

Table 42. Delphi Example – Round 3

	Desirability	Weight	Feasibility	Weight
Project Management Efficiency				
Reduce construction duration	4.89	29%	4.65	28%
Optimal use of resources	4.1	24%	4.21	26%
Reduce capital costs	3.97	24%	3.85	23%
Reduce operations and maintenance cost over life of project	3.88	23%	3.78	23%
Subtotal	16.84	100%	16.49	100%
Traffic Condition and Performance				
Reduction/improvement over typical work zone delay	4.23	36%	4.17	36%
Maintain peak-period congestion to preconstruction level	3.67	31%	3.59	31%
Reduce typical/expected work zone area queue length	3.84	33%	3.89	33%
Subtotal	11.74	100%	11.65	100%
Environmental/Community				
Noise pollution reduction	4.23	36%	4.17	36%
Reduce impacts to local businesses	3.67	31%	3.59	31%
Reduce impacts to neighborhoods	3.84	33%	3.89	33%
Subtotal	11.74	100%	11.65	100%
Safety				
Reduce incident rate	4.68	55%	4.71	55%
Reduce accident severity	3.89	45%	3.78	45%
Subtotal	8.57	100%	8.49	100%

Findings from the final round will enable the evaluator(s) to identify the optimum list of factors that should be used to screen the work zone alternatives. It also will guide the evaluator(s) into determining weights that could be assigned to each factor.

Factor Analysis

Approach Overview

Factor analysis is a **statistical approach that can be used to analyze interrelationships among variables** and to explain these variables in terms of their common underlying dimensions, also known as factors. Factor analysis has several applications. For the purpose of factor prioritization, factor analysis can be used for the following:

- **Determine Factor Groupings –** Factor analysis can be used to determine groups/categories amongst potential criteria elements. For example, delay reductions, queue lengths, and throughput are interrelated through a factor grouping that could be called "Traffic Performance Indicators."
- **Consolidate Factors –** Factor analysis can be used to identify the criteria elements that may be insignificant in terms of importance to the project. It also can identify those factors that may be redundant.
- **Prioritization Based on Level of Importance –** Factor analysis results can determine the level of significance or importance of each criteria element or variable.
- **Generate Factor Scores –** Factor analysis can be used to generate factor scores to compare and select the recommended alternative.

Two types of factor analysis include:[31]

1. **Exploratory factor analysis (EFA)** attempts to discover the nature of the constructs influencing a set of responses; and
2. **Confirmatory factor analysis (CFA)** tests whether a specified set of constructs are influencing responses in a predicted way.

EFA is better for determining the number of common factors influencing a set of measures as well as for determining the strength of the relationship between the factor and variables. CFA is primarily used to determine the ability of a predetermined factor model to fit an observed set of data. Therefore, the EFA method is better for determining a weighting scale for different variables.

The following provides an overview of the basic steps involved in applying the EFA. However, for more information on the application of factor analysis, there is a major resource in the field of multivariate statistical analysis.[32] In addition, several of the steps in an EFA can be more easily applied using statistical software such as SAS or SPSS. For information on using SAS for factor analysis applications, one helpful resource is by Hatcher (1994).[33]

The following lists the steps typically involved in an EFA:

1. **Conduct Data Collection –** Determine the variables or measures to include from a factor analysis. Data collection can come from case studies and best practices, as well as variables determined by a panel of experts, surveys, and questionnaires.
2. **Generate the Correlation Matrix –** Generates the correlations between variables (or criteria elements).
3. **Select the Number of Factors for Inclusion –** Determine the optimal number of factors to include using various methods that may use eigenvalue thresholds to determine which factors to include or exclude.
4. **Extract Initial Factor Solution –** Various methods can be used, though this is typically done through a statistical program.
5. **Conduct Rotation –** There are two major categories of rotations, orthogonal rotations, which produce uncorrelated factors, and oblique rotations, which produce correlated factors. One of the more common orthogonal rotations is Varimax.
6. **Extract Factor Matrix and Interpret Results –** A factor matrix is produced after the rotation step. This matrix presents values called factor loadings that indicate the strength of interrelatedness or relationships between the various factors. At this stage, the analyst can identify or define the factor groupings. They also can eliminate variables that do not meet a factor loading threshold, since this can indicate their lack of relationship to the other criteria elements.
7. **Construct Scales or Factor Scores to Use in Further Analysis –** There are several methods that can be applied to generate factor scores that vary in levels of complexity. Many come standard in statistical software such as SAS or SPSS and utilize the more complex methods such as regression, Bartlett, and Anderson-Rubin methods.[34]

Table 43. Pros and Cons of Factor Analysis

Pros	Cons
• Can reduce the number of variables/attributes used for screening to those most relevant • Can be both objective and subjective • Can identify how variables are related to each other • Identify additional insight into the variables and their impacts that may not be apparent with other factor prioritization methodologies	• The utility of the analysis tool depends on the evaluators ability to collect sufficient data on the attributes • The analysis may require more statistical knowledge or background

Example Application

In this example, an agency wants to refine the criteria elements that will form the basis of their work zone alternative decision framework. They follow the typical steps of an EFA using statistical software to run the factor analysis.

- **Step 1 –** The agency conducts a review of work zone literature, best practices, and case study results to develop a set of considerations and impacts relevant to their work zone project. For the purpose of this example, this initial set of considerations will be termed as the potential variables, shown on Table 44.

Table 44. List of Potential Variables

Potential Variables
• Reduce construction duration
• Improve construction operations
• Optimal use of resources
• Reduce costs
• Improve public image
• Reduce work zone delay
• Reduce incidents
• Improve travel information dissemination
• Reduce peak-period congestion
• Reduce queue length
• Air quality
• Noise pollution reduction
• Fuel consumption reduction
• Increase enforcement
• Reduce crash severity

- **Step 2 –** In order to narrow down the list of potential variables, the agency can administer a questionnaire internally and to stakeholders to rate the variables using a 1 through 5 scale, where 1 is "not important" and 5 is "most important" to the project. At this step, the agency also can eliminate the variables consistently deemed not important.
- **Step 3 –** Using the preferred software, the agency can run a factor analysis (using Steps 2 to 5 of the EFA methodology listed above) using the data collected in order to extract the primary variables to be used for the criteria. At the end of this analysis, the agency will

have developed a factor matrix such as the example shown in Table 45. The factor matrix determines the strength of the relationships amongst variables.

Table 45. Example Factor Matrix

Potential Variables	Factor 1	Factor 2	Factor 3	Factor 4
Reduce construction duration	0.888	0.245	0.132	0.103
Improve construction operations	0.957	0.143	0.007	0.112
Optimal use of resources	0.812	0.008	0.002	0.003
Reduce costs	0.755	0.005	0.001	0.002
Improve public image	0.004	0.003	0.002	0.012
Reduce work zone delay	0.071	0.915	0.231	0.089
Reduce incidents	0.009	0.771	0.005	0.979
Improve travel information dissemination	0.312	0.689	0.009	0.785
Reduce peak-period congestion	0.0813	0.876	0.34	0.321
Reduce queue length	0.0789	0.898	0.312	0.348
Air quality	0.002	0.001	0.889	0.004
Noise pollution reduction	0.001	0.001	0.651	0.009
Fuel consumption reduction	0.001	0.001	0.876	0.01
Increase enforcement	0.012	0.562	0.005	0.779
Reduce crash severity	0.001	0.387	0.002	0.985

- **Step 4 –** The agency interprets the results from the factor matrix. They decide that the variables within the set of factors with loadings greater than 0.5 can be grouped. Based on this exercise, the agency was able to define the factors due to the similarities between the variables contained within the group. In the example in Table 45, Factor 1 could be called "Project Management and Efficiency" as the variables interrelated (scoring above 0.5) seem to be benefits regarding construction or project management. Factor 2 can be defined as "Traffic Condition and Performance" and Factor 3 can be defined as "Environmental." In addition, note that the variable "Improves public image" will be eliminated because it did not have loadings greater than 0.5 across the factors.
- **Step 5 –** The agency can then decide to generate factor scores to develop a scale or weights, as shown in Table 46. The agency can use the regression method standard to their statistical software package. In the regression method, each variable is weighted proportionally to its involvement in a pattern. Therefore, the more involved or more relevant a variable, the higher the weight. The factor scores can be interpreted to mean that the particular case has a major impact on the factors the farther away they are from zero. The sign indicates whether it is a positive or a negative impact. The closer to zero indicates that the strategy has little relevance or less of an impact on the factor and vice versa. These scores are standardized, which means they have been scaled to have a mean of zero and the values lie between +1.00 and -1.00.

An example is shown in Table 46. In this example, the analyst can use the factor scores as part of a weighting or scaling technique. It can be assumed that through the agency's literature review and/or modeling analysis efforts they would gather data for each alternative that addresses the variables listed. The analyst can then multiply those data values by the associated variable factor scores and sum those for each of the factors: Project Management Efficiency; Traffic Condition and Performance; and Environmental. Using their weighting/scaling

technique, the agency can then select the recommended alternative based on the final scores from the three factors.

Table 46. Example Factor Scores

Priority Variables	Project Management Efficiency	Traffic Condition and Performance	Environmental	Safety
Reduce construction duration	1.879	0.075	0.011	0.013
Improve construction operations	1.741	0.019	0.013	0.013
Optimal use of resources	1.782	-1.101	0.003	-0.954
Reduce costs	1.825	-1.001	-0.907	-1.455
Reduce work zone delay	0.092	1.311	0.004	0.098
Reduce incidents	-1.492	0.965	-0.791	1.679
Improve travel information dissemination	-1.482	0.765	-0.781	1.098
Reduce peak-period congestion	-0.007	1.13	0.023	0.054
Reduce queue length	-0.012	1.542	0.042	0.044
Air quality	-1.281	-1.733	0.812	-1.329
Noise pollution reduction	-0.619	-1.277	0.829	-1.278
Fuel consumption reduction	-0.101	-0.761	0.801	-1.341
Increase enforcement	-1.248	0.049	-0.021	1.763
Reduce crash severity	-1.112	0.038	-0.091	1.589

Ranking System

Approach Overview

In the ranking system, the decision-maker(s) rank the criteria by level of importance. The ranking is then used to calculate the weights using the following formula:[35]

$$W_i = \frac{n - r_i + 1}{\sum_{i=1}^{n}(n - r_i + 1)}$$
(2)

Where:

W_i = Normalized weighting for the ith criterion;
r_i = Ranking score for the ith criterion; and
n = Number of decision criteria.

Table 47. Pros and Cons of the Ranking System

Pros	Cons
• Simple and comprehensible for technical analysts, planners, and policy-makers. • Weighting scales are flexible and easy to adapt or change based on the goals, objectives, and the performance measures of the project. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds.	• Because methodology may require polling a group for their rankings. Obtaining survey results could be time-consuming. • Rankings are subjective and are not necessarily required to be justifiable based on field data, literature, case studies, etc.

Example Application

A combined example for ranking analysis, ratio analysis, paired comparison, and 100-point distribution is provided towards the end of this section.

Ratio System

Approach Overview

With the ratio system, decision-makers assign scores to criteria based on how they rate in importance relative to other criteria. For instance, decision-makers can give a score of 1 to the least important criterion. All other criteria are given greater scores relative to their level of importance in comparison to the least important criterion. Normalized importance weighting for each criterion can be calculated using the following formula:[36]

$$W_i = \frac{z_i}{\sum_{i=1}^{n} z_i}$$ (3)

Where:
   W_i = Normalized weighting for the ith criterion;
   Z_i = Weight score assigned to the ith criterion; and
   n = Number of decision criteria.

Table 48. Pros and Cons of the Ratio System

Pros	Cons
• Simple and comprehensible for technical analysts, planners, and policy-makers. • Weighting scales are flexible and easy to adapt or change based on the goals, objectives, and the performance measures of the project. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds.	• Because methodology may require polling a group for their rankings. Obtaining survey results could be time-consuming. • Results are subjective since choosing the least desirable options is not necessarily required to be justifiable based on field data, literature, case studies, etc. • Limited comparability since ratios are based primarily on what is considered the least desirable/important option.

Example Application

A combined example for ranking analysis, ratio analysis, paired comparison, and 100-point distribution is provided towards the end of this section.

Paired Comparison Analysis

Approach Overview

In a paired comparison analysis, a range of options are compared to each other, determining the preferred option in each case. When comparing two options for instance, the option that is preferred could be given 2 points, while the other option receives 0 points. If both options are equally preferred, then both receive 1 point. After all options have been considered and compared by the individual or group polled, the scores are tallied. The option with the highest score is considered the preferred option or ranked first priority. In the example shown in Table 49, there are three options to choose from. After polling a group, the results show that Option C scored the highest with 4 points. Option B is in second place, and Option A is the least preferred of the options.

Table 49. Example of a Paired Comparison Analysis

Option	Option			
	A	B	C	Total Score
A	–	–	–	0 points
B	B (2)	–	–	2 points
C	C (2)	C (2)	–	4 points

Table 50. Pros and Cons of the Paired Comparison Analysis

Pros	Cons
• Simple and comprehensible for technical analysts, planners, and policy-makers. • Weighting scales are flexible and easy to adapt or change based on the goals, objectives, and the performance measures of the project. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds.	• Because methodology may require polling a group for their rankings. Obtaining survey results could be time-consuming. • Assigning the weights are subjective and is not necessarily required to be justifiable based on field data, market research, expert panels, recorded observations, etc. • Limited comparability since scores are based on two options at a time.

Example Application

A combined example for ranking analysis, ratio analysis, paired comparison, and 100-point distribution is provided towards the end of this section.

100-Point System

Approach Overview

The 100-point system is a method where a total of 100 points is distributed amongst the attributes or factors. The distribution of the 100 points can be determined by an individual, through group consensus, or through a ranking system. Decision-makers can choose to distribute the points equally amongst the criteria or by level of importance.

Table 51. Pros and Cons of the 100-Point Distribution

Pros	Cons
• Simple and comprehensible for technical analysts, planners, and policy-makers. • Weighting scales are flexible and easy to adapt or change based on the goals, objectives, and the performance measures of the project. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds.	• Depending on the methodology, establishing the criteria weights may require a group consensus or polling a group of people for their opinions. Obtaining group consensus and/or obtaining survey results could be time-consuming. • Assigning the weights are subjective and is not necessarily required to be justifiable based on field data, market research, expert panels, recorded observations, etc. • Rater may be biased.

Example Application for Ranking, Ratio, Paired Comparison, and 100-Point Distribution

For this particular example, the same criteria will be prioritized and assigned weights using four methods: Ranking, Ratio, Paired Comparison, and 100-point distribution. The examples shown serve to highlight the methodologies. The values and criteria weights resulting from the example are illustrative only, and it is recommended that agencies utilize the methodologies presented to develop project-specific values.

- **Step 1 –** The first step is the same regardless of the analysis method selected to develop the weighted-criteria. During this step, the evaluator(s) must determine the set of performance measures that will be used, such as queue length impacts, delay, travel time, and speeds.
- **Step 2 –** The evaluator then takes the set of criteria and applies a selected methodology to determine criteria weights:
  - **Ranking Method –** A group selected by the evaluator were asked to rank the criteria elements on a scale of 1 to 5, where 1 is considered most important and 5 as least important. Criteria weights were assigned using the equation for the ranking method. The results are shown in Table 52. As shown, Capital and Operations and Maintenance Cost (Capital and O&M) is the highest weighted criteria, while Project Duration is assigned the lowest weight.

Table 52. Assigning Criteria Weights – Ranking Method

Criteria	Rank	n-r(i)+1	Weight
Speed Reduction Potentials	2	4	0.27
Capital and O&M Costs	1	5	0.33
Queue Length	3	3	0.20
Travel Times	4	2	0.13
Project Duration	5	1	0.07
Total		**15**	**1.00**

- **Ratio Method –** Similar to the ranking method, the evaluator chooses a group of participants to compare the criteria elements against each other. In this situation, the evaluator considered the Project Duration criterion as least important and assigned it a value of "1." The evaluator then asks the participants to determine how much greater the other criteria are in comparison to Project Duration. From their responses, the

evaluator determines the ratio scores. The example ratio scores are shown in Table 53. Criteria weights were assigned using the equation for the ratio method. As shown, Capital and O&M Costs is the highest weighted criteria while Project Duration is assigned the lowest weight.

Table 53. Assigning Criteria Weights – Ratio Method

Criteria	Ratio Score	Weight
Speed Reduction Potentials	1.75	0.23
Capital and O&M Costs	2	0.27
Queue Length	1.5	0.20
Travel Times	1.25	0.17
Project Duration	1	0.13
Total	**7.5**	**1.00**

- **Paired Comparison Analysis –** In this analysis methodology, the evaluator assembles a group of survey participants. The evaluator asks the participants to compare pairs of criteria elements. For each pair comparison, the participants are asked to note which of the two is considered most important or equally important. After all the results were turned in, the scores were tallied for each criteria element. Table 54 shows the results from the poll. As shown, Capital and O&M Costs receives the highest score while Project Duration is scored the lowest.

Table 54. Assigning Criteria Weights – Paired Comparison Method

	Speed	Capital and O&M Costs	Queue Length	Travel Times	Project Duration	Scores
Speed Reduction Potentials	–	–	–	–	–	6
Capital and O&M Costs	Capital and O&M Costs (2)	–	–	–	–	8
Queue Length	Speed Reduction (2)	Capital and O&M Costs (2)	–	–	–	3
Travel Times	Speed Reduction (2)	Capital and O&M Costs (2)	Queue Length (1), Travel Times (1)	–	–	2
Project Duration	Speed Reduction Potentials (2)	Capital and O&M Costs (2)	Queue Length (2)	Project Duration (1), Travel Times (1)	–	1

- **100-Point Distribution –** The evaluator, in this situation, decides how to distribute the 100-point scale amongst the various criteria elements. Table 55 depicts a potential scenario where the 100 points are distributed so that speed, queue length, and travel time measures each receives 20, Capital and O&M Costs receives 25, and project duration receives 15.

Table 55. Assigning Criteria Weights – 100-Point Distribution

Criteria	Weight
Speed Reduction Potentials	20
Capital and O&M Costs	25
Queue Length	20
Travel Times	20
Project Duration	15

- **Step 3 –** The evaluator can then use the generated weighted criteria to evaluate and compare work zone alternatives. Methodologies and tools that can be used to compare work zone alternatives are discussed further in Section 5.3.

5.3 WEIGHTING/SCORING TECHNIQUES

This section provides information on specific methodologies and tools that aid an agency in choosing among work zone alternatives. At this stage, the agency should have established a set of prioritized and weighted criteria to use for screening alternatives using the factor prioritization tools as detailed in Section 5.2. Many decision-making frameworks use weighted criteria to score alternatives. Alternatives are then compared and selected based on these scores. These Weighting/Scoring techniques are most commonly used to compare and choose amongst alternatives. This section highlights a few of these methods.

There are additional tools that have been created by researchers and developers that either automate a weighting/scoring technique or utilize a unique methodology for comparing alternatives. Several of these tools are given mention in Section 5.4. Ultimately, the evaluation frameworks and tools discussed in this and the following section can aid decision-makers in choosing an alternative or combination of alternatives that best meet their criteria.

This following is structured to provide information on the methodologies and tools and their applications for an MOTAA, including:

- Overview of the methodology/tool, including application steps;
- Additional considerations, including pros and cons; and
- Example work zone application of methodology or tool.

Overview

There are a variety of different weighting/scoring methods that can be applied in a work zone MOTAA process. Most take a common structure such as that depicted in Figure 18. Where the approaches tend to differ is in the establishment of criteria weights and how those weights are used to choose a recommended alternative. Some of the most common approaches in these weighting/scoring techniques are based in **Multi-Criteria Decision-Making Models (MCDM)**. Using mathematical methodologies that assign weight to criteria, MCDM models enable analysts to **evaluate and compare the utility or relevancy of criteria or factors to a problem.** There are a variety of MCDM models that can be applied for work zone MOTAA. The more common MCDM models used for various decision-making applications include weighted sum model,

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weighted product model, analytical hierarchy process, ELECTRE, and TOPSIS. For the purpose of this guide, two MCDM models will be discussed in further detail. The two models are the weighted sum model or simple additive weighting and analytical hierarchy process (AHP). The weighted sum is typically deemed the simplest of the MCDM models and AHP is one of the most commonly used MCDM models for decision-making.

Additional weighting or scoring techniques that can be applied for evaluating alternatives include Kepner-Tregoe Method and Benefit/Cost Analysis. Kepner-Tregoe Decision Methodology can be used for gathering, prioritizing and evaluating information. It also incorporates ranking and scoring within its decision-making framework. Benefit/cost analysis is an economic decision-making approach that weighs and values an alternative's expected benefits and costs. A benefit/cost analysis can generate Benefit/Cost ratios (B/C ratios) that can be used to compare and choose amongst alternatives.
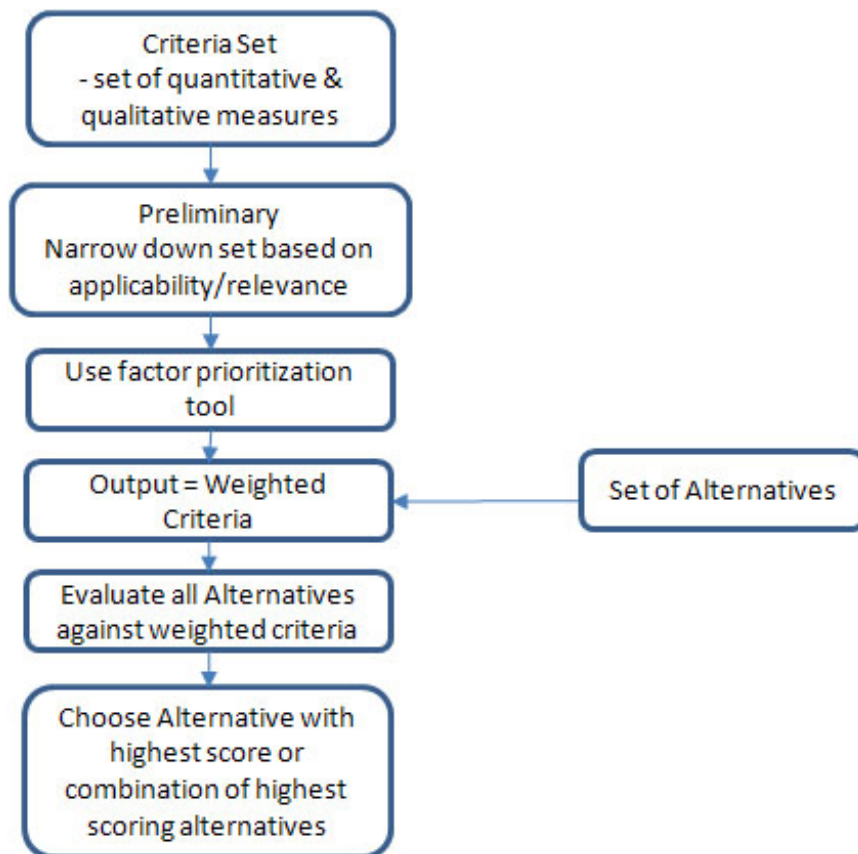
Figure 18. Weighting/Scoring Technique Framework

Table 56 summarizes the various features and capabilities of the different weighting and scoring techniques. More details on each tool can be found in the subsections that follow.

Table 56. Evaluation Tools and Methods for Comparing Alternatives

Methods/ Considerations	Project Complexity Suited For	Analysis Complexity	Level of Data Needs	Development Time	Analysis Time	Number of Criteria Elements
Traditional	Low-Medium ○	○	⊘	○	○	○
Simple Additive Weighting (SAW)	Low-Medium ○	○	⊘	○	⊘	⊘
Analytical Hierarchy Process	Medium-High ⊘	●	⊘	⊘	●	●
Kepner Tregoe Method	Medium-High ⊘	●	●	●	●	●
Benefit/Cost	Medium-High ⊘	⊘	●	●	⊘	●

○ Low   ⊘ Medium   ● High

MCDM Models – Weighted Sum Method or Simple Additive Weighting (SAW)

The weighted sum method is commonly deemed as the more simple of the MCDM models. The weighted sum states that if there are m alternatives and n criteria, an alternative's score is determined using the following equation:

$$S_i = \sum_{j=1}^{n} a_{ij} w_j \qquad\qquad\qquad (4)$$

Where:
    S_i = The SAW score of the alternative;
    a_{ij} = The ith alternative's score for the jth criterion; and
    w_j = The weight of the jth criterion.

In this method, the decision-maker must accomplish two tasks prior to applying SAW. The first is to determine the criteria weights and the other is to develop a way to obtain each alternative's relevancy scores. Once these two tasks have been completed, the decision-maker can apply the SAW equation to each alternative to calculate their weighted scores. The alternative that scores the highest is typically recommended.

Example Application of SAW

To evaluate and choose amongst a set of work zone alternatives using the SAW method, the decision-maker can take the following steps:

- **Step 1** – The evaluator or analyst decides to use the weighted criteria using the ranking method (see Section 5.2).
- **Step 2** – The analyst assembles a panel of decision-makers that will score the alternatives based on how well they meet the criteria elements. The evaluator asks them to score the alternatives (e.g., such as the scale shown in Table 57).
- **Step 3** – The analyst averages the scores for each alternative by criterion. The SAW equation is applied to determine the final weighted score for each alternative. The final scores are shown in Table 58. In this example, Alternative 2 scores the highest and is recommended.

Table 57. Example Score for Alternatives

Scale for Scores	
Most Effective	30
Mediocre	20
Not Effective	10

Table 58. SAW Example

Alternative	Criteria and Weights					
	Speed Reduction Potentials 0.27	Capital and O&M Costs 0.33	Queue Length 0.20	Travel Times 0.13	Project Duration 0.07	Score
1	25	20	15	30	15	21.30
2	10	30	20	30	30	22.60
3	30	10	30	10	10	19.40

Table 59. Pros and Cons of SAW

Pros	Cons
• Simple analysis. • Applicable to various problems. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds.	• Requires polling a group of people for their opinion on ranking or score, which could be time-consuming. • Assigning of rankings/scores are subjective and are not necessarily required to be justifiable based on field data, market research, expert panels, recorded observations, etc.

MCDM Models – Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is an MCDM decision-making approach that utilizes a multiple choice criterion that is structured in a hierarchical format. It involves assessing the relative importance of the criteria (assigning criteria weights), comparing alternatives for each criterion, and determining an overall score or ranking for the alternatives.

Example Application

This example demonstrates how an AHP can be used to evaluate and choose amongst work zone alternatives. The following outlines the preliminary steps in beginning an AHP analysis:

- **Step 1 –** Determine the objective of the analysis: In this case, it is "To choose the preferred alternative amongst three potential choices."
- **Step 2 –** Define the criteria: Speed Reduction Potentials, Capital and O&M Costs, Queue Length, Travel Times, and Project Duration.
- **Step 3 –** Determine a set of alternatives. For this example, the alternatives will be labeled as: Alternatives 1, 2, and 3.
- **Step 4 –** Arrange the information in a hierarchical format (e.g., Figure 19).
- **Step 5 –** Use pairwise comparisons to determine the criteria weights. Similar to the Paired Comparison Analysis, the pairwise comparison in the AHP measures the importance of one criterion relative to another. An example is shown in Table 60.
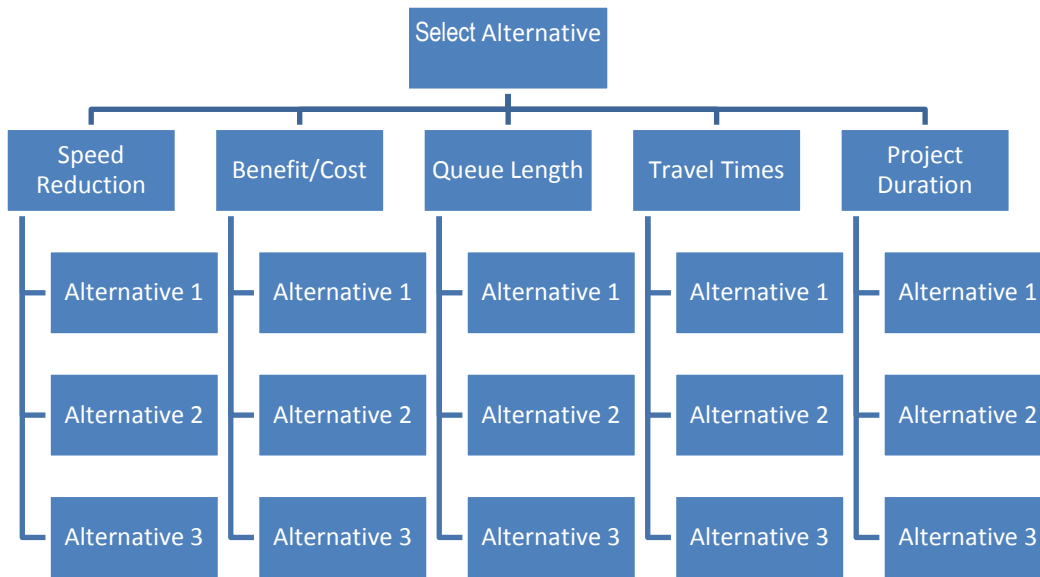
Figure 19. AHP Hierarchical Tree Example

Table 60. Pairwise Comparison Matrix

	Speed Reduction Potentials	Capital and O&M Costs	Queue Length	Travel Times	Project Duration
Speed Reduction Potentials	1/1	4/5	4/3	4/2	4/1
Capital and O&M Costs	5/4	1/1	5/3	5/2	5/1
Queue Length	3/4	3/5	1/1	3/2	3/1
Travel Times	2/4	2/5	2/3	1/1	2/1
Project Duration	1/4	1/5	1/3	1/2	1/1

- **Step 6 –** Turn the pairwise comparison matrix into a prioritization matrix using eigenvector. In order to do this, the matrix shown in Table 60 must be converted into its decimal values, as shown in Table 61.

Table 61. Pairwise Matrix in Decimal Form

	Speed Reduction Potentials	Capital and O&M Costs	Queue Length	Travel Times	Project Duration
Speed Reduction Potentials	1.00	0.80	1.33	2.00	4.00
Capital and O&M Costs	1.25	1.00	1.67	2.50	5.00
Queue Length	0.75	0.60	1.00	1.50	3.00
Travel Times	0.50	0.40	0.67	1.00	2.00
Project Duration	0.25	0.20	0.33	0.50	1.00

- **Step 7 –** Square and normalize the matrix. The matrix in Table 61 is squared to generate the new matrix shown in Table 62. The row sum and row total (sum of the row sum) are calculated. The values are normalized by dividing the row sum by the row total. The final column in Table 62 represents the eigenvector.
- **Step 8 –** Iteratively square the matrix. The matrix from Table 62 (columns Speed Reduction through Project Duration) is squared once more and a new set of eigenvectors

is generated. The analyst is recommended to go through multiple iterations of this
process until the eigenvector solution does not change from the previous iteration.

Table 62. Generating the Eigenvector

	Speed Reduction Potentials	Capital and O&M Costs	Queue Length	Travel Times	Project Duration	Total	Normalize (Row Sum/Row Total) = EIGENVECTOR
Speed Reduction Potentials	1.00	0.64	1.78	4.00	16.00	23.42	0.2909
Capital and O&M Costs	1.56	1.00	2.78	6.25	25.00	36.59	0.4545
Queue Length	0.56	0.36	1.00	2.25	9.00	13.17	0.1636
Travel Times	0.25	0.16	0.44	1.00	4.00	5.85	0.0727
Project Duration	0.06	0.04	0.11	0.25	1.00	1.46	0.0182
Total						**80.50**	**1.00**

- **Step 9 –** Check for matrix stability. After several iterations, the eigenvectors stabilize to
  the values listed in Table 63. These values represent the criteria weights.

Table 63. Criteria Rankings/Weights

	Ranking
Speed Reduction Potentials	0.2907
Capital and O&M Costs	0.4543
Queue Length	0.1634
Travel Times	0.0725
Project Duration	0.0180

- **Step 10 –** Generate the pairwise comparisons. This pairwise comparison for the
  alternatives is used to determine the preference of each alternative over the other relative
  to the criterion. Table 64 shows the pairwise comparisons for the alternative for criterion,
  Speed Reduction Potentials.

Table 64. Pairwise Comparison of Alternatives

	Speed Reduction Potential		
Alternative	Alternative 1	Alternative 2	Alternative 3
1	1.00	2.00	3.00
2	0.50	1.00	2.00
3	0.33	0.50	1.00

- **Step 11 –** Compute the eigenvector of each alternative for each criterion and select the
  preferred alternative. As shown in Table 65, to generate the final score of each
  alternative, the alternative rankings are multiplied by the criteria weights. In this
  example, Alternative 2 scores the highest and is chosen.

Table 65. AHP Final Score and Recommendation

Alternative	Speed Reduction Potentials 0.2907	Capital and O&M Costs 0.4543	Queue Length 0.1634	Travel Times 0.0725	Project Duration 0.0180	Final Score (Criteria Ranking Alternative Ranking)
1	0.3846	0.3333	0.2308	0.4286	0.2727	0.3370
2	0.1538	0.5000	0.3077	0.4286	0.5455	0.3631
3	0.4615	0.1667	0.4615	0.1429	0.1818	0.2990

Table 66. Pros and Cons of AHP

Pros	Cons
• Applicable to various problems. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds. • Checks the consistency of evaluation measures and alternatives in an effort to reduce bias.	• Requires polling a group of people for their opinion on ranking or score, which could be time-consuming. • Determining the eigenvectors, if done manually, could be time-consuming as well. • Different hierarchical structures could lead to different results. • Pairwise comparison – limited comparability. • Rank reversal – depending on how the question is framed may get different results.

Kepner-Tregoe (KT) Method

The Kepner-Tregoe decision-making methodology can be used for prioritizing and evaluating alternatives. The method features a step-by-step approach that can aid a decision-maker to choose amongst alternatives by evaluating each of their impacts, risks, and opportunities. It typically involves the following steps:

1. **Preparing the Decision Statement** – This establishes the objectives, the desired result, and the action required.
2. **Defining the Objectives** – At this step, the objectives are classified according to their relative importance as "musts" and "wants." Certain objectives will be considered mandatory and will, therefore, be considered as "musts." Those that are desirable will fit into the "wants" category.
3. **Ranking the Objectives and Assigning Relative Weights** – At this step, "wants" objectives are ranked on a 1 through 10 scale, where rank 10 is considered most important and 1 is least important.
4. **Listing Alternatives** – At this stage, a list of potential alternatives are brought into the analysis.
5. **Evaluating the Alternatives** – The alternatives are evaluated based on the "must" and "wants" objectives. The first step in evaluating the alternatives is to eliminate those that do not fit the "must" or mandatory objectives. The remaining alternatives are then scored by how they meet the "wants" objectives. The alternatives are rated against each "wants" objective on a scale of 1 through 10, where 10 means the alternative best satisfies the "want." The final score for each alternative will be a weighted value calculated by multiplying the "want" objective's weight times the alternative's satisfaction score.

6. **Choosing the Top Alternatives** – After Step 5 has been exercised for all of the alternatives, the top two or three may be considered for the next stage where the alternatives are rated against potential future adverse effects.
7. **Evaluating the Alternatives against Potential Negative Effects** – In this step, a set of potential consequences will be generated. The impact of each consequence will then be determined by evaluating the probability of it occurring and the severity of the impact should this event occur. The probability and impact scores are again determined on a 1 through 10 scale, where 10 is highest probability of occurrence or most serious degree of impact.
8. **Choosing the Preferred Alternative** – The preferred alternative will be the one that satisfies the "must" objectives, scores the highest on the "wants" objectives analysis, and provides best potential to minimize the adverse impacts.

Example Application

The following example is derived from the *Work Zone Road User Costs – Concepts and Applications.*[36]

Step 1 – Prepare Decision Statement

The KT decision analysis process begins with a precise statement of what needs to be done (i.e., the purpose or the intended result) and how it will be done (i.e., actions required). This statement provides the focus for all other steps that follow and sets the limits on the range of alternatives that would considered in the decision analysis. This statement must be defined consistent with the work zone-related agency policies and project-specific needs.

The decision statement for a hypothetical project "Pavement Reconstruction of U.S. 00" is presented as follows:

Example 1

U.S. 00 serves as a major arterial road connecting the regional industrial hub with the twin metros. The pavement has reached its useful life and needs major reconstruction. The route carries significant amounts of commuter and truck traffic. The alternative routes for the detour have limited lane capacity and can accommodate only a portion of the work zone traffic volume.

Decision Statement

The purpose of the decision analysis is to identify the most appropriate strategy for maintaining traffic on U.S. 00 during the reconstruction of the pavement segments between Mileposts 100 and 105.

Step 2 – Define Objectives

The objectives are the decision criteria that describe the required and desired attributes of the resulting choice, and the explicit limits imposed on the decision process. The objectives include:

- **MUSTS** – These are the mandatory attributes required for an alternative to be considered in the decision process. These attributes are considered mandatory to guarantee a successful decision. Any alternative that cannot comply with a MUST objective is eliminated for further consideration, while those that comply with all the MUST objectives qualify as feasible alternatives. The MUST objectives should be measurable and provide an absolute GO/NO GO judgment.

- **WANTS –** These are the desired attributes based on which preferred alternative is selected from the pool of feasible alternatives (i.e., alternatives that fulfill all the MUST objectives). A mandatory or high-priority objective can be considered as a WANT objective, if that objective is not measurable or a relative assessment is preferred over an absolute GO/NO GO judgment. A MUST objective also can be considered as a WANT objective by rephrasing the objective statement for relative assessment of feasible alternatives.

In other words, the MUSTs decide who gets to play, but the WANTS decide who wins.

A list of MUST objectives for the "Pavement Reconstruction of U.S. 00" example is presented as follows:

1. Maintain a minimum of one lane each direction for work
   zone traffic during weekday peak hours..Go/No Go
2. No lane closure between 7:00 a.m. through 10:00 a.m.
   and 4:00 p.m. through 8:00 p.m. during weekdays ....Go/No Go
3. Queue length not more than 0.75 miles for more than one hour ....Go/No Go
4. Delay time not more than 30 minutes..Go/No Go
5. Alternative detour route exceeds capacity? ....Go/No Go

A list of WANT objectives for the example is presented as follows:

1. Minimize daily road user costs ($)
2. Minimize number of days for project completion
3. Minimize traffic control and construction engineering costs ($)
4. Minimize length of detour (miles)
5. Minimize queue length (lane-miles)
6. Minimize average delay time per vehicle (minutes)
7. Minimize percent motorist traveling at a speed 15 mph less than the posted limit
8. Minimize average time to clear a noninjury incidence (minutes)
9. Maintain emergency services (adjectival ratings – poor, average, good)
10. Reduce environmental impacts (adjectival ratings – low, moderate, severe)

Selection of Objectives

One of the commonly cited concerns with a decision analysis is the interdependency among objectives. It is a phenomenon where two or more objectives are highly correlated. The presence of interdependence among objectives in a decision analysis can produce erroneous or misleading outcomes. Interdependence leads to double counting and tends to weigh heavily toward the interdependent factors, while diminishing the significance of other factors in the analysis. Therefore, it is imperative that a decision analyst screen for interdependency among the objectives and validate them.

For example, consider the list of WANT objectives presented above. The factor "daily road user costs" is highly correlated with the following factors: length of detour, maximum queue length, average delay time, average time to clear noninjury incidence, and percent traveling at a speed

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15 mph less than the posted speed limit. These factors all contribute to the computation of the daily road user cost value. Similarly, the factors "the number of days for project completion" and "traffic control and construction engineering costs" also are highly correlated.

One common technique used by practitioners in screening the interdependency among objectives is sensitivity analysis. A sensitivity analysis can be conducted formally or informally to evaluate the effects of varying one objective (numerical or adjectival) on other objectives and final outcomes. The results of the sensitivity analysis will help to identify correlations among analysis factors. Both the degree of correlation and the logical dependency between the factors should be taken into account while identifying the dependent pairs. The purpose here is to avoid double counting rather than eliminating all correlated factors.

Consider the dependency between two pairs: 1) average delay time versus daily road user cost; and 2) average delay time versus average time to clear a noninjury incidence. In the former case, considering both the factors in the analysis will lead to double counting as the factor "daily road user cost" is a monetized aggregation of various impacts, including the factor "average delay time." Any change in the average delay time will result in a proportional change in the daily road user cost. In such cases, it is suggested to eliminate the factor "average delay time" or break the factor "daily road user cost" into individual components.

In the latter case, the factor "the change in average time to clear a noninjury incidence" also causes a proportional change in the average delay time and, hence, is highly correlated. However, considering the probability of a noninjury incidence and the importance of clearing the incident, the analyst may prefer to list both factors to emphasize the effectiveness on traffic incident management in MOT alternative selection and to distinguish it from other traffic delay control strategies. Therefore, it is imperative to use engineering judgment and experience in selecting the objectives so that the intended purpose of the analysis and the complexity of the problem are not diluted.

Interdependency can be countered effectively by defining the objectives in near similar hierarchical order. The problem of interdependency may occur if one objective is defined at the aggregate/generic level while another is defined at the component/specific level. For example, in the list of WANT objectives presented above, the interdependency between the factor "daily road user cost" and other factors is a result of mixing up the factors from different hierarchical order, as illustrated in Figure 20. This figure presents the relationship between "daily road user costs" and only those delay-related WANT objectives listed in the example. The factors listed on the left (queue length, average time to clear a noninjury incidence, etc.) contribute in determining the average delay time which, is used in the daily road user cost computation.
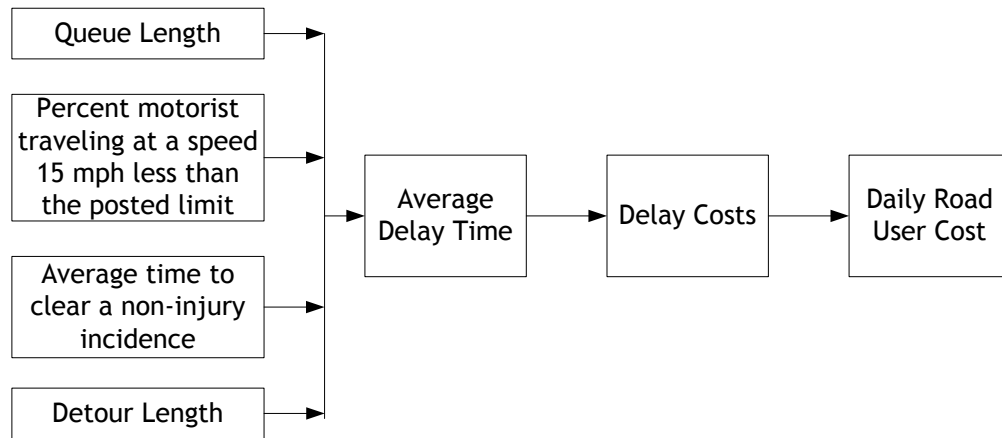
Figure 20. Illustration of Relationships among Factors

A modified list of WANT objectives for the example is presented as follows:

1. Minimize delay costs
2. Minimize vehicle operating costs
3. Minimize number of days for project completion
4. Minimize traffic control and associated construction costs (e.g., shoulder widening, temp bridges), etc.
5. Minimize average time to clear a noninjury incidence (minutes)
6. Maintain emergency services (adjectival ratings – poor, average, good)
7. Reduce environmental impacts (adjectival ratings – low, moderate, severe)

Step 3 – Weighting the Objectives

All MUST objectives are assigned with GO and NO GO options. Each WANT objective is weighted on a scale of 1 to 10 based on their relative importance in the decision process, with the weight of 1 indicating "least preferable" and 10 indicating "most preferable." The weights assigned to the WANT objectives should reflect the agency's work zone policies and project-specific needs.

The following issues should be evaluated while assigning the weights:

- Too many high weights may indicate either unrealistic expectations or a faulty perception of which objectives can guarantee success;
- Too many low weights suggest the possible inclusion of unimportant details in the analysis; and
- Biased objectives may produce an ineffective analysis.

The following illustrates the assigning of weights to each of the WANT objectives considered in the "Pavement Reconstruction of U.S. 00" example:

No.	WANT Objective	Assigned Weight
1	Delay costs	10
2	Vehicle operating costs	8
3	Number of days for project completion	10
4	Traffic control and associated construction costs ($)	8
5	Average time to clear a noninjury incidence (minutes)	4
6	Maintenance of emergency services (adjectival ratings – poor, average, good)	6
7	Environmental impacts (adjectival ratings – low, moderate, severe)	3

(Source: Federal Highway Administration, 2011.)

Step 4 – Identify Candidate Alternatives

Identify all potential alternatives, whether immediately feasible or not, to be evaluated and measured as MUST and WANT objectives. Use the alternatives identified in Step 4 as candidate alternatives for decision analysis.

The candidate alternatives for the "Pavement Reconstruction of U.S. 00" example are listed as follows:

Daytime partial lane closure – closed between 7:00 a.m. to 5:00 p.m.

Nighttime partial lane closure – closed between 8:00 p.m. to 6:00 a.m.

Nighttime partial lane closure – closed between 9:00 p.m. to 7:00 a.m.

Nighttime full lane closure – closed between 9:00 p.m. to 6:00 a.m.

Truck traffic diverted through alternative detour routes during peak hours.

Step 5 – Summarize the Findings of Work Zone Impact Assessment

A detailed work zone impact assessment for each candidate alternative should be done to evaluate both MUST and WANT objectives for quantitative and qualitative results. Use the findings of the preliminary and detailed impact assessments for evaluation. The assessment findings should be summarized for each alternative against the objectives.

The following summarizes the impact assessment findings of all alternatives against the MUST objectives considered in the "Pavement Reconstruction of U.S. 00" example:

MUST Objective	Alternative Evaluation				
	A	B	C	D	E
Maintain a minimum of one lane each direction for work zone traffic during weekday peak hours	Yes	Yes	Yes	Yes	Yes
No lane closure between 7:00 a.m. through 10:00 a.m. and 4:00 p.m. through 8:00 p.m. during weekdays	No	Yes	Yes	Yes	Yes
Maximum queue length (miles)	1.6	0.0	0.0	0.5[a]	0.5[b]
Average delay time per vehicle (minutes)	19.0	6.0	3.0	10.0[a]	20.0[b]
Alternative detour route exceeds capacity?	No	No	No	No	Yes

(Source: Federal Highway Administration, 2011.)

[a] Calculated for the selected detour route.

[b] Weighted average for both mainline and detour routes.

The following summarizes the impact assessment findings of all alternatives against the WANT objectives considered in the "Pavement Reconstruction of U.S. 00" example:

WANT Objective	Alternative Evaluation				
	A	B	C	D	E
1. Delay costs	$5,300	$3,125	$2,800	$4,700	$6,800
2. Vehicle operating costs	$1,484	$656	$728	$1,175	$1,836
3. Number of days for project completion	150	84	84	60	90
4. Traffic control & associated construction costs ($)	$55,000	$94,000	$75,000	$109,000	$85,000
5. Average time to clear a non-injury incidence (minutes)	20	25	25	15	10
6. Maintenance of emergency services (adjectival ratings – poor, average, good)	Moderate	Moderate	Moderate	Good	Good
7. Environmental impacts (adjectival ratings – low, moderate, severe)	Moderate	Severe	Severe	Low	Low

(Source: Federal Highway Administration, 2011.)

Step 6 – Evaluation of Alternatives against MUST Objectives

Evaluate all available alternatives against each of the MUST objectives identified in the earlier step. Any alternative is eliminated from further consideration if it fails to satisfy one or more of the MUST objectives; only those satisfying all the MUST objectives are considered as feasible alternatives.

The results obtained from the evaluation of alternatives against MUST objectives are presented as follows:

MUST Objective	Alternatives				
	A	B	C	D	E
Maintain a minimum of one lane each direction for work zone traffic during weekday peak hours	Go	Go	Go	Go	Go
No lane closure between 7:00 a.m. through 10:00 a.m. and 4:00 p.m. through 8:00 p.m. during weekdays	No Go	Go	Go	Go	Go
Queue length not more than 0.75 mile for more than one hour	No Go	Go	Go	Go	Go
Delay time not more than 30 minutes	Go	Go	Go	Go	Go
Alternative detour route exceeds capacity?	Go	Go	Go	Go	No Go

(Source: Federal Highway Administration, 2011.)

Outcome:

Alternatives A and E are eliminated.

Alternatives B, C, and D qualify as feasible alternatives.

Based on the evaluation results, Alternatives A and E are eliminated from further consideration as these alternatives did not satisfy all the required attributes. The remaining Alternatives B, C, and D are carried into the next step.

Step 7 – Evaluation of Alternatives against WANT Objectives

In this step, each alternative is assigned with a score of 1 to 10 against each WANT objective based on how well the alternative meets that objective. This step involves not only assessing each alternative individually against each WANT objective but also comparing the alternatives with each other against each WANT objective. The results obtained from the evaluation of alternatives against WANT objectives are presented as follows:

WANT Objective	Alternative Score				
	A	B	C	D	E
Delay costs		9	10	6	
Vehicle operating costs		10	8	7	
Number of days for project completion		7	7	10	
Traffic control and associated construction costs ($)		8	8	10	
Average time to clear a noninjury incidence		6	6	10	
Maintenance of emergency services		6	6	10	
Environmental impacts		3	3	10	

(Source: Federal Highway Administration, 2011.)

Step 8 – Weighting the Scores of Alternatives

The weighted score of each feasible alternative should be computed to determine the relative performance of the alternatives.

The weighted score is the score of an alternative multiplied by the weight of the WANT objective to which the score refers. For example, the weight of the objective "Length of detour" is 7 and the score of Alternative D against this objective is 2. Therefore, the weighted score of Alternative D on that objective is 14. For each alternative, all the weighted scores are added up to calculate the total weighted score for that alternative.

The total weighted score of an alternative indicates how well an alternative stacks up against each of the other alternatives for overall performance against WANT objectives. In other words, the total weighted scores function as a visible comparative performance of the alternatives. For the "Pavement Reconstruction of U.S. 00" example, the individual and the total weighted scores of each feasible alternative are presented as follows:

WANT Objective	Alternative Score				
	A	B	C	D	E
Delay costs		90	100	60	
Vehicle operating costs		80	64	56	
Number of days for project completion		70	70	100	
Traffic control and associated construction costs ($)		64	64	80	
Average time to clear a noninjury incidence		24	24	40	
Maintenance of emergency services		36	36	60	
Environmental impacts		9	9	30	
Total Weighted Score		373	367	426	

(Source: Federal Highway Administration, 2011.)

In this example, Alternative D is considered as the tentative choice.

Step 9 – Evaluation of Adverse Consequences (Optional)

After the completion of the alternative evaluation using MUST and WANT objectives, the feasible alternatives can be further evaluated against potential risks. The objective of this step is to understand the consequences of selecting an alternative.

This step is deemed optional as the potential risks are expected to be identified in the work zone impact assessment and incorporated into the decision analysis as a MUST or WANT objective.

This step is particularly recommended when the total weighted scores of all the alternatives are closer. In the "Pavement Reconstruction of U.S. 00" example, the total weighted scores of alternatives B, C, and D are 373, 367, and 426, respectively. Since these scores are close, a risk assessment may be warranted to ensure that the best decision is being made. Suppose, if the total weighted scores of these alternatives were 100, 110 and 633, respectively, alternative D stands out among the feasible ones by an order of magnitude and, therefore, a risk assessment is not required.

