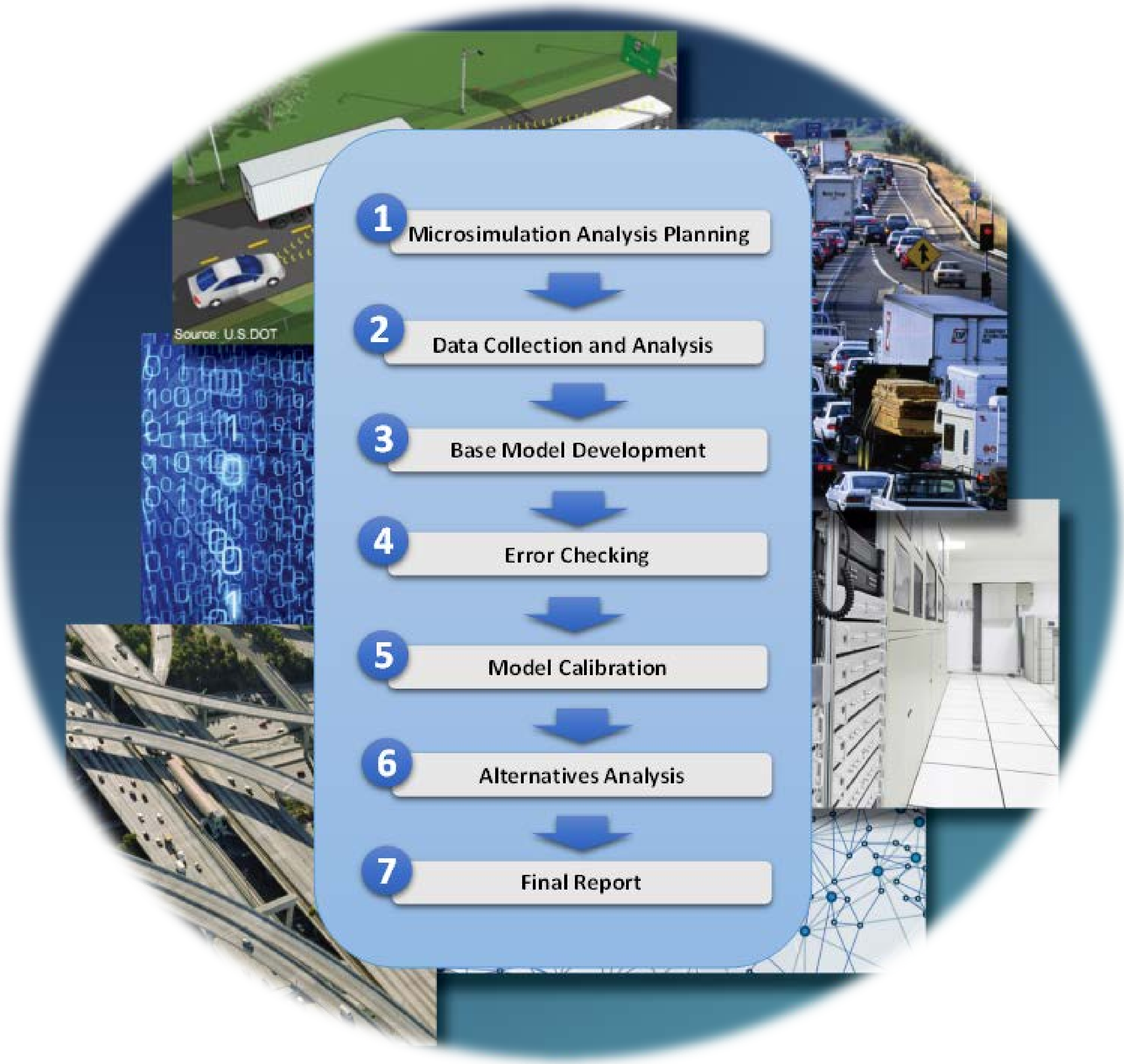
Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software

2019 Update to the 2004 Version



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16. Abstract

Microsimulation is the modeling of individual vehicle movements on a second or sub-second basis for the purpose of assessing the traffic performance of highway and street systems, transit, and pedestrians. Microsimulation analyses are increasingly visible and important – fostered both by the continued evolution of microsimulation software capability and increasing application within transportation engineering and planning practices. These guidelines provide practitioners with guidance on the appropriate application of microsimulation models to traffic analysis problems, with an overarching focus on existing and future alternatives analysis.

This 2019 Update of the original 2004 guide [1] includes significantly enhanced and detailed technical guidance dealing with data collection and analysis (Chapter 2), model calibration (Chapter 5), and alternatives analysis (