The risk assessment begins with the tentative choice (i.e., the alternative with the highest total weighted score). For this alternative, the probability of an adverse consequence and the severity of the impact (i.e., performance of an alternative under that event) is assessed and rated on a High-Medium-Low scale or a scale of 10 (high probable/very severe) to 1 (unlikely/not severe). This step is repeated for each potential adverse consequence to produce the "adverse consequence totals." The risk assessment is then repeated for other feasible alternatives.

For the "Pavement Reconstruction of U.S. 00" example, three potential risks were considered:

- Event of flooding;
- High severity crashes (involving multiple crashes and longer incidence time); and
- Event of an emergency evacuation due to a natural catastrophe.

The likelihood of these events occurring and the performance of an alternative under these situations were rated as probability and severity ratings, respectively. The weighted score for each risk factor is calculated to produce the total adverse consequence score of an alternative. The example is presented as follows:

Adverse Consequence	Alternative								
	B			C			D		
	Probability	Severity	Score	Probability	Severity	Score	Probability	Severity	Score
Flood impact	3	5	15	3	5	15	3	5	15
High severity crashes	5	4	20	5	4	20	5	7	35
Emergency evacuation	1	7	7	1	7	7	1	9	9
Total adverse consequence score			42			42			59

Step 10 – Selection of the Preferred MOT Strategy

For each alternative, the net score is calculated by subtracting the total adverse consequence score from the total weighted score. The alternative with the highest net score is selected as the preferred MOT strategy.

In the "Pavement Reconstruction of U.S. 00" example, Alternative D (i.e., Nighttime full lane closure between 9:00 p.m. and 6:00 a.m.) is selected as the preferred MOT strategy.

Alternative	Description	Total Weighted Score	Total Adverse Consequence Score	Total Score	Rank
A	Daytime partial lane closure – closed between 7:00 a.m. to 5:00 p.m.	Eliminated	–	–	–
B	Nighttime partial lane closure – closed between 8:00 p.m. to 6:00 a.m.	373	-42	331	2
C	Nighttime partial lane closure – closed between 9:00 p.m. to 7:00 a.m.	367	-42	325	3
D	Nighttime full lane closure – closed between 9:00 p.m. to 6:00 a.m.	426	-59	367	1
E	Truck traffic diverted through alternative detour routes during peak hours.	Eliminated	–	–	–

(Source: Federal Highway Administration, 2011.)

Table 67. Pros and Cons of Kepner-Tregoe Method

Pros	Cons
• Applicable to various problems. • Does not have to be too resource intensive. It does not require additional tools or software, or personnel with technical backgrounds. • Accounts for some risk analysis.	• Requires polling a group of people for their opinion on ranking or score, which could be time-consuming. • Still has some bias since individual or group must decide on the relevancy, probability, and severity scores.

Benefit/Cost Analysis

A benefit/cost analysis (BCA), though primarily based on financial information, can be used to compare and choose among alternatives. An agency can choose from various readily available tools or customize their own. There are a variety of tools created for transportation-related projects, including the FHWA's HERS-ST, California DOT's (Caltrans) Cal-B/C, and Texas Transportation Institute's MicroBENCOST. Different B/C tools may be best fit for certain projects. The FHWA currently is working on developing a Benefit/Cost desk reference tool which will have a feature that will match the appropriate B/C tool to an agency's project type and needs.

The B/C method typically includes the following steps:

- **Step 1 –** Identify and select the data for use in the BCA;
- **Step 2 –** Determine the benefits elements;
- **Step 3 –** Determine the cost elements; and
- **Step 4 –** Compare the sum of the costs with the sum of the benefits and determine a benefit/cost ratio.

For a work zone MOTAA analysis, there are several factors that can influence the benefit/cost analysis. Benefit elements that can be used in evaluating and comparing alternatives could include monetary value of travel time savings, road user cost reductions, emissions reductions, and other cost savings. Cost elements could include capital, operations and maintenance, and other costs and fees associated with the project. For more details on the specific work zone-related considerations that should be incorporated in a work zone MOTAA-specific BCA, please refer to Chapter 6 of this document. For additional information on how to calculate specific work zone-related costs, please refer to *Work Zone Road User Costs – Concepts and Applications*.[36]

Example Application

- **Step 1 –** The first step in a benefit/cost analysis for a work zone project would be to determine relevant project information that would serve as input data for the BCA. Such input data could include:
  - **Project Characteristics –** Length of construction period, project type, and length of peak period affected;
  - **Design and Traffic Information –** Work zone strategy (i.e., lane closure, corridor reconstruction, etc.), average daily traffic, speeds, and vehicle make-up of traffic; and
  - **Safety and Accident Statistics –** Fatal and injury accident rates.
- **Step 2 –** The benefits for the project alternative are calculated using the selected analysis tool. The performance measures are monetized based on the value of each performance measure. These benefits are typically calculated over the lifetime of the project and are brought to a Net Present Value (NPV).
- **Step 3 –**The project costs information are determined by looking at all direct costs associated with construction, operations and maintenance of the project alternative, as

well as additional costs associated with any mitigation measures needed. The costs are typically calculated over the lifetime of the project and are discounted to a NPV.

- **Step 4 –** The results of the analysis will produce the total NPV of the benefits and costs of the project. Typically a Benefit/Cost ratio is determined as a common measure to compare different project alternatives. The B/C ratio is determined by dividing the total benefits by the total costs of the alternative. This process is conducted for all alternatives. The alternative with the best B/C ratio should be chosen as the preferred alternative. For reference, a summary results sheet from one BCA tool, Cal-B/C, is shown in Figure 21.[37]

INVESTMENT ANALYSIS
SUMMARY RESULTS

			Average Annual	Total Over 20 Years
Life-Cycle Costs (mil. $)	$46.7	**ITEMIZED BENEFITS (mil. $)**		
Life-Cycle Benefits (mil. $)	$67.9	Travel Time Savings	$1.9	$39.0
Net Present Value (mil. $)	$21.2	Veh. Op. Cost Savings	$1.3	$25.4
		Accident Cost Savings	$0.1	$2.1
Benefit / Cost Ratio:	1.5	Emission Cost Savings	$0.1	$1.4
		TOTAL BENEFITS	$3.4	$67.9
Rate of Return on Investment:	6.5%			
		Person-Hours of Time Saved	324,483	6,489,664
Payback Period:	17 years	Additional CO_2 Emissions (tons)	-5,349	-106,972
		Additional CO_2 Emissions (mil. $)	-$0.1	-$2.8

Figure 21. Benefit/Cost Analysis Summary Results Example'

Table 68. Pros and Cons of Benefit/Cost Analysis

Pros	Cons
• Applicable to various problems • Accounts for costs, risks, and performance – all critical to determining the feasibility of the alternative • Based on data that is verifiable through field data, case studies, etc.	• May be data intensive • Could provide erroneous results if calculations, forecasts, and estimates are unrealistic • Benefits and cost elements included in the analysis are subject to the analyst or decision-maker(s) • Some benefits or costs may not be easily quantifiable

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5.4 DECISION-MAKING TOOLS FOR WORK ZONE ALTERNATIVES ANALYSIS

The previous sections described how to prioritize and establish criteria weights and then use those weighted criteria in a decision-making evaluation framework to evaluate and choose among potential alternatives. This section will provide information on various tools that automate or package decision-making analysis methods into a readily available tool or software. The section is structured as follows:

- Overview of the methodology/tool, including application steps;
- Additional considerations, including pros and cons; and
- Case study of tool application for work zones.

Knowledge-Based Systems (Case-Based Reasoning)

Overview of Methodology/Tool

Case-based reasoning (CBR) is a **methodology for storing and retrieving previous cases and adapting them to a new solution.** A case-based reasoning system is one methodology for solving problems that uses prior knowledge to adapt new solutions. The CBR framework featured in this section is based upon the CBR model developed by Karim and Adeli (2003) for work zone traffic management.[38]
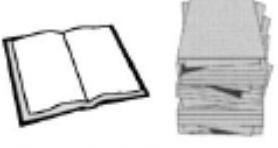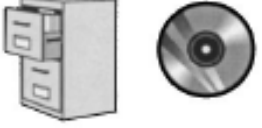
Typical components of a CBR are illustrated in Figure 22.[38] The following sections provide further explanation on how each of these elements can be applied to a work zone traffic management example. The use of CBR for work zone MOTAA analysis differs from the other decision methods because unlike the other frameworks, the agency does not have to create a preliminary list of potential alternatives. If there is a sufficient database that supports the CBR tool, the outputs of the analysis should present the optimal alternative(s) based on the project characteristics inputs and the weights set by the agency analyst.

Case Models for the Work Zone Traffic Management – Domain Information

The domain information serves at the base of CBR, providing a structure for the problem identification and formulation and also the collection of experiences that will serve as references for the solution and calculation of impacts. Karim and Adeli's research sets to explain the use of the CBR system for work zone traffic management through a four-set case model that consists of the following:

- **General** – The general set contains information that provides historical information and previous experiences for future reference.
- **Problem** – The problem set includes information that defines the constants of the work zone traffic control problem. This set typically contains project characteristics.
- **Solution** – The solution set contains information regarding the work zone layout, strategies, and traffic mitigation measures.
- **Effects** – The effects set contains information about the traffic impacts for the work zone.

Figure 23 provides an example of the data components and work zone parameters considered within the four-set case model.[38]

Figure 22. Elements of CBR

(Source: Karim and Adeli, 2003.)

Case

General | Problem | Solution | Effects

Description
ID
Description
Freeway/
direction
Location
Comments

Time
Start time
Duration

Cost
CCC
MTC

Layout
No. of lanes

**Traffic Flow
Characteristics**
Flow rate
Percent trucks
Driver
behavior

**Work
Characteristics**
Phase
duration
Work
intensity

Layout
No. of open
lanes
Layout

**Road User
Cost**
Queue length
Delay time
Complaints
Safety
Corridor
capacity

**Traffic Control
Measures**

A ← B

Object A contains Object B

**Inside
Work Zone**
Speed limit
Lane width
Gawk/glare
screens

**Outside
Work Zone**
Advance
warning
Real-time
traffic info
Alternate
route

Figure 23. Four Set Case Model – Work Zone Example

(Source: Karim and Adeli, 2003.)

Case Representation

The second element of CBR is representation, which defines a data structure for the collected experiences or cases stored as reference. The type of representation used in this CBR research is attribute-value. The attribute-value system consists of three elements: attribute field name, attribute type, and value.

Case Retrieval

Another element of CBR is retrieval, which is the retrieval of a potential solution and determining similarities between the problem and previous cases. In the CBR system, retrieval starts with the formulation of a query. Based on this query, the system retrieves cases that can serve as potential solutions to the problem. These cases are retrieved due to their match or degree of similarity to the query/problem.

Factor Prioritization and Criteria Weights

The use of criteria weights is explained in further detail in the example application section. Weights can be determined using the factor prioritization methods detailed in the previous section.

Evaluation of Criteria Scores and Recommending an Alternative

As previously mentioned, cases are retrieved from a series of queries. The cases retrieved are ranked based on a similarity score that denotes how similar the case is to the reference case. In the CBR system, the level of similarity or similarity score ranges from 0 to 1, where 0 indicates no similarity and 1 means full similarity. The cases retrieved are ranked and presented to the user. The case with the highest score serves as the potential solution. Additionally, the evaluator can modify this case to better fit the reference case or the project objective.

Table 69. Pros and Cons of the CBR Tool

Pros	Cons
• Tool is simple and user-friendly • Provides a database of and case studies of work zone strategies	• Can require a lot of data • There may not be enough case data available • Development of tool and database modules could become complex

Example Application

The procedure for the creation of work zone traffic control plans using the CBR system for work zone traffic management is shown in Figure 24.[38] When a traffic analyst decides to create a traffic control plan for a given work zone scenario, the analyst begins with basic project information, such as number of lanes and flow rate. This background information is fed into the CBR system by responding to queries made by the system. The queries are done iteratively until the best fit case is found. The first query may start with basic information, such as number of

lanes and the flow rate. To narrow down results further, additional queries can be made with other information about the work zone, such as phase duration or work zone intensity.

New work zone scenario
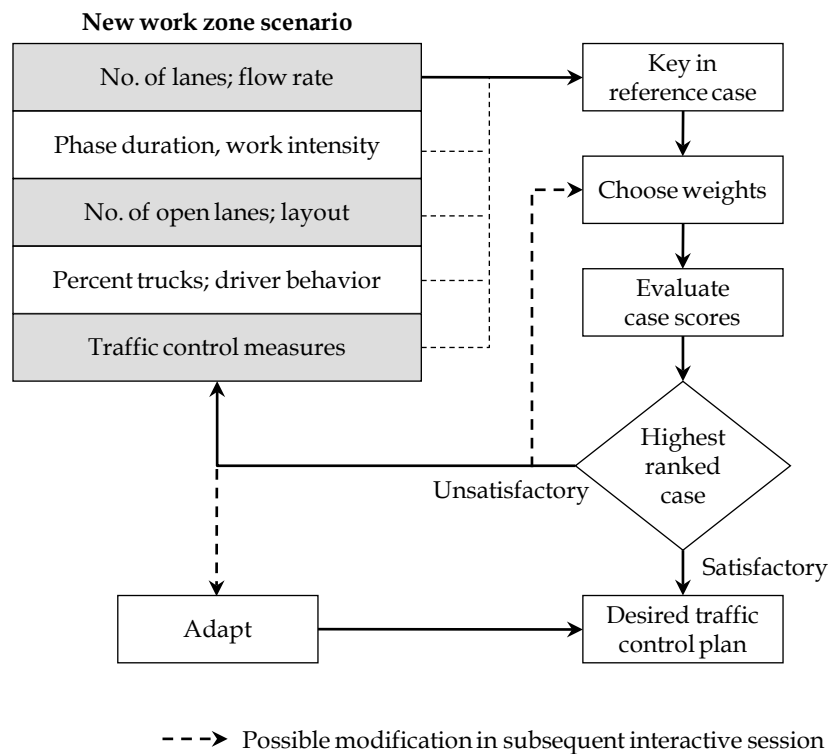
Figure 24. Work Zone Traffic Control CBR System

(Source: Karim and Adeli, 2003.)

The traffic analyst also can assign weights to certain attributes to further filter results based on priority or mandatory work zone characteristics. Finally, after the queries and weights have been applied, the analyst can compare the final results to each other based on their similarity scores. The higher the score indicates a closer match to the reference case and weights inputted by the user.

Additionally, the CBR system can evaluate the final list of cases retrieved and measure their impacts on motorists, the number and type of traffic control measures, and the maintenance of traffic cost. The best fit case or the case with the highest score can, therefore, provide insight regarding some potential work zone alternatives and mitigation strategies that could optimize the reference project's operations and benefits. The CBR analysis will allow the analyst to modify their reference case/project with a desired solution or set of alternatives. The agency also can modify an existing case to obtain an improved solution or set of alternatives that will enable them to meet their particular goals, objectives, and/or criteria. Figures 25 to 28 provide snapshots of the CBR system used for work zone analysis following the four sets: General, Problem, Effects, and Solution.[38]

		Types:	c	c	c	c	c	n	n	n	c
		Maps:									
	Field Names:	ID	Description	Freeway	Location	Start time	Duration	CCC	MTC	Comments
	Weights:	1	1	1	1	1	1	1	1	1
	Reference:									
Scores	Cases									
0.992	Case1	OH-0142	Resurfacing	I-71/NB	Franklin	1998/02	25	2500	25	
0.986	Case2	OH-0258	Pavement repair	I-75/NB	Morrow	1999/06	5	500	15	
0.986	Case3	OH-0268	Bridge work	I-71/NB	Delaware	1999/08	20	250	15	
0.984	Case4	OH-0555	Resurfacing	I-71/SB	Delaware	2000/07	35	2000	20	
0.987	Case5	OH-0233	Pavement rehabilitation	I-70/EB	Franklin	1999/04	60	4500	30	
0.982	Case6	OH-0325	Resurfacing	I-70/EB	Franklin	2000/03	15	1500	20	
0.992	Case7	OH-0382	Pavement marking	I-71/NB	Franklin	2000/04	5	250	5	
0.980	Case8	OH-0422	Lane addition	I-70/WB		2000/06	75	5500	25	
0.984	Case9	OH-0501	Utility work	I-71/SB		2000/06	5	35	5	
0.984	Case10	OH-0155	Pavement joint work	I-71/SB	Delaware	1998/03	15	25	10	
0.988	Case11	OH-0298	Bridge work	I-80/EB		1998/12	15	250	5	
1.000	Case12	OH-0333	Pavement marking	I-80/EB		1999/04	10	10	3	
0.986	Case13	OH-0482	Resurfacing	I-77/NB		2000/05	35	125	10	
0.984	Case14	OH-0186	Stripping	I-77/SB		1998/04	10	55	5	
0.986	Case15	OH-0208	Pavement rehabilitation	I-71/NB		1999/03	45	325	25	
0.980	Case16	OH-0342	Pavement repair	I-71/SB		2000/03	25	200	15	
1.000	Case17	OH-0329	Culvert work	I-77/SB		2000/03	10	80	5	
0.998	Case18	OH-462	Pavement marking	I-77/SB		2000/05	5	15	3	
0.985	Case19	OH-444	Utility work	I-80/WB	Cuyahoga	2000/04	5	25	5	
0.977	Case20	OH-0218	Lane addition	I-70/EB	Franklin	1999/08	55	480	20	

Figure 25. CBR System General Set

(Source: Karim and Adeli, 2003.)

		Types	Maps			
n	n	n	c	n	c
Lanes	Flow rate	% trucks	D. behavior	Phase duration	Intensity
1	1	1	1	1	1
3	1400				
3	1800	5	Urban	8	Medium
2	1300	3	Rural	4	Medium
2	1500	7	Rural	4	Medium
2	1600	7	Rural	8	Low
4	1600	5	Urban	6	High
4	1900	5	Urban	12	Medium
3	1800	5	Urban	4	Low
2	1800		Urban	8	
2	1600	5	Urban	8	
2	1600		Urban	4	
2	1400	8	Urban	5	
3	1400		Rural	12	
2	1500	3	Rural	8	
2	1600	5	Rural	4	
2	1500	4	Rural	4	
2	1800		Rural	12	
3	1400	9	Rural	8	
3	1500		Rural	8	
4	1700	3	Urban	6	
2	2000	5	Urban		

Figure 26. CBR System Problem Set

(Source: Karim and Adeli, 2003.)

Microsoft Excel - workzone.xls

File Edit Data Case Database Answers Utilities

Z2

	Z	AA	AB	AC	AD
1					
2					
3					
4	n	n	c	c	c
5					
6	Queue length	Delay time	Complaints	Safety	C. capacity
7	1	1	1	1	1
8					
9					
10					
11	1	750	Low	High	High
12	2	1000		High	
13	0.5				
14	0.5	500			
15	0.5	300	High		
16	2	400			
17	1		Medium	High	High
18	0.5				
19	1		Low	High	
20	1.5	700			
21	3				
22	0.5	200		Medium	
23	4		High		
24	1			High	
25	2	500	Medium		
26	1		Medium		
27	2			High	Medium
28	0.5				
29	1			High	High
30	1		Low	High	
31					

Figure 27. CBR System Effects Object

(Source: Karim and Adeli, 2003.)

Figure 28. CBR System Solution Set

(Source: Karim and Adeli, 2003.)

	R	S	T	U	V	W	X	Y
4	n	c	n	n	c	c	c	c
6	Open lanes	Layout	Speed limit	Lane width	Screens	A. warning	RT info	A. route
7	1	1	1	1	1	1	1	1
11	2	Merging			Yes	Yes	No	Yes
12	1	Merging			No	Yes	No	No
13	1	Merging			yes	Yes	No	No
14	2	Shifting			No	Yes	No	No
15	2	Merging		11	No	Yes	No	Yes
16	2	Merging	45		No	Yes	Yes	No
17	1	Merging	45			No	No	No
18	2	Shifting				Yes	Yes	Yes
19	1	Merging	35		Yes	No	No	No
20	1	Merging			No	Yes	No	No
21	1	Xover			No	Yes	No	No
22	2	Merging				Yes	No	No
23	1	Shifting	45		No	Yes	No	Yes
24	1	Merging			No	Yes	No	No
25	2	Shifting	45		No	Yes	No	No
26	2	Shifting			No	Yes	No	No
27	2	Merging			Yes	Yes	No	No
28	2	Merging			No	Yes	No	No
29	3	Merging			No	Yes	No	No
30	2	Xover		11	No	Yes	No	No

Matrix-Based Decision Support Tool

Overview of Methodology/Tool

The Matrix-Based Decision Support Tool was created through a study funded by the FHWA and Texas Transportation Institute to **determine the most effective strategies or combination of strategies to support construction, traffic management, and public information during work zone activities in high-traffic environments**.[39] The research presents a series of decision-support matrices that include:

- Preliminary strategy selection matrix;
- More detailed matrices focused on construction, traffic management, and public information strategies; and
- An interdependency matrix that considers synergy among multiple strategies.

The use of these three matrices lends to a three-step process. To develop this process, the authors used information from literature reviews, case studies, and opinions of experts. Using the literature review and case studies, they developed the *Preliminary Strategy Selection Matrix*. This matrix maps the observed successful use of various construction, traffic management, and public information strategies. Using the literature review and case studies, they also gathered information regarding the benefits of each strategy. Using the benefits information, they

developed the second matrix, the *Secondary Strategy Selection Matrix*. Separate matrices were developed for each of these three categories of strategies: construction, traffic management, and public information. Using the information sources, the researchers also observed that several of the strategies that were applied concurrently have synergic benefits. From the information regarding the different levels of synergy among strategies, the researchers created the third matrix, the *Strategy Interdependency Matrix*.

Preliminary Screening of Alternatives

Preliminary Strategy Selection Matrix

The Preliminary Strategy Selection Matrix presents various motivations or concerns related to construction, traffic management, and public information. It then identifies which strategies have been shown to mitigate or address such concerns using the three data sources previously mentioned. This matrix only identifies those strategies that positively address the associated motivations/concerns. Blank cells mean a negative or an unconfirmed positive relationship between the strategies and motivations/concerns.

Factor Prioritization and Criteria Weights

No factor prioritization methodology is necessary for this evaluation framework. However, the next strategy selection matrix aids the decision-maker to further reduce the set of strategies in consideration.

Secondary Strategy Selection Matrix: Construction

There are three *Secondary Strategy Selection Matrices*: 1) construction; 2) traffic management; and 3) public information. **This secondary matrix provides additional information regarding the relative impacts and benefits of each strategy and rates them as either a high, medium, or low impact**. The *Secondary Matrix* categorizes strategies into the following: contract administration, planning/scheduling, project management, constructability, and construction practices. It uses project examples from the case studies and identifies which strategies apply to which projects. It also identifies the anticipated benefits of each strategy as it relates to:

- Enhanced communications/coordination;
- Project speed and efficiency;
- Construction quality; and
- Work zone safety.

Evaluation of Criteria Scores and Recommending an Alternative

The three matrices work to decrease the initial set of strategies to those with a high level of relevance or significance to the project and the objectives. Additionally, the inclusion of the interdependency matrix also can provide insight into the optimal combination of strategies that could address the project objectives.

Strategy Interdependency Matrix

The third matrix, *Strategy Interdependency Matrix*, **depicts the level of interdependencies between strategies.** The interdependency levels are rated High, Medium, or Low. Similar to the *Preliminary Strategy Selection Matrix*, the *Strategy Interdependency Matrix* only identifies those combinations that have been shown to produce positive benefits. Therefore, blank cells reflect a disbenefit or an unconfirmed positive combination of strategies.

Table 70. Pros and Cons of the Matrix-Based Decision Support Tool

Pros	Cons
• Simple and comprehensible for technical analysts, planners, and policy-makers • Provides insight into optimal combination of strategies • Database of benefits and case studies of work zone strategies	• Requires a lot of data • Data for all strategies may not be available • Narrows down strategies and denotes relevant strategies, but does not specifically recommend an alternative(s)

Example Application

Application of the matrices involves a three-step process that utilizes tables such as those shown in Figures 29 to 31.[39] The process is explained in further detail below.

- **Step 1 – Preliminary Identification of Candidate Strategies –** Use the *Preliminary Strategy Selection Matrix* to identify the appropriate strategies to address project considerations in the areas of construction, traffic management, and public information. The items included in the matrix's top column labeled "Motivations/Concerns" can be used to guide project considerations.
- **Step 2 – Further Investigation of Candidate Strategies –** Use the *Secondary Strategy Selection Matrix: Construction, Traffic Management, and Public Information Matrices* to obtain more information about the candidate strategies generated from Step 1. This step provides further insights into the benefits and disbenefits of each strategy. Using the information from this matrix, the user can further narrow down their list of strategies to those that would provide benefits over a certain threshold or impact level.
- **Step 3 – Identification of Synergistic Opportunities Among Candidate Strategies –** After consolidating the initial list of strategies in Step 2, the third matrix, Strategy Interdependency Matrix, can be used to determine the optimal combination of strategies based on synergistic levels as a guide.

Figure 29. Preliminary Strategy Selection Matrix

STRATEGIES	I-710 Long Beach, CA	I-95 Bridgeport, CT	I-285 Atlanta, GA	I-465/70 Indianapolis, IN	I-70 Columbus, OH	I-15 SLC, UT	I-95 Richmond VA	Various Springfield, VA	I-10 Pomona, CA	I-15 Devore, CA	I-85 Atlanta, GA	US-23 Northern MI	I-496 Lansing, MI	Lamar Austin, TX	I-65 Nashville, TN	Communication/ Coordination	Speed/ Efficiency	Construction Quality	Work Zone Safety
CONTRACT ADMINISTRATION																			
CA1 Contractor Screening[1]												✓					M		
CA2 Partnering									✓			✓	✓			M	L		
CA3 Incentives/Disincentives									✓		✓	✓	✓	✓		L	H		
CA4 A+B Contracting												✓				L	H		
CA5 Lane Rental																L	H		
CA6 Production-based Contract Length									✓										
PLANNING/SCHEDULING																			
PS1 Joint Schedule Review Meetings												✓				H			
PS2 Accelerated Schedule									✓		✓			✓			M		
PS3 Detailed Hourly Schedule										✓						M			
PS4 Dynamic Project Schedule									✓				✓				M		
PS5 Weekend Construction								✓		✓			✓				L		L
PS6 Nighttime Construction									✓	✓	✓						L		L
PS7 Early Utility Work Completion													✓				M		
PS8 Contingency Plan									✓		✓						M		
PS9 Responsive Adverse Weather Plan									✓	✓	✓						M		
PS10 Rest Days									✓	✓									M
PROJECT MANAGEMENT																			
PM1 Daily Construction Meetings									✓				✓			H			
PM2 Effective Communication												✓				M			
PM3 On-site Agency Decision-makers												✓	✓			H	H		
CONSTRUCTABILITY																			
CO1 Formal Constructability Review																		M	
CO2 Optimization Software[2]	✓							✓	✓								M		L
CONSTRUCTION PRACTICES																			
CP1 Concrete Accelerator Admixture									✓	✓			✓				M		
CP2 On-site Batch Plant										✓	✓	✓		✓			H	M	
CP3 Exclusive Batch Plant										✓	✓	✓		✓			M		
CP4 Two-lane Slip Form Paver									✓	✓							H		
CP5 Pre-cast Concrete Paving								✓										M	
CP6 Dowel Bar Inserter Paver											✓						H		L
CP7 Backup/Reserve Equipment								✓			✓			✓			M		
CP8 Noise Reduction Strategies											✓	✓							L

Figure 30. Example Secondary Strategy Matrix: Construction

STRATEGIES		CA1	CA2	CA3	CA4	CA5	CA6	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	PS10	PM1	PM2	PM3	CO1	CO2	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8
RELATIVE LEVEL OF INTERDEPENDENCE Low, Medium, High																														
CONTRACT ADMINISTRATION																														
CA1	Contractor Screening		H						H		H							H					M							
CA2	Partnering	H							H										M											
CA3	Incentives/Disincentives				M		M		M																					
CA4	A+B Contracting			M			H		M																					
CA5	Lane Rental								M	M																				
CA6	Production-based Contract Length			M	H				M																					
PLANNING/SCHEDULING																														
PS1	Joint Schedule Review Meetings								M																					
PS2	Accelerated Schedule	H	H	M	M	M	M	M						H	H	H		M					M						M	
PS3	Detailed Hourly Schedule				M																									
PS4	Dynamic Project Schedule	H																												
PS5	Weekend Construction																												M	
PS6	Nighttime Construction																							M			H			M
PS7	Early Utility Work Completion								H																					
PS8	Contingency Plan								H																					
PS9	Responsive Adverse Weather Plan								H																					
PS10	Rest Days																													
PROJECT MANAGEMENT																														
PM1	Daily Construction Meetings	H																												
PM2	Effective Communication		H						M																					
PM3	On-site Agency Decision-makers																													
CONSTRUCTABILITY																														
CO1	Formal Constructability Review																													
CO2	Optimization Software																													
CONSTRUCTION PRACTICES																														
CP1	Concrete Accelerator Admixture	H							M															H						
CP2	On-site Batch Plant		M										M										H							
CP3	Exclusive Batch Plant																													
CP4	Two-lane Slip Form Paver																													
CP5	Pre-cast Concrete Paving												H																	
CP6	Dowel Bar Inserter Paver																													
CP7	Backup/Reserve Equipment								M			M																		
CP8	Noise Reduction Strategies												M																	

Figure 31. Level of Interdependence Matrix

6.0 RECONCILING INCONSISTENCIES AND CONDUCTING SENSITIVITY ANALYSIS

Throughout the project development process, several factors can cause variations in performance measures and outputs used to compare and analyze the benefits and impacts of work zone alternatives.

- The first section of this chapter describes the typical variations that can be expected in the analysis outputs and measures of effectiveness extracted during various stages of a work zone traffic analysis.
- The second section describes several ways to reconcile the variations and inconsistencies that can occur in modeling or analysis results.
- The third section describes how sensitivity analysis can be used to validate and rectify issues with the variations and inconsistencies resulting from the work zone modeling and analysis.

6.1 VARIATIONS IN THE MEASURES OF EFFECTIVENESS, TOOLS, AND OUTPUTS

The project type and scale can affect the structure, the level of data collection and analysis efforts, and decision-making framework that is incorporated into developing and evaluating the project and the project development process (PDP). Each PDP stage will be driven by a different purpose and objectives, which may require different types of analysis efforts and tools. Using different tools can yield differences in output results and variations in measures of effectiveness (MOE).

Table 71 presents common measures that can be extracted from different classes of analysis tools. The table shows that although the same type of performance measures may be collected from each analysis tool, the definition of the measure and the types of outputs needed in order to calculate the MOE may differ depending on the tool used. For instance, while both signal optimization and travel demand modeling tools can report delay, only signal optimization can report intersection delay effectively.

Table 71. Performance Measures and Outputs by Tool Type

Analysis Tools	Performance Measures	Outputs	Tool Focus
Sketch-Planning – Analytical/ Deterministic Tools	• Travel Time	• Vehicle-Hours Traveled (VHT)	Sketch-planning tools can be used for systemwide measures. Deterministic tools are better suited for facility-specific measures.
		• Person-Hours Traveled (PHT)	
	• Delay	• Intersection Total Delay	
		• Intersection Control Delay	
		• Stop Delay	
	• Queue	• Freeway Facility Queue Density	
		• Percentile Probability Queues	
	• Speed	• Average Speed	
		• Space Mean Speed	
	• Volume	• HCM V/C Ratio	
	• User Costs	• N/A	

Analysis Tools	Performance Measures	Outputs	Tool Focus
	• Density	• For Freeway Facilities – Average Density by Segment or Across Facility	
		• Multilane Highways – Mean Passenger Car Density	
	• LOS	• HCM LOS	
Travel Demand Model Tools	• Travel Time	• Total Travel Time	Systemwide measures.
	• Delay	• N/A	
	• Queue	• N/A	
	• Speed	• Average Speed	
	• Volume	• V/C Ratio	
		• Link Volumes	
	• User Costs	• N/A	
	• Density	• N/A	
	• LOS	• N/A	
Traffic Signal Optimization Tools	• Travel Time	• Total Travel Time	Facility-specific measures.
	• Delay	• Total Delay	
		• Control Delay	
		• Stop Delay	
		• Queue Delay	
	• Queue	• Average Queue	
		• Maximum Queue	
		• 50th and 95th Percentile Queue	
	• Speed	• Average Speed	
	• Volume	• HCM V/C Ratio	
	• User Costs	• Fuel Consumption	
		• Fuel Economy	
	• Density	• N/A	
	• LOS	• HCM and Intersection Capacity Utilization (ICU) LOS	
Macroscopic Simulation Tools	• Travel Time	• Total Travel Time	Facility-specific.
	• Delay	• Total Delay	
		• Delay by Facility Type (i.e., Freeway, On-Ramp, and Off-Ramp)	
	• Queue	• Congested Length or Queue Length	
	• Speed	• Average Speed	
	• Volume	• Volume (Expressed as Flows at an Hourly Rate)	
		• V/C Ratio	
	• User Costs	• Fuel Consumption	
	• Density	• Average Density (Vehicles per Mile per Lane)	
	• LOS	• LOS (Calculated as a Function of Density)	
Mesoscopic Simulation Tools	• Travel Time	• Travel Time, Trip Time (VHT)	Facility-specific.
	• Delay	• N/A	
	• Queue	• Entry Queues	
		• Vehicle Queue Length	
	• Speed	• System Average Speed	
		• Average Link Speed (mph)	
	• Volume	• Number of Vehicles	

Analysis Tools	Performance Measures	Outputs	Tool Focus
	• User Costs	• N/A	
	• Density	• Link Density (Average Passenger Car/Lane-Mile)	
		• Mean Passenger Car Density of Moving Vehicles	
	• LOS	• N/A	
Microscopic Simulation Tools	• Travel Time	• System- and Link-Based VHT	Facility-specific.
		• Total Time per Vehicle	
	• Delay	• Average Delay (by Link, Node, and Network-Wide)	
		• Delay Time or Lost Time (the Difference between the Theoretical Travel Time versus Actual Vehicle Travel Time) per Vehicle	
		• Delay Time Rate (Minute/Mile)	
		• Queue Time	
		• Stop Time, Stopped Delay, Average Stopped Delay	
		• Total Delay (Network-Wide)	
	• Queue	• Average Queue Length	
		• Maximum Queue	
		• Percent of Link Storage	
	• Speed	• Average Speed by Link	
		• Network-Wide Average Speed	
	• Volume	• Volume Count and Flow (Vehicles per Hour)	
	• User Costs	• Fuel Consumption	
	• Density	• Average Density per Link Segment during Analysis Time Period (Vehicles/Lane-Mile)	
	• LOS	• Most microsimulation tools do not report LOS. Paramics Analyzer reports HCM LOS using Passenger Car Unit (PCU) Densities	

Different tools also are better suited for certain levels of analysis. The levels of analysis include systemwide and facility-specific. Systemwide measures report mobility, safety, and environmental impacts for the entire system or network while facility-specific focus either on a specific link, localized area, or facility type. For instance, macroscopic models and travel demand models are best suited for systemwide measures. Due to the level of detail and complexity involved in microscopic simulation analysis, microscopic simulation tools, while capable of generating systemwide MOEs, are best utilized for reporting measures at a more localized or facility-specific level than evaluating larger systems.

The project characteristics, goals, and how the PDP is structured will affect and be impacted by the types of tools, measures, and outputs generated. The following section describes how to reconcile these issues to aid in better decision-making. It also will feature an example that depicts how variations in MOEs can occur due to the use of different analysis tools, as well as how to reconcile those inconsistencies.

Variations Based on Project Type

The types of tools utilized during a work zone traffic analysis can vary based on the characteristics of the project and the project site. Different analysis tools may yield different outputs and performance measures.

One of the major project characteristics that can impact the type of tools and MOEs used on projects include the project's size.

- Small-scale, site-specific projects may have a more concentrated impact, a shorter construction and project development period, and potentially more limited resources. These projects may utilize sketch-planning and HCM/deterministic models, where the analysis could be done simply and quickly, with a smaller-scale data collection effort. Example measures of effectiveness (MOE) for a smaller scale project may, therefore, be at a facility level.
- Larger, systemwide projects have wider-range impacts, with longer durations, and potentially more resources. These projects, due to their size, will require tools that can handle larger networks and a range of measures that include mobility, safety, and environmental factors. The performance measures would most likely be at a systemwide level.

The goals and objectives of the project along with the work zone characteristics also will dictate what tool may be used and consequently what types of outputs and measures can be generated. If the project's main objectives, for instance, require that the site be maintained at a certain level of service, the type of tools and MOEs that an agency may choose will be different if the objectives focus on issues related more to safety.

Variations Based on Project Stage

Each project stage will have a different objective and timeframe for when an action or decision has to occur. Specific tools may be more applicable for certain objectives and timeframes. Therefore, different tools or combination of tools may be utilized for various stages of the project development process (PDP). The following describes the types of variations in MOEs, tools, and outputs that occurs during specific phases of the project.

- **Project Planning and Scoping –** At the project planning stage, agency staff and decision-makers define and prioritize the goals and objectives of the project. Therefore, at the planning stage, these evaluators will typically **look at measures at a systemwide level**. Tools that may be used include sketch-planning tools and travel demand models.
- **Environmental, Preliminary Design/Project Approval Stage –** The objectives at this stage of the project are to develop the preliminary design and operations plan, obtain environmental clearance, and receive approval to proceed with the next stage. At this stage, a preliminary design and list of potential alternatives will be evaluated for the project. The short- and long-term benefits and traffic and environmental impacts of the project also will be determined. The measures presented at this stage of the project will

be targeted for decision-makers and the public. In order to determine the benefits and impacts of the project, several different tools may be used depending on the size and complexity of the project.

- For broad- and system-level performance measures, travel demand models supported by sketch-planning tools may be appropriate.
- For more complex analysis that may look at the performance of a specific facility or the performance of major highways along with adjacent arterials, a signal optimization model, mesoscopic, and/or microscopic simulation tools may be used.
- **Plans, Specifications, and Estimates (PS&E), Construction, and Operation Analysis Stage**:
  - During the PS&E phase of the project, the agency prepares design plans and project specifications. At this stage, work zone traffic analysis is conducted in order to support the project design. The traffic analysis results ensure that the project will have the capacity to meet or service the demand for the facility.
  - During construction, the agency's objectives in conducting any modeling or analysis effort are to determine how to safely and efficiently construct a project with minimal impacts to the environment, the community, and workers. Modeling and analysis efforts for the construction stage are focused less on mobility and more towards evaluating how effective the project or work zone strategies are at improving safety and or project/construction efficiency.
  - During the operations stage, agency objectives are focused on evaluating the level of service of the facility and the traffic performance of the work zone. The types of measures at this stage include mobility measures such as delay, average speed, and queue lengths. At this stage, a larger data collection effort and more complex modeling and analysis tools may be brought in.
- **Alternatives Analysis –** When choosing among work zone alternatives, the analyst will consider the various performance measures generated in the different project stages in order to make a decision regarding which alternative to recommend.

6.2 ACHIEVING CONSISTENCY OF RESULTS WHEN USING MULTIPLE TOOLS

The previous section discussed the variations in measures of effectiveness, tools, and outputs that an analyst can encounter when conducting a work zone traffic analysis. **These variations can cause inconsistencies in results, inaccuracies in calculating benefits and impacts, and misinformation in deciding among various alternatives.** This section describes the need for consistency when using different analysis tools and reconciling the inconsistencies that may occur with different modeling outputs and measures of effectiveness. This section will provide background on consistency within the project development process, describing how inconsistencies occur and the importance of achieving consistency in outputs and measures. The section also will describe how to evaluate and ensure consistency throughout the various project stages.

Background on Consistency

"The goal of achieving or maintaining consistency throughout the project development process (PDP) ensures that the initial decision to proceed with the project is still the correct choice at the

end of the process."[40] There are two resources that describe the potential variations and inconsistencies in MOEs and analysis results when using multiple tools. One resource is the FHWA-sponsored research, *Guide on the Consistent Application of Traffic Analysis Tools,* and the other is *Traffic Analysis Toolbox Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness*.[40,41] These two resources provide guidance on how different types of analysis tools produce particular MOEs and how to reconcile the potential inconsistencies that may result from using multiple tools. For further details on many of the concepts addressed in this section, please refer to these two documents.

Achieving consistency in terms of outputs, performance measures, and results is important for the following reasons:

- Consistency ensures quality and accuracy of results;
- Consistent and accurate results leads to verifiable decision-making process and outcomes;
- Consistency enhances the agency's credibility and effectiveness;
- Consistency assures that the analysis process is effective and efficient; and
- Consistency ensures that the analysis procedures are more refined and flexible enough to be reapplied even through certain parameter changes.

As mentioned in the previous section, variations in MOEs, tools, and outputs can occur naturally depending on the project type and project development stages. When different tools and types of performance measures are used throughout one project, inconsistency in results can occur. Additionally, inconsistency may occur due to the following factors:[41]

- Overuse of defaults;
- Calibration mistakes;
- Inaccurate data or demand forecasts;
- Failure to check for reasonableness of results; and
- Differences in performance measure definitions across different tool types.

Reconciling Measures of Effectiveness

As discussed in Section 6.1 of this document, variations in MOEs can occur at different project stages and through the use of different analysis tools. The use of different tools can produce inconsistencies in MOE results and challenges when comparing measures across different analysis tools. **In order to reconcile the potential inconsistencies that can result from the use of different tools, the analyst should keep in mind the characteristics of the tool – its strengths and limitations.** For further information on the capabilities and limitations of different traffic analysis tools, refer to Chapter 3 of this document. In order to reconcile the variations in MOEs that occur from the use of different tools, the analyst should account for the following when choosing the appropriate tool:

- Choose the tool most reliable for extracting the outputs needed to generate the performance measures established.
- Choose the tool that is most appropriate for producing MOEs by the focus level (i.e., facility- or system-specific) required for the particular project stage.
- If MOEs need to be compared across tools, find the least common denominator amongst the two. According to the FHWA-sponsored *Traffic Analysis Toolbox Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness*, "the comparison of results between tools and methods is possible only if the analyst looks at the lowest common denominator shared by all field data collection and analytical tools."[41] In this guide, vehicle trajectories are recognized as the lowest common denominator. However, the NCHRP Report 3-85-20 notes that because vehicle trajectories may be defined differently across different tools, the lowest common denominator is field observations. Because analysis tools and models should be calibrated or validated by measures from the field, field observations serve as a common link across different tools and methodologies.[42]

Reconciling Different Tools

There are several ways to reconcile the variations or inconsistencies that may be present in analysis results due to the utilization of different tools during the project development process.

- **When utilizing results from different tools, the most reliable tool should always take precedence over the results from the less reliable ones**. For instance during the project planning stage of an MOTAA, a travel demand model coupled with a sketch planning may be used to determine the potential work zone alternatives to be considered for a project.
- **When possible the same tool should be used throughout the various project stages**. For instance, if a microsimulation model was developed during the environmental clearance stage, that model can be carried over to subsequent project stages, especially during the alternatives analysis.
- **While the results from the more reliable or robust tool may be used, the analyst should still review the outputs from the less reliable tools to QA/QC the preferred tool's results**. One way to do this is to use another analysis tool's results to determine whether common trends appear in both models. For instance, when comparing the mobility impacts of a ramp closure, a traffic optimization tool may note that nearby parallel signalized arterial intersections experience a degradation of LOS from an LOS B to an LOS D. A microsimulation tool may express this degradation in mobility levels with measures such as delay, speed reduction, or queue length. Although the values and measures are different, the two tools should agree that there are congestion issues at that particular section of the project area.
- **Further checks on the modeling and analysis tool results should include error checking of the model network coding, volumes, and speeds by comparing the model inputs and outputs with observed traffic statistics**.

Reconciling Outputs

When different tools must be used during the project development process, inconsistencies amongst model outputs are likely to occur. The following presents various ways to reconcile these differences:[40]

- **The tool that is used to report the facility-specific performance analysis should be used to report all facility performance results**. For instance, if CORSIM was used to generate facility travel times, it also should be used to identify bottlenecks, queues, speeds, and delays for the facility. This would be the same for system-specific performance measures.
- **When different tools have similar outputs but are defined differently, the analyst should be able to compare and understand the differences between the tools**.
- If neither tool provides the best or most complete solution to a problem, the analyst may want to consider the following:
  - **Additional data processing may be needed to reconcile the differences by using revised outputs that utilize a combination of the outputs from the different tools**.
  - **It may be necessary to convert one tool's outputs so that it can be compared at the same level as the other tool**.

Reconciling Variations and Inconsistencies Example: I-15 Ontario Corridor Pavement Reconstruction Project

An example of a work zone project that used different tools throughout the various stages of the project was the I-15 Pavement Reconstruction Project in Ontario, California. This work zone project required the reconstruction of two of three truck lanes in each direction of the interstate. For further details regarding the project refer to the *Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation – A Guide for Analysts*.[2] Figure 32 shows the analysis process for I-15 project and presents when each analysis tool was used and for which stage of the project. Table 72 shows the various tools, measures, and outputs utilized throughout various stages of the project.
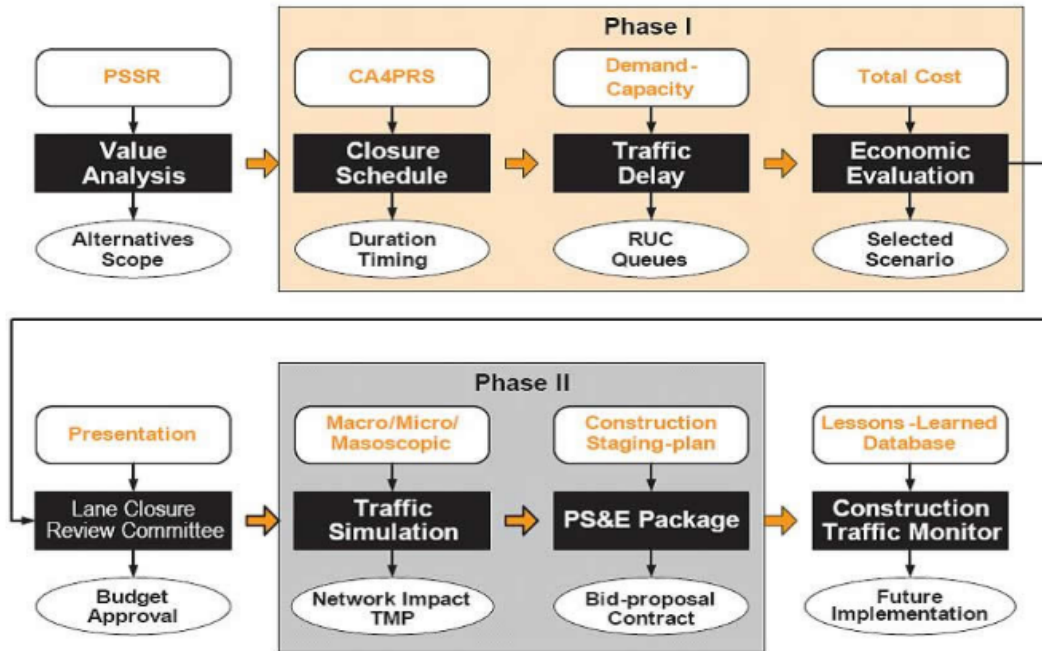
Figure 32. I-15 Analysis Process

(Source: Hardy and Wunderlich, 2009.)

**Table 72. MOEs, Tools, and Outputs Utilized for
I-15 Pavement Reconstruction Case Study**

Phase	Stage	MOEs	Analysis Tool	Outputs
1	• Planning/Scoping (Preconstruction Plans)	• Systemwide measures	• Sketch-Planning – CA4PRS	• Total number of lane closures
	• Alternatives Analysis (Preconstruction Plan)	• Facility-specific (delays reported for the entire corridor but only one facility type, freeway involved in analysis)	• HCM Demand-Capacity Model	• Total and max delay; road user cost
2	• PS&E and Operational Analysis	• Systemwide • Facility-specific	• Sketch – CA4PRS • Dynameq	• Staging analysis plan (number of weekends needed, working days, etc.) • Delay in minutes (reported by segmentation defined by the six construction staging scenarios)

The I-15 project used three traffic modeling tools, including the Construction Analysis for
Pavement Rehabilitation Strategies (CA4PRS), Highway Capacity Manual Demand-Capacity
Model (HCM), and Dynameq mesoscopic traffic simulation tool. During the preconstruction
planning, alternatives development, and initial alternatives analysis portion of the project, the

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analysts utilized CA4PRS and HCM to analyze six alternative construction scenarios. Table 73 shows the preconstruction analysis results from HCM and CA4PRS. As shown by the results, Scenario 1 was the most cost-effective and was, therefore, chosen as the preferred alternative.

Table 73. I-15 Preconstruction Analysis Results

| Scenario Name | Closure Scheme | Closure Assessment (Number of Closures) | Traffic Analysis | | Cost Analysis | Total Cost[a] |
			RUC (Million Dollars)	Delay (Minutes)		
Original	Median and structure widening	35 weekends	3	16	78	79
Rapid Rehab 1	Full closure one roadbed	35 weekends	119	363	83	123
Rapid Rehab 2	Full closure one roadbed	8 weeks	123	363	77	118
Traditional	Partial closure	1,220 nights	133	22	88	113
Long-Life CSOL	Full closure one roadbed	20 weekends	69	363	60	83

[a] Total Cost = (RUC/3) + Cost Analysis.

The second phase of the project entailed the development of a construction staging plan and traffic management plan. The agency, therefore, had to conduct further analysis of the preferred alternative in order to develop a construction staging plan that optimized construction schedule and resources while minimizing impacts to the public. CA4PRS was used to develop the more detailed construction staging plan of the preferred alternative and mesoscopic simulation tool, Dynameq, was used to evaluate the mobility impacts (delay) associated with the staging plan options. The final six construction staging scenarios included the following:

- **2B** – Closure of I-10W to I-15S and I-15S to Jurupa ramps;
- **2C** – Closure of I-10E to I-15S ramp;
- **2D** – Closures of I-15S to I-10W and from 4th Street to I-15S ramps;
- **3D** – Closures of Jurupa to I-15N and I-15N to I-10E and I-10W ramps;
- **3F** – Closure of EB I-10 to NB I-15 connector and both NB ramps at 4th Street; and
- **4B** – Closure of SB I-15 to WB and EB SR 60.

The following describes how each tool was used:

- **CA4PRS** is a sketch-planning tool that was used in the preconstruction analysis and planning stage in order to identify rehabilitation strategies such as closure schemes that optimized construction production, schedule, and minimized inconvenience to the public. It was used in the second phase to analyze the preferred alternative and develop a more detailed staging analysis plan. CA4PRS also was chosen because results from this tool were easily integrated into traffic simulation tools for the calculation of road user costs.
- **HCM Demand-Capacity Model (HCM)** was used to analyze the impacts of the work zone closure strategies identified through CA4PRS. Using this model, the analysts were

able to calculate total and maximum delays as well as road user costs. The California Freeway Performance Measurement System (PeMS) was used to estimate traffic demand.

- **Dynameq**, a mesoscopic simulation modeling tool, was used to assist in the development of the transportation management plan (TMP). Dynameq was used to evaluate the delays stemming from the six staging scenarios. It also was used because it incorporated the impacts of detour routes in generating the delay calculations.

Although different tools were utilized during the various stages of the project, the agency managed to achieve consistency by following some of the concepts stated earlier in this chapter:

- **Choose the tool most reliable for extracting the outputs needed to generate the performance measures established**.
  - The agency needed a simple analysis using historical work zone data that could guide them towards appropriate work zone and lane closure strategies. Sketch-planning tools, specifically, CA4PRS was best used for determining appropriate work zone strategies based on data from projects with similar characteristics and particular traffic conditions and scenarios.
  - Since CA4PRS did not have the appropriate modules for conducting HCM calculations at the time, the agency made the appropriate choice to use another tool, HCM demand-capacity model, order to calculate the necessary mobility measures needed to evaluate and compare the lane closure alternatives.
  - In order to determine appropriate detour routes, the analysts needed the use of a traffic modeling tool that analyzed diversions and route shifts. The agency chose the appropriate tool that would generate these performance measures, mesoscopic tool Dynameq.
- **Choose the tool that is most appropriate for producing MOEs by the focus level**.
  - One example of how the agency followed this concept is through their choice of using a mesoscopic model. Since the traffic analysis for the project was for a larger study area, it might have been appropriate to use a macroscopic model. However, because of the number of detour routes involved in the analysis, macroscopic could not be used and microscopic simulation would be too resource intensive and complex for a study area of this size. The analysts, therefore, chose the most appropriate tool, mesoscopic, for the size of the project area and the scope of the analysis.
- **Further checks on the modeling and analysis tool results should include error checking of the model network coding, volumes, and speeds by comparing the model inputs and outputs with observed traffic statistics**.
 - PeMS was used to verify the travel demand forecasts.

6.3 SENSITIVITY ANALYSIS

The previous sections discussed the potential for inconsistencies with the analysis results and described how to reconcile those differences. Because of the dynamic nature of traffic conditions, sensitivity analysis can be used for verifying the quality and accuracy of results as well as providing further insight into acceptable ranges of results based on different traffic conditions and scenarios. This section is structured to provide an introduction to sensitivity analysis and its role within a work zone traffic analysis. The subsequent parts of the section

provide an overview of how and when to use sensitivity analysis during different stages of the project, such as during:

- Demand forecasting and capacity analysis;
- Model validation and calibration; and
- Alternatives analysis – decision-making and performance monitoring.

Each section describes how sensitivity analysis can be used for that particular stage. Case studies and examples explain the key concepts for applying such analysis tools and methods.

Introduction and Purpose of Sensitivity Analysis

Sensitivity analysis is a quantitative methodology that can be employed to do the following:

- Reconcile the variations in MOEs and analysis results;
- Determine the robustness of a result;
- Support recommendations or decisions;
- Identify critical values or solutions;
- Better understand the relationship between different variables, inputs, and outputs;
- Identify potential errors; and
- Improve and ensure accuracy of a model.

How a sensitivity analysis is conducted or structured can differ depending on its purpose and the resources available to conduct the analysis. There are some common steps involved in most sensitivity analysis. These steps include the following:

- Defining the objective of the sensitivity analysis – answering the question "What to test?"
- Determining which parameters to vary and which to remain constant.
- Determining what to observe.
- Determining which analysis outputs are relevant to the objective.
- Determining the design of the analysis – such as the combination of parameters, which parameters to vary, when they should change, and by how much.

Sensitivity Analysis in Demand Forecasting and Work Zone Capacity Analysis

This section provides an overview of how sensitivity analysis can be used to further support results from demand forecasting as well as work zone capacity analysis. As with most analysis tools there are limitations and gaps in a travel demand model's capability to capture the potential impacts of work zone alternatives and mitigation strategies (i.e., travel demand management, intelligent transportation systems, and traveler information strategies), as well as the effects of certain scenarios and travel conditions (i.e., normal peak and off-peak conditions, incident, special events, and work zones).

All forecasts are subject to uncertainty, as minor changes to certain model parameters can significantly impact the demand and capacity results of a model. It also can impact the measures

derived from demand and capacity such as the project's mobility (delay, queue, and speed) impacts, benefits, and costs. Therefore, it is important to understand the potential variations in demand forecasts and capacity estimations, especially when using such to estimate other impacts and benefits.

Sensitivity analyses can be conducted to validate and support the methodologies used to estimate work zone traffic demand and capacity. It also can aid in identifying the factors that impact demand and capacity, as well as the appropriate demand and/or capacity ranges that could be expected for particular work zone projects and alternative scenarios. The following provides examples describing how sensitivity analyses can be used to support demand and capacity measures for work zones.

Demand/Capacity Scenarios – Q-DAT

In one sensitivity analysis approach, the Texas Transportation Institute (TTI) utilizes their developed tool, Q-DAT, **to evaluate potential work zone alternatives by varying demand and capacity levels to determine how they impact delay and queues in the project area**. In Q-DAT, the delay and queue estimation function of the tool calculates delay per vehicle and average queue length for three scenarios with varying traffic volumes and work zone capacities, "Expected Case," "Best Case," and "Worst Case."

- **Expected Case –** In the "Expected" case, the traffic volumes and work zone capacity are based on user input. These could be based on experience, historical information, or field observations.
- **Best Case –** The "Best Case" reflects traffic volumes that are 10 percent lower and work zone capacity 10 percent higher than the user inputs.
- **Worst Case –** The "Worst Case" scenario is based on traffic volumes that are 10 percent higher and work zone capacity that is 10 percent lower than the user input.

Analyzing the variations in queue and delay impacts of these three scenarios serves as a sensitivity analysis for determining how varying demand and capacity levels impact mobility within a work zone. By evaluating a work zone project based on these three scenarios, an agency can have a wider spectrum or range of potential mobility impacts that could be expected at the work zone. Such information can be used to shape mitigation strategies as well as potential work zone alternatives (i.e., nighttime construction, partial and full lane closures, and detours) they may consider.

Variations in Traffic Demand and Capacity Parameters Due to Specific Travel Conditions

Sensitivity analyses can be used to determine appropriate demand and capacity values for various traffic conditions and scenarios. One example of this approach is an FHWA sponsored research report, *Development of Highway Capacity Manual Methodologies To Assess Advanced Traffic Management Strategies That Influence Traffic Demand*, which presents a methodology using different demand/capacity scenarios to develop travel time estimates that can be used to support the analysis of active transportation and demand management (ATDM) strategies' impacts.[43] To predict the variability of demand in a project area, historical demand

data is collected. The demand scenarios utilized in the report include 5 percent, 20 percent, 50 percent, 80 percent, and 95 percent demand scenarios. Additionally, capacity scenarios are generated. The capacity scenarios are constructed from historic data on incident and weather data for the facility (or facilities). After evaluating various scenarios with different combinations of capacity and demand values, the analyst determines a set of demand and capacity adjustment factors as shown in Tables 74 and 75.[43] These factors can be applied to the original model volumes and demands to adjust for particular mobility conditions.

Table 74. Example Scenario Demand Adjustment Factors

Demand Factors	Demand Scenarios				
Capacity Scenarios	5th Percentile	20th Percentile	50th Percentile	80th Percentile	95th Percentile
Fair Weather, No Incidents	0.88	0.93	0.96	0.99	1.01
Fair Weather, Single Lane Closed	0.88	0.93	0.96	0.99	1.01
Fair Weather, 2+ Lanes Closed	0.88	0.93	0.96	0.99	1.01
Poor Weather, No Incidents	0.88	0.93	0.96	0.99	1.01
Poor Weather, Single Lane Closed	0.88	0.93	0.96	0.99	1.01
Poor Weather, 2+ Lanes Closed	0.88	0.93	0.96	0.99	1.01

(Source: Dowling, 2011.)

Table 75. Example Scenario Capacity Adjustment Factors

Capacity Factors	Demand Scenarios				
Capacity Scenarios	5th Percentile	20th Percentile	50th Percentile	80th Percentile	95th Percentile
Fair Weather, No Incidents Present	1.00	1.00	1.00	1.00	1.00
Fair Weather, Single Lane Closed[a]	0.58	0.58	0.58	0.58	0.58
Fair Weather, 2+ Lanes Closed[a]	0.25	0.25	0.25	0.25	0.25
Poor Weather, No Incidents Present	0.93	0.93	0.93	0.93	0.93
Poor Weather, Single Lane Closed[a]	0.51	0.51	0.51	0.51	0.51
Poor Weather, 2+ Lanes Closed[a]	0.18	0.18	0.18	0.18	0.18

(Source: Dowling, 2011.)

[a] Capacity Adjustment Factor = 1.00 – Proportion Capacity Reduction.

   For incidents, capacity adjustment factor is applied only to section and time slices where and when incident is present. For weather, capacity adjustment factor is applied to all sections and time slices.

This methodology allows analysts to evaluate the impacts and benefits a variety of ATDM strategies that may be considered to mitigate the impacts of various work zone configurations and construction alternatives. This also ensures that the analyst's model of the work zone is calibrated to the specific demand and capacity values expected in the field for particular scenarios. Adjustments of the demand and capacity values enable analysts to attain improved confidence for their calculated travel times and other performance measures.

Travel Demand Diversion

A sensitivity analysis also can be used for estimating and/or evaluating trip diversion due to the work zone. One such tool, NETZONE, has the ability to estimate demand diversion based

on different work zone project types and strategies. In NETZONE, the demand diversion model, which estimates the reduction in total demand and the diversion to other routes due to the construction work, is developed based on data from multiple work zone projects under different travel conditions (i.e., weekday, weekend, peak, off-peak, etc.) in California.[44]

With NETZONE an analyst may have to apply the demand diversion model. Several scenarios can be run using the demand diversion model. NETZONE was run on a case study for the SR 41 corridor network in Fresno, California. The three scenarios analyzed included:

- **Scenario I –** Before construction;
- **Scenario II –** During construction (do nothing scenario); and
- **Scenario III –** During construction with pre-trip information and media campaign.

The results of the demand diversion model provide general statistics about the facility or project. These statistics include total cost, delay, average cost, and maximum delay, as shown in Table 76.[44] This analysis can be used to gain further insight on how variations in demand affect mobility measures and costs. Additionally, this analysis also can be used to compare and select among various alternatives or scenarios.

Table 76. NETZONE Example General Statistics

Scenario	Total Cost (Hour)	Total Delay (Hour)	Average Cost (Hour)	Maximum Delay (Hour)
I	11,560	3,796	0.0049	0.1783
II	13,303	5,232	0.0054	0.9083
III	12,378	4,659	0.0052	0.9156

(Source: Zhang, Shen, Nie, and Ma, 2012.)

Sensitivity Analysis in Model Validation and Calibration

This section provides an overview on the use of sensitivity analysis to verify model outputs, as well as the accuracy or credibility of the model results. **The sensitivity analysis also can be used to identify potential errors in model analysis outputs and/or MOEs.**

The FHWA Report *Traffic Analysis Toolbox Volume III* noted that a sensitivity analysis was recommended to assess the reliability of microsimulation results.[29] The sensitivity analysis for this effort could include varying certain model parameters or changing the demand levels to determine what the impact may be on the simulation results. Some examples of its use include determining driving behavior parameter values that will best fit the project and the area. Impacts can be compared to field observations to verify what the parameter values should be. As a result of the sensitivity analysis, parameters can be customized to the work zone site characteristics, instead of using defaults. This helps to ensure the accuracy of the model outputs and analysis results.

VISSIM Example

A study by Chatterjee, et al. (2009) from the University of Missouri-Columbia involved a sensitivity analysis testing combinations of VISSIM model parameter values in order to determine the appropriate values for particular work zone configurations.[45] The study evaluated combinations of three different parameter values for several work zone configurations such as a two- to one-lane work zone and a three- to two-lane work zone. The three parameters included:

- **CC1** – Desired time headway. This parameter was evaluated between the values of 0.9 to 1.8 seconds in increments of 0.1 second.
- **CC2** – This parameter corresponds to the threshold that restricts longitudinal oscillation beyond a certain safety distance that varied. The parameter was evaluated between the values of 15 to 60 feet at increments of 5 feet.
- **Safety Distance Reduction (SRF) Factor** – This parameter refers to the reduction in safety distance to the trailing and leading vehicle in the desired lane and the safety distance to the leading vehicle in the current lane. This parameter was evaluated from the default value of 0.6 to 0.15 at increments of 0.05.

Scenarios of different combinations of the three parameters for each of the work zone configurations were generated and modeled using VISSIM (version 4.3). Note that the parameters and their values may vary in more recent versions; however, the following methodology should still be applicable for determining work zone capacity. Outputs such as occupancy and delay performance were collected to compare the different scenarios. The scenarios or combinations where model occupancy volumes exceeded the occupancy thresholds (determined through field occupancy data) were discarded from the analysis results. The end product of this sensitivity analysis included look-up tables that show the appropriate parameter values for different work zone configurations. In order to use the look-up tables, an analyst must first determine where their project or work zone alternative fits on a lane distribution plot based on the percentage of trucks in the field and work zone configuration. In this plot, an analyst would find the index number that best corresponds with the estimated capacity and percent of traffic on the right lane of their project. An example lane distribution plot is shown in Figure 33.[45] If an agency has a 2 to 1 configuration with a 5 percent truck percentage on the field, their analyst(s) can use this figure to determine the appropriate model parameter values to use when conducting the simulation. If the project area has a proportion of 11 percent for right lane traffic and a capacity of 1,550 vphpl, the lane distribution plot shown in Figure 33 shows that the index number associated with their project is number 19.
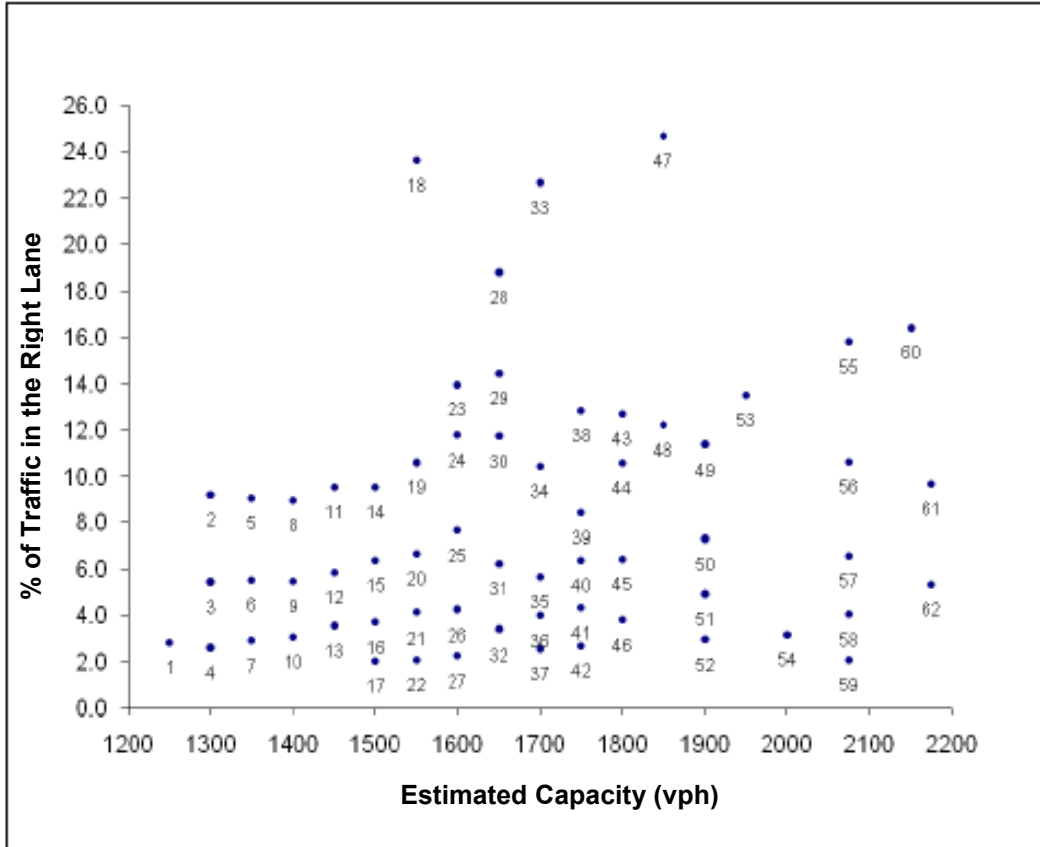
Figure 33. Lane Distribution at 1,000 Feet Upstream of Taper for Five Percent Trucks in a Two to One Configuration

(Source: Chatterjee, Edara, Menneni, and Sun, 2009.)

In the next step, the analyst would then refer to the look-up tables shown on Figure 34 to find the corresponding CC1, CC2, and SRF factor parameter associated with index number 19.[45] According to the table, the parameter values associated with this example project are: 1) CC1 of 1.4; 2) CC2 of 40; and 3) SRF factor of 0.55.

Index	CCI	CC2	SRF	Index	CCI	CC2	SRF	Index	CCI	CC2	SRF
1	1.8	55	0.60	48	1.4	15	0.15	95	1.0	50	0.50
2	1.8	45	0.60	49	1.1	30	0.40	96	1.1	45	0.50
3	1.8	45	0.55	50	1.0	35	0.40	97	1.5	20	0.30
4	1.8	45	0.50	51	1.0	35	0.35	98	1.0	45	0.40
5	1.7	45	0.60	52	1.0	35	0.30	99	1.0	45	0.45
6	1.7	45	0.55	53	1.3	15	0.15	100	1.0	45	0.50
7	1.7	45	0.50	54	1.0	30	0.25	101	1.3	30	0.35
8	1.6	45	0.60	55	1.0	25	0.35	102	1.4	25	0.30
9	1.6	45	0.55	56	1.0	25	0.30	103	1.4	20	0.30
10	1.6	45	0.50	57	1.0	25	0.25	104	1.5	15	0.20
11	1.5	45	0.60	58	1.0	25	0.20	105	1.0	40	0.40
12	1.5	45	0.55	59	1.0	25	0.15	106	1.0	40	0.45
13	1.5	45	0.50	60	1.1	15	0.15	107	1.2	30	0.35
14	1.4	45	0.60	61	1.0	20	0.20	108	1.0	40	0.50
15	1.4	45	0.55	62	1.0	20	0.15	109	1.1	35	0.45
16	1.4	45	0.50	63	1.8	55	0.55	110	1.5	15	0.15
17	1.4	45	0.45	64	1.8	55	0.60	111	1.3	20	0.30
18	1.8	15	0.20	65	1.8	45	0.60	112	1.4	15	0.20
19	1.4	40	0.55	66	1.7	45	0.50	113	1.0	35	0.45

Figure 34. Parameter Combinations for Two- to One-Lane Configuration

(Source: Chatterjee, Edara, Menneni, and Sun, 2009.)

Alternatives Analysis – Decision-Making and Performance Monitoring

This section describes how **sensitivity analysis can be used in the decision-making process for choosing among different work zone alternatives or for determining which strategies and/or mitigation measures can be used to maintain a certain level of mobility across the work zone area**. The following lists examples of these uses:

- Sensitivity analysis could be used to determine the impacts of varying the number of lanes closed, extent of closures, and the duration of construction;
- Sensitivity analysis also can be used to determine the optimal methods for dissemination of travel information, as well as for evaluating the impacts of this mitigation strategy on mobility; and
- Sensitivity analysis can be conducted to determine the impacts if traveler information was disseminated within 5 minutes of an incident occurring at the work zone versus 10 minutes or 15 minutes.

For choosing amongst alternatives, sensitivity analysis can be used to**:**

- Determine a threshold or range that the project must meet in order to achieve the construction schedule or financial objectives**;** and
- Determine the sensitivity of total project costs to various measures and project characteristics such as traffic flow rates and work zone length**.**

An example of how sensitivity analysis can be used for determining optimal work zone alternatives is a study by Tang and Chien (2009) where the researchers developed a model for optimizing work zone schedules jointly considering the time-varying traffic diversion, variable maintenance cost, and production rate of different maintenance crews.[46] The authors' model identifies the total cost (agency and user cost) associated with different combinations of these factors. An agency may use such a model to plan maintenance activities cost-effectively and choose among different work zone alternatives. This model optimizes a work zone schedule based on two modules:

1. Diversion module that determines the time-varying traffic diversion; and
2. Genetic Algorithm (GA) module that uses the redistributed traffic flows from the Diversion module in order to generate improved work zone schedules and update the initial/previous work zones schedules for the next iteration.

The work zone schedule goes through several iterations of Modules 1 and 2 until an optimal schedule is achieved when a threshold, in this case the minimized total cost, is reached.

This approach was applied on a resurfacing project in New Jersey. The analysis served to analyze different combinations of scenarios, including the following:

- **Scenario A** without traffic diversion; and
- **Scenario B** with traffic diversion.

Additionally, the analysis applied four potential maintenance crews with varying maintenance costs and production times to the two scenarios, which brought the total number of scenarios to eight as shown in Figure 35.[46] The table also summarizes the combined effects of traffic diversions and different construction methods on the project total cost.

TABLE 6 Scenarios "A" and "B": Summary of Cost Components for Various Maintenance Crews ($AADT_m$ = 45,000 and $AADT_a$ = 25,000)

| Scenarios | Index of Maintenance Crews | Numbers of work zones / work breaks | Maintenance Cost ($) | Idling Cost ($) | Road User Cost | | | | Minimal Total Cost ($/lane) | Project Duration (Hours) |
					Queuing Delay Cost ($)	Moving Delay Cost ($)	VOC& Crash Cost ($)	Sub Total ($)		
"A" Without Traffic Diversion	1	5 / 4	129,300	9,200	13,190	4,807	868	18,865	157,365	55.25
	2	5 / 4	129,915	12,800	3,665	3,628	250	7,543	150,258	53.50
	3*	3 / 2	129,215	5,400	4,489	4,426	306	9,221	143,836*	36.50
	4	3 / 2	134,055	6,800	1,085	3,405	83	4,573	145,428	34.00
"B" With Traffic Diversion	1	2 / 0	126,300	0	6,118	13,215	445	19,778	146,078	37.75
	2	2 / 1	126,915	2,400	2,805	9,229	216	12,250	141,565	34.50
	3*	3 / 2	129,215	4,600	2,665	4,603	190	7,458	141,273*	35.50
	4	3 / 2	134,055	5,600	1,809	3,654	131	5,594	145,249	32.50

Figure 35. **Summary of Cost Comparison for Scenarios and Maintenance Crews**

(Source: Tang and Chien, 2010.)

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After the scenarios were developed, a sensitivity analysis was conducted in order to evaluate the benefit of traffic diversion by varying the mainline AADT ($AADT_m$) incrementally from 30,000 vpd to 60,000 vpd for both Scenarios A and B. The minimized total costs associated with the sensitivity analysis are shown in Figures 36 and 37. The sensitivity analysis showed that in comparing maintenance crews 1 and 2 (Figure 36), diverting traffic proved to be the most economical strategy if less productive maintenance crews were employed for work zones on heavily traveled highways. However, it also showed that a more productive maintenance crew would be just as cost-effective if traffic was not able to divert to alternate routes.
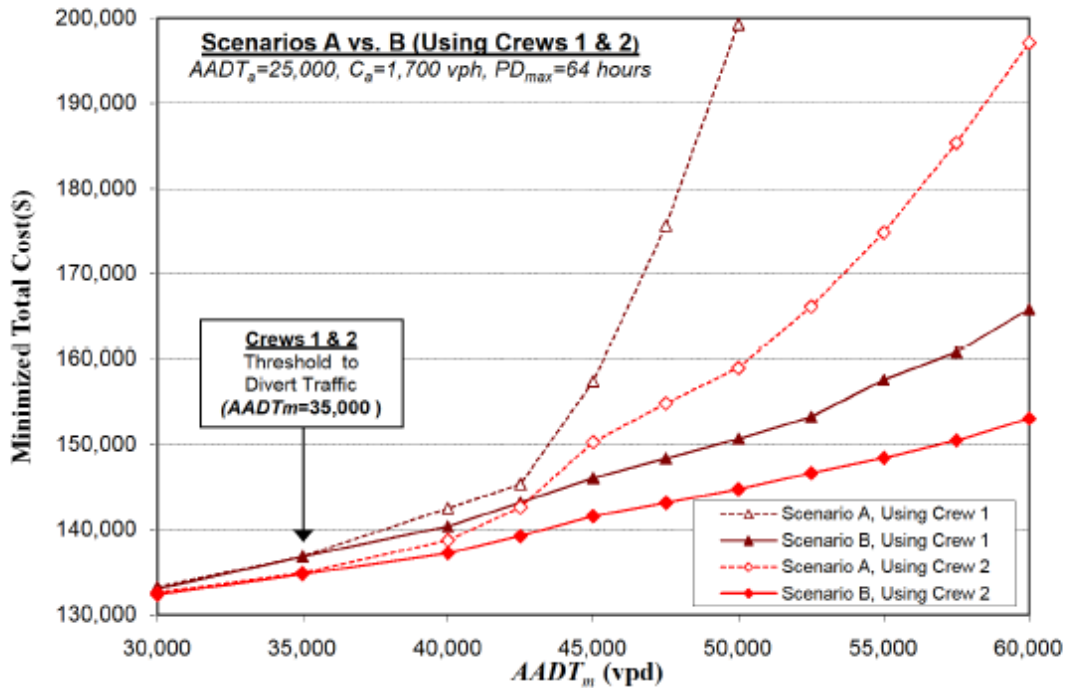
Figure 36. Sensitivity Analysis Results for Crews 1 and 2

(Source: Tang and Chien, 2010.)

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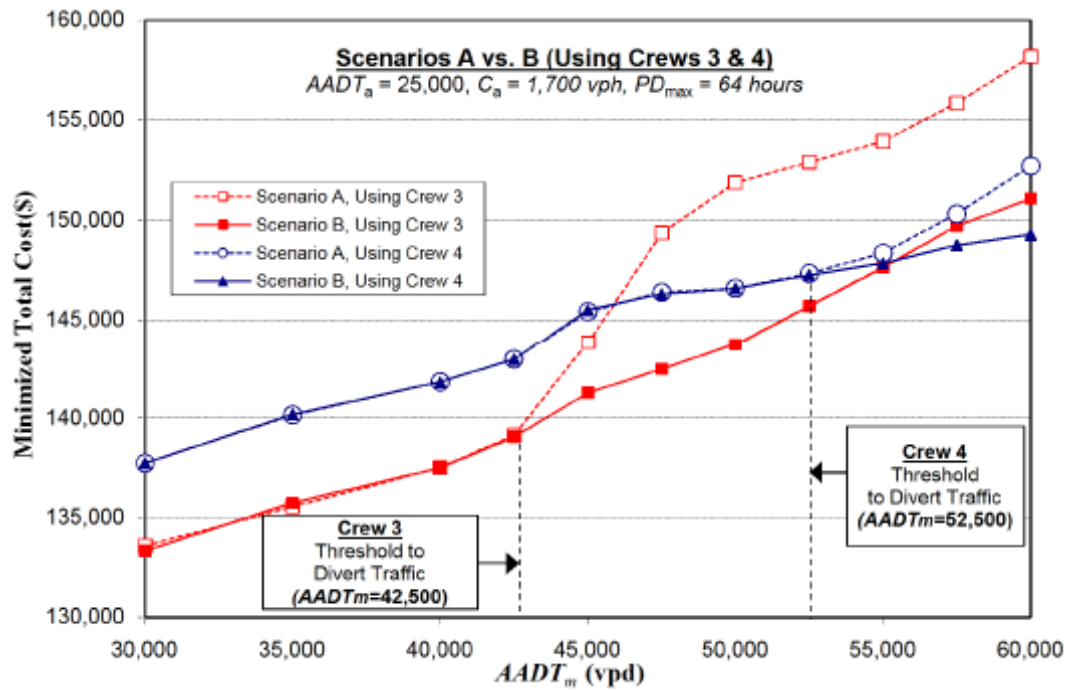
Figure 37. Sensitivity Analysis Results for Crews 3 and 4

(Source: Tang and Chien, 2010.)

7.0 EVALUATING FACTORS FOR MOTAA RECOMMENDATIONS

This chapter presents a mix of quantitative and qualitative factors that should be considered in a Maintenance of Traffic Alternatives Analysis (MOTAA), in addition to the mobility-based performance measures generated through the traffic modeling analysis. The first section of this chapter describes the various factors and details how they can be incorporated into the evaluation and comparison of alternatives. The second section is dedicated to measures of safety in relation to a work zone traffic analysis. Typical work zone safety analysis utilizes historical crash data to measure the safety impacts of the work zone, as well as to identify potential mitigation measures that minimize safety impacts. This section also describes an additional form of measuring the safety impacts of projects through surrogate measures of safety, and how to generate the safety measures, and where these considerations fit into the MOTAA process.

7.1 WORK ZONE KEY FACTORS

While modeling analysis tools produce certain measures that could be used to evaluate and compare work zone alternatives, there are additional qualitative and quantitative measures that may not be easily captured by such tools. This section describes how these key factors can be used to support the development and evaluation of work zone alternatives.

This section is structured to present the key factors into two categories: 1) development of potential work zone alternatives; and 2) evaluating and comparing work zone alternatives. Subfactors within the first category include those related to traffic operations, public information and awareness, and construction and contracting options. Subfactors within the category of evaluating work zone alternatives include environmental and land use impacts, project financial factors, and road user costs.

Development of Potential Work Zone Alternatives

There are several factors that an agency may need to consider early on in the project development process in order to develop the potential work zone alternatives that will be modeled or evaluated during the alternatives analysis. These factors have the ability to shape the development of the alternative. Additionally, these factors also can address which supporting strategies could be incorporated within those alternatives. Incorporated into the work zone alternatives, these strategies have the potential to affect the mobility and safety impacts and performance measures of various alternatives. Three such factors, i.e., traffic operations, construction and contracting factors, and public information and awareness, are discussed in this section.

Traffic Operations

The Traffic Operations factor includes strategies and programs that serve to improve and/or optimize mobility and safety within the work zone area. This factor is considered in order to evaluate and compare work zone alternatives and to assess the effectiveness of certain mitigation measures that could help the agency meet their project goals and objectives. There are certain

strategies that support the key factor of traffic operations. The following lists examples of such strategies as well as how they can be used to shape and support work zone alternatives.

- **TDM Strategies** – Demand management strategies provide mode shift incentives that encourage people to use alternative modes of transportation as a way of relieving traffic congestion. TDM strategies can include transit, HOV, and park-and-ride incentives and programs. These strategies should be considered as mitigation strategies that can support the work zone alternatives and aid an agency with meeting their goals and objectives. For instance, an agency may choose to implement park-and-ride and transit incentives in order to reduce congestion during peak travel in the work zone project area.
- **Traffic Operational Improvements** – Traffic operational strategies include projects and programs that help optimize or improve traffic flow along transportation facilities. Some examples of these improvements include signal phasing/coordination, geometric improvements, and temporary signals. Similar to TDM, traffic operational improvements can support existing work zone alternatives in order to minimize or mitigate the work zone's mobility impacts. For instance, one potential work zone alternative may be to establish diversion routes. To ensure these detour options are able to handle the additional demand, signal phasing/coordination improvements can optimize traffic flow and operations along these routes.
- **Incident and Enforcement Strategies** – Incident and enforcement strategies can aid in clearing incidents and/or diverting traffic quickly and efficiently. These strategies could include improving service patrols response, traveler information, and signage. Such strategies can help support work zone alternatives and aid the agency in achieving certain project goals and objectives, especially those related to improving safety and reducing mobility impacts in and around the project area.
- **Work Zone Safety** – Increasing work zone safety strategies can aid in preventing incidents along work zone corridors. Work zone safety strategies can serve as forms of mitigation techniques to achieve certain safety goals and objectives. Additionally, alternatives could be evaluated for how effectively they address work zone safety project goals and objectives such as reducing worker incidence and crash frequency and severity rates. Safety is discussed in greater detail in Section 8.2.

Construction and Contracting Factors

The construction and contracting factors address the various options that may have the ability to optimize the project schedule, construction duration, use of resources, and costs. Consideration of such factors can aid an agency in shaping their list of work zone alternatives and in achieving project goals and objectives. Various strategies that may be considered as part of these factors can serve as alternatives or may be incorporated into the work zone alternatives considered for the MOTAA. Example strategies related to construction and contracting include the following:

- **Construction Phasing/Staging Strategies** – Staging of projects refer to how the contractor will position the equipment and material. Phasing refers to the sequencing of various aspects of a project. These types of strategies can serve as potential work zone alternatives that address different options for work zone strategies (i.e., full road closure,

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lane closures, and detours) and phasing options for when, and in which order, construction tasks and/or project sections are completed.

- **Contracting Strategies and Project Delivery Methods** – These types of strategies provide alternative ways of contracting the work and delivering the project. These could be incorporated into certain work zone alternatives as ways of accelerating construction duration and they may be considered as options for work zone alternatives analyzed within an MOTAA. Some examples of alternative contracting strategies that have the potential to optimize and/or accelerate project delivery and schedule include:
  - A+B Bidding – This contract combines the cost to perform the work (component A) and the time to complete the project (component B). The bidder with the lowest overall A and B combined bid is awarded the contract.
  - Incentive/Disincentive Contracts – With these contracts, the contractor is provided a monetary incentive for completing the project ahead of schedule and is penalized with a disincentive fee for delays. A similar version of the incentive/disincentive contract is the "No excuse incentives" contract where a contractor is given a firm completion date with incentives for completing the work by or before that date.
  - Design-Build – This is a project delivery method where the agency combines procurement for both the design and construction services into a single contract from one private entity.
  - Construction Manager/General Contractor – This is a two-phase project delivery method in which a construction manager is selected for both the preconstruction and construction services of a project.
- **Other Innovative Construction Strategies** – These include innovations in construction strategies and use of materials that aid in improving the project schedule. Examples include using precast members, prefabricated structural systems, rapid strength concrete, and polymer modified concrete. These strategies also could be incorporated into the development of particular work zone alternatives considered for an MOTAA.

Public Information and Awareness

The public information and awareness factor include strategies that inform nearby residents, businesses, and facility users of the project's progress, updates, and impacts. Informing all relevant stakeholders that may be involved or impacted by the project is key for project approval, keeping on schedule, and reducing mobility and safety impacts in and around the project area. This factor and supporting strategies should be considered within an MOTAA to support work zone alternatives and mitigate impacts of the project. Strategies that fall into this factor category may include:

- **Media Outlets for Project Background and Information** – These types of public information and awareness strategies provide the community background on the project, goals, and objectives as well as a forum for the public to voice comments, concerns, and suggestions. Such strategies could include community and stakeholder meetings, the distribution of brochures and press releases, creation of a promotional web site, and provision of a hotline to provide information and updates regarding the project and construction progress. These strategies inform the agency of specific concerns and issues that may impact the effectiveness and/or success of the project and work zone

alternatives considered. Furthermore, such strategies can support particular work zone alternatives. For instance, public information strategies could inform users of detour routes and when to avoid the project area due to lane and road closures.

- **Traveler Information** – Traveler information strategies are another form of public information techniques that can help an agency support work zone alternatives and achieve their project goals and objectives. Traveler information strategies include web sites providing vital traveler information (i.e., 511), highway advisory radio (HAR), and dynamic message signs (DMS). These provide road users pre- and en-route information regarding expected travel times, congestion levels, and detour options due to the construction. Such strategies can be incorporated into work zone alternatives to help mitigate safety and mobility impacts.

Evaluating and Comparing Work Zone Alternatives

The previous chapters on alternatives analysis presented some of the types of performance measures that could be extracted from some of the modeling and analysis tools. These outputs primarily consist of mobility measures that could be used to compare and evaluate alternatives. As previously mentioned, there are additional qualitative and quantitative factors that also should be considered in an alternatives analysis. This section presents several types of factors that should be incorporated into the criteria and measures used to select a preferred work zone alternative. These factors, as discussed in the following sections, include environmental and land use impacts, project costs, and road user costs (RUC).

Environmental and Land Use Impacts

Environmental and land use factors require the agency to evaluate how a work zone alternative may impact the environment, as well as the residential and business community near the project area. Consideration for these factors can be used to ensure that the potential work zone alternatives are able to meet certain environmental standards. Additionally, these should be incorporated into an alternatives analysis or decision-making criteria in order to minimize negative impacts on surrounding residents, businesses, and services. Such considerations can include the following:

- **Right-of-Way** – An agency should consider any need for the acquisition or purchase of right-of-way for the specific work zone alternatives involved. The amount of right-of-way should be incorporated into evaluating the land use and community impacts of the work zone alternatives.
- **Air Quality Impacts** – This factor accounts for the vehicle emissions and greenhouse gas impacts of the project and/or work zone alternative. The air quality impacts of the work zone alternatives can be used as a criterion for evaluating and comparing the work zone alternatives, as well as identifying the need for certain mitigation strategies to reduce such impacts.
- **Noise Impacts** – This factor accounts for noise-level issues caused by the project that substantially exceed noise abatement criteria or existing noise levels in the area. Considerations for such impacts also can be used to compare and evaluate different work

zone alternatives as well as identify mitigation strategies to relieve or reduce noise impacts.

- **Impact to Retail Neighborhoods, Businesses, Employment Centers, Major Activity Hubs** – Residential and business community impacts should be a factor considered in comparing the impacts of various work zone alternatives. Consideration of this factor can be used to identify certain mitigation measures that can minimize the negative impacts of the project or work zone alternative on the community. Examples may include customer access to facilities and businesses, parking loss, change in property values, and decrease in sales and profits as a result of the work zone.
- **Political Sensitivity** – This factor considers the risk to the project due to any political issues and/or opposition to the project. The project and proposed alternatives would be evaluated early on in the project to assess the feasibility and probability of it obtaining approval. This factor can be used to eliminate certain alternatives that may potentially generate political opposition or involve unwarranted risk.

Project Costs

This factor includes the costs associated with implementing the project through the particular work zone or construction strategy selected, costs associated with incorporated mitigation and monitoring strategies, and any right-of-way costs. Such **costs are typically a major criteria element** of whether an agency will consider or recommend a particular work zone alternative. Several work zone-related project costs include:

- **Costs for Implementing Work Zone Alternative Strategies** – These costs could be related to the costs of pursuing the alternative strategies listed in the Construction Methodology and Innovation section versus the cost of traditional construction and contracting strategies.
- **Costs for Mitigation and Monitoring Strategies** – These costs would be related to implementing any mitigation measures identified to minimize the impacts of the project. It also should cover cost considerations for any monitoring activities put in place.
- **Right-of-Way Costs** – These costs are related to the acquisition of right-of-way for the project.

Road User Costs

Another factor for consideration when comparing and evaluating work zone alternatives is road user costs. Work Zone Road User Cost (WZ RUC) is defined as the incremental cost or value incurred by highway users and the community at-large as a result of a work zone alternative.[36] WZ RUC primarily refers to **monetary and nonmonetary components of work zone impacts.** These could include quantitative measures such as user delay, vehicle operating cost, and crash cost. WZ RUC also includes considerations for qualitative measures such as the environmental, business, and societal impacts of the work zone project. The costs of such impacts can be used to evaluate and compare the different work zone alternatives.

The following lists the typical components and considerations needed for calculating the WZ RUC. A work zone example also is used to illustrate the key points and processes involved for calculating the cost of delay. For the more detailed step-by-step process for calculating WZ RUC, including how the work zone example featured in this document can be used to calculate vehicle operating costs and other RUC components, please refer to the *Work Zone Road User Costs – Concepts and Applications*.[36]

> **Work Zone Example Project Description**
>
> The following example illustrates the work zone RUC methodology as detailed in the FHWA's *Work Zone Road User Costs: Concepts and Applications*. In this example, a pavement rehabilitation work zone project is being performed on a six-lane, urban interstate. The work zone features a single-lane closure in the northbound direction of the interstate. The following illustrates how the methodology can be used to compute the total delay costs generated by the work zone.

Step 1 – Inputs for Demand-Capacity Analysis

One of the first components of the WZ RUC calculation process is the data collection effort. The inputs needed to estimate the work zone impacts for computing the RUC of a project include: hourly traffic demand, traffic composition, work zone capacity, travel speeds, work zone configuration, and the maintenance of traffic (MOT) strategy(s).

> For the example, the input data would include the following:
>
> - The northbound lane carries an average daily traffic of 33,000 vehicles, of which eight percent are single-unit trucks and four percent are combination trucks.
>
> - There are also ramp closures. Traffic volumes on the closed ramps equal 1,000 vehicles per day, of which three percent are single-unit trucks and two percent are combination trucks.
>
> - The work zone project area is two miles long with a 24-hour/day single-lane closure. The estimated construction duration period is 20 days.
>
> - The unrestricted upstream approach has a speed limit posting of 55 mph. In the work zone area, the speed limit posted is 45 mph.
>
> - There is a three-mile detour road provided where the average speed is 40 mph.

Step 2 – Computing the Monetary Value of Delay

The total delay time is calculated as the sum of delay due to speed changes, speed reductions, stopping, queue, and detours that occur as a result of the work zone's implementation. The monetary value of delay due to these components is computed by multiplying the total delay time with the monetary value of travel time. The monetary value of travel time is the sum of the value of personal, business, and truck travel time, as well as the cost of freight inventory delay (for trucks only) and cost of vehicle depreciation (for all vehicles). The following steps describe how to calculate the monetary value of delay using the example.

1. **Value of travel time for passenger cars.**

- To determine the value of travel time for passenger cars, the analyst must first determine the total delay time. The total delay time is the sum of speed change delay, reduced speed delay, stopping delay, queue delay, and detour delay. Figure 38 presents how the total delay time of 10,192.6 vehicle-hours per day is computed for the example work zone.

- The next step is to determine travel delay costs per passenger by multiplying the total delay time with the unit travel time values per passenger.

- To determine these travel time values the analyst must estimate the unit value of personal and business travel time. For this example, personal travel time is determined to be $20.88/vehicle-hour. Business travel time is valued at $36.89/vehicle-hour.

- The analyst can then compute the hourly time value of passenger cars using the weighted average of travel time values considering both personal and business travel time. 2009 NHS statistics state that 93.7% of passenger cars are expected to be on personal travel while 6.3% are on business. Using these statistics and the hourly time values computed in the previous step, the weighted average travel time values can be computed for passenger cars through the following: *Hourly time value of passenger cars = (93.7% * $20.88) + (6.3%*$36.89) = $21.89/hour.*

- To estimate the delay costs for passenger cars on the northbound lanes, the analyst can use the following:
    - Percent of passenger cars on NB lanes = 88%
    - Estimated delay time for all vehicles = 10,192.6 vehicle-hours/day
    - Estimated delay time for passenger cars = 0.88* 10,192.6 = 8969.49 vehicle-hours/day
    - Estimated delay costs for passenger cars = 8969.49*$21.89/hour = $196,342.10 per day

2. **Value of travel time for trucks.**

- To determine the travel delay costs for trucks, the analyst must determine the truck travel time value. For this example, the hourly time value of single-unit trucks is $23.06/hour. The hourly time value of combination trucks is $29.65/hour.

- The analyst will then have to estimate the delay costs for both classes of trucks for the project using percentage of trucks, delay time for all vehicles, and the travel time unit values determined in the previous step.
    - *For single-unit trucks:*
        - Percent of single-unit trucks in example = 8%
        - Estimated delay time for all vehicles = 10,192.6 vehicle-hours/day
        - Estimated delay time for single-unit trucks = 8%*10,192.6 = 815.4 vehicle-hours/day
        - Estimated delay costs for single-unit trucks = 815.4 * $23.06/hour = $18,803.31/day
    - *For combination trucks:*
        - Percent of combination trucks in example = 4%
        - Estimated delay time for combination trucks = 4%*10,192.6 = 407.7 vehicle-hours/day
        - Estimated delay costs for combination trucks = 407.7*$29.65 = $12,088.42/day
        - *Estimated delay for all trucks = $18,803.31 + $12,088.42 = $30,891.73*

3. Time-related vehicle depreciation costs for all vehicles.

The third step in determining total delay costs for all vehicles is to determine the time-related vehicle depreciation costs for the three vehicle types: passenger cars, single-unit trucks, and combination trucks.

- Passenger Cars – Through previous calculations, the analyst has determined that the percent of passenger cars is 88 percent and that the estimated delay time for this vehicle class is 8,969.49 vehicle-hours/day. Therefore, if the hourly time-related depreciation cost for passenger cars is $1.225/hour, the estimated depreciation cost for passenger cars = 8969,49 * $1.225/hr or $10,987.62/day.

- Single-Unit Trucks – Previous calculations have shown that this example can expect 8 percent of all vehicles to be single-unit trucks. Additionally, this percentage of trucks generates a total delay time of 815.4 vehicle-hours/day. If the hourly depreciation cost for this truck class is $3.09/hour, the estimated depreciation cost for single-unit trucks is = 815.4 * $3.09/hr= $2,519.59/day.

- Combination Trucks – Previous calculations have shown that there are 4 percent combination trucks in this example that generate a total delay time of 407.7 vehicle-hours/day. If the hourly depreciation cost for combination trucks is $9.29/hour, then the estimated time-related depreciation cost *for this vehicle class is equal to 407.7 * $9.29/hour = $3,787.53/day.*

- *The* estimated *time-related depreciation cost for all vehicles = $10,987.62 + 2,519.59 + 3,787.53 = $17,294.74/day.*

4. Cost of freight inventory delay.

The final delay value component is the cost of freight inventory delay. This cost is determined by multiplying the number of trucks carrying freight by the hourly cost of freight inventory valuables.

- The first step in this process is to estimate the hourly cost of freight inventory valuables. For single-unit trucks this is $0.18/hour and for combination trucks this is $0.31/hour.

- The next step is to estimate the number of loaded freight trucks. For this example, the number of loaded single-unit trucks is 1,874 and loaded combination trucks are 964.

- The third step is to estimate the cost of freight inventory delay. With the average delay time for a vehicle per day at .309 hour/vehicle/day, the cost of freight inventory delay for trucks can be computed as the product of average payload * number of trucks * average delay time.

  - *For single-unit trucks = $0.18/hour * 1,874 * 0.30 hour/vehicle/day = $104.23/day*

  - *For combination trucks = $0.31 * 964 * 0.309 = $92.34/day*

  - ***Cost of freight inventory delay for all trucks = $104.23 +92.34 = $196.57/day***

5. The Total Delay Costs.

The total delay costs is equal to the sum of value of travel time for passenger cars, the value of travel time for trucks, time-related depreciation costs for all vehicles, and cost of freight inventory delay.

Total Delay Costs for the example = $196, 342.10 + 30,891.73 + 17,294.74 + 196.57 = $244,725.10/day.

Time	Mainline Traffic Volume	Total Delay Time (minutes/vehicle)					Delay Time for all vehicles (veh-hours /day)
		Speed Change	Reduced Speed	Stopping	Queuing	Total	
00-01	304	0.07	0.24	0	0	0.32	1.60
01-02	304	0.07	0.24	0	0	0.32	1.60
02-03	304	0.07	0.24	0	0	0.32	1.60
03-04	456	0.07	0.24	0	0	0.32	2.41
04-05	646	0.07	0.24	0	0	0.32	3.41
05-06	988	0.07	0.24	0	0	0.32	5.22
06-07	1558	0.07	0.24	0	0	0.32	8.22
07-08	2964	0.40	0.24	0.40	23.81	24.85	1227.34
08-09	3610	0.40	0.24	0.40	23.81	24.85	1494.84
09-10	2470	0.40	0.24	0.40	23.81	24.85	1022.79
10-11	1786	0.40	0.24	0.40	23.81	24.85	739.55
11-12	1710	0.47	0.24	0.40	23.81	24.92	710.20
12-13	1634	0.07	0.24	0	0	0.32	8.62
13-14	1710	0.07	0.24	0	0	0.32	9.03
14-15	1862	0.07	0.24	0	0	0.32	9.83
15-16	2470	0.07	0.24	0	0	0.32	13.04
16-17	3002	0.40	0.24	0.40	23.81	24.85	1243.08
17-18	3534	0.40	0.24	0.40	23.81	24.85	1463.37
18-19	2432	0.40	0.24	0.40	23.81	24.85	1007.05
19-20	1482	0.40	0.24	0.40	23.81	24.85	613.67
20-21	1254	0.47	0.24	0.40	23.81	24.92	520.81
21-22	684	0.07	0.24	0	0	0.32	3.61
22-23	456	0.07	0.24	0	0	0.32	2.41
23-24	380	0.07	0.24	0	0	0.32	2.01
Total delay time of mainline through traffic							=10,115.32
Detour delay time = 2.32 min/vehicle * 2000 vehicles= 4636 min							= 77.28
Total estimated delay time per day							10,192.6

Figure 38. Work Zone Travel Delay Analysis

Step 3 – Computing Vehicle Operating Costs (VOC)

Vehicle operating costs (VOC) are the costs incurred by road users as a result of vehicle use. It is calculated as the sum of vehicle operating costs associated with the speed change, stopping, queue idling, and detouring that occur as a result of the work zone. The vehicle operating costs is an aggregate measure of the consumption of the following resources while driving a vehicle between two points. It includes considerations for: fuel consumption, engine oil consumption, tire wear, repair and maintenance, and mileage-related depreciation.

Step 4 – Computing Crash Costs through Crash Analysis

The crash costs associated with work zones are a function of the changes in crash rates due to the presence of the work zone. Crash-related inputs for this part of the WZ RUC analysis include: crash rate at work zones, crash severity rating, and unit cost of crashes.

Step 5 – Emissions Analysis

Work zone-related emission costs are computed by determining the costs associated with the additional vehicle emissions resulting from reduced speeds and queuing. Vehicle emissions considerations include air pollutant emissions and greenhouse gases. Emissions cost is the product of the vehicle miles traveled, emission rate, and unit costs (cost/mile) by emission type. Several models such as the Static Emission Factor Model and Dynamic Instantaneous Emission Model can be used in order to estimate emission rates. The monetary values for emissions are typically derived from economic analyses of health impacts caused by the different types of emissions. Two sources of emission costs include the California Department of Transportation (Caltrans) estimates and HERS-ST Technical Report.

Step 6 – Accounting for Nonmonetary and Qualitative Factors

Additionally, WZ RUC analysis also takes into consideration additional factors such as noise, business, and societal impacts. Further details on these considerations are provided in the previous section on Environmental and Land Use Factors.

I-15 Devore Example

Background and Overview

In 2004, Caltrans applied an innovative, fast-track reconstruction program to a heavily traveled Long-Life Pavement Rehabilitation Strategies (LLPRS) project on I-15 in the area of Devore in southern California. This area covered a 4.5-kilometer (2.8-mile) stretch of badly damaged concrete lanes. It was rebuilt in only two single-roadbed continuous closures (also called "extended closures") totaling 210 hours, using counterflow traffic (opposite direction to the main traffic flow) and 24-hour-per-day construction operations. Traditional nighttime-only closures would have required 10 months worth of work. Instead, the reconstruction took 19 days, with each extended closure for one roadbed lasting 9 and one-half days.

The following describes the factors project managers and engineers considered before and during construction. Such strategies assisted decision-makers with selecting the optimal and most cost-effective work zone alternatives, use of resources, and traffic operation mitigation strategies to employ.

Development of Work Zone Alternatives and Mitigations Measures

The I-15 Devore Project included four closure work zone alternatives: 72-hour weekday, 55-hour weekend, 1-roadbed continuous (24 hours per day, 7 days per week), and 10-hour nighttime.[47] The factors, supporting strategies, and mitigation measures that were incorporated into the development of these strategies include the following:

- **Operational Considerations** – The project's traffic operational strategies included the use of moveable barriers during construction, which provided dynamic lane configurations that helped to balance traffic and accommodate peak direction traffic. The

travel demand management strategies implemented with this project included free commuter bus service to promote ridesharing. The enforcement and monitoring strategies included the provision of a project command center (agency coordination and monitored traffic and construction using CCTVs), the Construction Zone Enhanced Enforcement Program, which improved traffic control and enforcement in the construction work zone, and increased funding for California Highway Patrol to increase enforcement within the project area.

- **Construction Method and Innovation** – The project used innovative materials such as rapid-strength concrete mix, incentive/disincentive contracts.
  - For pavement design and material alternatives, Caltrans used a software model to make comparisons from the perspective of production scheduling and traffic inconvenience. As a result, Caltrans selected: 1) rapid-strength concrete with a 12-hour curing time rather than fast-setting hydraulic cement concrete with a 4-hour curing time; 2) a 15-centimeter (6-inch) new AC base, rather than a 15-cm lean concrete base; and 3) a widened 4.3-meter (14-foot)-wide lane, rather than the usual 3.7-meter (12-foot)-wide lane tied to a new concrete shoulder on the outermost truck lane.
- **Public Information and Awareness** – The project included a multifaceted outreach program. The project utilized systems that provided real-time work zone travel information through changeable message signs, the project web site, and a telephone hotline. Caltrans received and shared feedback from the local community through the High Desert Commuter Advisory Committee. Prior to construction, large employers and affected businesses were informed through project fliers, public meetings, and media outreach.

Factors Considered in Alternatives Analysis and Decision-Making

The following factors were considered when evaluating and deciding among the four closure scenarios:

- Project, Road User Costs, Construction Duration, and Mobility Impacts:
  - A preconstruction analysis was conducted in order to arrive at the optimal construction closure scenario and pavement design and material alternatives.
  - Project engineers used traffic simulation modeling analysis software to arrive at an optimal and economical scenario for rehabilitation closures.
  - The analysis compared the scenarios by cost, schedule duration, and delay impacts as shown on Table 77. The analysis concluded that the continuous/extended closure scenario would be the most economical.
  - Compared with traditional 10-hour nighttime closures, the preconstruction analysis indicated that the extended closure scenario would generate about 80 percent less total closure time, about 30 percent less road-user cost due to traffic delay, and about 25 percent less agency cost for construction and traffic control.
  - The I-15 northbound roadbed was closed for reconstruction, and northbound traffic was switched to the southbound side via median crossovers at the ends of the work zone. Traffic in the two directions shared the southbound lanes as counterflow traffic separated by the moveable barrier. The same process was repeated for reconstruction of the southbound roadbed.

Table 77. Closure Options for I-15 Devore Project

| Closure Scenario | Schedule Comparison | | Traffic Delay | | Cost Comparison (Million Dollars) | |
	Number of Closures	Closures (Hours)	Road User Cost (Million Dollars)	Maximum Delay (Minutes)	Agency Cost	Total Cost to Users and Agency
72-Hour Weekday	8	512	6.6	75	12.6	19.2
55-Hour Weekend	10	550	12.7	196	15.1	27.8
1 Roadbed Continuous	2	400	6.1	196	9.9	16.0
10-Hour Nighttime	220	2,200	10.0	36	20.4	30.4

7.2 WORK ZONE SAFETY ANALYSIS

This section discusses work zone safety factors and considerations within an MOTAA process, with a focus on surrogate measures of safety as it relates to work zone traffic analysis. The section introduces measures of safety by providing an overview of the differences between traditional traffic safety analysis versus the development of surrogate safety measures as a way of predicting and preventing future crashes. The section then provides examples of surrogate safety measures and their role in an MOTAA procedure.

Purpose of a Work Zone Safety Analysis

In general, most work zone assessment studies agree that crash rates appear to be higher during work zone periods than preconstruction conditions. The diverse and sometimes conflicting range of results from work zone research occur because the various projects studied often incorporate different work zone configurations and strategies, and exhibit different types of roadway and traffic characteristics. For instance, incident rates are typically seen to increase by approximately 20 to 30 percent within work zones relative to the area's normal crash rates.[48] Additionally, among these work zone incidents the predominant crash type seen are rear-end crashes.[49] Due to the significant potential increases in crash frequencies during work zone conditions, it is important for agencies to conduct work zone safety analyses to identify potential mitigation and/or preventative strategies that could improve safety within the project area. Additionally, when conducting a work zone safety analysis, agencies should be aware of the potential variations in results from work zone safety research. When possible, agencies and analysts should conduct work zone safety studies and analyses customized to their specific work zone's design and strategies, as well as the project area's traffic and road geometric characteristics.

Traditional Work Zone Safety Analysis

Work zone crashes are typically divided into two categories: crashes due to the presence of the work zone and crashes that would have occurred regardless of the work zone. Traditional work zone safety analysis consists of reviewing existing crash patterns prior to construction. These historical crashes are reviewed in order to estimate the potential crashes that would have

occurred regardless of the work zone's presence. In order to estimate potential crashes due to the work zone, traditional safety analysis typically requires reviewing crash patterns of a previous work zone project that has similar characteristics to the subject project. Although the traditional work zone safety analysis procedures may vary slightly between agencies, the process typically involves the following steps:

1. Identify completed work zone projects that share similar characteristics to the new project;
2. Review crash data for the similar work zone projects;
3. Review existing preconstruction crash data at the project location;
4. Determine best practices of design and mitigation measures for the new project based on review conducted in Step 2; and
5. Based on results from Steps 3 and 4, determine if there are crash patterns that could be addressed through design or mitigation strategies that minimize crash rates and severity prior to and during construction.

Using historical crash data, accidents also can be valued and used to compare the safety implications of work zone alternatives. For example, a United Kingdom Department for Transport (DfT) sponsored computer program, Quadro (Queues and Delays at Roadworks) estimates the increase in accident rates along a transportation facility as a result of the presence of construction.[50] It then converts this increase into a monetary value that can be used to evaluate and compare different work zone alternatives. In order to perform this calculation, the Quadro tool utilizes historical crash data. Crash rates for each facility type are collected during preconstruction conditions and with various types of work zone traffic control strategies. These rates are then multiplied by the estimated traffic volumes in the work zone to estimate the potential number of crashes that will occur when the work zone project is implemented. The difference between the crash rates at preconstruction and during construction is then converted to a monetary value by multiplying the average comprehensive cost for each crash severity level.[51]

Table 78 shows the Quadro road user cost outputs from a Wisconsin Department of Transportation work zone traffic analysis of a 24-hour freeway lane closure project. In this example, Wisconsin DOT analyzed the mobility and road user cost impacts associated with one of the project's diversion routes.

Table 78. Quadro Road User Cost Output Example

	Output Result
Average Accident Numbers (PIA[a]/Day)	
Main route without works	0.0767
Main route with works	0.0736
Diversion	0.1385
Impacts on Road Users	
Road user costs per day (dollars)	$45,587
Congested hours per day[b]	3

[a] PIA – Personal Injury Accidents.

[b] Delays Exceeding 15 Minutes.

Overview of Surrogate Safety Measures

While traditional safety analysis primarily focuses on mitigation measures based on historical crash data, **surrogate measures of safety addresses predictive and preventative strategies to improve safety within work zones**. Surrogate measures of safety are especially helpful in the absence of reliable or accurate historical crash data. The results of surrogate safety measures research and studies can serve a variety of different purposes:

- Such studies can be used to determine how certain project, facility, and driver behavior characteristics impact the probability of accidents occurring;
- These measures can determine how certain project and/or traffic characteristics relate to crash severity; and
- Surrogate safety measures can provide further insight on which mitigation measures will be most effective in minimizing the safety impacts of the work zone.

Research Developments and Analysis of Safety Analysis Surrogate Measures

Several research efforts have analyzed and developed surrogate safety measures with applications for work zones. Surrogate measures of safety can be characterized into two categories: conflict events and driver behavior characteristics. This section presents surrogate safety measures research conducted for these two specific categories.

Surrogate Safety Measures: Conflict Events

Much of the research has dealt with surrogate measures in regards to traffic conflicts. Conflict events can be described as potential crash situations due to safety concerns regarding the roadway design. Conflict events can lead to potential rear-end or angled collisions due to turns, merges, and lane changes. Some examples of surrogate measures regarding traffic conflicts that could be used to evaluate the severity of conflict within work zones include time to collision, post encroachment time, and deceleration rates.[52]

There also have been development efforts for modeling and analysis tools that provide insight on surrogate measures of safety in relation to conflict analysis. One of these tools is the Surrogate Safety Assessment Model (SSAM), which is an FHWA-sponsored project that analyzes narrowly averted vehicle-to-vehicle collisions in order to assess and predict the safety of a traffic facility and prevent or reduce the frequency of accidents occurring.[53] SSAM combines microsimulation and automated conflict analysis to calculate the following surrogate safety measures:

- Minimum time-to-collision (TTC);
- Minimum post encroachment time (PET);
- Initial deceleration rate (MaxD);
- Maximum speed (MaxS);
- Maximum speed differential (DeltaS); and
- Vehicle velocity change had the event proceeded to a crash (DeltaV).

SSAM provides outputs that include a table of conflicts identified in the analysis, including information regarding, time, location, vehicle information, and measures of conflict severity. Figure 39 provides a snapshot of the SSAM user interface with conflict icons color coded to display varying values of time-to-collision.
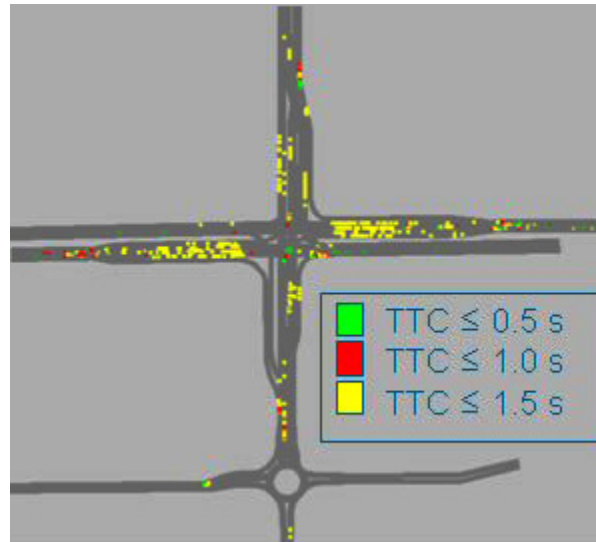
Figure 39. SSAM Screenshot

(Source: Federal Highway Administration, 2008.)

Surrogate Safety Measures: Driver Behavior Parameters

Other research efforts study the relationships between surrogate measures of safety and driver behavior characteristics. Several of these studies provide insight on how certain driver behavior characteristics can impact the frequency and severity of crashes. Some examples of how driver behavior characteristics have been used to develop surrogate measures of safety include:

- **Evaluating the relationship between driver behavior parameters and rear-end collisions –** One study by Sun and Benekohal (2004) looked at driver gap characteristics for evaluating the risk of rear-end collisions for vehicles in platoons.[54] This research quantifies the relationship between car-following parameters and safety performance measures in work zones. It involves studying the variations of time headway for different car-following models and work zone types.
- **Evaluating the relationship between driver behavior parameters and crash severity –** A research study by Li and Bai (2008) evaluated the use of measures such as deceleration rate, maximum speeds, and speed differentials at work zones to develop a measure that provides insight on the severity of potential collisions within construction zones.[55]
- **Evaluating the safety at ramp junctions –** Additionally, certain microsimulation tools can generate outputs and performance measures related to surrogate measures of safety. For instance, AIMSUN can be used for evaluating the safety at ramp junctions using

measures such as speed differential, maximum speed of the follower, and the deceleration rate of the follower vehicle during ramp-merging events.[56]

Use of Surrogate Safety Measures Within a MOTAA

For the most part, surrogate safety measures have been used at the research or academic level. Currently, there are very few instances of real-world applications of surrogate safety measures, particularly in work zones. Despite this, surrogate measures of safety can still serve a role within the MOTAA process. Some examples of how these measures could be used in evaluating work zone alternatives include the following:

- Surrogate measures of safety can be utilized as criteria elements for evaluating and comparing alternatives during the decision-making stage of an MOTAA.
- Additionally, the surrogate safety measures can be used to identify safety issues regarding the project or work zone alternative design. Such measures can provide insight on how to adapt or modify a particular alternative in order to meet a certain level of safety.
- Alternatively, they can be used to identify and determine the effectiveness of certain mitigation strategies for addressing work zone safety.

Summary of Surrogate Measures of Safety

Table 79 provides a summary of the example surrogate safety measures discussed. The table highlights the analysis method employed, the required data inputs, outputs, and limitations in evaluating and utilizing the safety measure.

Table 79. Summary of Safety Surrogate Measures

Measure	Analysis Method	Input Data	Purpose of Research and the Measure	Limitations	Reference
Crash Severity Index (CSI)	Statistical analysis	Driver Characteristics, Time, Environmental Conditions, Road Conditions, Crash Information, Traffic Control	CSI models were designed to quantify the risk level of a work zone with a numerical value between zero and one. A CSI of one indicates a very high-risk level in a given work zone, which infers that a fatal crash might take place if a crash occurs.	Predicted CSI values for fatal crash cases were not consistent with the actual severity outcomes collected with the research. Further research with crashes of varying severity levels is required to improve the CSI models.	Li, Y., and Y. Bai, 2008, Development of Crash-Severity-Index Models based on Work Zone Crash Severity Analyses, Transportation Research Board Conference Proceedings.
Platoon and Gap Analysis	Statistical analysis	Work Zone Type, Hourly Volume, Maximum Platoon Size	The probability of a rear-end crash and how many vehicles might be involved in this crash.	Work zone safety performance is difficult to evaluate due to the lack of reliable work zone crash data.	Sun, D., and R. Benekohal, 2004, Analysis of Car-following Characteristics for Estimating Work Zone Safety, Transportation Research Board Conference Proceedings.
Time-to-Collision (TTC), Post Encroachment Time (PET), and Deceleration Rate (DR)	SSAM, in conjunction with microsimulation	Conflict Point, Vehicle Speed, Acceleration, Driver Behavior, Traffic Signalization	Lower TTC, Lower PET, and Higher DR indicate higher probability of collision.	Large quantity of input data may be needed specific to the location.	Gettman, D., and L. Head, 2008, Surrogate Safety Measures from Traffic Simulation Models, Transportation Research Board Conference Proceedings.
MaxS and DeltaS	SSAM, in conjunction with microsimulation	Conflict Point, Vehicle Speed, Acceleration, Driver Behavior, Traffic Signalization	The measures provided insight regarding the likely severity of the (potential) resulting collision if the conflict event had resulted in a collision instead of a near-miss. Higher MaxS and DeltaS indicate higher severity of the resulting collision.	Large quantity of input data may be needed specific to the location.	Gettman, D., and L. Head, 2008. Surrogate Safety Measures from Traffic Simulation Models, Transportation Research Board Conference Proceedings.

Measure	Analysis Method	Input Data	Purpose of Research and the Measure	Limitations	Reference
Unsafety Density Parameter (UD)	Postprocess microsimulation modeling results	Car-following model parameters, section length, position, speed, and max breaking capacity of follower and lead vehicle, number and duration of simulation steps	The analysis highlighted the difference in safety level between fluid and "jerked" traffic flow using UD as the safety indicator. The analysis compared a ramp section under a metering scenario and a without-metering scenario. Results showed higher UD values are correlated with higher levels of congestion.	The analysis has primarily been used for comparing scenarios. Its use also is limited to evaluating highway segments since its focus is primarily on the potential for rear-end collisions. The accuracy of the modeling results also is dependent on the quality of the driver behavior parameters.	Torday, A., and A. Dumont, 2002, Safety indicator for Microsimulation-Based Assessments, Swiss Federal Institute of Technology, Laboratory of Traffic Facilities, LAVOC-EPFL, Lausanne, Switzerland.

8.0 ANALYSIS REPORT STRUCTURE

This chapter presents the essential components of an MOTAA report, including:

- Introduction and project background;
- Existing and future conditions;
- Alternatives considered;
- Alternatives analysis and decision framework methodology;
- Analysis results, recommended alternative, and mitigation strategies; and
- Post implementation and monitoring plan.

8.1 INTRODUCTION AND PROJECT BACKGROUND

This section of the report provides background information on the project, the constraints, and the roles and responsibilities of staff and stakeholders involved. It contains the following components:

- **Project Area** – This component of the project background section includes information on the location of the project or study area.
- **Project Description** – This component describes the general scope of and the need for the project. It covers details regarding the project type, the proposed changes and concept plans for the project, and the general schedule and time line of the work involved.
- **Project Goals and Objectives** – After providing an overview of and the need for the project, the agency identifies the specific goals that the agency would like to achieve in relation to the work zone-related efforts of the project. Additionally, it specifies the objectives that are need in order to achieve those goals.
- **Project Constraints** – In this section, the agency details the constraints associated with the project, including any concerns regarding the timing of the project, impacts on existing facilities, communities, and businesses, political sensitivity of the project, and potential conflicts with adjacent projects.

8.2 EXISTING AND FUTURE CONDITIONS

This section of the report describes the existing and predicted future conditions along the project area. The existing conditions section provides an overview of the current facility characteristics (i.e., geometries, lane configurations, etc.), traffic operations (traffic controllers, meters, and signal timings/phasing), traffic data (volumes, speeds, and travel times), and crash data. For describing the future conditions of the corridor, the section includes traffic growth estimates, as well as traffic predictions during construction. This section also provides an overview of any politically sensitive issues associated with the project, as well as any potential community, business, and environmental concerns.

8.3 ALTERNATIVES CONSIDERED

This section of the report presents the various work zone alternatives considered for the project. These alternatives include options for construction sequencing or phasing/staging. The section should provide a description and/or concept plans for each alternative. Additionally, the section should detail any assessments or analysis methodology(s) used to eliminate or prioritize alternatives. Additionally, it also should detail any type of mitigation strategies that may be incorporated with the project to fully capture the range of impacts during the alternatives analysis/modeling stage.

8.4 ALTERNATIVES ANALYSIS AND DECISION FRAMEWORK METHODOLOGY

This section of the report should provide an overview of the methodology employed to evaluate and compare each of the alternatives and the decision framework used to recommend a preferred alternative. This section includes three components: the modeling/analysis efforts needed for assessing the impacts of the alternatives, any additional qualitative and quantitative considerations that provide supplemental information for the impact assessment, and the decision framework selected.

Alternatives Analysis Methodology

The section on the alternatives analysis methodology should include the following components:

- The necessary measures of effectiveness (MOE) and/or thresholds related to achieving the project goals and objectives;
- The data collection efforts; and
- Overview of the modeling/analysis tool selected, modeling efforts needed, and justification for tool selection.

Qualitative and Quantitative Considerations

This section should account for additional qualitative and quantitative considerations that may not be fully captured in the modeling/analysis effort identified in the previous step. This could account for the additional factors specified in Chapter 8 of this document. Examples of additional considerations include:

- Traffic and travel demand considerations;
- Business and community impacts;
- Environmental impacts;
- Construction/contracting strategies and considerations; and
- Financial considerations, such as Road User Costs.

Decision Framework

The final component of this section of the report should detail how the modeling/analysis results, as well as the assessment of additional qualitative and quantitative considerations were factored into the final criteria used for comparing and choosing among the different alternatives. This component should describe the methodology employed to prioritize the factors used in the development of the criteria. The description of the decision framework selected should detail how the prioritized factors were incorporated into the criteria utilized in comparing and choosing amongst alternatives.

8.5 ANALYSIS RESULTS, RECOMMENDED ALTERNATIVE, AND MITIGATION STRATEGIES

This section should provide a synopsis of the analysis results and detail how a preferred alternative was chosen. The section provides details on the performance measures for the analysis and the results of the decision-making criteria employed. Additionally, this section also should detail any selected mitigation strategies incorporated into the recommended alternative(s) in order to minimize the work zone's impact on travel, the surrounding community, businesses, and the environment.

8.6 POST-IMPLEMENTATION AND MONITORING PLAN

The final section should include any plans for monitoring the performance of the work zone during the construction period. Monitoring post-implementation of the project aids in validating the impact assessment and improves future analysis efforts for similar work zone projects. The section should include information for the following:

- Monitoring requirements;
- Data needs and performance measures for the monitoring effort; and
- Plan for using monitoring data and results to feed back into the impact assessment.

Table 80 features a checklist that summarizes the components described in this chapter.

Table 80. MOTAA Reporting Components Checklist

A. Project Background	
• Project area	
• Project description	
• Project type	
• Proposed changes	
• Concept plans	
• Proposed construction staging/phasing	
• General schedule and time line	
• Project goals and objectives	
• Project constraints	
• Roles and responsibilities	
• Managers, key staff, stakeholders, and review committees	

B. Existing and Future Conditions	
• Existing facility characteristics (current geometries)	
• Existing and historical traffic data (volumes, speeds, bottlenecks, etc.)	
• Existing traffic operations (traffic controllers, ramp meters, etc.)	
• Historical incident and crash data	
• Local community and business concerns/issues	
• Environmental concerns/issues	
• Political sensitivity concerns/issues	
• Traffic growth rates	
• Traffic predictions during construction	
C. Alternatives Considered	
• Description of alternatives considered. Alternatives can consist of:	
– Construction approach (phasing/staging strategies)	
– Work zone impacts management strategies	
• Preliminary alternatives analysis (i.e., fatal flaw analysis)	
• Potential mitigation strategies to be incorporated into impacts assessment	
D. Alternatives Analysis and Decision Framework Methodology	
• Impact assessment methodology	
– Measures of effectiveness and/or thresholds	
– Description of data collection efforts needed	
– Analysis tool/methodology selection and justification	
• Other qualitative and quantitative considerations – These could include additional factors considered when comparing and choosing among different alternatives, such as:	
– Traffic and demand considerations – These include traffic operations and travel demand management strategies	
– Business and community impacts	
– Environmental impacts	
– Construction and contracting strategies	
– Financial Considerations (including Road User Cost)	
• Decision framework methodology	
– Development of criteria: methodology used to prioritize factors used in comparing and evaluating alternatives	
– Decision framework for comparing and choosing amongst alternatives – Selection of methodology and justification	
E. Analysis Results, Recommended Alternative, and Mitigation Strategies	
• Synopsis of analysis/modeling results and performance measures	
• Recommended alternative or combination of alternatives and justification	
• Selected project coordination, construction, contracting strategies	
• Selected transportation operations and travel demand management strategies	
• Selected safety and enforcement strategies	
• Selected public and traveler information strategies	
F. Post Implementation and Monitoring Plan	
• Monitoring requirements	
• Monitoring data needs	
• Performance measures for monitoring	
• Plan for feeding back monitoring results into the impact assessment methodology and analysis	

9.0 WORK ZONE CASE STUDIES

The following examples of work zone projects featured in this chapter were selected to demonstrate the MOTAA process outlined in Chapter 2 of this guide. This chapter features various work zone project types and analysis tools, providing a diverse set of MOTAA applications. This chapter follows the featured projects step by step throughout the MOTAA, including the planning stage, the modeling analysis, and the decision framework used in identifying a preferred work zone alternative. While the example projects featured in this chapter vary by project and modeling characteristics, they also vary based on when the MOTAA process was applied. For instance, while several of the examples featured in this chapter present real-world implementation of the MOTAA process on work zone projects, there also are some examples where the MOTAA process was implemented on previously completed work zone projects. In these cases, the work zone project was used for a study, academic research, or as an example that demonstrated a particular analysis methodology of conducting an MOTAA. There also are a few projects featured in this chapter that are hypothetical examples but are based upon real-world applications of the MOTAA process. Table 81 provides a summary of the case studies presented in this chapter.

Table 81. Work Zone Case Studies Summary

Section	Project Type	Work Zone Type	State	Category of Analysis Tool	Analysis Tool	Note
9.1	Rural Arterial	Simple Flagging	MD	Traffic Signal Optimization	Synchro	Hypothetical project
9.2	Rural Freeway	Lane Closure	MD	Sketch Planning	Lane Closure Analysis Program (LCAP)	Hypothetical project
9.3	Rural Freeway	Lane Closure	TX	Mesoscopic Simulation	DynusT	Real-world application
9.4	Rural Freeway	Lane Closure	IA	Microscopic Simulation	CORSIM	Conducted after WZ project completed
9.5	Urban Freeway	Lane Closure	NC	Analytical/Deterministic Tools (HCM-based)	FREEVAL-WZ	Conducted after WZ project completed
9.6	Urban Freeway	Lane Closure	MI	Sketch Planning	IDAS	Real-world application
9.7	Bridge	Temporary Two-Way One-Lane Operation	MD	Traffic Signal Optimization	Synchro	Hypothetical project
9.8	Urban Arterial	Lane Closure	MD	Traffic Signal Optimization	Synchro/ SimTraffic	Hypothetical project
9.9	Interchange	Ramp Closure	IN	Traffic Signal Optimization and Microsimulation	Synchro and PARAMICS	Real-world application
9.10	Urban Freeway/ Bridge	Lane Closure	OH	Travel Demand Modeling	TRANPLAN	Real-world application
9.11	Urban Freeway	Lane Closure/ Ramp Closure	NJ	Mesoscopic Simulation	INTEGRATION	Real-world application

9.1 SIMPLE FLAGGING WORK ZONE PROJECTS USING TRAFFIC SIGNAL OPTIMIZATION TOOLS – SYNCHRO

Project Background – MD 144 Flagging Work Zone Project

This case study, featured in the MD SHA describes the agency's recommended MOTAA procedures for analyzing a hypothetical flagging work zone project.[15] This hypothetical project features the reconstruction of the unsignalized intersection of MD 144 (Frederick Road) and Dutton Avenue. Frederick Road runs east-west, while Dutton Avenue that runs north-south. Both roadways are two-lane, two-way, undivided roadways. The project's base and alternative models were analyzed using the traffic analysis tool, Synchro. The following sections describe the MD SHA's MOTAA process and detail how the agency's process fits the recommended procedure described in Section 4.4 of this document.

Application of the MOTAA Process

Step 1 – Problem Definition, Scope, Goals, and Objectives

For this intersection reconstruction case study, the objectives of the analysis include the following:

1. Determine if the reconstruction of the intersection can be performed under flagging operations, or if a detour should be used; and
2. If flagging operations is determined to be suited for this project, additional analysis is needed to determine during what periods of the day flagging should be used.

Step 2 – Establishing the MOEs and Thresholds

The Synchro model outputs extracted from the analysis include control delay and LOS. These outputs are then evaluated to determine if they meet the established mobility thresholds of the agency. In this case study, the threshold is set at a maximum LOS D and control delay of 30 seconds.

Step 3 – Choosing the Analysis Tool

Most arterials and freeways across the State of Maryland have been modeled using Synchro and CORSIM, respectively. To reduce data collection and model development efforts, Synchro was, therefore, chosen as the analysis tool.

Step 4 – Identify the Alternatives

In this case study, only one work zone alternative was determined prior to running the model. The first work zone scenario evaluated features a four-way flagging work zone layout. The second work zone scenario was later established when the four-way flagging work zone configuration failed to meet the mobility thresholds specified in Step 3. The second work zone scenario features a three-way flagging work zone layout and is described in Step 6.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

The goals and objectives of the analysis were described in Step 1 of this section. After determining the goals and objectives of the analysis, the next step is data collection. For this case study, the analyst(s) obtained existing traffic control, road geometry plans, and demand data. There were no recent turning movement counts for the area, so the agency had new field counts taken at the intersection from 6:00 a.m. to 7:00 p.m. during a one-day period.

Step 5B – Existing Conditions Model Development

After project scoping and data collection, the next step of the MOTAA is to develop an existing conditions model with the appropriate geometry, controls, traffic demands, and capacities. Since there was not an existing Synchro model, a new model was coded using the information (intersection control, timing plan, and geometry) from the data collection effort.

Traffic Demands and Volumes

Although not discussed in this example, an origin-destination matrix estimation (ODME) process may be needed in order to determine entry volumes and balanced turning movements for the project. For further information on handling volumes during model development using traffic signal optimization tools, refer to Chapter 4, Section 4.4 of this document.

Step 5C – Existing Conditions Model Calibration

Since the intersection had low volumes, the analysts assumed that model calibration was unnecessary.

Model Calibration and Validation Options

If an existing conditions model calibration process is needed, each traffic signal optimization software package has a set of user-adjustable parameters that enable the analyst to calibrate the software to better match specific local conditions. This calibration process involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Additionally, each agency and project may have different calibration guidelines and requirements. Section 4.4 of this document provides guidance on the considerations and steps involved in the calibration of traffic signal optimization models.

Step 5D – Work Zone Base Conditions Model Development

The next step is the development of a work zone base conditions model by modifying the existing conditions model. In preparation for the analysis, the analyst must determine the scope of the modeling analysis effort. One of the first steps an analyst must take is to determine the limits of the study network to be analyzed. For this example, it is assumed that during the construction, the intersection would operate under flagging operations, which is comparable to a four-way stop control intersection. To model this type of control in Synchro, the intersection was assumed to operate under four-way split phasing with a cycle length of 180 seconds and 5-second clearance intervals. All work was restricted to off-peak hours.

A summary of the data and assumed traffic operations for the project is presented in Table 82. The work zone lane configurations assumed for the Synchro model is shown in Figure 40. No changes to the traffic volumes were assumed for this analysis.

Work Zone Base Model Development Modifications

Although there were no changes to the traffic demands in this cases study, typical modifications incorporated into the development of a work zone base model include changes to road geometry, traffic controls, and traffic demands.

Table 82. Summary of Data and Assumptions

Approach	Approach Volume (VPH)	Thru Green (Seconds)	Cycle Length (Seconds)	Estimated Queue Length	
				By Number of Vehicles	By Vehicle Length (Feet)*
Eastbound	764	90	180	19	475
Westbound	542	60	180	9	225
Northbound	14	5	180	1	25
Southbound	41	5	180	1	25

*Average vehicle length of 25 feet assumed.
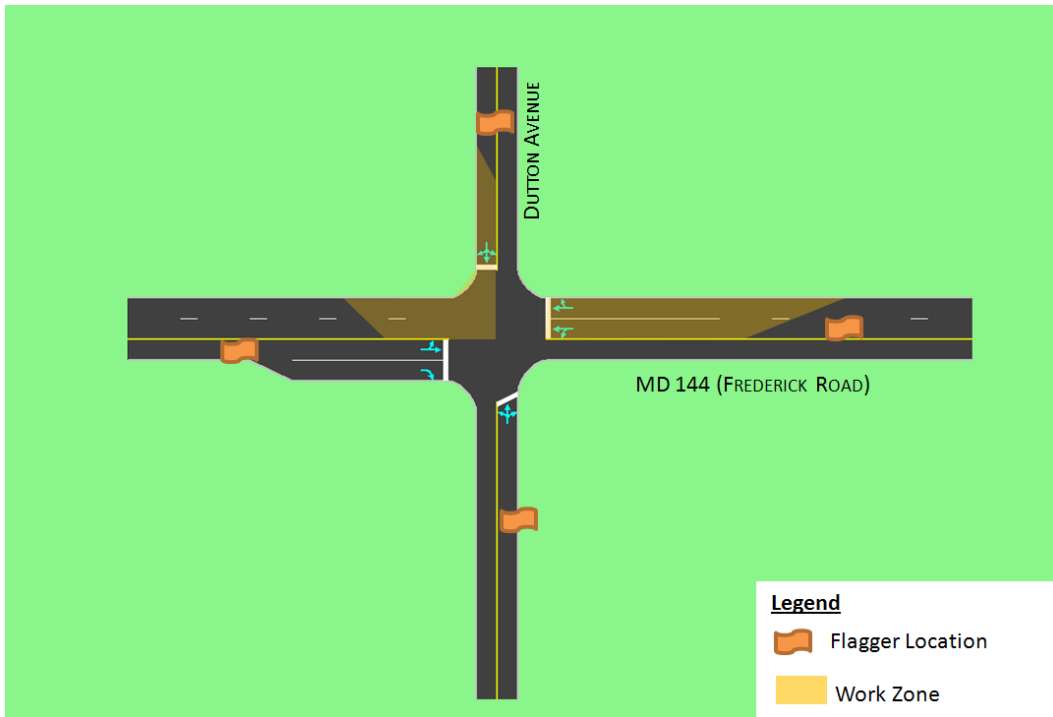
Figure 40. Four-Way Flagging Work Zone Layout

(Source: Maryland State Highway Administration, 2008.)

Step 5E: Work Zone Base Conditions Model Calibration

No work zone base conditions model calibration was conducted for this case study.

Work Zone Base Conditions Model Calibration Options

Work zone model capacity and performance measures can be calibrated to field data and or prior experiences (from similarly implemented work zone projects). In order to calibrate to field data or case studies of similar work zone types, the analyst can evaluate the work zone's queues, travel times, delays, and speeds. Additionally, the analyst may study parameters related to driving behaviors in work zones of similar types. Such observations and measures will aid the analyst in the work zone calibration process.

Step 6 – Alternatives Analysis

The next step in the MOTAA is to perform model runs in order to analyze the different alternatives. The analysis involves running the model and obtaining outputs and measures, such as control delay and LOS. The results of the four-way alternative is presented in Table 83. Because this alternative did not meet the mobility thresholds of a maximum of LOS D and control delay of 30 seconds, the agency decided to develop and test another alternative.

Table 83. Alternative 1 – Synchro Model Outputs

Intersection	Control Delay (Seconds)	LOS
MD 144 at Dutton Avenue	144.9	F

The alternate work zone model, developed by the agency, features a three-way flagging work zone layout. For this alternative, the eastbound and westbound approaches were changed to each have one shared left-through-right lane. These lanes would be shifted throughout the construction to permit the approaches to operate concurrently. This alternative's work zone configuration is shown in Figure 41. To represent the three-way flagging operations, this alternative was modeled by changing the existing condition's intersection control into an actuated-uncoordinated signal control with split phasing for the minor approaches. The model results for this alternative are shown in Table 84.
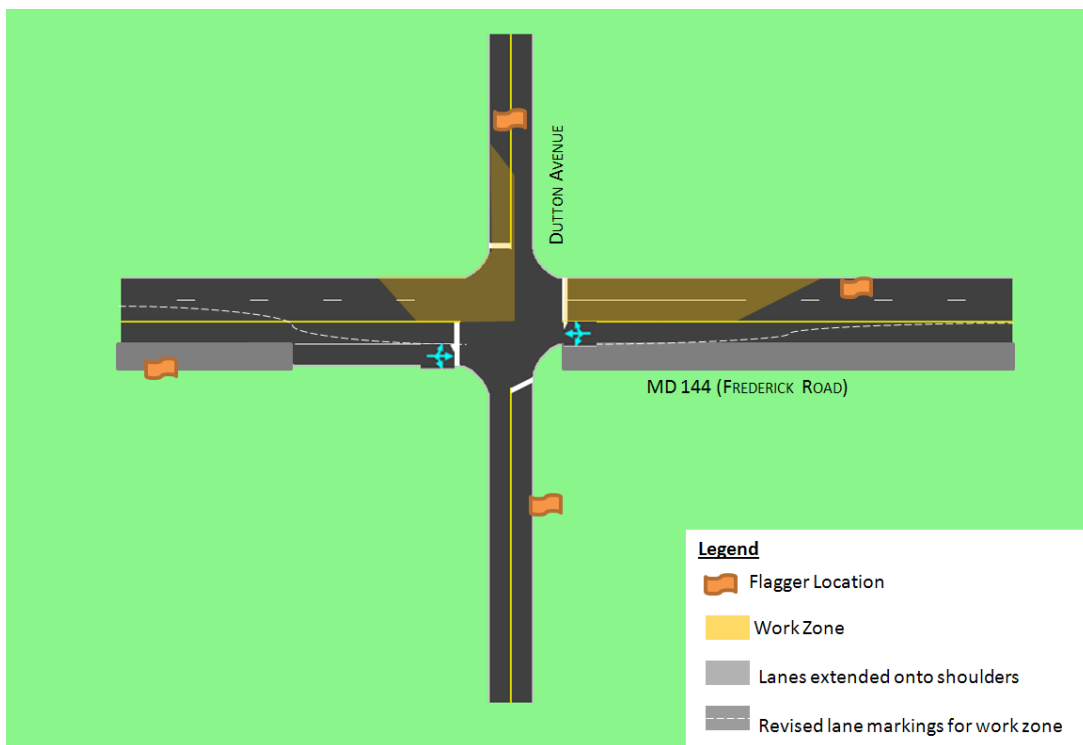
Figure 41. Three-Way Flagging Work Zone Configuration

(Source: Maryland State Highway Administration, 2008.)

Table 84. Alternative 2 – Synchro Model Outputs

Intersection	Control Delay (Seconds)	LOS
MD 144 at Dutton Avenue	22.2	C

As the results show in Table 84 Alternative 2 meets the mobility thresholds and is chosen as the recommended alternative. Additional analysis was performed in order to determine when it was best to implement the flagging operations. Table 85 presents the recommended work zone alternative and work hour restrictions.

Table 85. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Perform reconstruction in the intersection using flagging operations on all approaches, permitting concurrent eastbound/westbound movements	Monday-Friday: 9:00 a.m.-3:00 p.m.

Alternative Analysis Options

The alternative analysis process may differ based on the agency and the project. In this case, a second work zone alternative was considered because the primary alternative did not meet the mobility thresholds. Another alternatives analysis approach may involve analyzing several alternatives concurrently and then using a set of different performance measures to compare and choose among the alternatives. In this situation, the criteria for selecting the preferred alternative depended only on mobility thresholds. For other decision-making framework options, refer to Chapter 5 of this document.

9.2 RURAL FREEWAY LANE CLOSURES USING SKETCH PLANNING – MARYLAND STATE HIGHWAY ADMINISTRATION (SHA) LANE CLOSURE ANALYSIS PROGRAM (LCAP)

Project Background

This case study is based on the hypothetical application of Maryland SHA's lane closure analysis methodology on I-95, an eight-lane, two-way divided interstate highway that runs in the north-south direction through Howard County, Maryland. This case study, featured in Maryland SHA's Work Zone Analysis Guide, evaluates the impacts of a resurfacing project on both directions of I-95 approximately between MD 216 and I-895, as shown on Figure 42.[15] The roadway resurfacing excludes the ramps. The work is to be completed by resurfacing two travel lanes at a time and in one-mile-long segments.
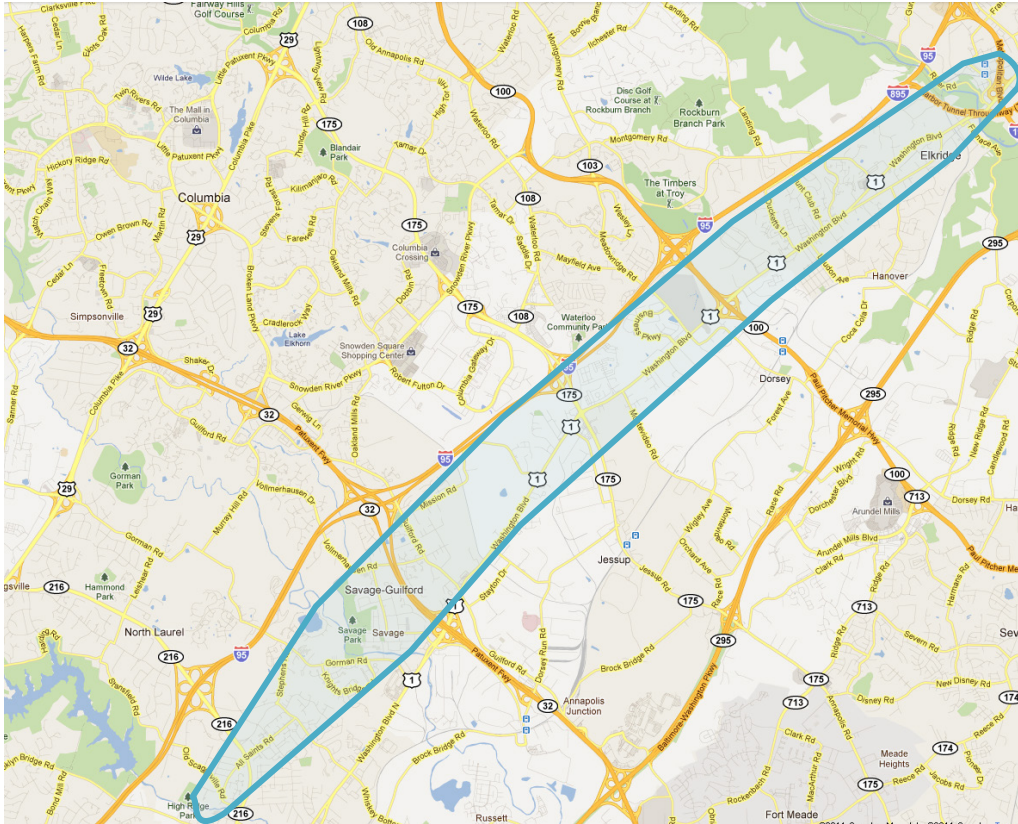
Figure 42. I-95 Howard County, Maryland Study Area Map

(Source: Maryland State Highway Administration, 2012.)

Application of the MOTAA

Step 1 – Problem Definition, Scope, Goals, and Objectives

The objective of the analysis is to determine the time periods when it would be most appropriate for three lanes on the mainline to be closed.

Step 2 – Establishing the Measures of Effectiveness and Thresholds

Performance measures and outputs extracted from the analysis include maximum queue length across different days of the week and lane closure durations. The freeway lane closure mobility thresholds established by the agency are that queue length should be less than one mile for any duration and that queues between 1 and 1.5 miles should last less than two hours.

Step 3 – Choosing the Analysis Tool

Because of the simplicity of the work zone, the agency decided to perform the analysis using the lane closure analysis program (LCAP).

Step 4 – Identify the Alternatives

The analysis will determine which combinations of days of the week and lane closure durations will meet the threshold indicating when a three-lane closure is acceptable. There is an alternative for each day of the week per direction of traffic along I-95. Therefore, there are a total of 14 alternatives. Each of these alternatives is presented in Step 6.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the objectives of the analysis, the scope of the modeling or analysis effort, and identify the data needed for the modeling analysis effort.

- **Scope –** As previously mentioned this case study involves a sketch-level planning analysis using MD SHA's LCAP. Because it was assumed that the resurfacing will be performed in one-mile-long segments, the study area will include the one-mile work zone length plus the buffer and taper lengths for the study area. In this case study, for a one-mile-long work zone with a three-lane closure, the buffer and taper lengths is approximately one-half mile. Therefore, the total study area network length for the analysis is one and one-half miles.
- **Data Collection –** The data inputs for this analysis include the following:
  - Volume – Existing (preconstruction conditions) traffic volume data from the permanent count station near the junction of I-95 and MD 103 were obtained from MD SHA. Volume data were collected for the month of May since it had the highest traffic volumes of the year according to MD SHA Common Reports from *Traffic Trends*.[57]
  - Lane Configuration – The SHA's *Highway Location Reference* manual was used to verify the number of mainline lanes throughout the study area.[58]

Step 5B – Existing Conditions Model Development, and Step 5C – Existing Conditions Model Calibration

The next step of the MOTAA is to develop the existing conditions model. Because simulation modeling was not needed to analyze the study area, there was no need for an existing conditions model and calibration effort.

Step 5D and 5E – Work Zone Base Conditions Model Development and Calibration

Due to the nature of this analysis, there was no need for model development for both the existing conditions as well as work zone base. Therefore, a calibration effort also was deemed unnecessary. For information on the analysis conducted, refer to Step 6, Alternatives Analysis.

Step 6 – Alternatives Analysis

Typically, if modeling was involved, the alternatives analysis step included two stages:
1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results. In this case study, the stages are varied slightly. The first stage of this case study is to 1) determine the inputs to the LCAP analysis, and then 2) produce model outputs after running LCAP.

Step 6A Alternatives Model Development – LCAP Inputs

For this case study, the first stage of the work zone base conditions model development was to determine the input to the LCAP. One of the main inputs to the program is work zone capacity. There are three capacity approximations methodologies featured in LCAP:

- **Method 1 – SHA Work Zone Guidelines –** The work zone capacity using SHA's Lane Closure Analysis Guidelines is not available to analyze the capacity of a four-lane facility that drops down to one lane. However, the MD SHA guide does note that a facility that goes from three lanes to one lane is expected to have a work zone capacity of 1,170 vphpl.
- **Method 2 –** University of Maryland Equation assumes that a facility with 13 percent trucks, 1.5 miles work zone length, and one-foot lateral clearance will have a work zone capacity of 1,277 vphpl.
- **Method 3 –** HCM 2000 Short-Term Work Zone equation states that assuming the facility has 13 percent trucks and rolling terrain, the work zone capacity is approximately 1,339 vphpl.

Therefore, the average of the work zone capacity from these three equations equals 1,260 vphpl, the work zone capacity used for this analysis.

After determining the work zone capacity, the next stage is the development of an LCAP model using data such as existing traffic volumes, number of lanes (existing and work zone conditions), and capacity (existing and work zone). The model was set up assuming at least four consecutive hours will be needed for mobilization, resurfacing, and demobilization.

Step 6B – Alternatives Analysis Model Runs and Results

After setting up the model with the required inputs (detailed in Step 6A), the next step in the LCAP procedure is to run the program. With this case study several iterations were run using different combinations of closure time periods and days of the week to determine which periods in the day could accommodate a three-lane closure that would meet the agency's mobility thresholds. The trial and error process is depicted by Figure 43 and Figure 44. Figure 43 shows one trial where the closure along I-95 northbound lasted from 10:00 p.m. Wednesday through 5:00 a.m. Thursday. This scenario or trial produced queues that violated the agency's mobility thresholds. The other trial shown on Figure 44 depicts a more feasible alternative. A maximum queue length was determined for each alternative or combination. Figure 45 summarizes the maximum queue length associated with the lane closure duration for each day of the week.

Based on the results shown on Figure 45, the queues for each closure period meet the mobility threshold specified in Step 2. Therefore, the results show that there is at least one four-hour period every night that can accommodate a three-lane closure along I-95 for the resurfacing project.

Project: I-95 Resurfacing - Howard County (Columbia Area)
Analyst:
Date: 04/01/2007

Start Time	End Time	Base Demand	Approach Volume	Roadway Volume	Vehicles In Queue	Queue Length (Miles)	Workzone Up
Wed-12:00	Wed-13:00	5804	5804	5804	0	0.00	
Wed-13:00	Wed-14:00	6317	6317	6317	0	0.00	
Wed-14:00	Wed-15:00	6526	6526	6526	0	0.00	
Wed-15:00	Wed-16:00	7438	7438	7438	0	0.00	
Wed-16:00	Wed-17:00	7871	7871	7871	0	0.00	
Wed-17:00	Wed-18:00	7617	7617	7617	0	0.00	
Wed-18:00	Wed-19:00	7314	7314	7314	0	0.00	
Wed-19:00	Wed-20:00	5195	5195	5195	0	0.00	
Wed-20:00	Wed-21:00	3965	3965	3965	0	0.00	
Wed-21:00	Wed-22:00	3489	3489	3489	0	0.00	
Wed-22:00	Wed-23:00	2585	1260	2585	1325	1.74	X
Wed-23:00	Thr-0:00	1904	1260	3229	1969	2.59	X
Thr-0:00	Thr-1:00	1257	1260	3226	1966	2.59	X
Thr-1:00	Thr-2:00	848	1260	2814	1554	2.04	X
Thr-2:00	Thr-3:00	737	1260	2291	1031	1.36	X
Thr-3:00	Thr-4:00	782	1260	1813	553	0.73	X
Thr-4:00	Thr-5:00	1121	1260	1674	414	0.54	X
Thr-5:00	Thr-6:00	2381	2795	2795	0	0.00	
Thr-6:00	Thr-7:00	4604	4604	4604	0	0.00	
Thr-7:00	Thr-8:00	6456	6456	6456	0	0.00	
Thr-8:00	Thr-9:00	6678	6678	6678	0	0.00	
Thr-9:00	Thr-10:00	5786	5786	5786	0	0.00	
Thr-10:00	Thr-11:00	5348	5348	5348	0	0.00	
Thr-11:00	Thr-12:00	5903	5903	5903	0	0.00	
Thr-12:00	Thr-13:00	6138	6138	6138	0	0.00	
Thr-13:00	Thr-14:00	6193	6193	6193	0	0.00	
Thr-14:00	Thr-15:00	6754	6754	6754	0	0.00	

**Figure 43. I-95 NB, Howard County, LCAP Output Trial 1 –
Closure from 10:00 P.M. Wednesday to 5:00 A.M. Thursday**

Project: I-95 Resurfacing - Howard County (Columbia Area)
Analyst:
Date: 04/01/2007

Start Time	End Time	Base Demand	Approach Volume	Roadway Volume	Vehicles In Queue	Queue Length (Miles)	Workzone Up
Wed-13:00	Wed-14:00	6317	6317	6317	0	0.00	
Wed-14:00	Wed-15:00	6526	6526	6526	0	0.00	
Wed-15:00	Wed-16:00	7438	7438	7438	0	0.00	
Wed-16:00	Wed-17:00	7871	7871	7871	0	0.00	
Wed-17:00	Wed-18:00	7617	7617	7617	0	0.00	
Wed-18:00	Wed-19:00	7314	7314	7314	0	0.00	
Wed-19:00	Wed-20:00	5195	5195	5195	0	0.00	
Wed-20:00	Wed-21:00	3965	3965	3965	0	0.00	
Wed-21:00	Wed-22:00	3489	3489	3489	0	0.00	
Wed-22:00	Wed-23:00	2585	2585	2585	0	0.00	
Wed-23:00	Thr-0:00	1904	1260	1904	644	0.85	X
Thr-0:00	Thr-1:00	1257	1260	1901	641	0.84	X
Thr-1:00	Thr-2:00	848	1260	1489	229	0.30	X
Thr-2:00	Thr-3:00	737	966	966	0	0.00	X
Thr-3:00	Thr-4:00	782	782	782	0	0.00	X
Thr-4:00	Thr-5:00	1121	1121	1121	0	0.00	X
Thr-5:00	Thr-6:00	2381	2381	2381	0	0.00	
Thr-6:00	Thr-7:00	4604	4604	4604	0	0.00	
Thr-7:00	Thr-8:00	6456	6456	6456	0	0.00	
Thr-8:00	Thr-9:00	6678	6678	6678	0	0.00	
Thr-9:00	Thr-10:00	5786	5786	5786	0	0.00	
Thr-10:00	Thr-11:00	5348	5348	5348	0	0.00	
Thr-11:00	Thr-12:00	5903	5903	5903	0	0.00	
Thr-12:00	Thr-13:00	6138	6138	6138	0	0.00	
Thr-13:00	Thr-14:00	6193	6193	6193	0	0.00	
Thr-14:00	Thr-15:00	6754	6754	6754	0	0.00	

Figure 44. I-95 NB, Howard County, LCAP Output Trial 2 – Closure from 11:00 P.M. Wednesday to 5:00 A.M. Thursday

	Day of the Week	Closure Period	Maximum Queue
Northbound I-95	Sunday	Midnight – 5 AM (Mon.)	0.15 miles
	Monday	11 PM – 5 AM (Tues.)	0.61 miles
	Tuesday	11 PM – 5 AM (Wed.)	0.50 miles
	Wednesday	11 PM – 5 AM (Thur.)	0.85 miles
	Thursday	Midnight – 5 AM (Fri.)	0.29 miles
	Friday	Midnight – 5 AM (Sat.)	0.70 miles
	Saturday	Midnight – 7 AM (Sun.)	0.54 miles
Southbound I-95	Sunday	Midnight – 5 AM (Mon.)	0.57 miles
	Monday	11 PM – 5 AM (Tues.)	0.79 miles
	Tuesday	Midnight – 5 AM (Wed.)	0.57 miles
	Wednesday	Midnight – 5 AM (Thur.)	0.62 miles
	Thursday	Midnight – 5 AM (Fri.)	1.04 miles
	Friday	1 AM (Sat.) – 5 AM (Sat.)	0.61 miles
	Saturday	Midnight – 8 AM (Sun.)	0.89 miles

Figure 45. I-95 Howard County, LCAP Model Outputs

9.3 RURAL FREEWAY LANE CLOSURES USING MESOSCOPIC SIMULATION – DYNUST

Project Background

This case study describes the process used by Pesti, G., et al. (2010) from Texas Transportation Institute (TTI) to evaluate the impacts of two work zones on separate freeway corridors in El Paso, Texas, using a mesoscopic simulation tool.[59] Figure 46 shows the work zone locations of these two projects.

1. **I-10** – The construction project on I-10 requires closing one lane in this three-lane section from Zaragoza Road to Lee Trevino Drive in the westbound (WB) direction. The work zone is approximately 9,000 feet long. When the work zone is in effect, the discharge rate is set to 1,860 pcphpl, while the posted speed limit is lowered from 60 mph to 55 mph.
2. **Loop 375** – The work zone on Loop 375 is approximately 6,000 feet in length. It covers a portion of the southbound (SB) freeway segment from Pellicano Drive to Rojas Drive. During the construction, the discharge rate of the southbound traffic is set to 1,550 pcphpl, and the speed limit is reduced from 60 mph to 55 mph.

Figure 46. I-10/Loop 375 Case Study Project Area Map

(Source: Pesti, Chu, Balke, Zeng, Shelton, and Chaudhary, 2010.)

Application of the MOTAA

Step 1 – Problem Definition, Scope, Goals, and Objectives

The goal of the project was to determine the best construction sequence option that could minimize the disruption experienced by motorists.

Step 2 – Establishing the MOEs and Thresholds

The impact of construction was evaluated using LOS. The LOS criteria were based on HCM 2000. The criteria for freeways were based on densities and those for surface streets were based on link speeds.

Step 3 – Choosing the Analysis Tool

Dynamic Urban Systems for Transportation (DynusT), a dynamic traffic assignment (DTA)-based tool, was used in the analysis. It was chosen because of its ability to evaluate the regional impacts of multiple work zone projects.

> **Analysis Tool Selection Options**
>
> In this case study, DynusT was chosen based upon the tool's capabilities in evaluating the regional impacts of multiple work zone projects. Similar DTA-based tools can be applied for this case study as well.

Step 4 – Identify the Alternatives

Two project sequence options, with three scenarios, were evaluated in the case study; they are:

- **Option 1 –** Conduct one construction project at a time, which includes two subscenarios:
  - Scenario 1.1 – Construction project on Loop 375; and
  - Scenario 1.2 – Construction project on I-10.
- **Option 2** (Scenario 2.0) **–** Conduct both construction projects simultaneously.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the objectives of the analysis and identify the data needed for the modeling analysis effort. For this case study, the following types of construction data were collected:

- Project location;
- Capacity reduction; and
- The beginning and end time of each construction project.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model. The DynusT network was created in a separate Texas DOT Interagency Contract (IAC), in which the Texas Transportation Institute (TTI) converted the El Paso MPO's "Trans-Border" travel demand model for the year 2009 into a format that can be used by DynusT. Note that this network was limited to the U.S. side of the border and did not include the City of Juarez, except a few external zones for the border crossing.

The DynusT network was represented by 2,862 nodes, 6,203 links, and 690 traffic analysis zones. The network was quite detailed and captured all freeways, interchanges, major arterials, and intersections that were included in the El Paso regional travel demand model. In addition, smaller localized minor roads were coded in the project study area. This additional level of detail was consistent with the scope of the project and scale of the problem that it tried to address.

Step 5C – Existing Conditions Model Calibration

Major elements of the DynusT network of the El Paso region were reviewed and checked to ensure that they correctly represented the existing roadway system of El Paso. Where needed, some network elements or origin-destination (O-D) matrix values were corrected and updated. After verifying the most critical elements of the network, several test runs were performed. The test runs were performed on the verified network and used a time-varying O-D matrix calibrated in a previous Texas DOT IAC project using an O-D calibration method developed by the University of Arizona.

Steps 5D and 5E – Work Zone Base Conditions Model Development and Calibration

The existing conditions model was then modified to represent work zone conditions. In this case study, there was no work zone base conditions model developed or calibrated.

Work Zone Base Conditions Model Development and Calibration

Work zone base conditions models may not be necessary. In this instance, the two work zone alternatives are compared against each other to determine the relative merits of each. As such, there is no need for a "base" to check against.

Step 6 – Alternatives Analysis

The alternatives analysis step involves two stages: 1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results.

Step 6A – Alternatives Model Development

This case study featured three work zone alternative scenarios, which were created by modifying the existing conditions model.

1. **Scenario 1.1** – Construction project on Loop 375;
2. **Scenario 1.2** – Construction project on I-10; and
3. **Scenario 2.0** – Conduct both construction projects simultaneously.

Step 6B – Alternatives Analysis Model Runs and Results

The final steps of the MOTAA are to run the work zone alternative models using the selected traffic analysis tool and to extract select model outputs. As an example, Figure 47 shows lane-miles with LOS changes for Scenario 2.0, with C-C, N-C, and C-N representing traffic condition changes from congested to congested (C-C), noncongested to congested (N-C), and congested to noncongested (C-N).

	Freeway						Arterial					
	Total Lane-Miles							Total Lane-Miles				
End Time	7:00	8:00	9:00	10:00	11:00	Total	End Time	7:00	8:00	9:00	10:00	11:00	Total
C-C	183.41	2665.36	2774.35	1132.38	661.51	7417.01	C-C	2015.41	6406.11	7054.10	5828.11	5178.54	26482.27
N-C	253.61	560.68	625.72	446.00	430.59	2316.61	N-C	176.33	621.53	868.53	733.93	1150.77	3551.09
C-N	102.35	424.92	601.90	793.95	863.47	2786.58	C-N	150.13	636.17	672.02	447.05	767.53	2672.91

Freeway

Arterial
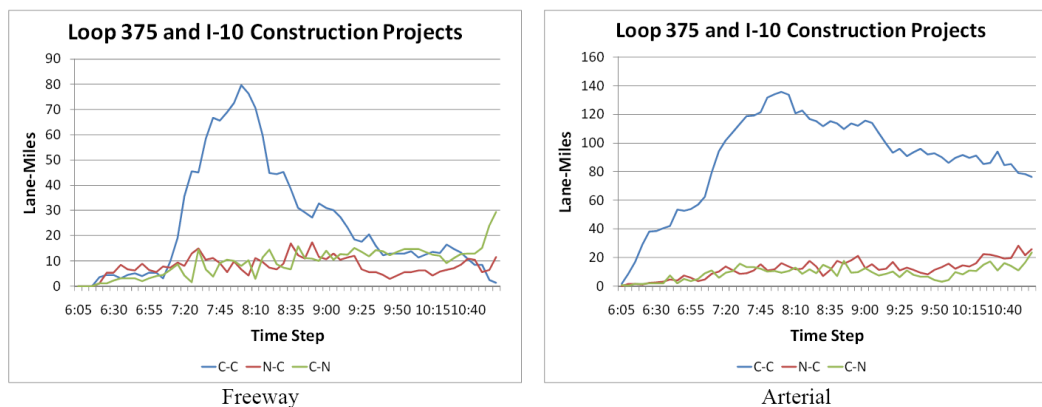
Figure 47. I-10/Loop 375 Case Study – Lane-Miles with LOS Changes for Scenario 2.0

*Conduct both I-10 and Loop 375 projects simultaneously.

Based on the analysis, it was concluded that conducting the construction projects simultaneously had similar impact on traffic as the I-10 project alone. The I-10 project had greater negative impact than the Loop 375 construction. A significant portion of traffic would be diverted to the southern portion of the Loop 375 crossing I-10 during the I-10 construction phase. Lastly, the two projects had similar impacts to the arterial traffic.

9.4 RURAL FREEWAY LANE CLOSURES USING MICROSIMULATION – CORSIM

Project Background

The following case study follows the research efforts and modeling analysis process employed by Schrock and Maze (2000) to evaluate the cost-effectiveness of delay-reducing work zone alternatives using microsimulation.[14] Schrock and Maze chose a completed Iowa DOT work zone project on rural Interstate 80 in Iowa County, Iowa, as a case study for this research effort and modeling analysis. This work zone project occurred in 1997 when a six-mile-long section of

I-80 was selected for pavement rehabilitation. Between 1988 and 1997, traffic levels on I-80 had increased by 44 percent. With age and increasing traffic levels, several of the older sections along this corridor were in great need of rehabilitation and repair. The Iowa DOT, therefore, proceeded with the pavement rehabilitation efforts in 1997, converting the facility from a four-lane highway to a two-lane, two-way operation (TLTWO) between May 31, 1997 until September 13, 1997, when the project was completed. Figure 48 depicts the study area location and detour routes used.
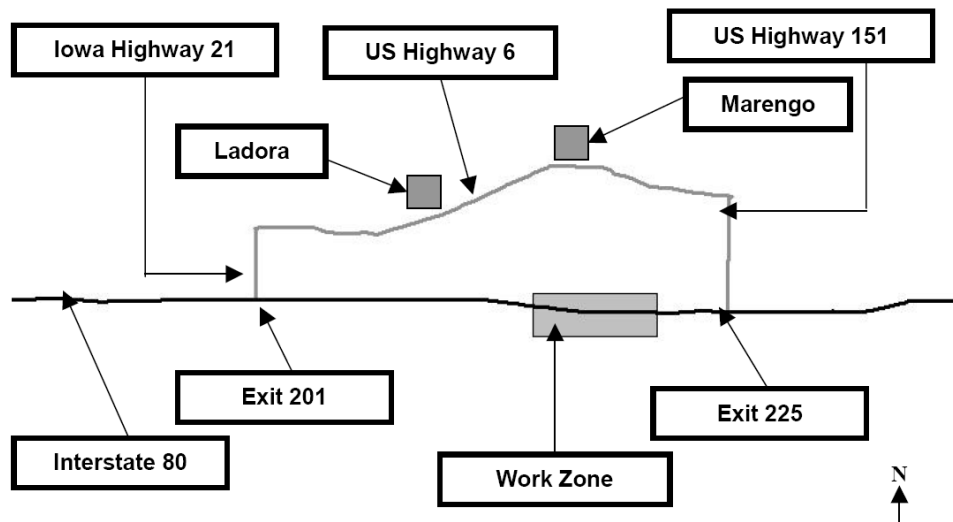
Figure 48. I-80 Work Zone Study Area

Application of the MOTAA Process

The following sections describe how Schrock and Maze employed the MOTAA process into their research and modeling analysis of the I-80 pavement rehabilitation project in 1997. The process follows the MOTAA process, as described in Chapter 2 of this document, as well as the microsimulation modeling procedure described in Section 4.7.

Step 1 – Problem Definition, Scope, Goals, and Objectives

The goal of this research and modeling effort was to evaluate different work zone alternatives through microsimulation in order to choose the most cost-effective strategy(s). Their objective was to compare the incremental benefits and costs of several hypothetical work zone alternatives against the actual 1997 I-80 pavement rehabilitation project to determine the alternative that would substantially reduce traffic congestion while efficiently using the resources allocated for the project. The researchers used the 1997 work zone data to develop a base case scenario that was then used to evaluate and compare the delays and costs associated with the various work zone alternatives.

Step 2 – Establishing the MOEs and Thresholds

After defining the goal and objective of the project, the next step in an MOTAA is to establish the MOEs and/or thresholds that would be used to evaluate and compare the different work zone alternatives. In order to compare and choose among these alternatives, the authors used MOEs, such as vehicle delay, travel time, user costs (costs due to delay), and agency costs. The researchers used these measures and converted them into dollar values for use in a benefit/cost analysis, which is described in further detail in Step 7.

Step 3 – Choosing the Analysis Tool

The next stage of the MOTAA process is to determine the type of analysis tool to be used and justification for the selection. In this case study, microscopic simulation was used to determine the amount of delay that would occur under different alternative scenarios during the lifetime of the work zone. Traffic Software Integrated System (TSIS) CORSIM package was chosen because of its ability to provide the data outputs and measures required for the benefit/cost analysis. The authors felt that obtaining these outputs would have been difficult to obtain from other analysis tools.

Analysis Tool Selection Options

Although performance measures is one factor that should be considered in determining which tool is appropriate for a work zone traffic analysis, there also are other factors that should be considered before making the final decision. Chapter 3 of this document describes these various factors in greater detail. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- Transportation Management Plan (tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies).

Step 4 – Identify the Alternatives

After determining the MOEs and the analysis tool, the next stage of an MOTAA process is the identification of work zone alternatives. In this case study, the researchers developed several alternatives that were compared against the base case or "Do-Nothing Alternative." The authors developed the following alternative scenarios:

- **Do-Nothing Alternative (Base Case) –** This alternative represents the traffic management plan that was actually used during pavement reconstruction in 1997, the TLTWO work zone configuration.
- **Nonstop Work Alternative –** The second alternative also represents a TLTWO work zone configuration, but at an accelerated pace by requiring the contractor to work 24

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hours per day, 7 days a week. A nonstop work schedule was assumed to lead to a completion date 56 days ahead of schedule, but at a premium of $1,000,000.

- **Four Traffic Lanes through the Work Zone –** The third alternative provided two additional traffic lanes through the work zone by strengthening and widening the work zones. In order to accommodate two traffic lanes in each direction, four bridges were assumed to be widened in this scenario. Iowa DOT estimated that the cost of widening the shoulders into travel lanes and widening the four bridges would cost about $4,946,000.

- **Diversion Route Alternative –** In this alternative, the Iowa DOT is assumed to divert a small percentage of vehicles off the interstate onto a diversion route. The diversion route consisted of using Iowa Highway 21 and U.S. Highways 6 and 151, as shown in Figure 48. This alternative also was divided into three sub-alternatives: 5 percent, 10 percent, and 15 percent vehicle diversion. Because this alternative could increase the delay over the entire network, the interstate delay savings must outweigh the detour's delay increases in order for this alternative to be beneficial. Assumptions regarding additional manpower and costs of running traveler information equipment and services were considered for determining the costs of each sub-alternative. The cost assumptions for the 5 percent, 10 percent, and 15 percent diversion sub-alternatives were $370,000, $470,000, and $670,000, respectively.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

At this stage of the MOTAA, the analyst already should have defined the objectives of the project and selected an appropriate tool that would be best for the project goals, objectives, and performance measures established. The next step of the MOTAA is defining the procedures necessary in preparing for modeling analysis. One of the first model preparation steps necessary is data collection. In this case study, the data collection efforts included:

- **Traffic Volumes –** Interstate traffic volumes were collected from Iowa DOT's Office of Transportation Data. Other sources of traffic volumes also include data from a permanent automatic traffic recorder (ATR) in the project area and on the detour route.
- **Truck Data –** Based on a previous study of I-80, 20 percent of the traffic stream was assumed to be heavy trucks.
- **Congestion and Bottlenecks –** Using data from Iowa DOT project files for the 1997 pavement rehabilitation work, the research analysts determined the number of congested days that occurred during the project's life span. According to their research, there were 34 days of high-traffic volumes.

Demands (Entry Volumes and O-D Tables) Options

This case study did not require the need for O–D tables. When using other microsimulation software, O–D estimation may be needed. Refer to Chapter 4 of this document for further details regarding the O–D estimation process.

Step 5B – Existing Conditions Model Development, and Step 5C – Existing Conditions Model Calibration

The next stage of the microsimulation modeling process within an MOTAA procedure is typically the development of the existing conditions model, which often emulates the preconstruction condition in the project area. This is then usually followed by a model calibration effort. Because this case study conducts the MOTAA process after the project has been completed, the researchers do not build an existing conditions model. Instead they proceed to Step 5D, the work zone base conditions model development.

Step 5D – Work Zone Base Conditions Model Development

After the existing conditions model development and calibration effort, the following step in an MOTAA process is typically the development of the work zone base conditions model. If an existing conditions model already has been developed, the work zone conditions model usually involves the modification of the previous model using data regarding road and lane geometric configurations, signal controls, traffic demands, and capacity changes associated with the presence of the work zone.

In this case study, the work zone base model or the "Do-Nothing" alternative was developed using the FRESIM component of the TSIS software package. The network model covers the six-mile section of I-80 with one lane blocked in each direction by an incident as a way of simulating the work zone location. The highways that make up the detour network were created using the NETSIM portion of the TSIS software.

Error Checking in Model Development

Although not specified in this case study, during model development, the analyst should make sure to perform error checks to identify and correct any model coding errors. The analyst can check the model network geometries and traffic control operations against existing plans or engineering drawings.

Step 5E – Model Calibration and Work Zone Calibration

After the development of the work zone base conditions model, the next stage in the modeling effort is typically a work zone base conditions model calibration. The work zone model calibration's purpose is to ensure that the model is sufficiently able to reproduce the local driver behavior, traffic characteristics, and work zone capacity during the project's duration. Because the modeling efforts conducted in this case study occurred after the work zone project was completed, the authors were able to calibrate their Do-Nothing model alternative using data collected during the implementation of the pavement rehabilitation project. The model was calibrated to the traffic conditions present when the work zone was active using the traffic data specified in the data collection section.

To appropriately model traffic behavior within the work zone area, adjustments and tests were conducted by varying the modeling tool's headway factor parameter values. To determine the appropriate headway adjustment factor, the researchers used a one-directional, two-lane interstate test section to run a sensitivity analysis that assessed the impacts of various values of

the headway factor. A hypothetical work zone was placed in the middle of the test section closing one lane of traffic. The work zone section had a speed limit of 55 mph and the rest at 65 mph. In this sensitivity analysis test, the headway factor was adjusted in increments of 10 percent between the values of 20 percent and 60 percent. The first iteration of the test started at a headway factor of 20 percent. Traffic volumes were input into the model using the traffic generator at a rate of 1,000 vehicles per hour (vph) with 20 percent trucks. The volumes were then increased by small increments up to a maximum of 1,500 vph at regular time intervals during the simulation. The test was repeated for the other headway adjustment factor increments of 30 percent, 40 percent, 50 percent, and 60 percent. The results were then analyzed to determine when delays began for each percentage of headway increase. Figure 49 depicts the results of the delay analysis for the various headway factor increments.

The results of the sensitivity analysis showed that a 40 percent increase in work zone headway can be associated with a vehicle delay beginning at about 1,250 vph, as shown in Figure 49. The capacity associated with the 40 percent headway factor parameter agrees with the results of a study conducted by the Iowa State University's Center for Transportation Research and Education (CTRE) on the capacity of rural Iowa interstate work zone, which showed typical work zone capacities between 1,216 to 1,302 vph. The 40 percent headway factor was, therefore, deemed most appropriate for the calibrated work zone model.

Sensitivity Analysis Options

In this case study, the authors conducted a sensitivity analysis using varying headway expansion factors. Other driver behavior model parameters could also be used for sensitivity analyses and work zone base conditions model calibration processes. Chang and Zou (2009) conducted a sensitivity analysis using CORSIM testing three parameters: free flow speed, rubbernecking factors, and car-following sensitivity in order to calibrate a model to work zone conditions in the field. For further information on this research effort, refer to the Maryland State Highway Administration Research Report, Project SP708B4B, *An Integrated Work-Zone Computer System for Capacity Estimation, Cost/Benefit Analysis, and Design of Control*.[60]
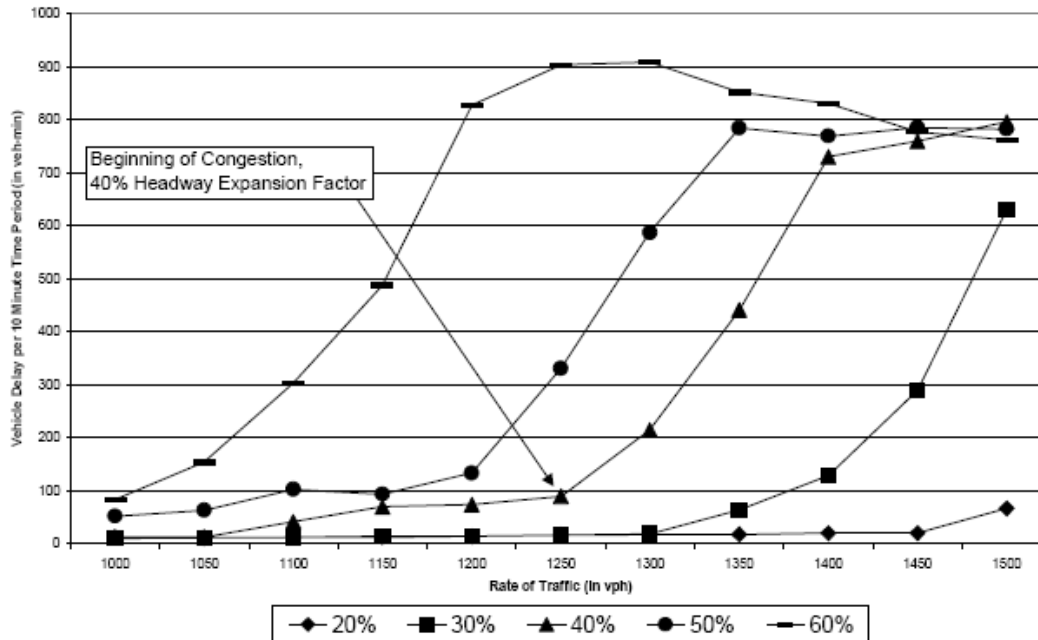
Figure 49. Delay Associated with Varying Headway Expansion Factors

Step 6: Alternatives Analysis

After the work zone model calibration, the analyst can proceed with modeling the alternatives analysis scenarios. The first step in this process is to create new models that reflect each alternative. This will require taking the "do-nothing" or base model and making the appropriate network model revisions. Afterwards the analyst will need to run the model alternatives multiple times, review the output, and extract relevant performance measures to be used in the next stage, the Decision-Making Framework.

Step 6A – Alternatives Model Development

CORSIM was used to develop and simulate the congested days condition for the six different alternatives (three alternatives and three sub-alternatives).

- **Nonstop Work Alternative** – For the nonstop work alternative, there were no geometric or control modifications to the Do-Nothing model. The only difference between this alternative and the Do-Nothing alternative was the project duration, since the nonstop alternative was completed 56 days earlier than the base case. The benefit associated with this alternative, therefore, is the value saved from those 56 days.
- **Four Traffic Lanes Work Alternative** – The only change this alternative required was a geometric revision to the base model through the addition of one additional lane in each direction.
- **Diversion Route Alternative** – In this alternative, no geometric changes were made to the base case model. Instead there were three diversion sub-alternatives modeled: 5 percent, 10 percent, and 15 percent diversion onto non-interstate traffic.

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Step 6B – Alternatives Analysis Model Runs

As previously mentioned, CORSIM software was used to perform the simulation runs for this stage of the analysis. Simulation runs were performed to model the 34 congested days for the six different alternatives. Additionally, five simulation runs were conducted for each day and alternative using different random seed numbers. The average total delay for each of the model alternatives was calculated, as shown on Table 86. The table presents the average delay, standard deviation, minimum value, maximum value, and range of delay for each alternative.

> **Number of Runs**
>
> In this case study, the authors decided upon five simulation runs. However, FHWA recommends an iterative approach that determines the appropriate number of model runs. For more information regarding this process, refer to Section 4.2 of this document or *Traffic Analysis Toolbox Volume III*.[28]

Table 86. Summary of Alternatives Analysis Modeling Results

Alternative	Average Delay	Standard Deviation	Minimum Value	Maximum Value	Range
Do-nothing	10,473	249	10,030	10,620	590
Nonstop work	1,428	11	1,416	1,439	23
Four-lane work zone	1,177	8	1,167	1,187	20
Five percent traffic diversion	7,092	18	7,071	7,111	40
Ten percent traffic diversion	4,589	290	4,426	5,107	681
Fifteen percent traffic diversion	3,029	149	2,913	3,218	304

Step 7 – Decision Framework and Recommendation of an Alternative

After obtaining the model output and mobility performance measures through the modeling analysis, the next stage of the MOTAA process is the application of a decision-making framework or criteria for evaluating and identifying the preferred alternative. In this case study, the researchers used the simulation results in a benefit/cost analysis (BCA). For further information on BCA and other decision-making frameworks that can be used during an alternatives analysis, refer to Chapter 5 of this document.

In order to convert the model delay values into dollar values, the authors used a previous Iowa DOT-sponsored study regarding the value of time. Table 87 shows the 1997 dollar values associated with delay. To determine the incremental benefits of each alternative to the Do-Nothing Alternative, the researchers determined the travel time savings that could be achieved for each scenario by determining the difference between the delay associated with the base scenario and the work zone alternatives. The delay differences were then converted to dollar values using the travel time value estimates shown in Table 87. The incremental cost represents the difference between the alternative's project costs when compared to the Do-Nothing Scenario. The comparisons between the incremental benefits and costs for each alternative are shown in Table 88.

Table 87. Value of Travel Time Savings

Minutes	Average Value
0 to 5	$5.37
5 to 10	$8.06
11 or more	$10.74

Table 88. Incremental Benefits and Costs for Each Alternative (in Thousands)

	Do-Nothing	Diversion 5 Percent	10 Percent	15 Percent	Nonstop Work	Four-Lane
Incremental Benefit	$0	$480	$909	$1,123	$2,034	$2,026
Incremental Cost	$0	$370	$470	$670	$1,000	$4,947

The BCA was completed in four stages as shown in Figure 50. In the first BCA step, the incremental benefits and costs of each alternative was compared to the Do-Nothing or Base Case Scenario. In the first step, the four-lane alternative was removed from consideration as the costs of the project far outweighed the benefits as seen by its BCA ratio of 0.41. The next option chosen in this step is the 5 percent Diversion alternative since it showed to have the lowest incremental cost as compared to the other alternatives. In the second iteration of the BCA, the incremental benefits and costs of each alternative are compared against the 5 percent Diversion alternative. The other alternatives still show a benefit over the 5 percent Diversion, with the 10 percent Diversion as the next option. The iteration is continued until the optimal case is found. In this exercise, the Nonstop Work alternative has an incremental BCA ratio of 2.03 when compared against the Do-Nothing alternative, and continued to be the most cost-effective throughout several iterations of the BCA comparison steps, as shown in Figure 50.

	Defender	Challenging Alternatives				
Step 1	Do-Nothing	5% Diversion	10% Diversion	15% Diversion	Nonstop Work	4-Lanes
Incremental Benefit	N/A	$480,000	$909,000	$1,123,000	$2,034,000	$2,025,000
Incremental Cost	N/A	$370,000	$470,000	$670,000	$1,000,000	$4,946,000
B/C Ratio		1.30	1.93	1.68	2.03	0.41
Outcome		Becomes New Defender	Remains a Challenger	Remains a Challenger	Remains a Challenger	Removed from Consideration
Step 2	5% Diversion	10% Diversion	15% Diversion	Non-Stop Work		
Incremental Benefit	N/A	$429,000	$643,000	$1,554,000		
Incremental Cost	N/A	$100,000	$300,000	$630,000		
B/C Ratio		4.28	2.14	2.47		
Outcome		Becomes New Defender	Remains a Challenger	Remains a Challenger		
Step 3	10% Diversion	15% Diversion	Non-Stop Work			
Incremental Benefit	N/A	$214,000	$1,125,000			
Incremental Cost	N/A	$200,000	$530,000			
B/C Ratio		1.07	2.12			
Outcome		Becomes New Defender	Remains a Challenger			
Step 4	15% Diversion	Non-Stop Work				
Incremental Benefit	N/A	$911,000				
Incremental Cost	N/A	$330,000				
B/C Ratio		2.76				
Outcome		**The non-stop work alternative is the most attractive alternative**				

Figure 50. Summary of Benefits and Costs for each Alternatives

9.5 URBAN FREEWAY LANE CLOSURES USING HCM/DETERMINISTIC TOOLS – FREEVAL

Project Background

The following case study, along Interstate Highway 40 in North Carolina was featured in a research report completed by the Institute for Transportation Research and Education (ITRE) and sponsored by the North Carolina DOT Research and Development Group.[61] The purpose of the research effort was to develop an analysis methodology for the evaluation of significant work zone impacts on North Carolina freeways using FREEVAL-WZ. The report demonstrates the capabilities of FREEVAL-WZ, a deterministic software tool that implements the freeway facility methodology featured in HCM 2010.

The report utilized the I-40 road widening project (STIP I-4744) in order to demonstrate the use of FREEVAL-WZ. For the purposes of this document, the I-40 example will be used as a case study to demonstrate the MOTAA process with urban freeway lane closure projects using FREEVAL-WZ for analysis. This work zone project involved an 18-month road widening by adding travel lanes in each direction of I-40 between State Road 1728 (Wade Avenue, Milepost 289) and the interchange with I-440/U.S. 1–64 (Milepost 293). The study area is shown by Figure 51. This segment of I-40 measures approximately 11.5 miles and includes a variety of different cross-sections (spanning two to four lanes per direction) of freeway segments, merge and diverge sections, and freeway weaving segments.

Application of the Maintenance of Traffic Alternatives Analysis

Step 1 – Problem Definition, Scope, Goals, and Objectives

The research objective of the NC DOT report in conducting the work zone traffic analysis of the I-40 project was to demonstrate the use of FREEVAL-WZ and evaluate its capability to replicate field-observed work zone conditions. Therefore, the goals and objectives of this analysis differ from a case study project that would have or has been implemented in the field. An analyst may still use the methodology specified in this section in order to achieve certain project goals and objectives such as minimizing the mobility impacts on the freeway during construction.
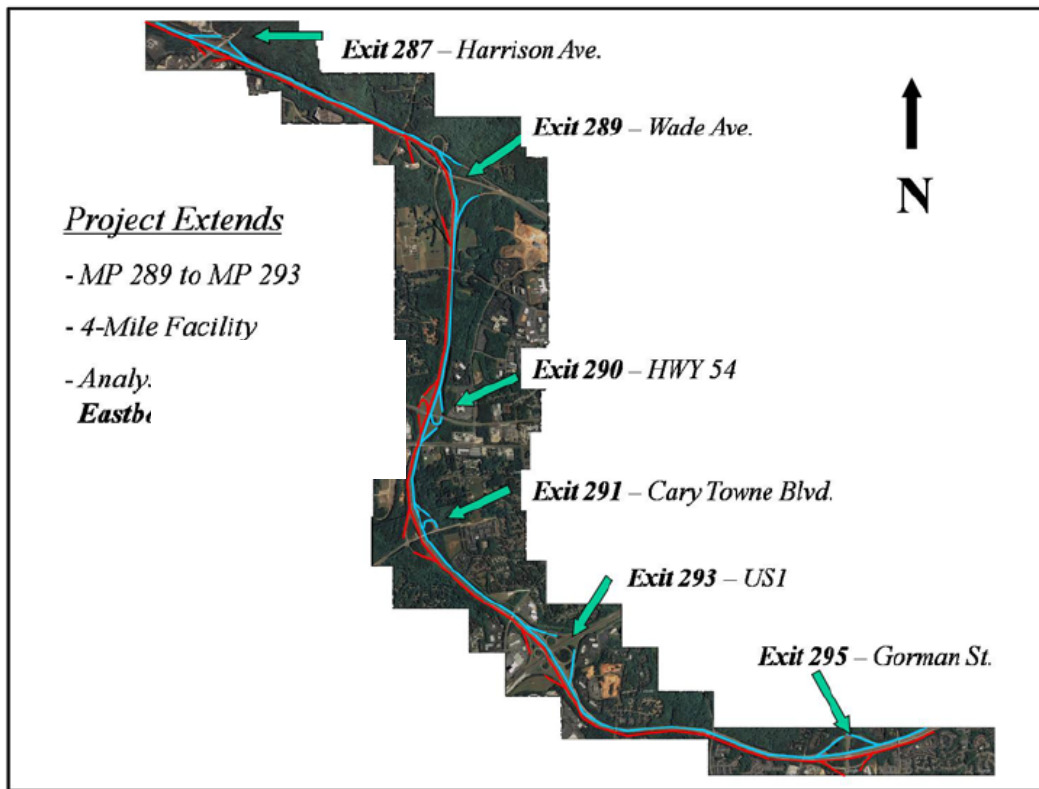
Figure 51. I-40 Case Study Project Overview

Step 2 – Establishing the MOEs and Thresholds

The facility MOEs reported for this case study included average travel time, mainline travel speed, and capacity.

Step 3 – Choosing the Analysis Tool

In the NC DOT report, the authors compared various analysis tools to FREEVAL-WZ. The authors first compared FREEVAL-WZ to other HCM/Deterministic tools. The authors note that while other deterministic tools such as QUEWZ-98 and QUICKZONE are limited to evaluating freeway segments, FREEVAL-WZ is able to evaluate demand changes on ramps and weaving segments in addition to freeways. Additionally, while the other tools have broader level, extended time periods for analysis, FREEVAL-WZ can be used as a peak hour analysis tool. Other differences between FREEVAL-WZ and other deterministic tools include output features and work zone-specific adjustments not available in other tools. These comparisons can be used by agencies and analysts to determine which deterministic tool is best suited for their project.

The authors also compared FREEVAL-WZ to simulation analysis tools such as mesoscopic and microscopic simulation software packages. While these tools can simulate and analyze the stochastic nature of traffic in relation to the work zone, there are certain advantages in using deterministic tools over simulation packages. For instance, the authors note that simulation tools can be more difficult to calibrate and are more data, time, and resource intensive as compared to

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deterministic tools. Therefore, depending on the analysis objectives, the level of complexity and detail needed for the analysis, and resource needs, an agency can determine which tool would be best suited for their project.

There also are new features and capabilities featured in FREEVAL-WZ that may add to an agency's tool selection considerations. FREEVAL-WZ features a planning-level interface that allows agencies to customize the tool based on the agency's needs and data resources. For instance, in the previous version of FREEVAL, traffic demand flows were required to be inputted into the tool as 15-minute increments. In the HCM 2010 version within the Planning-Level Analysis Module, traffic flows can now be directly inputted as average annual daily traffic (AADT), which is commonly used in planning-level analyses.

The authors also provided a summary table for comparing the capabilities of FREEVAL-WZ and other analysis tools in capturing work zone-specific impacts, shown in Figure 52.

Analysis Tool Selection Options

In this case study, FREEVAL was chosen based upon the tool's capabilities in meeting the data and performance measures typically required in the agency's work zone traffic analysis projects. Additionally, this option was also chosen based on the resource and data needs requirements of the tool as compared with other tool types. There are also additional factors that can be considered in selecting a tool. Chapter 3 of this document describes these various factors in greater detail. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (Tool should be able to capture the impacts of various traffic control and mitigation strategies.).

Workzone Analysis Inputs	Deterministic			Simulation				
	FREEVAL	QUEWZ-98	QUICKZONE	CORSIM	VISSIM	AIMSUN	PARAMICS	DYNASMART
Freeway Segment Type								
Basic	✔	✔	✔	✔ 1	✔ 1	✔ 1	✔ 1	✔ 1
Ramps and Weaving	✔	-	-	✔ 1	✔ 1	✔ 1	✔ 1	✔ 1
Analysis Details								
Max. Analysis Period	3-Hour	24-Hour	10 years	~52-Hour	~24-Hour	1000 H.	~24-Hour	24-Hour
Analysis Time Units	15 Min.	1 Hour	1 Hour	Flex.	Flex.	Flex.	Flex.	Flex.
Traffic Operations Impacts								
Capacity Reduction - # Lanes	✔	✔	✔	✔	✔	✔	✔	✔
Capacity Reduction - Factor	✔	✔	✔	- 2	- 2	- 2	- 2	✔
Speed Reduction	✔	-	-	✔	✔	✔	✔	✔
Demand Reduction	✔	✔	✔	✔	✔	✔	✔	✔
Re-Routing	✔ 3	✔ 3	✔	✔	✔	✔	✔	✔
Trip Retiming	✔ 3	✔ 3	✔	✔	✔	✔	✔	✔
Side-Street Demand Increase	-	-	✔	✔	✔	✔	✔	✔
Other Factors Impacting WZ Analysis								
High Truck Percentage	✔	✔ 3	-	✔	✔	✔	✔	✔
Off-Ramp Congestion	-	-	-	✔	✔	✔	✔	✔
Commuter vs. Tourist Traffic	-	-	-	-	✔ 4	✔ 4	✔ 4	✔ 4
Auxiliary Lanes (C/D Roads)	-	-	-	✔	✔	✔	✔	✔
Incidents	✔ 5	-	-	✔	✔	✔	✔	✔
Special Priorities (HOV, BRT)	-	-	-	✔	✔	✔	✔	✔
Facility Performance Measures								
Segment LOS	✔	-	-	PP	PP	PP	PP	PP
Vehicle Delay	✔	-	✔	✔	✔	✔	✔	- 6
Travel Time	✔	-	-	✔	✔	✔	✔	✔
Speeds	✔	✔	-	✔	✔	✔	✔	✔
Average Queue Length	-	-	-	- 7	✔	✔	✔	✔
Longest Queue Length	✔	✔	-	- 7	✔	✔	✔	✔
Queue Duration	✔	-	-	- 7	PP	PP	✔ 8	✔
User Cost	- 4	✔	✔	- 9	- 9	- 9	- 9	- 9
Emissions	-	✔	-	✔	✔	✔	✔	-
Network Performance Impacts								
Minor Street Queue Spillback	-	✔	✔	✔	✔	✔	✔	✔
Traffic Diversion	-	10		-	✔	✔	✔	✔
Visual Performance Output								
Bird's Eye View Animation	-	-	-	✔	✔	✔	✔	✔
4D Animation	-	-	-	-	✔	✔	✔	-
Network plots	-	-	-	PP	PP	PP	✔	PP
Data Plots by Time	✔	PP	✔	PP	PP	PP	✔	✔
Data Plot by Segment	✔	-	-	PP	PP	PP	✔	✔

	LEGEND	
✔	YES	
-	NO	
PP	Post-Processing necessary	

1 Segment types modeled implictly in simulation
2 Micro-Simulation arrives at capacity estimates implicitly through model agorithm (car-following, lane-changing ...)
3 Re-Routing and Trip Retiming modeled as modified demand flows
3 Truck Percentage specified for entire facility
4 Modeled implicity through different behavioral parameters by vehicle type
5 FREEVAL can model 15-minute incidents through lane closures or capacity reduction factors
6 DYNAMSART-P doesn't explicitly report delay, but does report travel time and average stopped time
7 CORSIM can only report queue length for arterial streets, not freeways
8 Performance Measure is % Time Queued
9 User cost can be easily obtained by mutliplying simulation total delay output and mutliplying by cost figure
10 Traffic Divesion based on maximum queue or delay assumption - not routing algorithm

Figure 52. Work Zone Impacts and Analysis Tools

Step 4 – Identify the Alternatives

For the I-40 case study, several scenarios were developed, including an existing conditions scenario during the p.m. peak as well as nighttime and weekend lane closure scenarios. All of the lane closure scenarios (Scenarios 1 through 6) were evaluated from 9:00 p.m. to 12:00 a.m. Lane closures were scheduled to take effect at 9:00 p.m. but often did not start until 10:00 p.m. The lane configurations of the base and lane closure scenarios are featured in Figure 53. The six scenarios included the following:

- **PM Peak Base** – This scenario was modeled for the 2010 p.m. peak hour. The base scenario was compared to conditions in August 2009 prior to the onset of construction at the work zone.
- **PM Peak Work Zone Base, Barrier Work** – This scenario represents conditions during the p.m. peak when construction was active but without lane closures. In this case study, the work will be completed behind barriers while maintaining all travel lanes open for traffic, but at reduced shoulder widths. The purpose of the p.m. peak barrier scenario is to explore the impacts of the construction activities and reduced shoulder width.
- **Scenario 1** – Four- to Three-Lane Closure during the Off-Peak;
- **Scenario 2** – Three- to Two-Lane Closure during the Off-Peak;
- **Scenario 3** – Four- to Two-Lane Closure during the Weekend Off-Peak;
- **Scenario 4** – Four- to One-Lane Closure during the Weekend Off-Peak;
- **Scenario 5** – Three- to One-Lane Closure during the Off-Peak (FREEVAL segment 8 is closed); and
- **Scenario 6** – Three- to One-Lane Closure during the Off-Peak (FREEVAL segment 16 is closed).

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

For the modeling effort of the I-40 case study, the authors developed a FREEVAL-WZ model that would include only the eastbound direction of the facility. In order to develop these models, the authors first had to conduct a data collection effort to obtain road geometry, volume, and traffic controls and operations data.
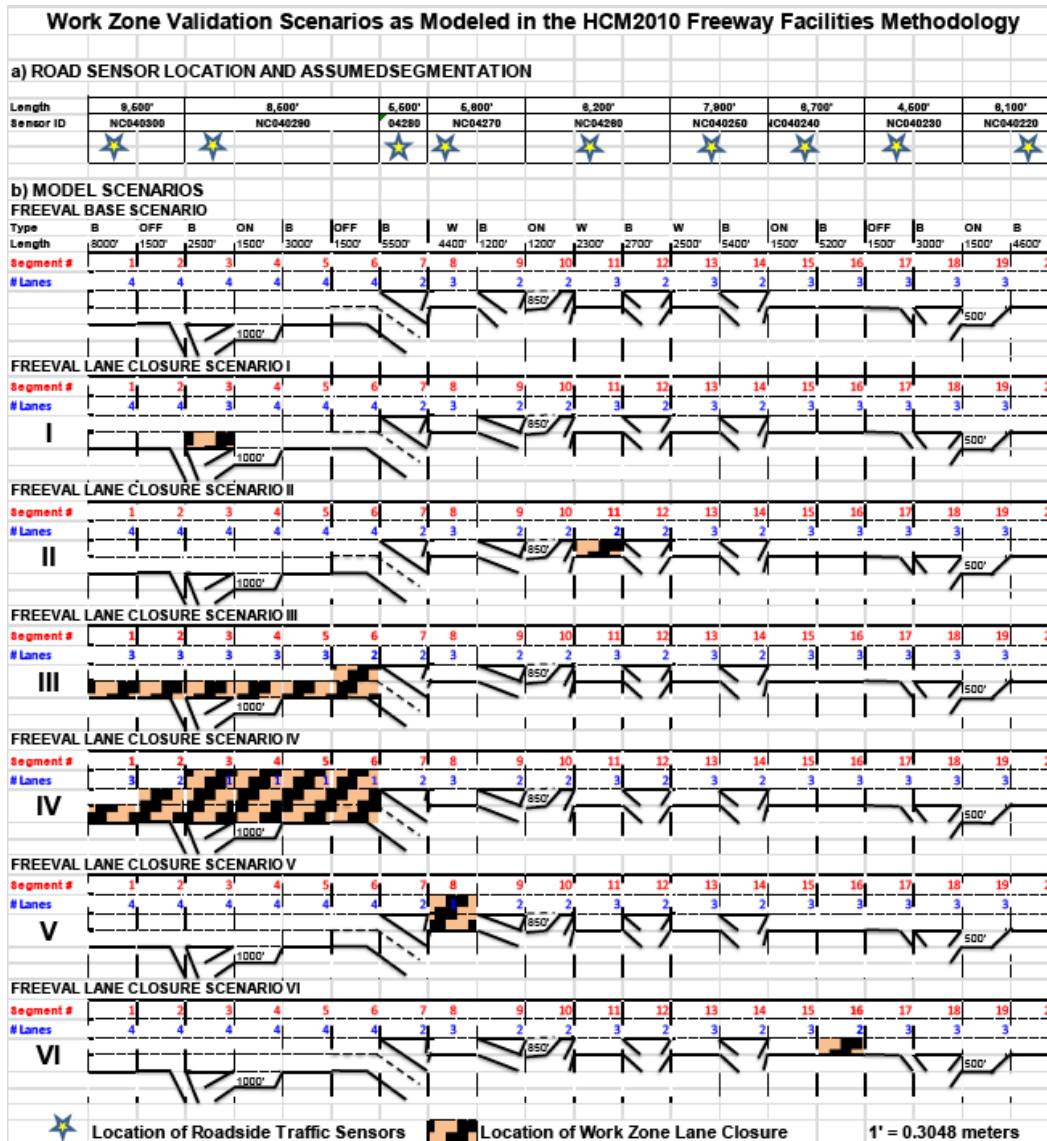
Figure 53. HCM 2010 FREEVAL-WZ, I-40 Case Study Scenarios

(Source: Schroeder, Rouphail, Sajjadi, and Fowler, 2011.)

Data Collection for Development of Models

The data collection effort for model development included inputs for the following:

- Lane geometry information.
- Traffic demand flows at all entry and exit points in 15-minute intervals – In order to develop the demand profile, the authors used the base year hourly data for the peak period. Using this information, the authors were able to develop a demand profile for the three-hour analysis period of 9:00 p.m. to 12:00 a.m. by converting the peak hour demand using a peak hour factor of 0.9. This effort, however, only represents volumes during off-peak base conditions and does not detail demand information for volumes during lane

closure conditions during the off-peak. In order to generate volume inputs for these conditions, the authors assumed a decreased demand pattern that was proportional to the peak hour distribution for each of the scenarios. The estimated demand profiles of the six work zone scenarios are shown in Figure 54.
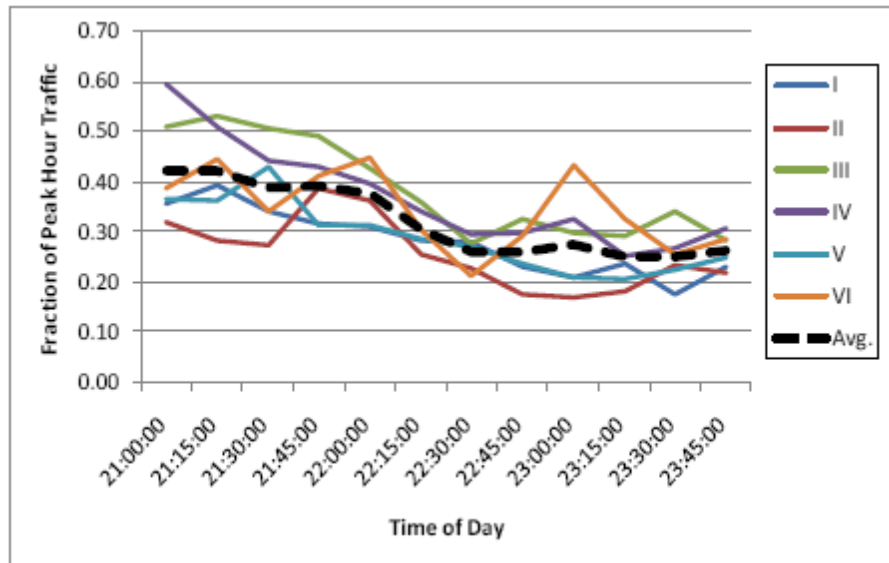
Figure 54. I-40 Work Zone Scenarios Demand Profiles

(Source: Schroeder, Rouphail, Sajjadi, and Fowler,2011.)

Data Collection for Validation and Development of FREEVAL-WZ Defaults

As previously mentioned, the main objective of the analysis was to evaluate how well FREEVAL-WZ could capture field-observed results. Therefore, in the initial stages of the project, significant traffic studies were performed in order to develop traffic stream models and capacity estimates for work zone operations specific to North Carolina. The initial studies involved an extensive data collection effort that analyzed sensor data regarding free-flow speeds, capacity, speed-flow relationships, segment speed and density, and travel time for various scenarios under freeway work zone conditions. During this stage of the modeling development and analysis, the authors utilized the following sources of information:

- **Work zone diaries** – These were obtained from the construction contractors that worked on two projects in Raleigh, North Carolina – I-40 Widening and the I-40 Rehab Project. These diaries reported construction activities by mile posting location and date. The authors used these diaries as a guide for determining what data to download from Traffic.com, a site that stores mobility data collected by side-fire radar units in a central database.
- **North Carolina DOT sensor data** – The authors also obtained lane-by-lane data from NC DOT roadside sensors and 15-minute roadside sensor data (to confirm the time and location of when lane closures took effect).
- **Field data travel times.**

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The field data provided traffic operations information such as speeds, capacity, and travel times for various work zone scenarios (these included different work zone lane closure configurations at various times of the day). They also aided the authors in developing plots that explained expected temporal distributions and speed-flow relationships by work zone scenario. Finally, analysis of the data also contributed to the development of capacity adjustment factors for each of the work zone scenarios. Such data were used to develop defaults for FREEVAL-WZ and were used to validate model results against field observations.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model with the appropriate geometry, traffic controls, demands, and capacities using the information from the data collection effort. To input the network geometry into FREEVAL, the analysts followed the methodology outlined in the HCM 2010 that divides a freeway facility into separate segments within four categories: Basic Segment, On-Ramp Segment, Off-Ramp Segment, and Weaving Segment. As shown in Figure 55, the facility is divided into 20 analysis segments. As mentioned in the previous step, traffic volume data for the p.m. peak hour was received from North Carolina DOT. As specified in Step 5A, additional processing was required in order to develop demand profiles for the off-peak lane closure scenarios.

Step 5C: Existing Conditions Model Calibrations

The base model calibration/validation effort was performed using the operational analysis function of FREEVAL-WZ. Calibration of peak hour conditions was conducted by comparing field observed data (specified in Step 5A) to FREEVAL-WZ base model performance. One of the key measures used for calibrating the base model was travel time. The travel time target was the average facility travel time for the three-hour analysis period and the maximum 15-minute travel time across the facility. Field observed travel times were compared to the model's travel time outputs.

In addition to travel times, the base model also was calibrated to speed data. Model speeds were calibrated using a visual comparison of space-mean speed plots or speed contour plots. Speed contour plots were generated for the existing conditions model and the work zone base conditions model. These were then compared to speed contour diagrams developed for four peak hour weekday work zone scenarios (generated using sensor data). The speed contour plots comparison is shown in Figure 55.

Model Calibration using Sketch-Planning and Deterministic Tools

Model calibration of sketch-planning and deterministic tools is typically conducted at a higher level and is often less time-consuming and resource-intensive as the calibration of macro-, meso-, and microscopic simulation models. The analysts' calibration/validation procedure of comparing model outputs with field observations is typical for models developed with this tool type.

Figure 55. Speed Contour Plot Comparisons

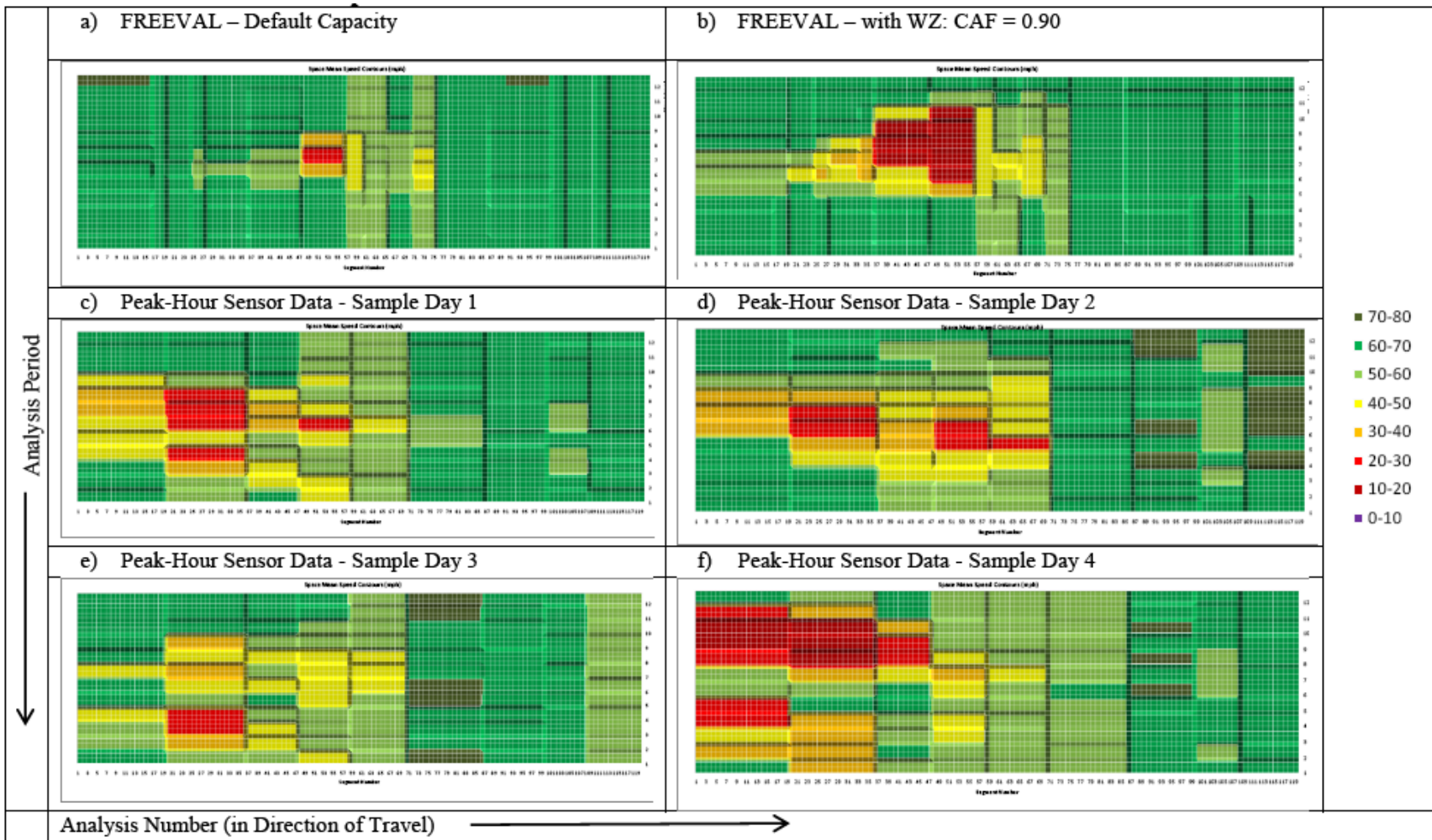(Source: Schroeder, Rouphail, Sajjadi, and Fowler,2011.)

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Step 5D – Work Zone Base Conditions Model Development

The PM Peak Work Zone Base, Barrier Work model follows the same configuration as the p.m. peak existing conditions model. The p.m. peak barrier scenario differs from the existing conditions model in that it represents construction activities along the corridor with reduced shoulder widths.

Step 5E – Work Zone Base Conditions Model Calibration

Calibration of the PM Peak Barrier Work model followed the same procedure as the existing conditions model. Calibration of the off-peak work zone scenarios were conducted using measures such as capacity, travel time, and speed contour plot comparisons.

- **Travel Time –** The targets for the work zone scenarios also are average facility travel time for the three-hour analysis period and the maximum 15-minute travel time. Figure 56 summarizes the travel time results for each scenario based on field-observed or field-estimated values and FREEVAL model outputs before and after calibration. Before calibration, several of the model scenario results significantly differed from the field-observed travel times. The authors determined that the default HCM 2010 work zone capacity estimates underestimated the resulting travel time on the facilities. The authors made adjustments to the default capacity adjustment factors (CAF) and generated new model travel times results. As shown in the table, the after calibration model travel times appeared to be more closely matched to field-observed results.
- **Capacity –** Following HCM 2010 methodology, a default work zone capacity and capacity adjustment factor (CAF) were estimated for each scenario. Following HCM guidance, the work zone scenarios were modeled by first reducing the number of lanes in the appropriate segments and then applying the CAF to each of the remaining lanes. After calibration (based on travel time results), a lower CAF was determined for most of the scenarios. The result of the capacity calibration step is detailed in Figure 57.
- **Space-Mean Speed Contours –** The final calibration step was the visual comparison of field and FREEVAL speed contours. The speed contour comparisons are shown in Figure 58. Ideally, the model results should replicate the conditions in the field. As the figure shows, the model speed contour diagrams do not fully replicate the extent of the congestion shown in the field-based speed plots. However, the bottleneck locations identified in both the field and model speed contour diagrams do coincide.

Scenario	Field Sensors		FREEVAL before Calibration		FREEVAL (after Calibration)		% Difference (before Calib.)		% Difference (after Calib.)	
	Avg. TT	Max TT	Avg. TT	Max TT	Avg. TT	Max TT	Avg. TT	Max TT	Avg. TT	Max TT
Base	12.4	16.4	10.9	12.56	11.9	14.9	-12.1%	-23.4%	-4.0%	-9.1%
Barrier	14.1	20	10.9	12.56	13.4	18.2	-22.7%	-37.2%	-5.0%	-9.0%
I	11.1	11.2	10.0	10.0	10.7	10.8	-9.9%	-10.7%	-3.6%	-3.6%
II	11.1	11.7	10.0	10.0	10.3	11.7	-9.9%	-14.5%	-7.2%	0.0%
III	11.3	11.5	10.0	10.1	10.2	10.8	-11.5%	-12.2%	-9.7%	-6.1%
IV	12	12.8	19.1	29.9	11.0	14.3	59.2%	133.6%	-8.3%	11.7%
V	22.7	41.4	18.8	27	26.3	37.1	-17.2%	-34.8%	15.9%	-10.4%
VI	12.9	15.7	10	10	11.4	15.5	-22.5%	-36.3%	-11.6%	-1.3%

Figure 56. I-40 Case Study Work Zone Scenarios Travel Time Comparisons

Scenario	Date	Lane Closure Milepost (Per Contractor)	Scenario Description	FREEVAL Segments Closed	HCM Default Capacity (pcphpln)	HCM Default CAF	CAF after Calibration
Base	8/30/2009	----	Base Case, PM Peak 2009	----	2400	1.00	0.95
Barrier	6/22/2010	----	Barrier Work, PM Peak 2010	----	2400	1.00	0.90
I	4/13/2010	289 to 291	4 to 3 LC, Off Peak	4	1500	0.63	0.55
II	9/15/2009	289 to 291	3 to 2 LC, Off Peak	11	1450	0.60	0.40
III	3/7/2010	288 to 289	4 to 2 LC, Weekend Off Peak	1 to 6	1450	0.60	0.60/0.70
IV	3/14/2010	285 TO 289	4 to 1 LC, Weekend Off Peak	1 TO 6	1350	0.56	0.75
V	3/18/2010	289 to 291	3 to 1 LC, Off Peak	8	1450	0.60	0.55
VI	6/22/2010	291 to 294	3 to 1 LC, Off Peak	16	1450	0.60	0.35

Figure 57. I-40 Case Study Work Zone Scenarios Capacity Comparisons

Step 6 – Alternatives Analysis

The alternatives analysis step involves two stages: 1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results.

Step 6A – Alternatives Model Development

The work zone alternatives or model scenarios were developed as a result of the work zone diaries obtained from the contractors (work zone diaries are described in further detail in Step 5A). Using the work zone diaries and sensor data, the authors were able to determine the lane closure scenarios that occurred during construction. The six-lane closure scenarios detailed in Step 4 resulted from this analysis. The inputs and geometric configuration of these six scenarios are shown in Figure 58.
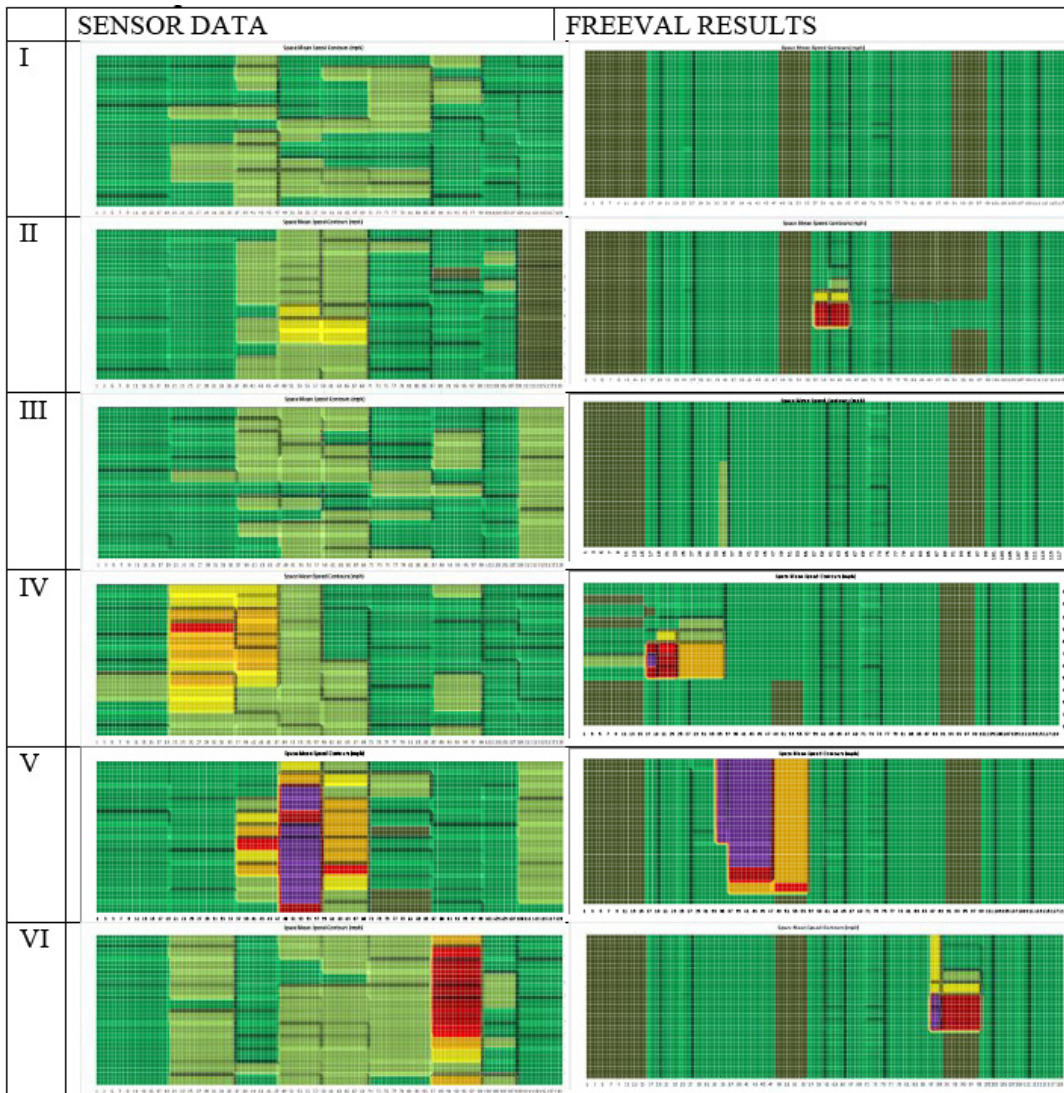
Figure 58. I-40 Case Study Work Zone Scenarios Speed Contour Comparisons

(Source: Schroeder, Rouphail, Sajjadi, and Fowler,2011.)

Step 6B – Alternatives Analysis Model Runs and Results

The final step of the MOTAA is to run the work zone alternative models and evaluate the performance measures extracted. The analysts used MOEs such as capacity, travel time, and comparisons of space-mean speed contour diagrams. Details regarding how these measures were extracted from the model are provided in Step 5D. As previously mentioned, the main objective of the analysis is to determine the capability of the FREEVAL-WZ models to capture and/or replicate field-observed work zone conditions and operations. As a result, the work zone scenarios were compared to field-observed conditions/data instead of to each other. Results of these comparisons are shown on Figure 56, Figure 57, and Figure 58.

Because the purpose of the ITRE report and the case study was to demonstrate the use of FREEVAL for work zone traffic analysis, the authors do not provide a recommended alternative. Therefore, no decision-framework was applied.

9.6 URBAN FREEWAY LANE CLOSURES USING SKETCH-PLANNING TOOLS – ITS DEPLOYMENT ANALYSIS SYSTEM (IDAS)

Project Background

This case study features a benefit/cost (B/C) assessment of the temporary ITS used for the I-496 reconstruction project conducted for Michigan DOT.[62] The Michigan DOT undertook a major effort to repair and rebuild parts of the I-496 corridor through downtown Lansing. The reconstruction project, which began in April 2001 with a total value of the investment of $42.4 million, covered the I-496 corridor from the I-96 interchange on the west, to Trowbridge Road in the City of East Lansing. A map of the construction project is shown in Figure 59.

Figure 59. I-496 Case Study Project Area Map

- **Phase 1 –** Scheduled for completion between April 2001 and August 2001. The eastern section of I-496 between U.S. 127 and Pine Street was entirely closed. This section is indicated in red in the maps shown in Figure 59. On northbound and southbound U.S. 127, two lanes were maintained at all times, except for a four-week period between Memorial Day and the Fourth of July, when U.S. 127 near Trowbridge Road was reduced to one.

- **Phase 2** – Scheduled for completion during September and October 2001. During this phase, the western section of I-496 between Pine Street and I-69/I-96 was restricted to one lane. This section of the corridor is indicated in orange in the maps shown in Figure 60. During construction, this section was reduced to one lane of traffic in each direction.

Figure 60. I-496 Reconstruction Project Phasing

Both stages of this massive highway construction project resulted in major changes in commuting patterns. Therefore, Michigan DOT embarked on a concerted effort to help employers and residents of the Lansing region cope with this major reduction in capacity of the region's transportation system. In addition to public education and outreach campaign, the following were the major efforts that were undertaken by Michigan DOT to mitigate the impacts of the construction project:

- **Intelligent Transportation Systems (ITS) technologies** were deployed to manage traffic and provide traveler information during the construction project. The system, dubbed the Temporary Traffic Management System (TTMS), utilized state-of-the-art traffic surveillance, detection, and communications technologies to manage traffic during the construction project. It provided real-time information to motorists to help them determine the best way to reach their destinations. Information on designated alternate routes (shown in green in the project maps) was distributed both in print and via electronic media as part of Michigan DOT's public outreach effort; and
- **Signal system timing and operations on selected arterial corridors** were upgraded to serve as alternate routes for the construction project. The type of improvements included traffic signal controller upgrades and signal interconnects between these intersections to implement traffic-actuated operations. Signal timing improvements were made to accommodate higher traffic volumes as a result of the closure of I-496. The signal timings on these corridors were adjusted periodically during the course of the project to manage the traffic diversions better.

This study focused on a benefit/cost (B/C) assessment of the TTMS used for the I-496 reconstruction project. Michigan DOT intended to use the lessons learned through the TTMS deployment and its B/C evaluation to assist in decision-making for the procurement and deployment of such systems in the future.

Application of the Maintenance of Traffic Alternatives Analysis

Step 1 – Problem Definition, Scope, Goals, and Objectives

The primary goals and objectives of this case study were outlined as follows:

- Identify the regional impacts of the TTMS on the roadway network in the Lansing region;
- Identify the benefits of the TTMS to Michigan DOT, motorists, and the environment;
- Perform a benefit/cost analysis for the deployment of the TTMS;
- Develop recommendations for Michigan DOT on the utility and relevance of ITS-based traffic management systems for improving mobility and safety in construction work zones; and
- Identify the benefits of the arterial signal system improvements that were performed on the alternate routes.

Step 2 – Establishing the Measures of Effectiveness and Thresholds

The following performance measures were used to identify the impacts and benefits of the system:

- **User Mobility (Time-Savings) –** These are time-savings realized by motorists through the use of the traveler information components of the TTMS, including the Portable Dynamic Message Signs (PDMS), video monitoring stations, and web-based traveler information. These time-savings are primarily realized through changing of travel routes, and (or) departure times. The mobility benefits of the TTMS are primarily realized by the road-users, but a significant portion of these benefits translates into customer satisfaction benefits that are realized by Michigan DOT. However, at that time, insufficient data were available to estimate the customer satisfaction benefits.
- **Travel Time Reliability –** These are time-savings realized by motorists under situations of nonrecurring congestion caused by incidents, such as crashes or vehicle breakdowns. ITS deployments that are aimed at improving safety and reducing the duration of incidents increase the reliability of the travel time in the region. The primary source of these benefits in the case of the Lansing TTMS are the incident detection/management components, including the CCTV-based incident management systems, traffic queue detectors and the associated communications, and information dissemination equipment. The construction work zone intrusion detection devices also indirectly contribute to these savings. Similar to the mobility benefits, travel time reliability benefits of the TTMS are realized primarily by road-users, but they also translate into both customer satisfaction and effective capacity utilization benefits for Michigan DOT. However, due to lack of sufficient data at that time, these benefits were not assigned explicitly to Michigan DOT.
- **Fuel Consumption and Emissions –** The ITS Deployment Analysis System (IDAS) model uses the performance statistics of the transportation network to estimate environmental performance measures. The model uses a series of detailed look-up tables that consider energy consumption and emissions rates based on specific network volume and traffic operating characteristics. The use of look-up tables provides the analyst with

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the ability to incorporate updated emissions and energy consumption rates as they become available. IDAS incorporates emissions and energy consumption rates from currently available sources, including Mobile 5 and California Air Resources Board EMFAC. Fuel consumption and emissions benefits of the Lansing TTMS were realized through all the components of the TTMS working together. Fuel consumption savings were realized by the traveling public, and both fuel consumption and emissions savings were applicable to the environment and society in general.

- **Accidents** – The IDAS model provides estimates of changes in the number and severity of accidents resulting from the implementation of ITS strategies. Based on performance statistics calculated from the travel demand model runs, IDAS determines the safety benefits by using detailed accident rates using a series of look-up tables. Similar to the energy consumption and environmental benefits, the IDAS model is flexible to allow use of updated accident rates as they become available. The accident savings estimated through the Lansing TTMS were primarily due to its incident management components. Accident savings were realized primarily by Michigan DOT and other public agencies, through reduced accident handling costs, reduced personnel time, and efficient management of incidents and the associated ripple effects on traffic flow and safety. Accident savings also were realized by the traveling public and the society, through reduction in the number of fatalities (fatalities are downgraded to injury accidents through quicker identification and response to accidents).

Step 3 – Choosing the Analysis Tool

The analysis used IDAS, a tool used to estimate the regional impacts and benefits of ITS deployments. IDAS was developed by FHWA and is intended to make the estimation of impacts and benefits of ITS deployments compatible with the methods used for other transportation projects. It utilizes existing regional travel demand models as the primary inputs for the analysis. The IDAS model is equipped with a comprehensive "ITS Benefits Database," which consists of nationally and internationally reported benefits of ITS deployments over several years. The IDAS ITS benefits database is the primary source of impacts and benefits.

Analysis Tool Selection Options

In this case study, IDAS was chosen based upon the tool's capabilities in estimating the impacts and benefits of ITS deployments, which was required by the agency (Michigan DOT). There also are additional factors that can be considered in selecting a tool. Chapter 3 of this document describes these various factors in greater detail. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (The tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies).

Step 4 – Identify the Alternatives

This case study differs from a typical work zone analysis as it was specifically to conduct a benefit/cost assessment of the predetermined TTMS and arterial signal systems upgrades. Therefore, no other alternatives were analyzed.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the objectives of the analysis and identify the data needed for the modeling analysis effort. For this case study, the following types of traffic data were collected:

- The presence and duration of traffic queues collected by the portable queue detectors;
- Travel time information collected by conducting test-vehicle travel time runs on alternate routes; and
- Traffic volume information collected by the queue detectors and microwave detectors.
- Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model. The IDAS model was developed based on the travel demand networks and trip tables provided by the Tri-County Regional Planning Commission (TCRPC), which is the MPO for the three-county (Ingham, Eaton, and Clinton Counties) Lansing metropolitan region. The Lansing travel demand models were updated in 2000.

Step 5B – Existing Conditions Model Calibration

The IDAS model was validated by comparing the Vehicle-Miles Traveled (VMT) values generated by IDAS with those from the regional travel demand model.

> **Model Calibration using Sketch-Planning and Deterministic Tools**
>
> Model calibration of sketch-planning and deterministic tools is typically conducted at a higher level and is often less time-consuming and less resource-intensive than the calibration of macro-, meso-, and microscopic simulation models.

Step 5C – Work Zone Base Conditions Model Development

The travel demand models provided by TCRPC were then altered to reflect the freeway closure and lane closure of the two phases of the I-496 reconstruction project. A similar analysis performed by the Michigan DOT Central Office on an older version of the Lansing travel demand model was used as the template for representing the field conditions during the construction project. The disbenefits or negative impacts of the I-496 reconstruction project, obtained by running these networks in IDAS were documented.

Step 5D – Work Zone Base Conditions Model Calibration

There was no calibration data available for this work zone scenario. Therefore, there was no calibration efforts conducted that compared the work zone base with field conditions or with results from previous work zones of similar types.

Step 6 – Alternatives Analysis

The ITS components were deployed on each of the travel demand models, and IDAS was run to estimate the impacts and benefits of the deployment. The impacts of the deployments on the different travel performance measures were documented and the benefit/cost ratio was then calculated by comparing the benefits of the deployments with the total cost.

As described earlier, the benefits of the Temporary Traffic Management System (TTMS) include four categories: 1) user-mobility savings; 2) travel time reliability savings; 3) accident savings; and 4) emissions savings. For instance, the benefits for Phase 1 of the TTMS and the Arterial Signal System Upgrades are summarized in Figures 61 and 62, respectively.

Because the purpose of the study was to conduct a benefit/cost assessment of the predetermined TTMS and arterial signal systems upgrades for work zone traffic analysis, no alternatives were available and, therefore, it was not necessary to provide recommended alternative. Hence, there is no decision-framework applied.

Impact Measure	Time Period	Impact	Percent Reduction
Mobility (Average hours of time-savings on a daily basis)	A.M. Peak Period	115 hours	- 0.3%
	Off-Peak Period	582 hours	- 0.3%
	P.M. Peak Period	166 hours	- 0.2%
Travel Time Reliability (Average hours of unexpected delay saved on a daily basis)	A.M. Peak Period	50 hours	- 29.0%
	Off-Peak Period	30 hours	- 30.0%
	P.M. Peak Period	409 hours	- 33.7%
Number of Fatalities (Reduction on a daily basis)	A.M. Peak Period	0.0002	- 2.1%
	Off-Peak Period	0.0007	- 2.0%
	P.M. Peak Period	0.0003	- 2.2%
Fuel Consumption Reduction (Average Gallons reduced per day)	A.M. Peak Period	1,407 gallons	- 1.6%
	Off-Peak Period	6,164 gallons	- 1.5%
	P.M. Peak Period	2,993 gallons	- 1.6%
Emissions Reduction (Average Tonnage reduction per day)	A.M. Peak Period		
	HC	0.029 tons	- 1.4%
	CO	0.197 tons	- 1.6%
	NOx	0.070 tons	- 1.8%
	Off-Peak Period		
	HC	0.126 tons	- 1.3%
	CO	0.869 tons	- 1.5%
	NOx	0.307 tons	- 1.7%
	P.M. Peak Period		
	HC	0.061 tons	- 1.4%
	CO	0.415 tons	- 1.6%
	NOx	0.148 tons	- 1.9%

Figure 61. I-496 Case Study – TTMS Benefits Summary (Phase 1)

Impact Measure	Time Period	Impact	Percent Reduction
Mobility (Average hours of time-savings on a daily basis)	A.M. Peak Period	286 hours	- 0.7%
	Off-Peak Period	344 hours	- 0.2%
	P.M. Peak Period	1,044 hours	- 1.3%
Travel Time Reliability (Average hours of unexpected delay saved on a daily basis)	A.M. Peak Period	6 hours	- 3.3%
	Off-Peak Period	1 hour	- 1.2%
	P.M. Peak Period	67 hours	- 5.5%
Number of Fatalities (Reduction on a daily basis)	A.M. Peak Period	Negligible	Negligible
	Off-Peak Period	Negligible	Negligible
	P.M. Peak Period	0.0001	- 0.32%
Fuel Consumption Reduction (Average Gallons reduced per day)	A.M. Peak Period	182 gallons	- 0.2%
	Off-Peak Period	203 gallons	- 0.1%
	P.M. Peak Period	721 gallons	- 0.4%
Emissions Reduction (Average Tonnage reduction per day)	A.M. Peak Period		
	HC	0.006 tons	- 0.3%
	CO	0.053 tons	- 0.5%
	NOx	0.004 tons	- 0.1%
	Off-Peak Period		
	HC	0.007 tons	- 0.1%
	CO	0.065 tons	- 0.1%
	NOx	0.003 tons	- 0.1%
	P.M. Peak Period		
	HC	0.022 tons	- 0.6%
	CO	0.188 tons	- 0.8%
	NOx	0.019 tons	- 0.3%

Figure 62. I-496 Case Study – Arterial Upgrades Benefits Summary (Phase 1)

9.7 TEMPORARY TWO-WAY ONE-LANE OPERATION ON BRIDGES USING TRAFFIC SIGNAL OPTIMIZATION TOOLS – SYNCHRO

Project Background

This case study, featured in the MD SHA Work Zone Analysis Guide (2008), describes the agency's recommended MOTAA procedures for analyzing a two-way, one-lane bridge operation work zone project.[15] The hypothetical project is located on MD 23, a two-lane, two-way roadway that runs in the east-west direction over Morse Road. As with the flagging operations

case study featured in Section 9.1, the main purpose of this and other case studies featured in the MD SHA Work Zone Analysis Guide is to demonstrate the application of the recommended MOTAA approach and guidelines.

Figure 63 depicts the study area location and nearby facilities. The nearest intersection to this bridge is where MD 23 terminates at MD 165, as shown in the project area map. There are no other access points between MD 23 and MD 165 west of Morse Road. The proposed work is to reconstruct the full length (100 feet) of the bridge.

Application of the MOTAA Process

Step 1 – Problem Definition, Scope, Goals, and Objectives

As previously mentioned, this case study features the reconstruction of the MD 23 bridge over Morse Road. Because of the lack of access, there are no detour routes available, posing a challenge to mitigating the mobility impacts of the construction work. It is, therefore, assumed that the construction work would need to be accomplished through a two-stage process, where one lane at a time would be closed on the bridge, permitting traffic to flow on the other lane.

For this bridge reconstruction case study, the objective of the analysis is to determine if the reconstruction of the bridge performed using the one-lane, two-way bridge operations with traffic signals on either end could meet the mobility thresholds. Although this process notes that traffic signals would be used to regulate the flow of traffic on the one open lane, the analysis procedure featured in this section also could be applied for flagging operations.
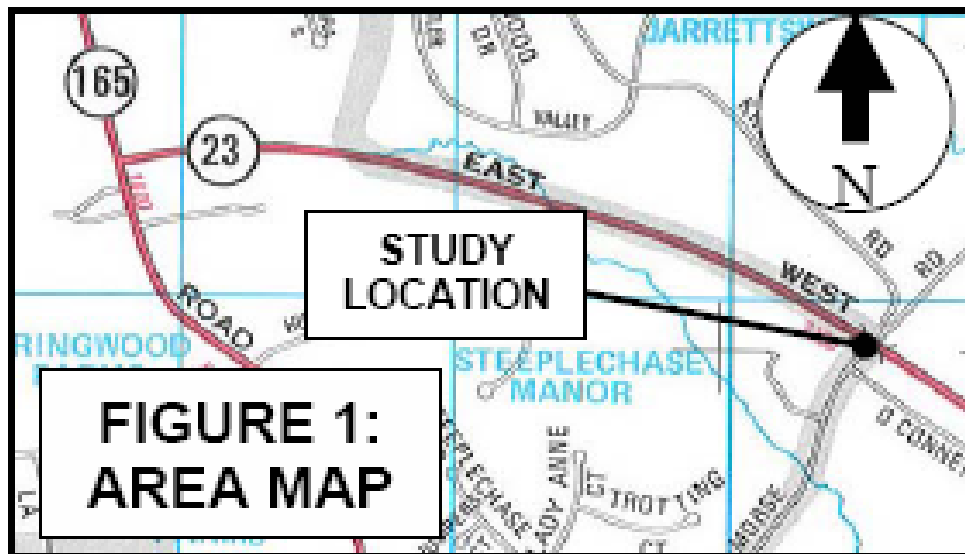
Figure 63. MD 23 Case Study Project Area Map

Step 2 – Establishing the Measures of Effectiveness and Thresholds

In this case study, the mobility threshold is set at a 15-minute travel time increase limit. The measures of effectiveness included control delay and travel time.

Step 3 – Choosing the Analysis Tool

Most arterials and freeways across the State of Maryland have been modeled using Synchro and CORSIM, respectively. To reduce data collection and model development efforts, Synchro was, therefore, chosen as the analysis tool.

Analysis Tool Selection Options

For this case study, Synchro was chosen because it reduced agency resource requirements and data collection efforts. Chapter 3 of this document describes other factors that can be considered when determining what type of analysis tool to use for the MOTAA. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (Tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies.).

Step 4 – Identify the Alternatives

In this case study, the agency did not predetermine a set of alternatives earlier on in the project. The first work zone scenario evaluated is the one-lane, two-way bridge operations with traffic signals on either end. A second work zone alternative is established should the primary scenario not meet the threshold. In this case study, no second work zone scenario was established because the primary scenario met the mobility thresholds, as shown in Step 6.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

The goals and objectives of the analysis were described in Step 1 of this section. After determining the goals and objectives of the analysis, the next step includes determining the scope of the analysis (identifying the geographic boundaries of the study area) and the data inputs required.

- **Scope** – The study area includes the full 100 feet length of the bridge and does not include any adjacent intersections since there are no nearby detour routes available.

Additionally, a queue length approximation analysis showed that expected queues were not anticipated to extend to other intersections in the study network.

- **Traffic Counts** – Traffic counts from February of 2004 were obtained from MD SHA. Traffic volumes were then adjusted to April (the heaviest travel month of the year) equivalent values. Additionally, a growth factor of 2.6 percent also was applied to the traffic counts in order to forecast volumes for the year of the analysis, 2007.

Step 5B – Existing Conditions Model Development

Because there were no existing intersections at or near the study area, no model was created for existing conditions.

Step 5C – Existing Conditions Model Calibration

No existing conditions model was built. Therefore, there was no need for an existing conditions calibration process.

Model Calibration and Validation Options

If an existing conditions model calibration process is needed, each traffic signal optimization software package has a set of user-adjustable parameters that enable the analyst to calibrate the software to better match specific local conditions. The calibration process involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Additionally, each agency and project may have different calibration guidelines and requirements. Section 4.4 of this document provides guidance on the considerations and steps involved in the calibration of traffic signal optimization models.

Step 5D – Work Zone Base Conditions Model Development

The next step in the MOTAA is the development of a work zone base conditions model. The one-lane bridge operations layout is shown in Figure 64. Model development for this case study includes considerations for geometric and signal controls.

- **Road Geometry** – The work zone area is expected to be 1,050 feet long, based on a roadway speed of 45 mph, the buffer length of 360 feet, and the taper of 270 feet. To create the model in Synchro, two intersections were placed 1,050 feet apart along the link representing roadway, MD 23.
- **Traffic Signal Control** – The two intersections were coded as fully actuated signal controlled.
  - Clearance Interval – Clearance timings for the two intersections were developed using MD SHA's *Policy for Determining Yellow Timings at Intersections* and the Institute of Transportation Engineers (ITE) Manual of *Traffic Signal Design*.[15,62] The results of the clearance interval calculations are shown in Table 89.
  - Cycle Length – The cycle length for the two signals were determined based on the requirement that the queues in each direction should clear during each cycle. This type of control parallels flagging operations since the flagger will only stop a particular direction once the queue has cleared. Cycle lengths were determined to be 250 seconds for the a.m. peak and 220 seconds for the p.m. peak. The equation used for determining the minimum cycle lengths is shown by the expression:

$$C = 2.2\ \frac{V * G}{3600} + 2CL \tag{5}$$

Where:

C = Total cycle length;
G = Cumulative green time per cycle for both directions;
V = Total hourly volume for both directions; and
CL = Total clearance interval for each direction.

Table 89. MD 23 Case Study – Clearance Interval Calculations

Interval	Equation	Duration (Seconds)
Yellow (Y)	$t\ + 1.47 * \dfrac{V_{posted}}{2a}$	4.5
All-Red (AR)	$\dfrac{W + L}{1.47} * V_{operating}$	21
Total Clearance	$\mathbf{Y\ + AR}$	25.5

Vposted = Posted speed limit (45 mph); t = Perception-reaction time; W = Total work zone length; L = Average vehicle length; and Voperating = Operating speed (35 mph).
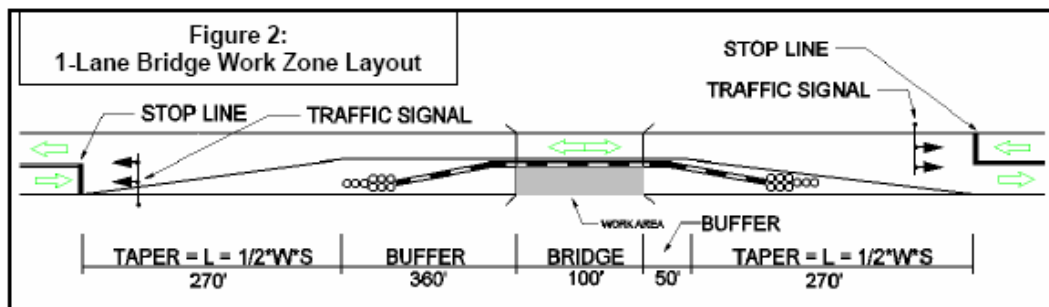
Figure 64. MD 23 Case Study – One-Lane Bridge Operations Layout

(Source: Maryland State Highway Administration, 2008.)

Step 5E – Work Zone Base Conditions Model Calibration

No work zone base conditions model calibration was conducted for this case study.

Work Zone Base Conditions Model Calibration Options

Work zone model calibration includes the calibration of work zone capacity and performance measures. Work zone model capacity and performance measures can be calibrated to field data and/or prior experiences (from similarly implemented work zone projects). In order to calibrate to field data or case studies of similar work zone types, the analyst will evaluate the work zone's queues, travel times, delays, and speeds. Additionally, the analyst may study parameters related to driving behaviors in work zones of similar types. Such observations and measures will aid the analyst in the work zone calibration process.

Step 6 – Alternatives Analysis

The next step is to perform model runs in order to analyze the different alternatives. The analysis involves running the model and obtaining outputs and measures such as control delay. The control delay results for the one-lane bridge operations during both peak periods are shown on Table 90.

Table 90. MD 23 One-Lane Bridge Operations – Synchro Model Outputs

| Approach | Control Delay (Seconds) | |
	AM Peak	PM Peak
Eastbound	195.2	221.4
Westbound	188.3	196.2

The next step applied for this case study was to determine if the alternative meets the agency's established mobility thresholds. According to the mobility thresholds for arterials established in the MD SHA *Work Zone Analysis Guide*, the work zone travel time cannot increase more than 15 minutes over the existing condition's travel time.[15] Based on the Synchro results, the control delay outputs are expected to be less than 3.7 minutes per vehicle for both approaches during either peak period. The control delay is, therefore, equal to the expected increase in travel time through the work zone and satisfies the travel time increase limit. No other alternative was, therefore, developed and evaluated.

Alternative Analysis Options

The alternative analysis process may differ based on the agency and the project. In this case, a second work zone alternative was not considered because the primary alternative met the mobility thresholds. Another alternatives analysis approach may involve analyzing several alternatives concurrently. Additionally, an analyst can compare and choose among various alternative's different types of performance measures. In this situation, the criteria for selecting the preferred alternative depended solely only on mobility thresholds. For other decision-making framework options, refer to Chapter 5 of this document.

9.8 SIGNALIZED CORRIDOR LANE CLOSURES USING TRAFFIC SIGNAL OPTIMIZATION TOOLS – SYNCHRO/SIMTRAFFIC

Shady Grove Road, Maryland

This case study, featured in the Maryland State Highway Administration's (MD SHA) Work Zone Analysis Guide, describes the agency's recommended MOTAA procedures for analyzing a hypothetical work zone project along the signalized corridor Shady Grove Road.[15] The main purpose of this and other case studies featured in the MD SHA Work Zone Analysis Guide is to demonstrate the applications of the agency's recommended MOTAA approach and guidelines.

This work zone example features the reconstruction of sidewalks, curbs, and gutters along the southbound direction of Shady Grove Road. Shady Grove Road is a six-lane, two-way, divided roadway running in the north-south direction. During construction, the right lane of the

southbound direction of Shady Grove Road is closed, reducing the number of lanes from three to two. The lane closure will occur between the intersection of Shady Grove with Comprint Court and Gaither Road.
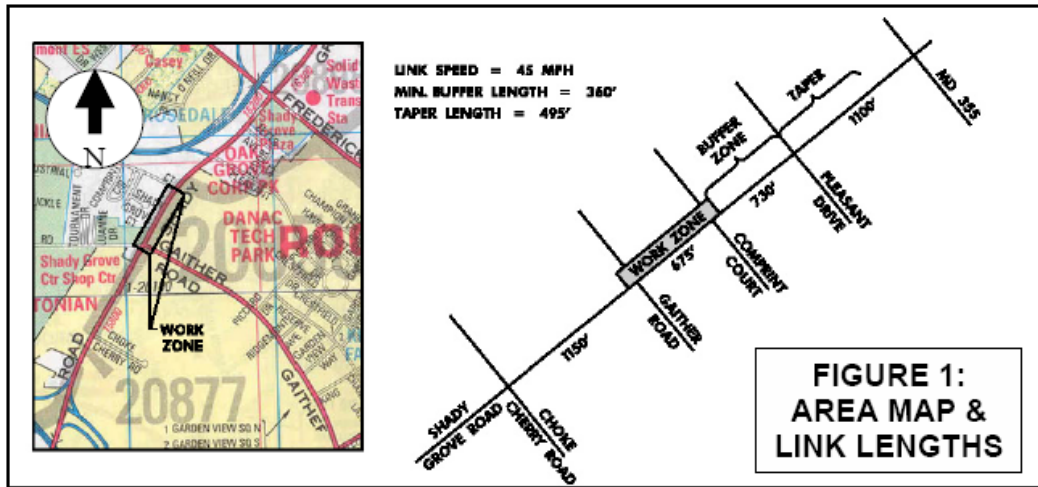
Figure 65. Shady Grove Road Work Zone Area Map

(Source: Maryland State Highway Administration, 2008.)

Application of the MOTAA Process – Shady Grove Road

Step 1 – Problem Definition, Scope, Goals, and Objectives

The first step in an MOTAA is to define the goals, and objectives of the analysis. The goals and objectives of the work zone analysis include the following:

- Determine if a lane closure can be permitted along Shady Grove Road (determining whether or not the work zone configuration will meet the arterial mobility thresholds established by the agency); and
- Determine what work hour restrictions are required to meet the mobility thresholds.

Step 2 – Establishing the MOEs and Thresholds

After defining the goals and objectives of the project, the next step in an MOTAA is to establish the measures of effectiveness and/or thresholds that would be used to evaluate and compare the different work zone alternatives. In this case study, the measures of effectiveness (MOE) are derived from the mobility thresholds established by MD SHA. The established thresholds compare pre-construction and work zone scenarios using measures such as travel time, control delay, and LOS.

Step 3 – Choosing the Analysis Tool

The next stage of the MOTAA process is to determine which traffic analysis tool is best suited for the project and to detail the justification for that selection. Because MD SHA has developed models for most arterials and freeways across the State using Synchro and CORSIM, the Synchro/SimTraffic package was chosen as the analysis tool for this and other arterial case studies featured in the MD SHA Work Zone Analysis Guide. Using these pre-developed models served to reduce data collection and model development efforts.

Analysis Tool Selection Options

Chapter 3 of this document describes several other factors that should be considered when choosing a traffic analysis tool. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (Tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies.).

Step 4 – Identify the Alternatives

After determining the MOEs and the analysis tool, the next stage of an MOTAA process is the identification of work zone alternatives. In this case study, a red flag analysis is first conducted in order to determine if the intended work zone configuration/schedule will meet the mobility thresholds. Should it not meet the mobility threshold, the work zone alternative will be modified to ensure the mobility threshold is reached. For example, in the Shady Grove case study it was assumed that the construction work and lane closure would occur during the midday peak period. Should this fail the red flag analysis, the alternative would be to evaluate the work zone as a weekend construction period.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the MOTAA, the analysts should identify the scope of the analysis, including the level of data collection effort needed. Establishing the scope of the analysis requires defining the limits of the study network. Because the work zone lane closure includes the area between the two signalized intersections, the analysis study area must include the impacts to these two intersections, as well as the mobility impacts that extends upstream of the work zone due to the lane closure.

A queue length analysis using field data collected (including a.m. peak hour traffic volumes and signal timings) also was performed in order to determine how far upstream of the work zone

should the analysis extend. Based on this queue length analysis, the analysts determined that the work zone analysis should extend at least 7,000 feet upstream of Gaither Road, the southernmost point of the lane closure. The recommended work zone analysis area is shown on Figure 66. No detour routes have been included in the analysis area as there are no nearby parallel routes. Also as shown by the figure, the study network extends from Choke Cherry Road to the EB I-370 On-ramp.

In addition to the identification of the size of the study area and the scope of the analysis, the analysts at this stage must identify the data needs required to model the alternatives. Data sources can include road geometry, signal timing plans, traffic demands, capacities, travel times, and queues. The following summarizes the data inputs to develop and run the Synchro/SimTraffic models:

- **Road Geometry** – Aerial imagery and field observations were used to confirm road geometry features.
- **Traffic Controls** – Existing signal timings for all signalized intersections in the study area were obtained from the Montgomery County Transportation Center.
- **Traffic Volumes Data** – Turning movement counts for the intersection of Shady Grove Road and Frederick Road (MD 355) were obtained from MD SHA. The turning movement counts for the intersection with Choke Cherry Road were obtained from a traffic study sponsored by the Montgomery County TMC. For the remaining intersections, TMCs were obtained from field data collection.
- **Additional Field Observed Data** – Additional data collected on the field included queue lengths, lane utilization, and truck percentages.
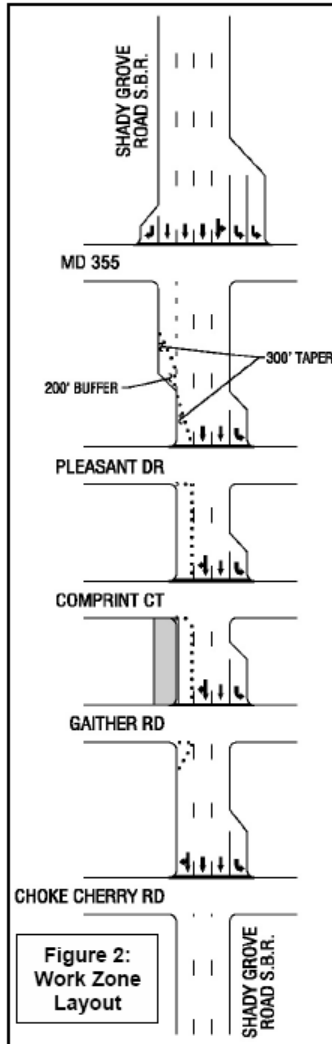
Figure 66. Shady Grove Road – Extent of Analysis

(Source: Maryland State Highway Administration, 2008.)

Field Data Collection Considerations

Although not specified in this case study, there are certain factors that should be considered when collecting volume and demand information from the field. First, the field analysts must consider the time periods when best to collect the data. For instance, if the work zone is to be completed during peak or off-peak periods, the time period for field data collection should be customized for when the work zone is planned/programmed to be active.

Second, analysts should consider the variations of daily traffic flow patterns and how this phenomenon can be captured through the data collection. In order to replicate the stochastic nature of traffic, the field analysts should plan to capture data through several days and/or multiple time periods. They should also consider the type of travel days (weekdays versus weekends) when data should be collected.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model with the appropriate geometry, traffic controls, demands, and capacities using the information from the data collection effort described in Step 5A. As previously mentioned, the MD SHA has coded most arterials in the State using Synchro. Typically, these can be used for the existing conditions model granted the study area already has been coded in these pre-developed networks. However, there were no existing Synchro models developed for the Shady Grove study area. Therefore, a new model was coded using information from the data collection effort.

Network coding of the study area was validated by field observations and supplied data by local, regional, and state agencies. The analysis time period also was determined from field observed traffic conditions. According to a fatal flaw analysis of these observations, the existing congestion level along Shady Grove Road in both the a.m. and p.m. peak periods would make the lane closure during these time periods infeasible. Therefore, the agency decided that construction needed to be conducted during the midday. As a result, all model scenarios were analyzed during the midday peak. Hence, only midday peak period signal timing, volume, and traffic conditions data were relevant for model development.

Step 5C – Existing Conditions Model Calibrations

After the development of an existing conditions model, the following step in the MOTAA process is model calibration. Calibration ensures that the operational performance of the model replicates field observed conditions. In the Shady Grove case study, the model was calibrated using peak hour factors, truck percentages, and lane utilization factors. Once calibrated to these factors, the model was validated to reflect the queue conditions and travel times observed on the field.

In order to obtain model outputs for the base condition preconstruction, five SimTraffic simulation runs of the existing conditions model were performed. The model outputs extracted included control delay, LOS, and travel time. The existing conditions model outputs are shown in Table 91.

Table 91. Shady Grove Existing Conditions Model Outputs

Intersection	Control Delay (Seconds)	LOS
Choke Cherry Road	10.1	B
Gaither Road	34.4	C
Comprint Court	9.4	A
Pleasant Drive	27.6	C
MD 355 (Frederick Road)	72.2	E
Solid Waster Entrance	3.7	A
The Great Indoors Entrance	4.0	A
Oakmont Avenue	36.0	D
Crabbs Branch Way	35.9	D
EB I-370 On-ramp	1.7	A
SB Travel Time: EB I-370 On-ramp to Choke Cherry Road		**6.8 minutes**

Step 5D – Work Zone Base Conditions Model Development

The next stage of the MOTAA is the work zone base conditions model development. If an existing conditions model was developed it can typically be modified to develop the work zone base conditions and alternative models. The first work zone alternative or work zone base scenario for this case study is the right lane closure in the southbound direction of Shady Grove Road during the midday peak. As shown on the work zone layout on Figure 66, the lane closure occurs between the intersections of Shady Grove and Gaither Road and Comprint Court. The work zone layout also includes a buffer length of 360 feet and a merging taper of 495 feet. The main changes between the existing conditions model and this work zone scenario include the geometric changes needed to incorporate the lane closure into the network. No changes were made in the O-D data and traffic volumes.

Step 5E – Work Zone Base Conditions Model Calibration

No work zone base conditions model calibration was conducted for this case study.

Step 6 – Alternatives Analysis

The alternatives analysis step typically involves two stages: 1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results. In this case study, model simulation results were first extracted from the developed work zone base case scenario prior to the development of the second work zone alternative.

Step 6A – Alternatives Model Development, and Step 6B – Alternatives Analysis Model

Runs and Results

As previously mentioned, the work zone base case scenario model was run before the development of the second work zone alternative, the weekend work zone model scenario. Similar to the existing conditions model, five SimTraffic simulations were run for the work zone base case. The measures extracted from these model runs are featured in Table 92.

Table 92. Shady Grove Road – Work Zone Base Model Outputs

Intersection	Control Delay (Seconds)	LOS
Choke Cherry Road	9.9	A
Gaither Road	**96.4**	**F**
Comprint Court	13.6	B
Pleasant Drive	**52.5**	**D**
MD 355 (Frederick Road)	72.2	E
Solid Waster Entrance	3.7	A
The Great Indoors Entrance	4.0	A
Oakmont Avenue	36.0	D
Crabbs Branch Way	35.9	D
EB I-370 On-ramp	1.7	A
SB Travel Time: EB I-370 On-ramp to Choke Cherry Road		**15.0 minutes**

The next step is to determine whether the work zone base model results meet the MD SHA mobility thresholds for arterials shown on Figure 67. The intersections with performance measures shown bolded in red in Table 92 have failed to meet the mobility thresholds. For instance, the Gaither Road intersection that had a control delay of 34.4 seconds and an LOS C during the existing conditions model (as shown in Table 91), must meet the mobility threshold of a maximum of LOS D and control delay that must be less than or equal to 45 seconds in the work zone conditions model. Since the level of service of this intersection worsened to an LOS F and increased to a control delay greater than 45 seconds, the intersection failed to meet the mobility threshold. The results indicated another work zone alternative or mitigation measures should be considered.

Because of the nature of the work, the agency did not think it was feasible to consider other alternatives, such as reversible lanes or full lane closures, which would cause greater mobility impacts and require a greater amount of resources. Therefore, the agency decided that only work zone alternatives that involved lane closures during the off-peak hours would be feasible. The second alternative, therefore, considered was weekend construction.

Signalized Intersections	
Existing Level of Service	**Mobility Threshold**
A, B or C	Maximum LOS D Control delay ≤ 45 seconds
D	Maximum increase in Control delay of 30%
E	Maximum increase in Control delay of 30%, or Control delay ≤ 80 seconds
F	No increase in Control delay
Unsignalized Intersections	
Existing Level of Service	**Mobility Threshold**
A, B or C	Maximum LOS D Control delay ≤ 30 seconds
D	Maximum increase in Control delay of 30%
E	Maximum increase in Control delay of 30%, or Control delay ≤ 50 seconds
F	No increase in Control delay
Arterials	
Existing Travel Time	**Mobility Threshold**
T	Travel time can not increase more than 15 minutes (Maximum of T+15)

Figure 67. MD SHA Work Zone Analysis Guide Mobility Thresholds for Arterials

Weekend Work Zone Alternative Model Development and Results

In order to develop the weekend work zone model, weekend data such as weekend peak hour counts needed to be collected. The weekend peak hour was assumed to occur on Saturday midday. The existing conditions and work zone base conditions model were modified to create this work zone alternative by revising the model volumes and signal timings to reflect the weekend conditions. All lane configurations and geometric network features remained the same.

Similar to the existing and work zone base models, five simulations also were run for the weekend work zone scenario. Table 93 shows the existing conditions performance measures and the weekend work zone model results in parentheses. Based on the results shown in this table, all of the intersections met the mobility thresholds. The overall corridor also met the travel time thresholds.

Table 93. Shady Grove Road – Existing (Weekend Work Zone) Model Outputs

Intersection	Control Delay (Seconds)	LOS
Choke Cherry Road	39.9 (39.3)	D (D)
Gaither Road	31.6 (33.7)	C (C)
Comprint Court	8.7 (10.7)	A (B)
Pleasant Drive	30.6 (31.9)	C (C)
MD 355 (Frederick Road)	87.8 (87.8)	F (F)
Solid Waster Entrance	4.3 (4.3)	A (A)
The Great Indoors Entrance	6.7 (6.7)	A (A)
Oakmont Avenue	20.5 (20.5)	C (C)
Crabbs Branch Way	24.4 (24.4)	C (C)
EB I-370 On-ramp	0.6 (0.6)	A (A)
SB Travel Time: EB I-370 On-ramp to Choke Cherry Road	**5.6 minutes (6.5 minutes)**	

Step 7 – Decision Framework and Recommendation of an Alternative

The final stage of the MOTAA is the recommendation of the preferred alternative. The decision criteria for the MD SHA case studies are based on whether the alternative meets the mobility thresholds. Based on the results shown in Table 93, the weekend work zone scenario is the recommended alternative.

Decision Framework Options

This case study's decision-making framework is based primarily on the mobility measures extracted from the Synchro/SimTraffic models. Although these results may be used in choosing a preferred scenario, there also are additional factors that an agency may want to consider when evaluating and comparing the alternatives. These factors are described in further detail in Chapter 7 of this document. A decision-making framework that incorporates these factors, as well as the mobility measures, can then be used to develop a methodology or criteria that can be used to compare the alternatives and choose a preferred option. Chapter 5 of this document features several different decision framework options that can fit projects of different complexities and resources.

9.9 RAMP CLOSURES AT MAJOR INTERCHANGES USING TRAFFIC SIGNAL OPTIMIZATION AND MICROSIMULATION – SYNCHRO AND PARAMICS

I-465 West Leg Reconstruction Project Background

This case study is based on the I-465 west leg reconstruction project in Indianapolis, Indiana as detailed in HCM 2010 Manual, Volume 4, Case Study 6.[64] The reconstruction along I-465 is about nine miles in length with a total of eight interchanges. Figure 68 provides an overview of the location and extents of the project.

This section provides an overview of the analysis methodology employed in evaluating the mobility impacts of the interchange reconstruction on one segment of the I-465 west leg reconstruction, the Rockville Road Interchange Reconstruction Project, shown in Figure 69.

Figure 68. I-465 West Leg Reconstruction, Indianapolis Overview

(Source: Transportation Research Board, 2010.)
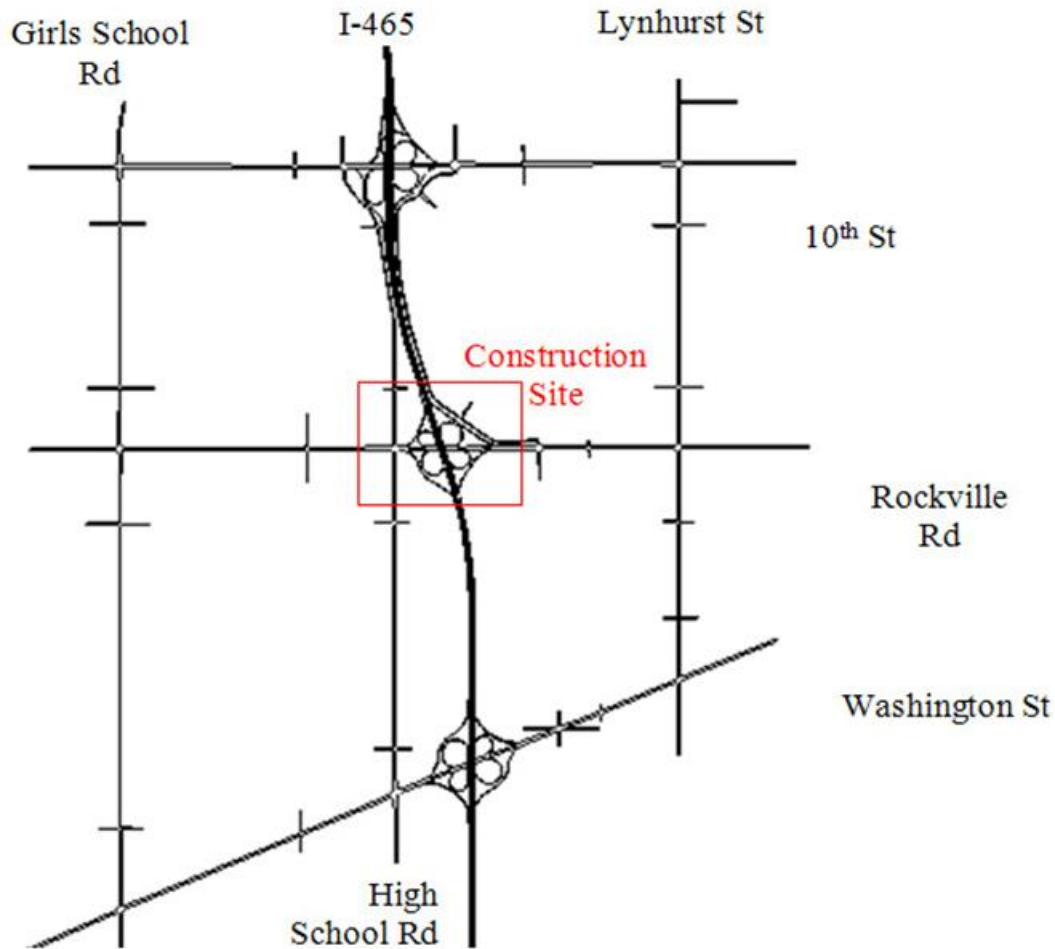
Figure 69. I-465 Case Study Rockville Road Interchange Reconstruction Study Area

(Source: Transportation Research Board, 2010.)

I-465 West Leg Reconstruction Project – Application of the Maintenance of Traffic Alternatives Analysis Process

Step 1 – Problem Definition, Scope, Goals, and Objectives

The main purpose of this case study as featured in HCM 2010, Volume IV was to demonstrate the systemwide analysis of freeway and arterial traffic together with various lane closure options through the use of traffic analysis tools and procedures. Because this case study was featured in HCM 2010 for a specific purpose, the agency's goals and objectives at the time of the reconstruction were not clearly stated. However, an example goal of an agency conducting a similar effort may be to find the optimal lane closure configuration that can minimize the mobility impacts of the work zone without sacrificing construction schedule/duration.

Tradeoffs typically exist between the duration of construction and the level of closures. While lane closures can improve construction duration, the mobility impacts can generate huge

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disbenefits to motorists, neighborhoods, and businesses. **The objective of the modeling analysis, therefore, could be to use the performance measures generated from the analysis to compare work zone configuration options and determine the optimal alternative for the interchange reconstruction.**

In addition, to identifying the goals and objectives of the project, another key part of this stage of the MOTAA is to identify the scope and extents of the analysis. The analysis extent covers the area shown in Figure 70. In this case study, five on- and off-ramps of the Rockville Road interchange will be closed during construction. These include four loop ramps and the I-465 NB to Rockville Road EB off-ramp. Ramps that are closed are marked by an "x" as shown in Figure 70.
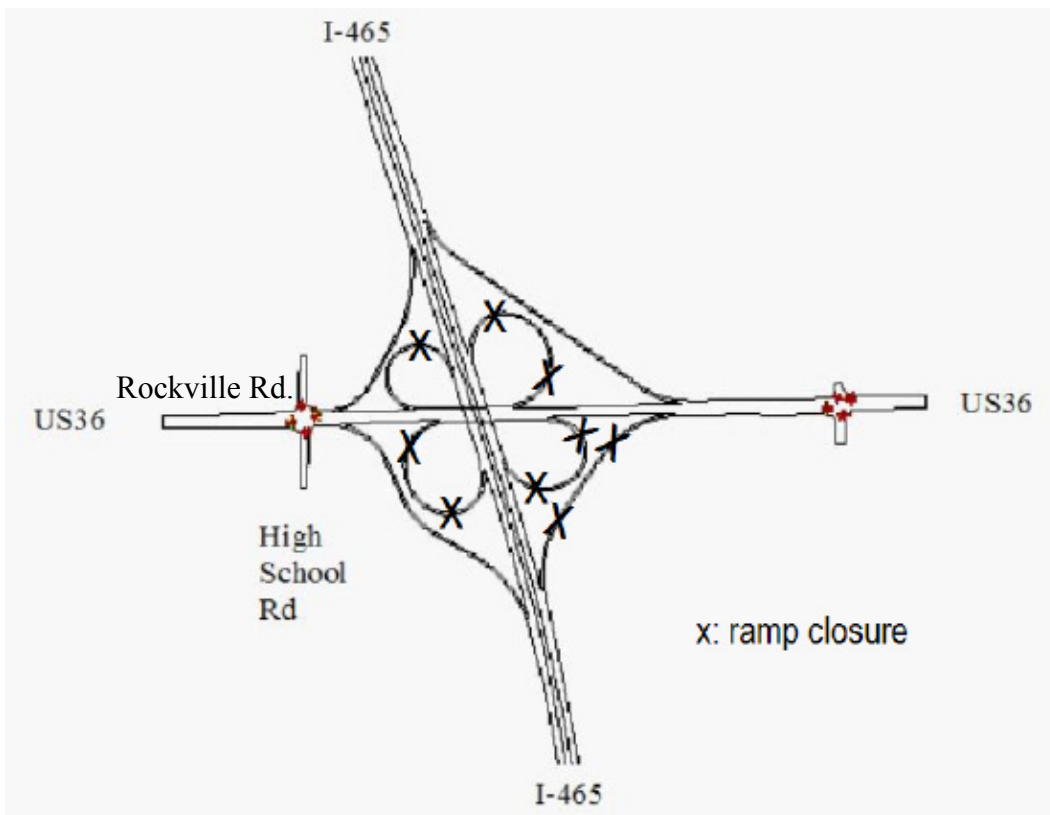
Figure 70. Rockville Road/U.S. 36 Interchange Ramp Closures

(Source: Transportation Research Board, 2010.)

Step 2 – Establishing the Measures of Effectiveness and Thresholds

After defining the goals and objectives of the project, the next step in an MOTAA is to establish the measures of effectiveness and/or thresholds that would be used to evaluate and compare the different work zone alternatives. For this case study the mobility performance measures chosen include average speed and average number of vehicles present in the network, as well as average and cumulative network delays. Another measure that was considered in this case study was construction duration.

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Step 3 – Choosing the Analysis Tool

The next stage of the MOTAA process is to determine the type of analysis tool to be used and the justification for that selection. In this case study, PARAMICS was selected as the simulation tool and Synchro was used to develop signal timing plans. According to the HCM 2010 write-up of this case study, HCM methodologies are not robust enough to generate results and performance measures that could aid in identifying the lane closure alternative that minimizes impacts while improving construction duration. Therefore, the combination of traffic signal optimization and microsimulation analysis tools was used.

Additionally, the analysts wanted to report measures at different levels of analysis (link-, facility-, and systemwide). While operational measures can be generated using HCM methodologies at a link-specific and intersection level, HCM is not suitable for reporting measures at a systemwide level such as for the interchange as a whole. On the other hand, microsimulation has the ability to conduct an operational analysis at link-specific, intersection, multi-facility, and systemwide levels. In the Rockville Road Interchange case study, microsimulation enables the analyst to conduct the impact analysis and generate performance measures for various facility sizes such as for the entire interchange, specific facilities (freeways, ramps, or arterials), or individual links. Additionally, microsimulation tools are useful for analyzing the temporal fluctuations of traffic operations. The combination of microsimulation and traffic signal optimization tools offered the analysts the capabilities required in order to generate the mobility measures identified in Step 2.

Analysis Tool Selection Options

This case study's tool selection process focused on the tools' capabilities to capture certain measures of mobility and the scope of the analysis. There are additional factors that an analyst can consider when selecting the appropriate analysis tool. Chapter 3 of this document describes these various factors in greater detail. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (Tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies.).

Step 4 – Identify the Alternatives

After determining the MOEs and the analysis tool, the next stage of an MOTAA process is the identification of work zone alternatives. As previously mentioned in Step 1 – Project Scope, lane closures on Rockville Road are flexible based on the mobility impacts of the work zone. As a result, the objective of the analysis is to evaluate various lane closure alternatives at Rockville Road and determine their impacts on mobility and construction duration. The three-lane closure scenarios at Rockville Road included the following:

- **Full Closure** – The first alternative is the complete closure of Rockville Road in addition to the ramp closures;
- **Partial Closure** – In the partial lane closure scenario, Rockville Road maintains limited capacity; and
- **No Closure** – In this scenario, Rockville Road remains fully operational during construction.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the scope of the analysis and identify the data needed for the calibration and modeling analysis effort. Part of project scoping is defining the study area that will be evaluated during the analysis. In this case study, the analysis covers the area consisting of the entire Rockville Road Interchange and the two intersections at the ramp termini on both sides of the interchange, as shown in Figure 71.

Extent of Analysis Considerations

Although the particular focus of this analysis is on the Rockville Road Interchange and two signalized intersections at the ramp termini, the extent of the analysis can be extended to one to two interchanges both north and south of the study area as well as the parallel arterials on either side of the interstate. Extending the area to be analyzed will enable the analyst to identify potential alternative routes and assess the mobility impacts of the Rockville Road ramp closures not only on Rockville Road, but also on adjacent interchanges and parallel arterials. An example of potential model size for analysis is shown in Figure 71.

In addition to determining the scope of the analysis, at this stage of the MOTAA the analyst also must identify the data inputs and assumptions needed to model the scenarios. Data collection efforts for microsimulation models typically require data on road geometry, controls, traffic demands, capacities, travel times, and queues. The baseline model of this case study will be based on 2006 existing conditions data. The following summarizes the data collection effort for the interchange reconstruction scenarios:

- **Field Observed Traffic Data** – Traffic counts for all entry and exit points into the study area were collected. Additionally, the analysts also collected intersection turning movement counts at the two intersections adjacent to the interchange.
- **Road Geometry** – Data for roadway geometry came from aerial images and CADD drawing files.
- **Traffic Controls** – Data for locations of speed limits and signal timings for the adjacent intersections were obtained through field observations and signal timing plans from stakeholder agencies.
- **Analysis Time Period** – This case study also considered a 24-hour period for analysis in order to evaluate before and after peak hour conditions.
- **Demand Data** – O-D trip tables were obtained from travel demand models developed by the agency. Figure 72 illustrates the locations of zones and Figure 73 shows an example

AM peak-period O-D table. However, for this case study, the analysts considered a 24-hour period. A 24-hour demand profile was constructed using a.m. and p.m. peak-period data. This demand profile is shown in Figure 74. As shown on the figure, total daily traffic totaled 410,000 vehicles with the a.m. peak hour (7:00 a.m. to 8:00 a.m.) at 28,000 vehicles; and the p.m. peak hour (4:00 p.m. to 5:00 p.m.) at 33,000 vehicles.

Demand Data and Analysis Period Considerations

For this case study, a 24-hour demand profile was constructed in order to evaluate travel conditions before, after, and during the peak periods. However, due to resource requirements and simulation processing and run times needed for microsimulation models, a 24-hour analysis period is atypical for this type of tool. Such models would typically be run for specific time periods such as a three- to four-hour window (i.e., peak period or off-peak). An example AM peak period O-D table for the study area network is shown in Figure 73.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model with the appropriate geometry, traffic controls, demands, and capacities using the information from the data collection effort, specified in Step 5A.

Error Checking in Model Development

Although not specified in this case study, during model development, the analyst should perform error checks to identify and correct any model coding and signal timing errors. The analyst can check the model network geometries and traffic control operations against existing plans or engineering drawings obtained in Step 5A.

Figure 71. Rockville Road Case Study – Example Model Extents

(Source: Transportation Research Board, 2010.)
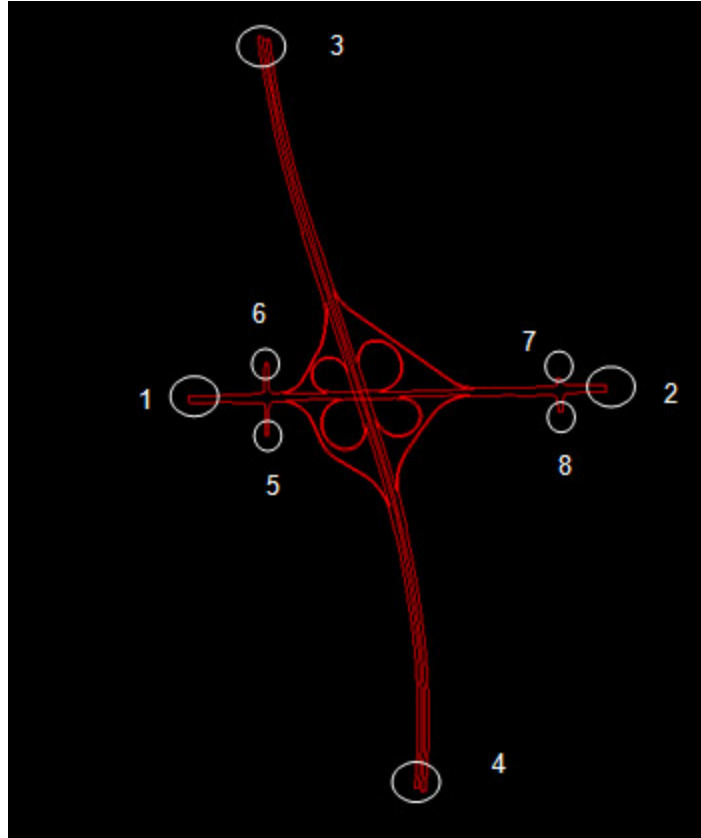
Figure 72. Rockville Road Interchange Case Study – Locations of Zones for O-D Table

(Source: Transportation Research Board, 2010.)

	to	1	2	3	4	5	6	7	8	Total
from	1	0	710	530	190	140	10	90	10	1680
from	2	230	0	230	110	30	5	20	10	635
from	3	360	390	0	5080	0	10	50	5	5895
from	4	440	130	4790	0	20	10	20	5	5415
from	5	160	120	90	30	0	110	15	5	530
from	6	20	15	10	5	160	0	5	0	215
from	7	150	50	140	70	10	5	0	10	435
from	8	20	10	80	40	5	0	20	0	175
Total		1380	1425	5870	5525	365	150	220	45	

**Figure 73. Rockville Road Interchange Case Study – Example AM Peak
Period Existing Conditions O-D Table**
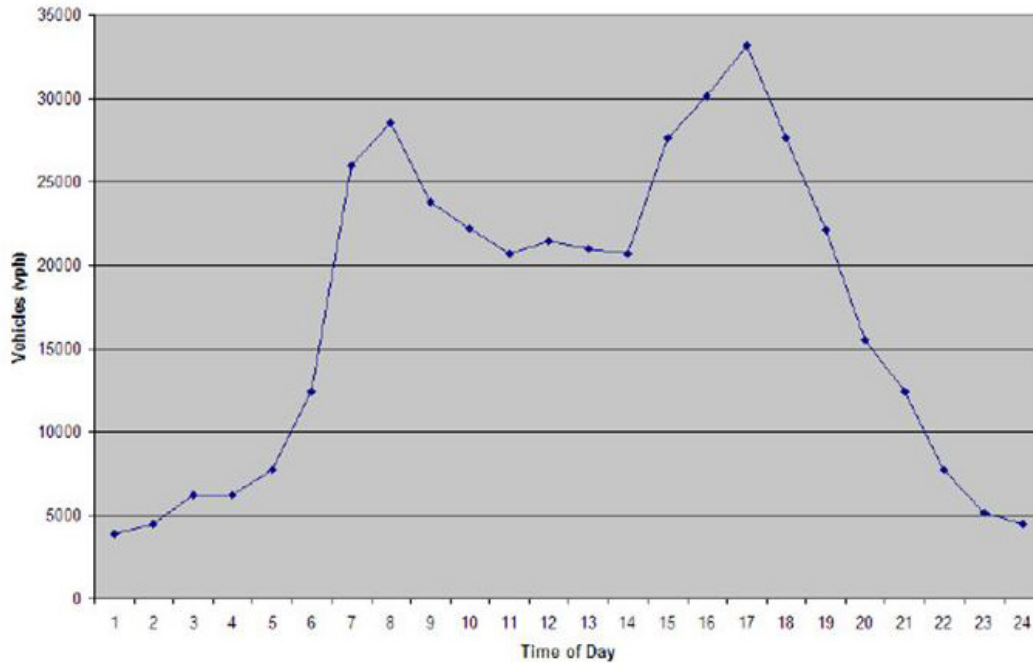
**Figure 74. Rockville Road Interchange – Existing Conditions
Model 24-Hour Demand Profile**

(Source: Transportation Research Board, 2010.)

Step 5C – Existing Conditions Model Calibrations

After the development of an existing conditions model, the following step in an MOTAA process is model calibration. Model calibration ensures that the operational performance of the model best reflects field observed conditions. The existing conditions model's volumes and speeds were validated with the information obtained during the data collection effort outlined in Step 5A.

Additional Considerations for Model Calibration

The model calibration effort for the Rockville Road Interchange Reconstruction was not described in great detail in HCM 2010. However, for additional guidance on model calibration, refer to Chapter 4 of this document. Additionally, the following lists the factors typically involved in a model calibration process:

- **Model Parameters –** One of the critical steps in the model calibration process is the adjustment of global and link-specific parameters to ensure the model behaves similarly to field conditions.
- **Model Runs and Random Seeds –** After the adjustments to the model, the analyst will have to extract outputs from the model that can be used to compare against field data. To mimic real-world traffic variations, simulation software packages introduce randomized seed numbers associated with the model runs. The analyst will then extract and average the output values from a determined number of model runs with different seed values. The analyst will therefore have to determine the appropriate number of runs to conduct for the model. Chapter 4 of this document presents one way of determining model runs when using microsimulation tools. However, an agency may also specify a standardized number of runs or methodology to be used in during analysis.
- **Calibration Acceptance Criteria –** The criteria should include mathematical targets related to traffic volumes and speeds that could be used to compare the model with field observed conditions. In the calibration process, the analyst should also determine and specify the target values that the model results/ outputs should achieve. Example criteria could include achieving model volumes and speeds within a certain percent difference of the field data.

Step 5D – Work Zone Base Conditions Model Development, and Step 5E – Work Zone Base Conditions Model Calibration

The next step in the MOTAA process is the development of the work zone base conditions model. If an existing conditions model was developed it can typically be modified to develop the work zone base conditions model, as well as the alternatives analysis scenarios. In this case study, there was no work zone base conditions model developed. Since no work zone base conditions model was developed, there was no need for a work zone base conditions model calibration.

Work Zone Base Conditions Model Calibration Options

As specified in Chapter 4 of this document, work zone model calibration includes the calibration of work zone capacity and performance measures. Work zone model capacity and performance measures, such as queue, travel time, delay, and speeds, can be calibrated to field data and or prior experiences (from similarly implemented work zone projects). Additionally, work zone base conditions calibration also entails that the analyst evaluate and identify the appropriate modeling parameters to use based on prior experiences modeling or analyzing work zones of similar types. Such observations and measures will aid the analyst in the work zone calibration process.

Step 6 – Alternatives Analysis

The alternatives analysis step involves two stages: 1) the development of models to capture the scenarios or alternatives; and 2) the methodology that describes how the models were run, the process for extracting outputs from the model, and the analysis of the results.

Step 6A – Alternatives Model Development

This case study featured three alternative scenarios, as described in Step 4. The following three models were coded by modifying the 2006 existing conditions model.

- **No Closure Scenario** – Since this scenario does not feature any lane closures on Rockville Road, the main difference from this and the baseline conditions scenario are the five on- and off-ramp closures. Additionally due to the ramp closures, traffic passing through the ramps is assumed to be 15 percent lower than the existing conditions scenario.
- **Partial Closure Scenario** – In addition to the ramp closures, Rockville Road is partially closed with only one lane open for through traffic in this scenario. Traffic passing through the ramps is reduced by 15 percent from the existing conditions scenario.
- **Full Closure Scenario** – In addition to the ramp closures, Rockville Road is completely closed during construction. Traffic passing through the ramps is assumed to be reduced by 30 percent from the existing conditions scenario.

Step 6B – Alternatives Analysis Model Runs and Results

The final steps of the MOTAA are to run the work zone alternative models using the selected traffic analysis tool and to extract the model outputs needed to generate the MOEs established in Step 3. The following summarizes the resulting measures of effectiveness generated for each model scenario:

- **Twenty-Four-Hour Profile of Average Network Speeds and Number of Vehicles** – As shown in Figure 75 overall average speeds across the network for all scenarios significantly decreased, while vehicle counts increased, as shown in Figure 76. The no- and partial-closure scenarios had similar average speeds and vehicle counts profile, while the full-closure scenario resulted in the greatest mobility impacts, especially during the p.m. peak period.
- **Average and Cumulative Network Delays** – Average and cumulative network delays across the four scenarios is shown in Figure 77 and Figure 78. Again, the full-closure scenario generated the greatest amount of mobility impacts with 5,000 vehicle hours of delay during the p.m. peak hour and 16,000 vehicles hours of delay for the entire day.
- **Construction Duration** – Another measure that can be used to compare the various alternatives is the length of construction duration. Figure 79 shows the cumulative network delays considering construction duration. As shown in the figure, the no closure is expected to have the longest construction duration at 16 months. The partial and full closures scenarios are assumed to take 8 and 4 months, respectively. The figure shows the tradeoffs between optimizing construction schedule and mobility impacts. For instance, while the full closure scenario offers the shortest construction duration, it results in the greatest amount of mobility impacts.
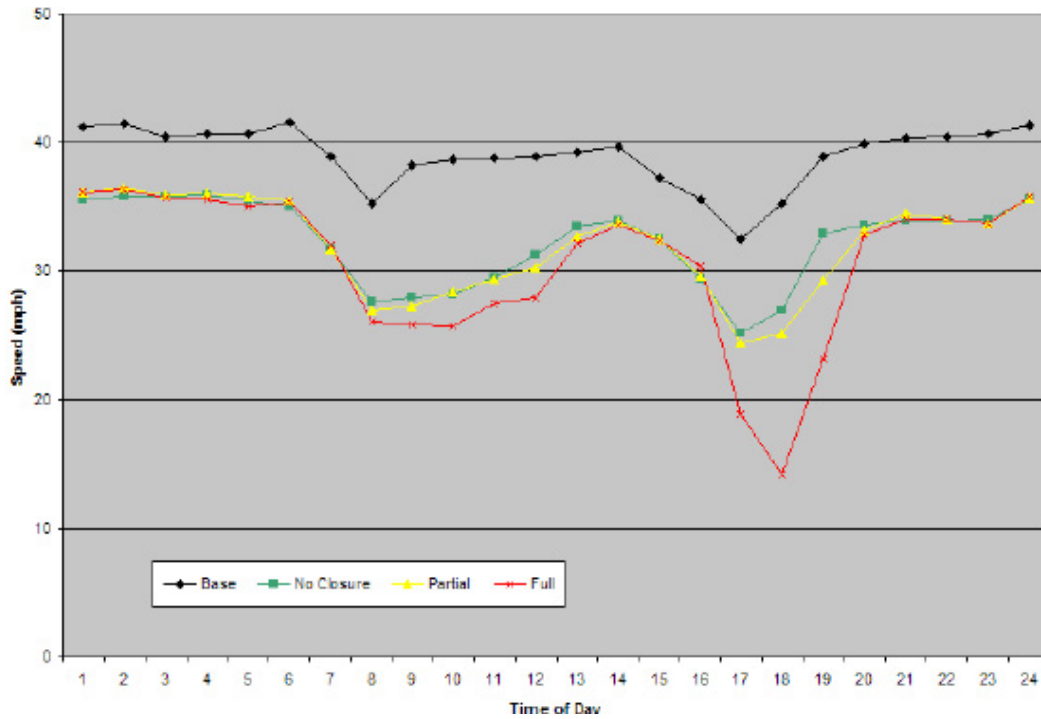
Figure 75. Rockville Road Interchange – Average Network Speed

(Source: Transportation Research Board, 2010.)
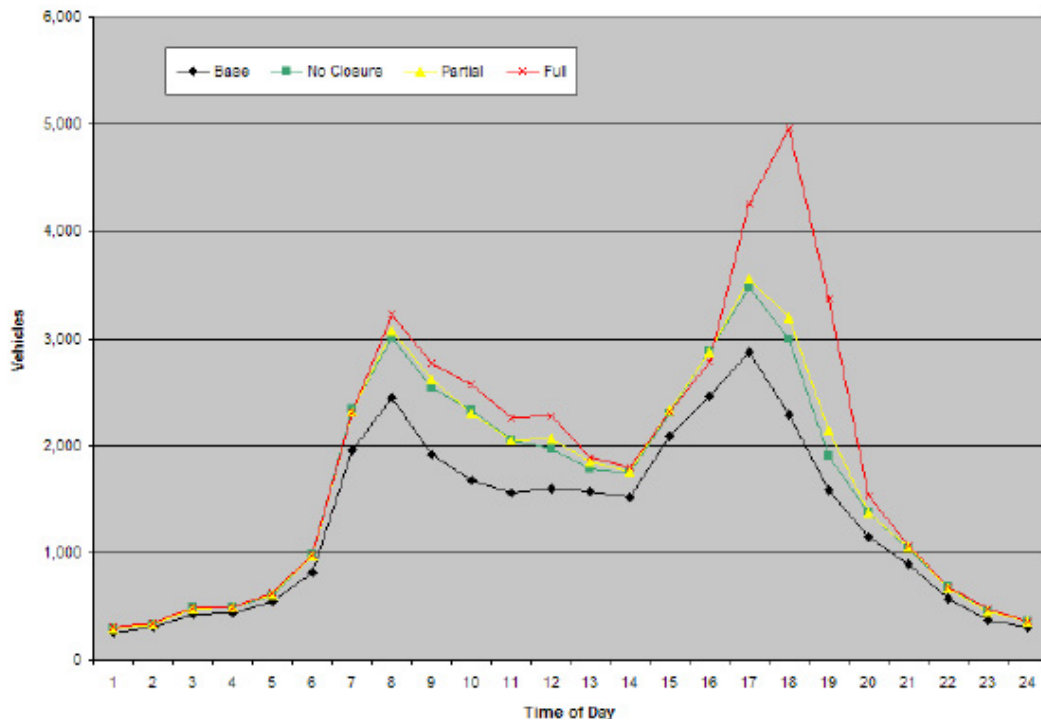
Figure 76. Rockville Road Interchange – Average Number of Vehicles

(Source: Transportation Research Board, 2010.)
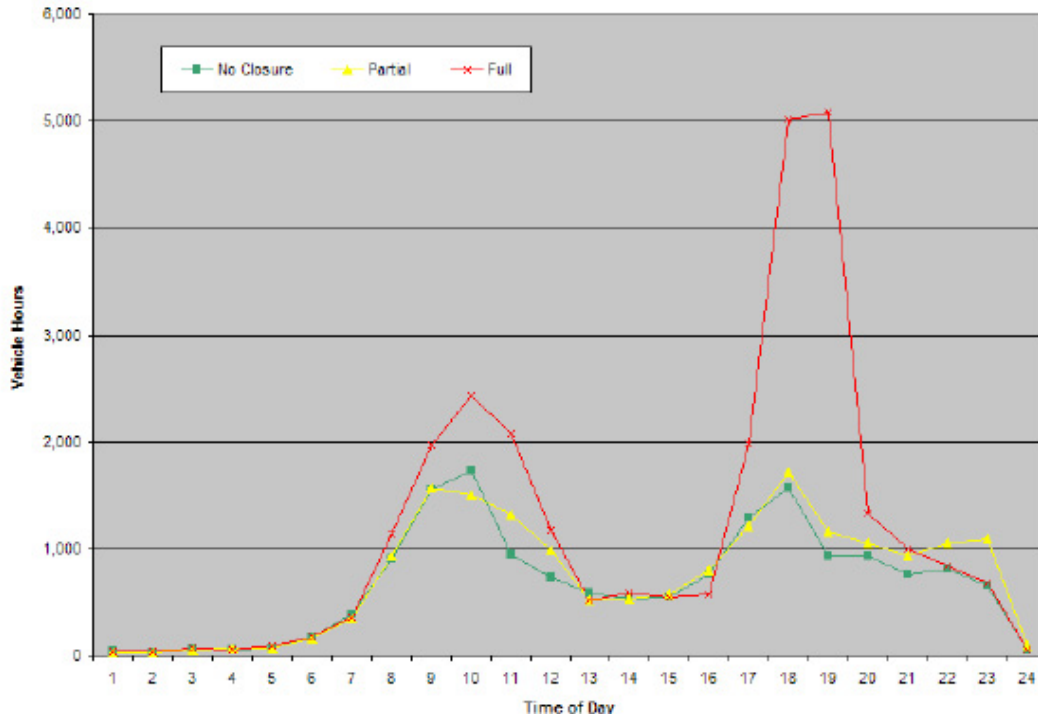
Figure 77. Rockville Road Interchange – Average Network Delays

(Source: Transportation Research Board, 2010.)
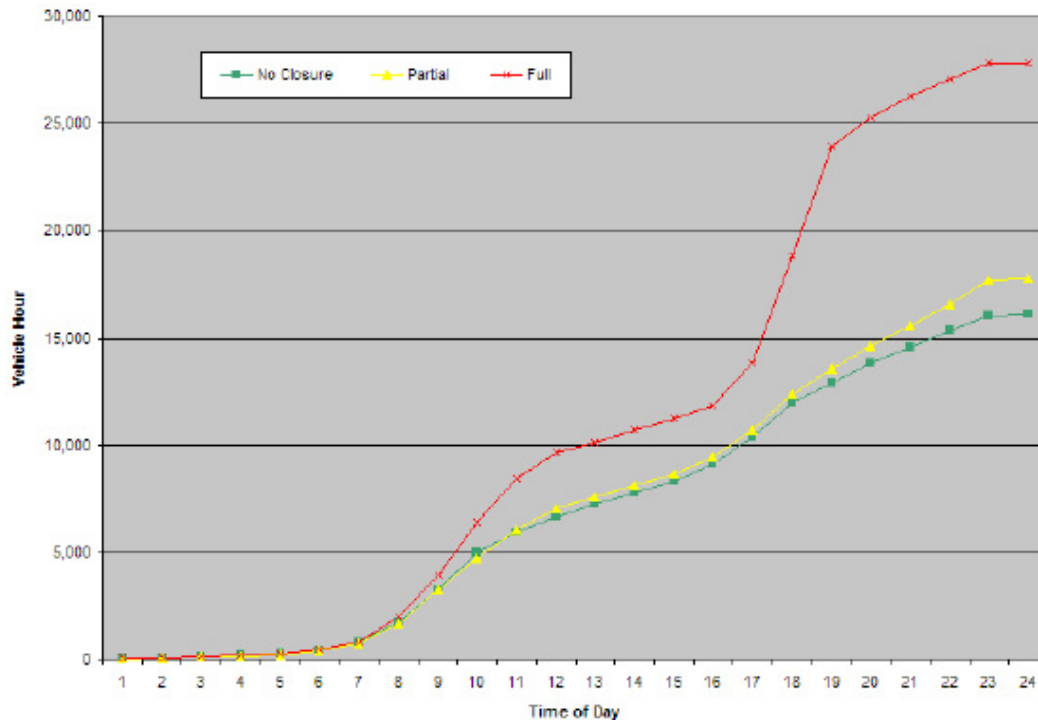
Figure 78. Rockville Road Interchange – Cumulative Network Delays

(Source: Transportation Research Board, 2010.)
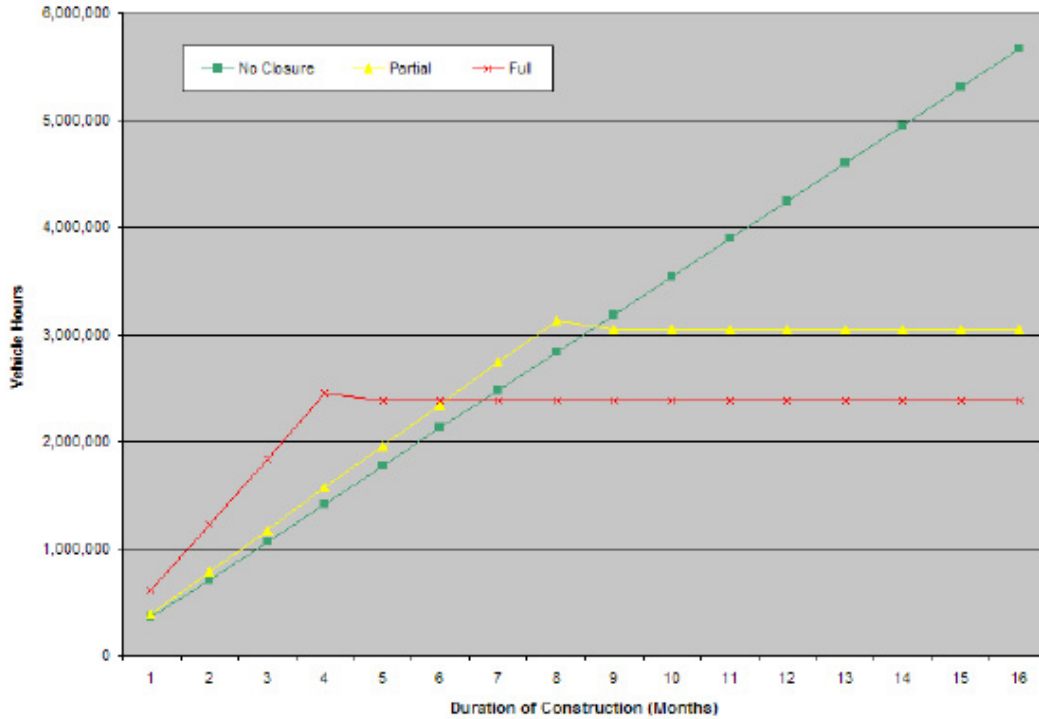
**Figure 79. Rockville Road Interchange Reconstruction – Cumulative
Network Delays during the Construction Period**

(Source: Transportation Research Board, 2010.)

Step 7 – Decision Framework and Recommendation of an Alternative

In the HCM 2010 Manual, the case study does not indicate which of the three alternatives should be recommended for implementation, nor how the alternatives analysis results can be used to select a preferred construction scenario.

Decision-Framework Options

Although this case study does not feature a decision-framework, the following example shown in Figure 80 illustrates an example showing how the alternatives analysis results can be used to develop decision-making criteria for identifying a preferred alternative. There are several decision-making frameworks that can be used to evaluate and choose among different work zone alternatives. Several of these frameworks are described in further detail in Chapter 5.

In the following example shown in Figure 80, a hypothetical 100-point scale was developed to score the various alternatives against a set of criteria. The table shows the alternatives' mobility measures extracted from the alternatives analysis results. It also includes assumed values for measures such as road user costs, construction duration, and safety for each alternative.

In some instances, the measure shown in Figure 80 refers to evening peak traffic conditions. In order to report these measures using this specific timeframe, the values associated with 4:00 p.m. to 7:00 p.m. from the 24-hour alternatives analysis results were averaged. Each alternative's performance measures were then compared against a set of criteria, which determines how many points should be allotted to each alternative based on the values of each MOE. According to the results of this hypothetical scoring technique, the No Closure alternative (highlighted in green) scored the highest of the three alternatives.

	Criteria Component Percentage of Total	Criteria	Full Closure Average Value	Points	Partial Closure Average Value	Points	No Closure Average Value	Points
Average Network Speed Over PM Peak Period	15%	10 < x ≤ 20 mph = 0 pts 20 < x ≤ 25 mph = 5 pts 25< x ≤30 mph = 10 pts 30 mph+ = 15 pts	22 mph	5	27 mph	10	30 mph	15
Average Number of Vehicles Present in the Network over PM Peak Period	15%	4000+ vehicles = 0 pts 3500 < x ≤ 4000 vehicles = 2 pts 3000 < x ≤ 3500 vehicles = 5 pts 2500 < x ≤ 3000 vehicles = 10 pts 2500 vehicles or less = 15 pts	3, 875 vehicles	2	3,050 vehicles	5	2,825 vehicles	10
Average Network Delays over the PM Peak Period	10%	2000+ vehicle hours = 0 pts 1500 < x ≤ 2000 vehicle hours = 2 pts 1000 < x ≤ 1500 vehicle hours = 5 pts 1000 vehicle hours or less = 10 pts	3,175 vehicle hours	0	1,250 vehicle hours	5	1, 150 vehicle hours	5
Cumulative Network Delays over the PM Peak Period	10%	20000+ vehicle hours = 0 pts 15000 < x ≤ 20000 vehicle hours = 2 pts 10000< x ≤ 15000 vehicle hours = 5 pts 10000 vehicle hours or under = 10 pts	17,000 vehicle hours	2	12,125 vehicle hours	5	11,875 vehicle hours	5
Road User Cost - *vehicle delay cost calculations only*	20%	$0K - $25K = 20 pts $25K - $50K = 10 pts $50K+ = 5 pts	$70K	5	$28K	10	$25K	20
Construction Duration	10%	Construction duration 12 months+ = 2 pts Construction duration 6 months -12 months = 5 pts Construction duration is less than 6 months =10 pts	4 months	10	8 months	5	16 months	2
Safety	20%	WZ crash rate is 20% lower than pre-construction condition = 20 pts WZ crash rate is equal to pre-construction condition = 15 pts WZ crash rate is up to 20% higher than pre-construction = 10 pts WZ crash rate is 20- 30% higher than pre-construction = 5 pts WZ crash rate is 30%+ higher than pre-construction = 0 pts	24% higher	5	10% higher	10	2% higher	10
Total	100%			29		50		67

Figure 80. I-465 West Leg, Rockville Road Interchange Reconstruction Decision Framework Example

9.10 CORRIDOR RECONSTRUCTION WITH COMPLEX NETWORK-WIDE IMPACTS USING TRAVEL DEMAND MODELING TOOLS – TRANPLAN

Cleveland Innerbelt Project Background

This case study describes the process to evaluate potential maintenance of traffic detour routes and a potential full closure option during the planning phase of the Cleveland Innerbelt Project in 2004 for the Ohio DOT.[65]

The Cleveland Innerbelt is a high capacity, limited-access interstate highway extending from Cleveland's Tremont neighborhood on the west side of the Cuyahoga River, across the Cuyahoga Valley, around the southern and eastern edges of downtown to the City's lakefront district at Burke Lakefront Airport. The Innerbelt includes portions of I-71 and I-90, and connects to I-77, I-490, SR 2, and SR 176, as shown in Figure 81.

A key component of the Innerbelt Freeway is the Central Viaduct Bridge, shown in Figure 82. The Central Viaduct Bridge is a primary river crossing, moving Interstate traffic from the south (I-71) and west (I-90) across the Cuyahoga River to the downtown distribution system of the Central Interchange and further east to the Innerbelt Trench. The near mile-long Central Viaduct Bridge is the critical link along this section of I-90 carrying over 130,000 vehicles per day.

Figure 81. Cleveland Innerbelt Project

(Source: Bugess & Nipple, Inc., 2004.)
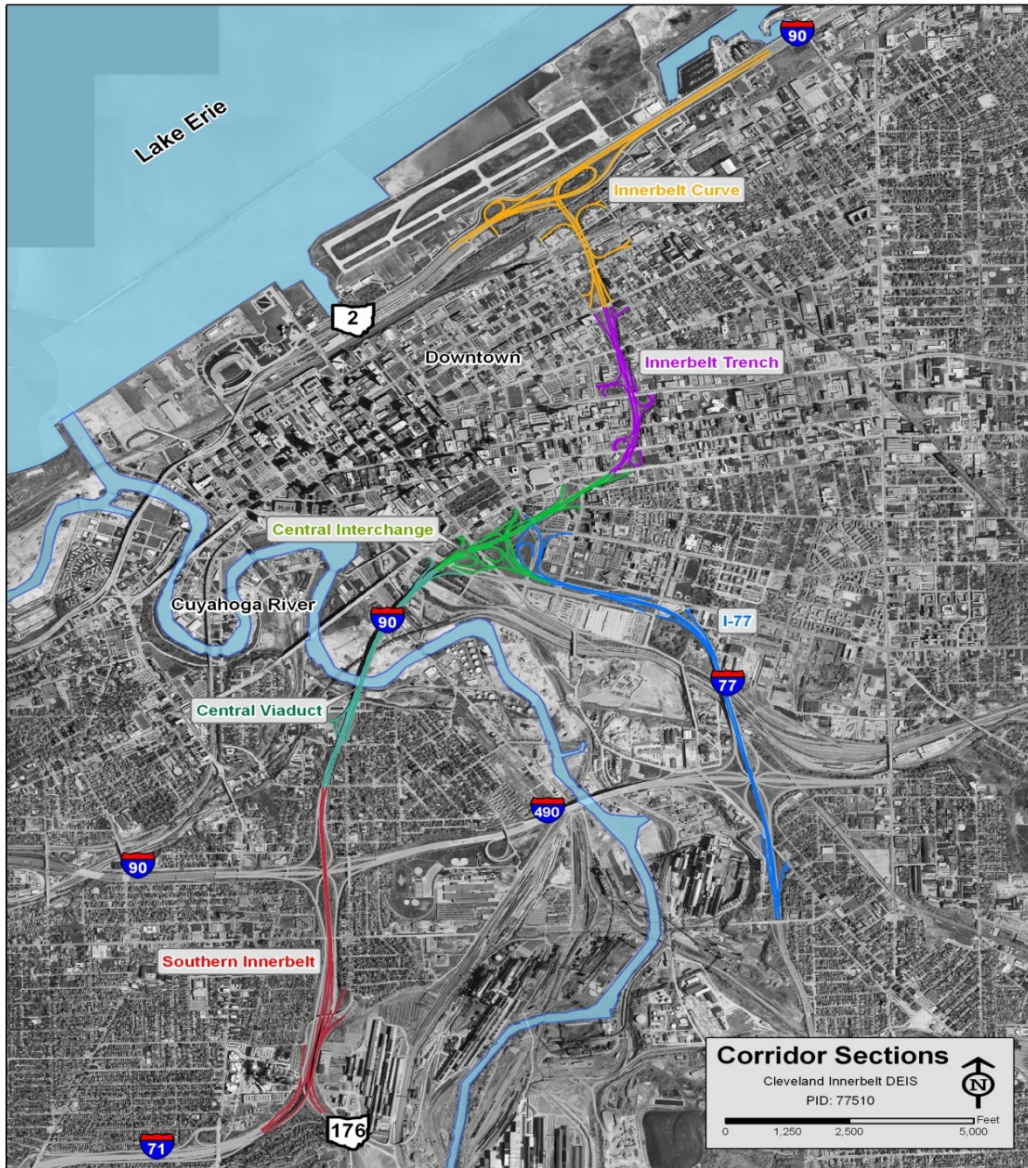
Figure 82. Cleveland Innerbelt Corridor Sections

(Source: Bugess & Nipple, Inc., 2004.)

Considerations for Maintenance of Traffic Alternatives Analysis

The daily recurring congestion presents a tremendous challenge for maintenance of traffic during construction. The entire length of the Innerbelt Freeway lacks adequate shoulders on which to perform or stage construction work. Further, Ohio DOT maintenance of traffic policies discourage long-term lane closures on this portion of I-90 due to high traffic demand and existing poor levels of service. As such, there is need to plan for a systematic phasing of the improvements, such that traffic can be maintained to the greatest extent practical.

In accordance with Ohio DOT Policy Number 516-003(P) *Traffic Management in Work Zones: Interstate and Other Freeways*, Ohio DOT District 12 has developed a Permitted Lane Closure Map (PLCM) (shown in Figure 83) that specifies how many lanes must remain open during what time periods in order to minimize construction-related congestion and delay.[66] The sequencing of construction needed to be programmed to minimize traffic delays throughout the corridor. Within construction areas, it was planned that traffic control measures using standard practices would be used.

Applying MOTAA in the Planning Process

During the Planning Phase of this project, a *Cleveland Innerbelt MOT Strategic Plan* was developed to assist in quantifying the potential impacts of MOT activities on the study area and to help identify additional projects that may need to be completed as part of the overall implementation strategy to help mitigate these impacts. To support this effort, the primary and secondary maintenance of traffic routes that may be utilized by motorists during construction, whether officially signed or not, needed to be identified.

The project also hosted an Accelerated Construction Technology Transfer (ACTT) review during the planning process. One of the issues raised at this ACTT review was the potential to accelerate the replacement of the Central Viaduct by initiating a full closure of the bridge and, thus, accommodating the full replacement of the structure on the existing alignment. The impact of this full closure also needed to be determined before additional project resources would be utilized to pursue it. As such, a "red flag"-level analysis was undertaken for this alternative.

ODOT Permitted Lane Closure

District:	12	County:	CUY	Route:	R-90	DIR:	EAST	Calculation Year:	2004	Section:	I-71 to I-77 (EAST)

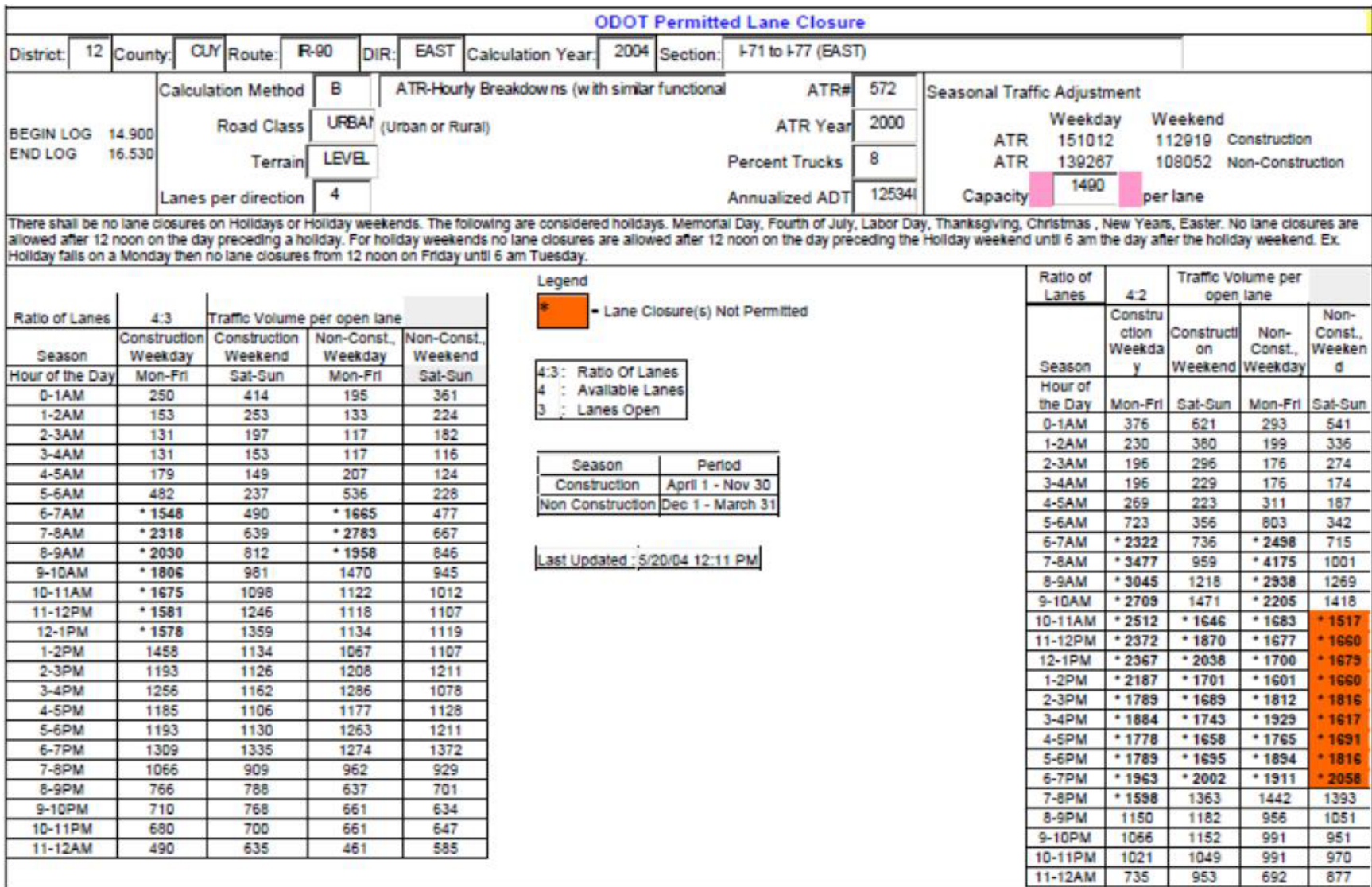|					
	Calculation Method	B	ATR-Hourly Breakdowns (with similar functional	ATR#	572
BEGIN LOG 14.900	Road Class	URBAN (Urban or Rural)		ATR Year	2000
END LOG 16.530	Terrain	LEVEL		Percent Trucks	8
	Lanes per direction	4		Annualized ADT	125341

Seasonal Traffic Adjustment

	Weekday	Weekend	
ATR	151012	112919	Construction
ATR	139267	108052	Non-Construction
Capacity	1490	per lane	

There shall be no lane closures on Holidays or Holiday weekends. The following are considered holidays. Memorial Day, Fourth of July, Labor Day, Thanksgiving, Christmas, New Years, Easter. No lane closures are allowed after 12 noon on the day preceding a holiday. For holiday weekends no lane closures are allowed after 12 noon on the day preceding the Holiday weekend until 6 am the day after the holiday weekend. Ex. Holiday falls on a Monday then no lane closures from 12 noon on Friday until 6 am Tuesday.

Legend

* = Lane Closure(s) Not Permitted

4:3 : Ratio Of Lanes
4 : Available Lanes
3 : Lanes Open

Season	Period
Construction	April 1 - Nov 30
Non Construction	Dec 1 - March 31

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Ratio of Lanes 4:3 — Traffic Volume per open lane

Season Hour of the Day	Construction Weekday Mon-Fri	Construction Weekend Sat-Sun	Non-Const., Weekday Mon-Fri	Non-Const., Weekend Sat-Sun
0-1AM	250	414	195	361
1-2AM	153	253	133	224
2-3AM	131	197	117	182
3-4AM	131	153	117	116
4-5AM	179	149	207	124
5-6AM	482	237	536	228
6-7AM	*1548	490	*1665	477
7-8AM	*2318	639	*2783	667
8-9AM	*2030	812	*1958	646
9-10AM	*1806	981	1470	945
10-11AM	*1675	1098	1122	1012
11-12PM	*1581	1246	1118	1107
12-1PM	*1578	1359	1134	1119
1-2PM	1458	1134	1067	1107
2-3PM	1193	1126	1208	1211
3-4PM	1256	1162	1286	1078
4-5PM	1185	1106	1177	1128
5-6PM	1193	1130	1263	1211
6-7PM	1309	1335	1274	1372
7-8PM	1066	909	962	929
8-9PM	766	788	637	701
9-10PM	710	768	661	634
10-11PM	680	700	661	647
11-12AM	490	635	461	585

Ratio of Lanes 4:2 — Traffic Volume per open lane

Season Hour of the Day	Construction Weekday Mon-Fri	Construction Weekend Sat-Sun	Non-Const., Weekday Mon-Fri	Non-Const., Weekend Sat-Sun
0-1AM	376	621	293	541
1-2AM	230	380	199	336
2-3AM	196	296	176	274
3-4AM	196	229	176	174
4-5AM	269	223	311	187
5-6AM	723	356	803	342
6-7AM	*2322	736	*2498	715
7-8AM	*3477	959	*4175	1001
8-9AM	*3045	1218	*2938	1269
9-10AM	*2709	1471	*2205	1418
10-11AM	*2512	*1646	*1683	*1517
11-12PM	*2372	*1870	*1677	*1660
12-1PM	*2367	*2038	*1700	*1675
1-2PM	*2187	*1701	*1601	*1660
2-3PM	*1789	*1689	*1812	*1816
3-4PM	*1884	*1743	*1929	*1617
4-5PM	*1778	*1658	*1765	*1691
5-6PM	*1789	*1695	*1894	*1816
6-7PM	*1963	*2002	*1911	*2058
7-8PM	*1598	1363	1442	1393
8-9PM	1150	1182	956	1051
9-10PM	1066	1152	991	951
10-11PM	1021	1049	991	970
11-12AM	735	953	692	877

Figure 83. Ohio DOT Permitted Lane Closure Map (PLCM)

Step 1 – Problem Definition, Scope, Goals, and Objectives

The first step in an MOTAA is to define the scope, goals, and objectives of the analysis. Based on the requirements of this analysis, it was necessary to identify primary and secondary maintenance of traffic corridors and to determine the feasibility of implementing a full closure of the Central Viaduct Bridge. A vital goal for controlling traffic through and around the projected construction work zones was to minimize the disruption of normal traffic flow and maintain reasonable access to all properties near the construction areas.

Step 2 – Establishing the MOEs and Thresholds

After defining the goals and objectives of the project, the next step in an MOTAA is to establish the measures of effectiveness and/or thresholds that would be used to evaluate and compare the different work zone alternatives. For this case study, the mobility measures of effectiveness (MOE) selected included percent increase or decrease in traffic and volume/capacity (v/c) ratio.

Step 3 – Choosing the Analysis Tool

The next stage of the MOTAA process is to determine the type of analysis tool to be used and the justification for that selection. In this case study, TRANPLAN, the regional travel demand model, was chosen as the operational model platform to simulate traffic assignments due to its ease of use, ready access, and ability to generate the measures of effectiveness determined in Step 2. Factors that impacted the decision to utilize a travel demand model as the analysis tool are as follows:

- As part of the overall study, improvements had been made to the existing regional travel demand model to enhance its utility as an analysis tool for the study area. This included splitting zones within the CBD area for better fidelity in assigning trips from the freeway to the arterial network due to the large number of access points in the CBD area (27 access points in the CBD alone). To further enhance this fidelity, a parking allocation model was developed, which assigned vehicle origins/destinations to the zone in which a car mode traveler would park in the CBD as opposed to the zone which would be their final destination.
- Due to controversy regarding the growth projection inputs to the travel demand model early in the study, a Neighborhood Planning Committee (NPC) had been formed from key stakeholders in each of the neighborhoods impacted by the project and key staff from the City of Cleveland. This NPC reviewed, in detail, the growth projections for the study area zone-by-zone and compared them to existing community plans. Once this process was successfully completed, public confidence in the predictive capabilities of the travel demand model increased.
- The ability of the model to react to the change in capacity due to the work zone with a potential change in both mode and route choice, as there is a substantial transit component in the study area.

Step 4 – Identify the Alternatives

After determining the MOEs and the analysis tool, the next stage of an MOTAA process is the identification of work zone alternatives. As a baseline for comparison, the existing conditions model would be utilized. In addition, two additional models will be utilized to determine potential impacts.

- **Alternative 1: Full Closure of Central Viaduct** – This alternative removed the Central Viaduct links from the highway link structure. This alternative will demonstrate the impact of a full closure of the Central Viaduct Bridge.
- **Alternative 2: Partial Closure of Central Viaduct** – This alternative reduced the capacity of the eastbound (inbound) I-90 travel lanes on the Central Viaduct Bridge from four lanes to two lanes in the a.m. peak period.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the objectives of the analysis and identify the data needed for the calibration and modeling analysis effort. This step was unnecessary as part of this analysis. Earlier efforts within the project to make improvements to the fidelity of the route assignment component of the model through splitting zones and adding a parking allocation model already had been completed. Further, the validation of the growth projections in conjunction with the Neighborhood Planning Committee also removed the need for additional data checks.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model with the appropriate geometry, traffic controls, demands, and capacities using the information from the data collection effort and the preliminary analysis. As discussed above, refinements to the existing model already had been undertaken as part of a parallel process during the project.

Step 5C – Existing Conditions Model Calibrations

The model calibration was conducted through the Neighborhood Planning Committee growth projection validation process. The validation was mainly focused on v/c ratio and traffic volumes on freeways and major arterials. For traffic volume validation, the acceptable threshold between modeled volumes and field counts on major freeways and arterials were within 10 percent.

Step 5D – Work Zone Base Conditions Model Development.

Once the existing conditions model has been developed and calibrated, it can then be modified for use during the work zone base conditions model development and calibration, as well as during the alternatives analysis stage. In this case study, there was no work zone base conditions model developed. The scenarios identified in Step 4 were considered as alternatives. Therefore, all runs would be compared to existing conditions, as there were no work zone base conditions.

Step 5E – Work Zone Base Conditions Model Calibration

No work zone calibration procedure was specified for this case study.

Work Zone Base Conditions Model Calibration Options

As specified in Chapter 4 of this document, work zone model calibration includes the calibration of work zone capacity and performance measures. Work zone model capacity and performance measures such as queue, travel time, delay, and speeds can be calibrated to field data and or prior experiences (from similarly implemented work zone projects). Additionally, work zone base conditions calibration also entails that the analyst evaluate and identify the appropriate modeling parameters to use based on prior experiences modeling or analyzing work zones of similar types. Such observations and measures will aid the analyst in the work zone calibration process.

Step 6 – Alternatives Analysis

The alternatives analysis step involves two stages: 1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results.

Step 6A – Alternatives Model Development

The analysts started with the existing conditions model and adjusted the roadway network to replicate each of the scenarios identified in Step 4. The adjustments included geometric configurations (e.g., number of lanes), capacities, and link length change to match work zone area. The model was run for the a.m. peak period only.

Step 6B – Alternatives Analysis Model Runs and Results

The final step of the MOTAA is to run the work zone alternative models and evaluate the mobility performance measures extracted from the model results. As previously mentioned, the analysts used percent increase or decrease in traffic and v/c ratio as MOEs. These results were then thematically displayed on a series of graphics showing the impact of each of the
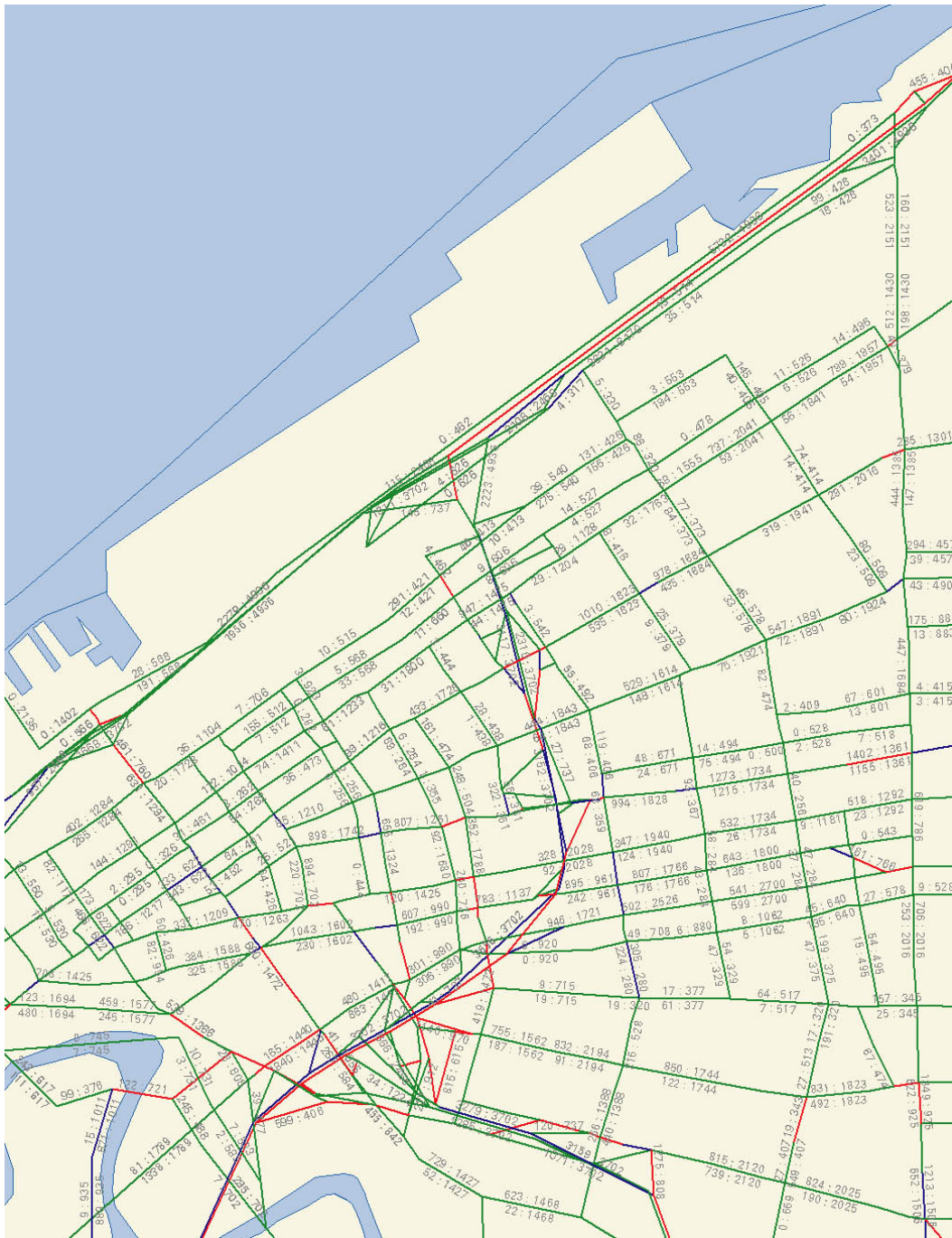
alternatives. Figures 84 and 85show the v/c ratio thematic plots for Alternative 1 (full closure) and Alternative 2 (partial closure), respectively.
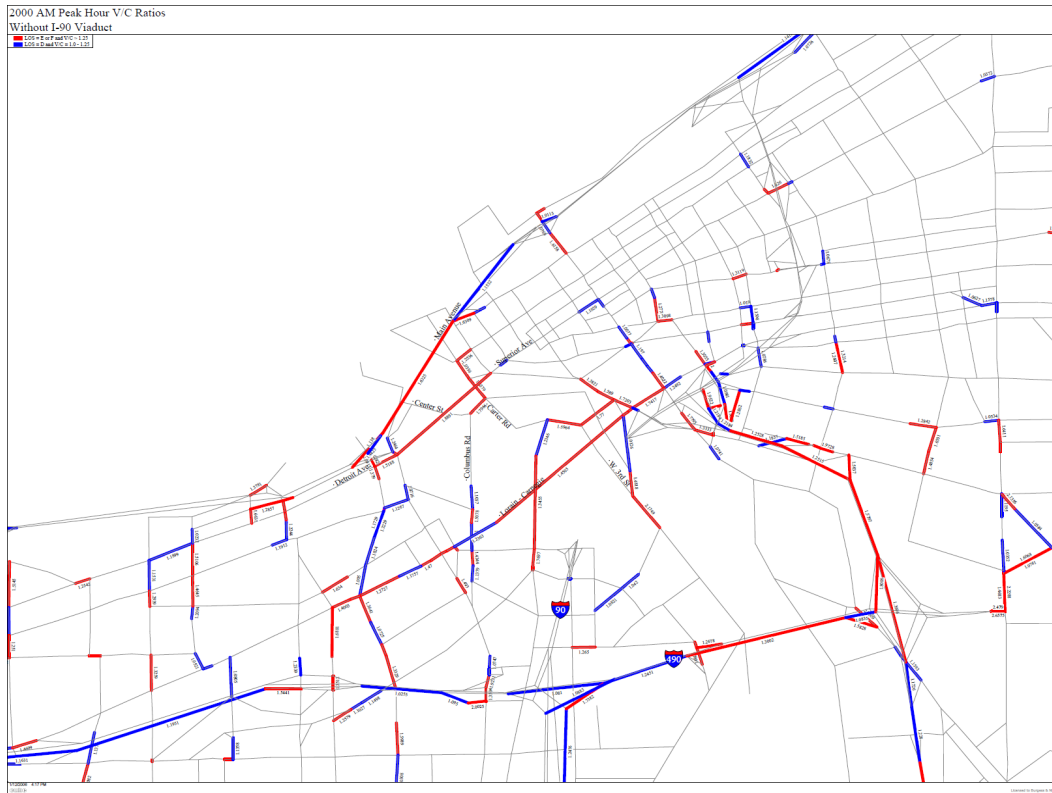
Figure 84. Cleveland Innerbelt Study: V/C Ratio Thematic Map (Alternative 1 – Full Closure)

(Source: Bugess & Nipple, Inc., 2004.)

**Figure 85. Cleveland Innerbelt Study: V/C Ratio Thematic Map
(Alternative 2 – Partial Closure)**

(Source: Bugess & Nipple, Inc., 2004.)

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Step 7 – Decision Framework and Recommendation of an Alternative

After obtaining the model output and mobility performance measures through the modeling analysis, the next stage of the MOTAA process is the application of a decision-making framework or criteria for evaluating and identifying the preferred alternative.
A red flag analysis of the concept of a full closure of the Central Viaduct Bridge (Alternative 1) was conducted. The thematic map (Figure 85 showed that by completely removing this critical link from the highway network, the potential detour routes were overwhelmed by diverting traffic. This would have had a critical impact on the ability to provide access to and from the CBD of Cleveland from both the south and west. As such, this alternative construction technique was removed from further consideration.

Alternative 2 was recommended based on a combination of engineering judgment and public involvement with key stakeholders to aid in the development of the plan. The thematic mapping results from the travel demand model were utilized to show where potential traffic diversion routes could be expected. This information was shared with key stakeholders in a charrette setting along with additional information regarding location of key community resources, adjacent land use, noise susceptible properties, minority populations, low-income populations, zoning, historic resources, etc. Working with the community in a facilitated environment, routes were identified as either primary or secondary maintenance of traffic routes (see Figure 86). As the project moves forward, as much traffic as can safely be accommodated should remain on the freeway. When traffic must be diverted to the arterial street system it should be focused onto the primary maintenance of traffic routes and discouraged from using the secondary routes. To accomplish this, the *MOT Strategic Plan* identified additional projects or concepts that would be added to the overall scope of the project to support the needs of accommodating this approach. Examples of these types of recommendations include:

- Quigley Road extension must be completed prior to the freeway construction phase, and will connect the I-71 ramps at W. 14th Street to Quigley Road. This project may include a roundabout at Quigley/W. 14th/Holmden and reconstruction of the interchange with I-490.
  - This improvement was implemented as the first construction project to come out of the implementation plan.
- Install a portion of the planned ITS system improvements necessary for MOT on this project.
  - The ITS component of this study was spun off as an individual project and proceeded on a separate track.
- Resurface all priority alternate streets and replace or upgrade new pavement markings to provide a minimum of two through lanes in each direction and create separate left turn lanes where needed.
- Identification of park-and-ride lot expansions that could occur outside the study area to reduce the impact to identified detour routes.
  - The expansion of several Park-and-Ride facilities was undertaken as "go early" projects during the development of the overall project implementation strategy.

Figure 86. Cleveland Innerbelt Study: Maintenance of Traffic Corridors Map

(Source: Bugess & Nipple, Inc., 2004.)

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9.11 CORRIDOR RECONSTRUCTION WITH COMPLEX NETWORK-WIDE IMPACTS USING MESOSCOPIC SIMULATION – INTEGRATION

I-80 Construction Staging Project Background

This case study describes the process used by Kremer, et al. (2000) to evaluate several construction staging proposals for the project improvements completed along the I-80 eastbound corridor in Saddle Brook, Bergen County, New Jersey in 1999.[67] The improvements occurred between Interchange 62 and 64 along I-80 and included roadway widening, noise wall erection, and bridge deck replacement. The improvements were necessary as I-80, a key commuter route for the region, was in great need of additional capacity. The work zone alternatives analysis was conducted in order to determine how to perform the improvements necessary with the least possible impacts to road users.

Figure 87 depicts the existing conditions or preconstruction configuration of I-80 eastbound. At one end of the study area, I-80 eastbound consisted of five lanes approaching a Collector-Distributor (C-D) Road that provided access to the Garden State Parkway and Saddle River Road. The section then became a four-lane section that eventually turned into a split configuration consisting of two express lanes and two local lanes. The express lanes provided direct access to the New Jersey Turnpike and George Washington Bridge. The local lanes provided access to all interchanges in between.

I-80 Construction Staging – Application of the MOTAA Process

The following subsections describe the work zone alternatives analysis procedure applied and documented in a Transportation Research Board paper by Kremer, et al. (2000) in evaluating the construction staging alternatives for the I-80 project improvements completed in 1999.[67] The purpose of the case study analysis was to present an alternative approach to the typical construction staging analysis. The authors described the typical construction staging analysis as a procedure that involved identifying critical demand and designing staging plans to ensure that sufficient capacity exists in the construction zone to meet that measured demand. The authors noted that this approach treats demand as isolated points instead of viewing flows as a system. Examining traffic flow at a systemwide level would ensure that the analysis accounted for both upstream and downstream conditions. The process they recommended offers a four-step approach that includes the following:

- **Targeted scope of investigation** – The first step of the process involves determining the goals, objectives, and constraints of the project. Additionally, this also entails structuring the scope of the analysis to fit the goals of the project.
- **Timely data collection to identify true demand** – The next step of the authors' process is to establish a data collection program that makes the distinction between measured and true demand.

- **Preliminary traffic engineering analysis** – This analysis is conducted prior to the simulation/modeling efforts in order to review the alternatives for any fatal flaws, as well as to apply Highway Capacity techniques in order to estimate roadway capacity.
- **Performance measures directly relevant to motorist experience** – The final step of the process is to ensure that the chosen performance measures extracted from the modeling analysis is consistent with the established goals and objectives.

The authors' four-step process parallels many of the concepts incorporated into the recommended MOTAA methodology described in Chapters 2 and 4 of this document. However, for the purpose of this guide, the authors' proposed process will be tailored to fit the step-by-step methodology described in Chapter 4.

Step 1 – Problem Definition, Scope, Goals, and Objectives

The first step in an MOTAA is to define the goals and objectives of the analysis. This also corresponds with the authors' first stage of their four-step process. In this case study, I-80 is a principal east-west travel route in New Jersey, providing vital linkages for travelers between local destinations within the State, as well as interstate between New York, New England, New Jersey, and Pennsylvania. The construction work zone was, therefore, located in one of the most heavily traveled sections of I-80 in the State. I-80 already is severely congested during the peak period and any other disruption and reduction in capacity would severely impede mobility. The goal of the project was, therefore, to determine the construction staging option that could minimize the disruption experienced by motorists through accommodating current traffic demand without a significant spatial or temporal shift.

Step 2 – Establishing the MOEs and Thresholds

After defining the goals and objectives of the project, the next step in an MOTAA is to establish the measures of effectiveness and/or thresholds that would be used to evaluate and compare the different work zone alternatives. For this case study the MOEs chosen included average speed, travel time, queue length, and vehicle throughput.
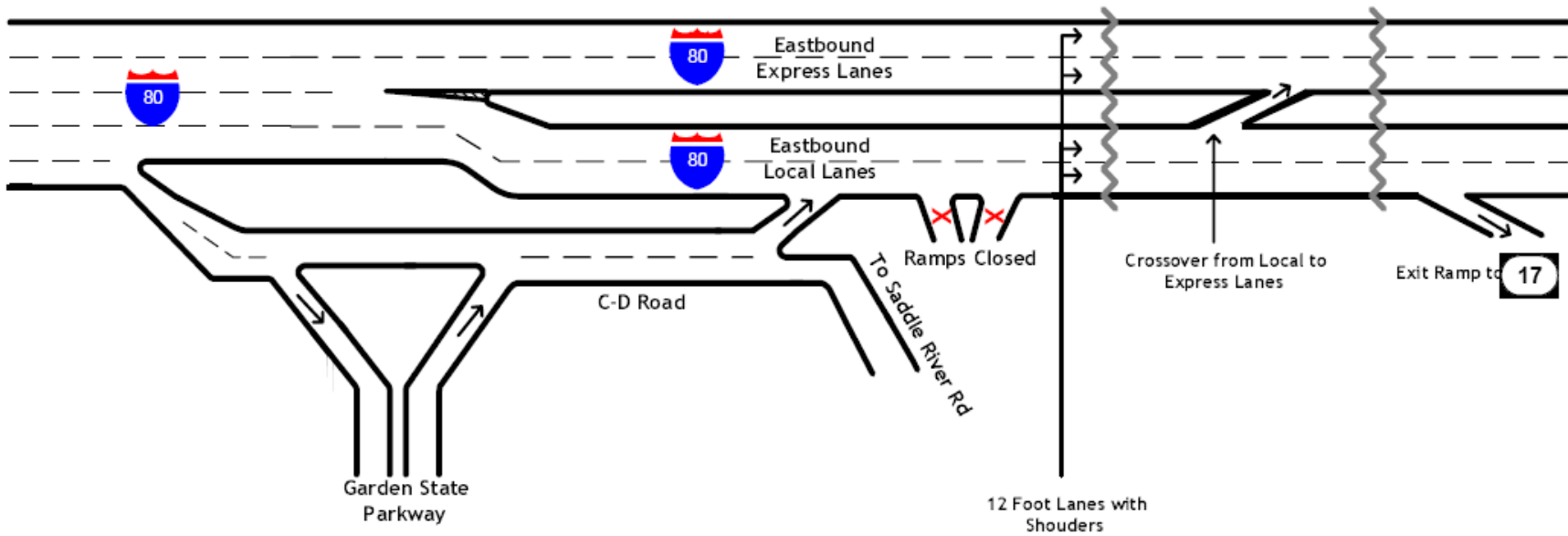
Step 3 – Choosing the Analysis Tool

The next stage of the MOTAA process is to determine the type of analysis tool to be used and the justification for that selection. In this case study, INTEGRATION was chosen as the operational model platform to simulate traffic operations due to its ease of use and ability to generate the measures of effectiveness determined in Step 2. A mesoscopic model was chosen because of its ability to allow users to test various scenarios and generate a more accurate range of performance measures for comparison among alternative design and operational scenarios as compared to travel demand models. It also was chosen because of its ability to generate various measures of effectiveness, including travel times by vehicle or link type, queue length, duration, and visual observations of queue formation and dissipation.

Analysis Tool Selection Options

There are additional factors that an analyst can consider when selecting the appropriate analysis tool. Chapter 3 of this document describes these various factors in greater detail. The recommended factors for identifying the appropriate modeling approach include:

- Project goals and objectives;
- Work zone characteristics;
- Agency resources;
- Performance measures;
- Data; and
- TMP (Tool should be able to capture the impacts of various traffic control, operations, and mitigation strategies.).

For this case study, the analyst chose a tool that was consistent with most of these factors. A mesoscopic simulation software package such as INTEGRATION was chosen based on the data needs, analysis goals and objectives, the transportation management plan, and performance measures required for the project.

Figure 87. I-80 Eastbound Existing Conditions

(Source: Kremer, Kotchi, DeJohn, and Winslow, 2001.)

Step 4 – Identify the Alternatives

After determining the MOEs and the analysis tool, the next stage of an MOTAA process is the identification of work zone alternatives. Aside from the existing conditions scenarios described in the Project Background portion of this section, the two alternatives/construction staging scenarios compared and evaluated in this case study includes:

- **Contract Staging Plan** – The first alternative was determined by the New Jersey DOT. Their analysis showed that the existing four-lane configuration (two lanes of expressway and two lanes local) must be maintained during construction based on existing travel volumes. The expressway would remain the same while the local roadway would remain open but with reduced lane widths (from 12 feet to 11 feet) without shoulders and with three emergency/breakdown areas. Figure 88 shows the Contract Staging Plan configuration.
- **Alternative/Contractor's Staging Plan** – After the construction project was awarded, the Contractor developed a staging plan that would have shortened the overall construction period by several months. This staging plan proposed the closure of the local lanes, forcing all traffic to merge onto the express roadway. In this alternative, the C-D road also would be extended to provide a third express lane. The express roadway would, therefore, be configured into three 11-foot lanes without shoulders. There would be no breakdown areas provided. Figure 89 depicts the Contractors Staging Alternative configuration.

Step 5 – Modeling Development and Application Process

Step 5A – Project Scope and Data Collection

During this stage of the modeling development and analysis, the analysts should define the objectives of the analysis and identify the data needed for the calibration and modeling analysis effort. Data collection efforts for microsimulation models typically require data on road geometry, controls, traffic demands, capacities, travel times, and queues. This step would correspond with the second stage of the four-step process identified by the authors.

The scope of this case study was to design and evaluate the construction staging area along I-80 eastbound between Interchanges 62 and 64. As previously mentioned, the objective of the analysis effort is to conduct the construction effort with minimal disruption to mobility. The analysis effort evaluated the study area during the a.m. peak period between 6:30 a.m. and 9:00 a.m.
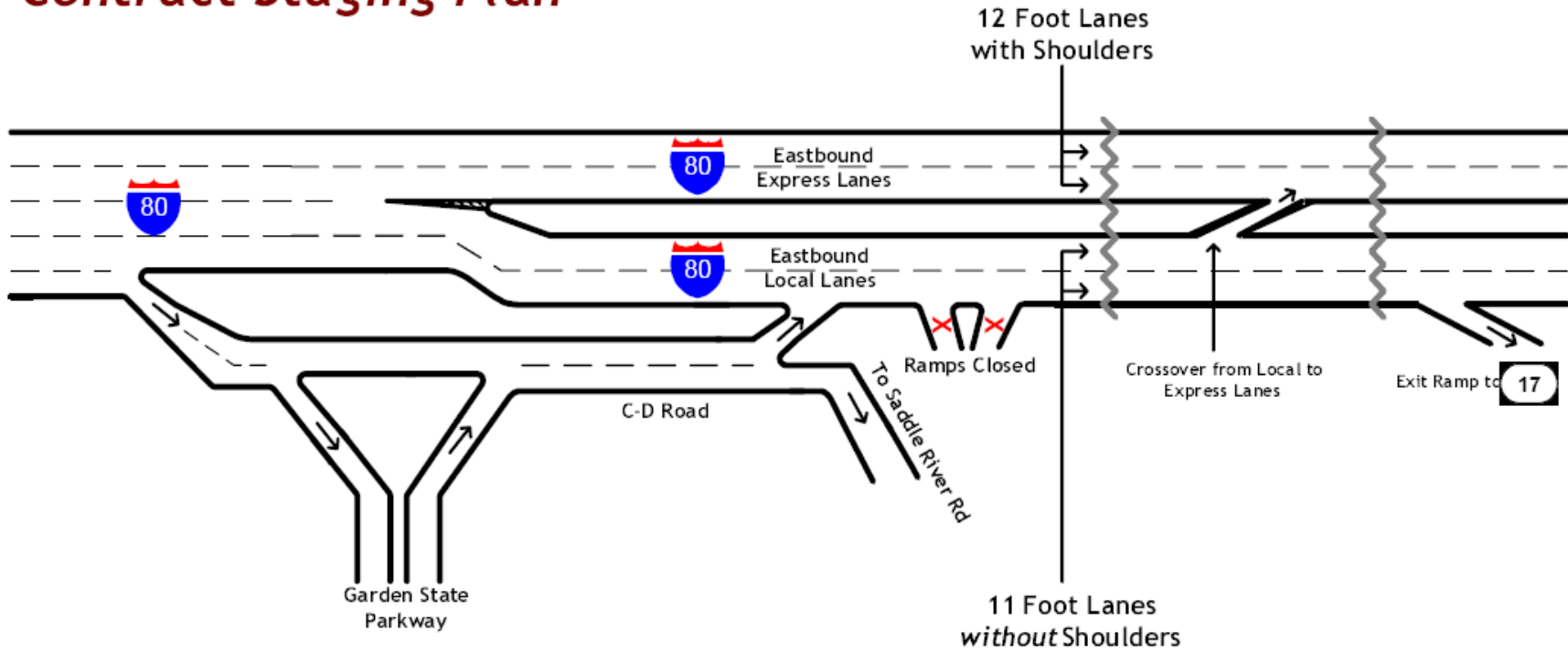
Figure 88. I-80 Eastbound Contract Staging Plan

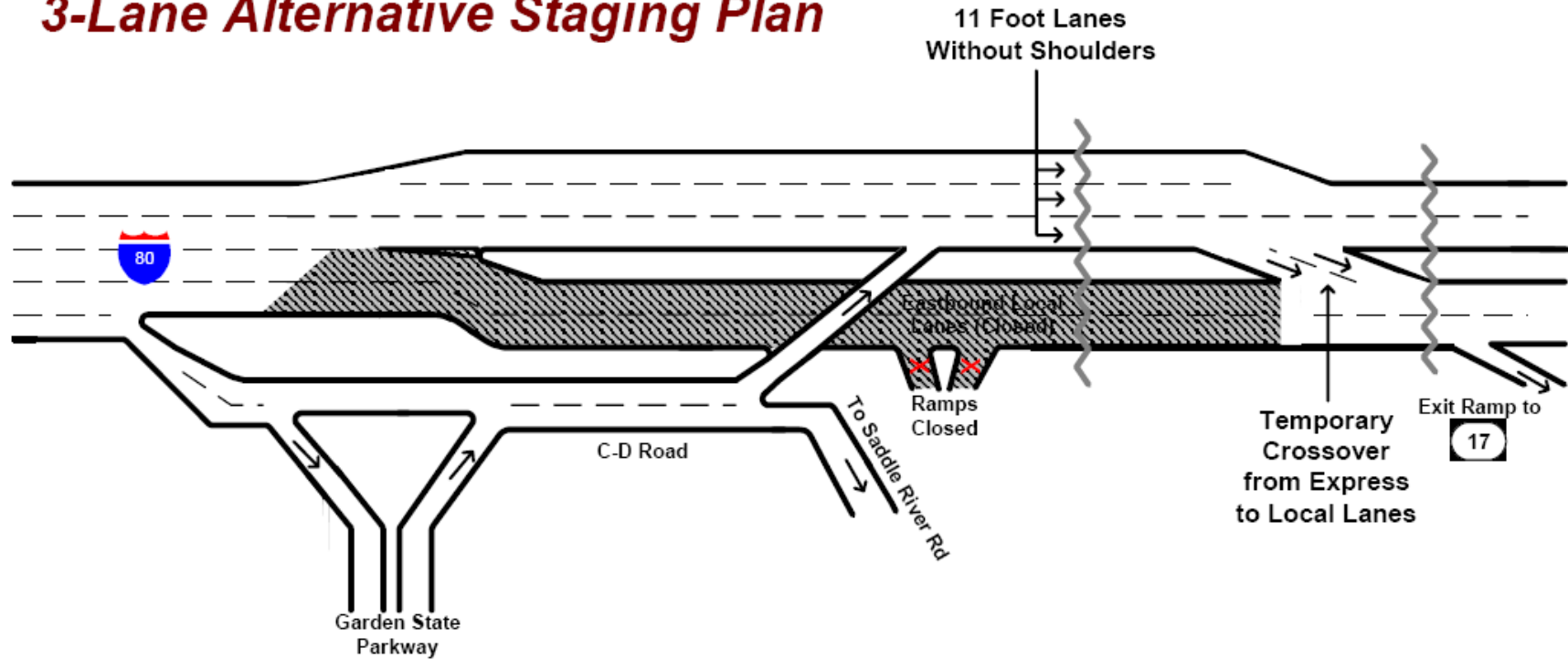(Source: Kremer, Kotchi, DeJohn, and Winslow, 2001.)

Figure 89. I-80 Eastbound Contractor Staging Alternative (Three-Lane Staging Plan)

(Source: Kremer, Kotchi, DeJohn, and Winslow, 2001.)

The data collection effort included:

- **Field Observed Traffic Data –** Two days of traffic data collected included traffic counts, speed and delay runs, and observations of queue formation and length. The count locations included critical entry and exit points to and from the study area.
- **Demand Data –** Origin-Destination data was not available, so the analysts used traffic counts to generate a trip table.
- **Road Geometry –** Using data collected from field visits, the analysts collected information regarding roadway characteristics and configuration.

A preliminary traffic engineering evaluation also was conducted to determine the roadway capacity and throughput in the study area. The preliminary traffic engineering evaluation included:

- **Fatal Flaw Analysis –** A fatal flaw analysis of the staging plans and traffic flow was conducted to ensure that existing traffic movements could be accommodated and that worker and motorist safety were not compromised with either of the staging plan alternatives. No fatal flaws were found. However, it was recognized that without an emergency/breakdown area it would be very difficult for traffic to recover from an accident or disabled vehicle.
- **Capacity Analysis –** A capacity analysis using 2000 HCM procedures was used to determine whether a three-lane expressway could accommodate the prevailing demand. Based on this evaluation, it was determined that the three-lane cross section was insufficient to meet the measured demand. However, the authors chose to keep the alternative and proceed with the modeling analysis efforts.

Step 5B – Existing Conditions Model Development

The next step of the MOTAA is to develop the existing conditions model with the appropriate geometry, traffic controls, demands, and capacities using the information from the data collection effort and the preliminary analysis. The process used in the case study for network coding and error checks included:

- **Road Geometry –** A GIS-based network editor was used to build the network. Error checks were conducted to ensure accurate coding of the network. The analysts used field visits to verify their network coding. They also used data from the New Jersey DOT Straight Line Diagrams as a quality control tool to verify the accuracy of the coded roadway characteristics and configuration. The edited network was then converted into an ASCII format and then to a format compatible with INTEGRATION.
- **Traffic Demands –** As previously mentioned in Step 5A, trip tables were generated using observed traffic volumes. The network consisted of seven entry/exits in the corridor. The analysts' first step in generating the trip table was to generate traffic volumes at all links and nodes, balance these counts, and distribute them throughout the corridor. Initial distribution assumptions were made based on observed traffic patterns and flows. The final trip table was divided into five 30-minute intervals and two vehicle trip types, auto and truck trips.

Step 5C – Existing Conditions Model Calibrations

The model calibration criteria consisted of three sources of existing conditions data: traffic counts, average travel speeds, and queuing observations. The calibration was determined to be within acceptable limits. Results of the calibration effort were not shared in the document.

Additional Considerations for Model Calibration

For this case study, the criteria measures used to compare model behavior with field observations were established. However, there are several other considerations involved in the model calibration process, including:

- **Model Parameters –** One of the critical steps in the model calibration process is the adjustment of global and link-specific parameters to ensure the model behaves similarly to field conditions.

- **Model Runs and Random Seeds –** After the adjustments to the model, the analyst will have to extract outputs from the model that can be used to compare against field data. To mimic real-world traffic variations, simulation software packages introduce randomized seed numbers associated with the model runs. The analyst will then extract and average the output values from a determined number of model runs with different seed values. The analyst will, therefore, have to determine the appropriate number of runs to conduct for the model. Chapter 4 of this document presents one way of determining model runs when using microsimulation tools. However, an agency may also specify a standardized number of runs or methodology to be used in during analysis.

- **Calibration Acceptance Criteria –** The criteria should include mathematical targets related to traffic volumes and speeds that could be used to compare the model with field observed conditions. In this case study, the authors have specified the measures used to compare the model with field data. In the calibration process, the analyst should also determine and specify the target values that the model results/outputs should achieve. Example criteria could include achieving model volumes and speeds within a certain percent difference of the field data. The criteria and acceptance targets may vary based on agency standards and/or preference.

Step 5D – Work Zone Base Conditions Model Development, and Step 5E – Work Zone Base Conditions Model Calibration

Once the existing conditions model has been developed and calibrated, it can then be modified for use during the work zone base conditions model development and calibration, as well as during the alternatives analysis stage. In this case study, there was no work zone base conditions model developed. The analysts assumed the same demand levels for all three scenarios (existing conditions, contract staging plan, and alternative staging plan). No work zone calibration procedure was specified for this case study.

Work Zone Base Conditions Model Calibration Options

As specified in Chapter 4 of this document, work zone model calibration includes the calibration of work zone capacity and performance measures. Work zone model capacity and performance measures such as queue, travel time, delay, and speeds can be calibrated to field data and or prior experiences (from similarly implemented work zone projects). Additionally, work zone base conditions calibration also entails that the analyst evaluate and identify the appropriate modeling parameters to use based on prior experiences modeling or analyzing work zones of similar types. Such observations and measures will aid the analyst in the work zone calibration process.

For many work zone projects, the absence of reliable work zone conditions data to calibrate has caused many agencies to abandon a work zone base calibration effort. Instead, many of the same assumptions, parameters, and demands are consistent across the existing conditions and work zone conditions models. However, in reality, demands and driver behavior can be very different in a work zone versus a typical driving commute. While this case study does not provide a work zone base calibration effort, the following suggested procedure provides some recommendations and guidance on the calibration of a work zone base model.

1. Identifying Calibrations Measures and Thresholds

In the existing model calibration, field measures and/or observations such as volumes, speeds, queues, and bottlenecks were used to calibrate/validate model outputs. Since typically the work zone base condition model development occurs prior to project implementation, there is typically no field data to calibrate to. Analysts can, therefore, use similar measures for calibration/validation, but must rely on sources outside of field data. One example of a measure that can be used for work zone calibration is capacity during work zone conditions. Chapter 4 of this document describes how work zone capacity can be determined. Analysts can determine work zone capacity using any of the following methods/sources:

- Implemented work zone projects with similar characteristics.
- HCM 2010 methods for calculating work zone capacity (discussed in Chapter 4). This also includes the use of tools, such as Q-DAT (presented in Chapter 7) that use HCM methodologies to determine capacity.
- Other work zone capacity studies and best practices.

2. Parameter Adjustments

The next step entails the adjustment of model parameters until the model is able to replicate or reflect the conditions identified by the previous step. For instance, if the measure being used for the calibration procedure is capacity, the analyst can conduct a sensitivity analysis that will identify which combinations and values of model parameters are able to produce the expected capacity for the work zone. Some example model parameters that could be adjusted for work zone base calibration in INTEGRATION and other mesoscopic, as well as microscopic tools include:

- Rubbernecking factors;
- Lane changing parameters;
- Driver behavior; and
- Traveler awareness and compliance parameters.

Through a work zone base calibration procedure, the model can better reflect the expected capacity, demands, queues, and diversions that may occur as result of the work zone.

Step 6 – Alternatives Analysis

The alternatives analysis step involves two stages: 1) development of models to capture the scenarios or alternatives; and 2) description of how these models were run, the outputs extracted, and analysis of the results.

Step 6A – Alternatives Model Development

The analysts used the existing conditions model and adjusted it to develop the two alternatives analysis scenarios according to design plans. The analysts assumed that the same trip table, developed in Step 5A would be used for all three models: existing conditions, contract staging plan, and the contractor's alternative staging plan. The analysis time period remained at 6:30-9:00 a.m., the morning peak period.

Step 6B: Alternatives Analysis Model Runs and Results

The final step of the MOTAA is to run the work zone alternative models and evaluate the performance measures extracted from the model results. As previously mentioned, the analysts used MOEs such as average speed, travel time, maximum queue length, and total vehicle throughput to evaluate and compare the work zone alternatives. The results of the analysis are shown in Figure 90.

	Existing Conditions	Contract Staging Plan	Alternative Staging Plan
Average Speed (MPH)	36	33	16
Travel Time for I-80 through trips (approximate in minutes)	12	12.5	25
Travel Time for GSP through trips (approximate in minutes)	6.5	10	22
Maximum Queue Length on I-80	¾ miles	2+ miles	4+ miles
Total Vehicle Throughput 6:30-9:00 AM	13,600	13,450	10,750

Figure 90. I-80 Eastbound Alternatives Analysis Results

Determining the Number of Runs

One of the key steps in the alternative analysis is determining the appropriate number of models runs as specified earlier in Step 5C, existing conditions model calibration. Section 4.7 of this document also discussed how to determine the number of runs.

Step 7 – Decision Framework and Recommendation of an Alternative

After obtaining the model output and mobility performance measures through the modeling analysis, the next stage of the MOTAA process is the application of a decision-making framework or criteria for evaluating and identifying the preferred alternative. In this case study, the authors chose the alternative that would generate the least amount of negative impacts on mobility along the corridor. According to the results shown in Figure 90, the Alternative Staging Plan would reduce the average travel speed by half, add 12 minutes to the travel time, and reduce throughput by about 3,000 vehicles as compared to the Contract Staging Plan. Therefore, the preferred alternative was the Contract Staging Plan.

Decision Framework Option/Example

The analysts in this case study chose the preferred alternative based on the mobility measures extracted from the modeling analysis. There are also additional factors outside of mobility measures that an agency may want to consider when evaluating the alternatives. These factors are described in further detail in Chapter 7 of this document. A decision-making framework that incorporates these factors, as well as the mobility measures from the simulation results can then be applied to compare the alternatives and choose a preferred option. Chapter 5 of this document feature several different decision-framework options that can fit projects of different complexities and resources.

The following illustrates the application of a decision-making framework, the Kepner-Tregoe (KT) Method, on the I-80 case study using the results from the alternatives analysis, as well as hypothetical values and assumptions for additional factors/measures. As discussed in Chapter 5 of this document, the KT Method involves the following steps:

1. Prepare the decision statement;
2. Define MUST and WANT objectives;
3. Assign weights to WANT objectives;
4. Identify candidate MOT alternatives;
5. Summarize the findings of the work zone impact assessment;
6. Evaluate the alternatives against the MUST objectives;
7. Evaluate the alternatives against WANT objectives;
8. Calculate the weighted scores of the alternatives;
9. Evaluate adverse consequences; and
10. Select the preferred MOT strategy.

Step1 – Prepare Decision Statement

The purpose of the decision analysis is to identify the most appropriate construction staging alternative for minimizing the project's impacts on motorists and the community.

Step 2 – Define MUST and WANT objectives

As described in Chapter 5, MUST objectives include all mandatory requirements that the alternatives must meet. WANT objectives includes the desired measures that will be used to weigh/rank alternatives. The following example includes lists of objectives that serve as hypothetical examples for the purpose of demonstrating the KT Method. These objectives are not representative of established thresholds, requirements, or objectives set by the New Jersey DOT during the implementation of this I-80 project.

Decision Framework Option/Example

The list of MUST objectives include:

- Maintain at least two lanes of traffic within the work zone;
- The maximum allowable queue length for any work zone duration is two miles; and
- Delays must be less than 30 minutes for complex projects.

The WANT objectives include:

- Minimize delay costs;
- Minimize vehicle operating costs;
- Minimize construction duration; and
- Maintain emergency services/provisions (rated at poor, average, or good).

Step 3 – Assign weights to WANT objectives

In the next step of the KT method, weights are assigned to WANT objectives that reflect their relative importance in the decision-making process. A score of 1 indicates "least preferred" and a score of 10 indicates "most preferable."

No.	WANT Objective	Assigned Weight
1	Delay Costs	10
2	Vehicle Operating Costs	8
3	Construction Duration	10
4	Maintenance of Emergency Services	6

Step 4 – Identify candidate MOT alternatives

The next step of the KT method is to identify the alternatives that will be compared and measured against the MUST and WANT objectives. The two work zone alternatives include the Contract Staging Plan and the Alternative Staging Plan.

Step 5 – Summarize the findings of the Work Zone Impact Assessment

The following table summarizes how the alternatives measure against the MUST objectives:

Decision Framework Option/Example

MUST Objectives	Alternative Evaluation	
	Contract Staging Plan	**Alternative Staging Plan**
1. Maintain at least two lanes of traffic within the work zone	Yes	Yes
2. The maximum allowable queue length for any work zone duration is two miles	Yes	Yes
3. Delays must be less than 30 minutes for complex projects	Yes	Yes

The following table summarizes the impact assessment of the two work zone alternatives against the WANT objectives established in Step 2 of the KT Method:

WANT Objectives	Alternative Evaluation	
	Contract Staging Plan	**Alternative Staging Plan**
1. Delay costs	$39,400	$54,700
2. Vehicle operating costs	$2,200	$3,000
3. Construction duration	16 months	8 months
4. Maintain emergency services/provisions (rated at poor, average, or good)	Good	Poor

Step 6 – Evaluate Alternatives against MUST Objectives

The results shown on the MUST objectives table from the previous step indicate that both alternatives satisfy the mandatory requirement and/or thresholds. Therefore, both alternatives proceed to the next step.

Step 7 – Evaluate Alternatives against WANT Objectives

In this step of the KT Method, the alternatives are assigned a score (value between 1 and 10) against each WANT objective based on how well the alternative meets that objective. The following table shows the results of this evaluation:

WANT Objectives	Alternative Score	
	Contract Staging Plan	Alternative Staging Plan
1. Delay costs	8	6
2. Vehicle operating costs	9	7
3. Construction duration	6	10
4. Maintain emergency services/provisions (rated at poor, average, or good)	10	5

Step 8 – Calculate the Weighted Scores of the Alternatives

This step applies the weights established in Step 3 to the results of the alternatives evaluation for WANT objectives (previous step) in order to generate weighted scores for each alternative. For example, the weight of WANT objective "Delay costs" is 10. In order to calculate the weighted score, the weight of the objective is multiplied with the alternative score. For example, the weighted score for the Contract Staging Plan for the "Delay costs" objective is 10*8 or 80. The weighted scores for each alternative against each objective is shown on the following table:

WANT Objectives	Weighted Alternative Score	
	Contract Staging Plan	Alternative Staging Plan
1. Delay costs	80	60
2. Vehicle operating costs	72	56
3. Construction duration	60	100
4. Maintain emergency services/provisions (rated at poor, average, or good)	60	30
Total weighted score	272	246

Step 9 – Evaluate Adverse Consequences – Risk Assessment

This next step involves weighing the feasible alternatives against potential risks identified in the work zone impact assessment. The scores from this risk assessment is two-fold and incorporates considerations for the likelihood of the event occurring and the severity of the impact. The scores range from values of 1 through 10. When evaluating the probability of a risk or event occurring, a score of 1 indicates that the particular risk is unlikely to occur while 10 means most probable. When evaluating the severity of impact, a score of 1 indicates that the impact is "inconsequential" and a score of 10 indicates that the impact is "very severe." The probability and the severity scores are multiplied in order to obtain the adverse consequence score by risk/event for each alternative. Once more, this example presents several hypothetical risk considerations. These risk considerations serve as examples for demonstrating the decision framework. These are not in any way representative of actual factors considered during the implementation of the I-80 project. Risks considered for this analysis include:

- High severity crashes;
- Emergency evacuation due to a natural catastrophe; and
- Flooding.

The following table summarizes the results of the Adverse Consequences Assessment for the two alternatives:

Adverse Consequence	Contract Staging Plan			Alternative Staging Plan		
	Probability	Severity	Score	Probability	Severity	Score
Flood Impact	3	5	15	3	5	15
High-Severity Crashes	5	4	20	5	4	20
Emergency Evacuation	1	6	6	1	8	8
Total Adverse Consequence Score			41			43

Step 10 – Select the Preferred MOT Strategy

In the final step of the KT Method, the total weighted score and the adverse consequence score are jointly considered in comparing the feasible alternatives. In this final step, each feasible alternative is ranked based on preference. For example, after weighing in on the weighted and risk assessment score, an analyst may choose to go with the Contract Staging Plan since it scored the highest total weighted score and had the lowest adverse consequence score.

Alternative	Total Weighted Score	Total Adverse Consequence Score	Rank
Contract Staging Plan	272	-41	1
Alternative Staging Plan	246	-43	2

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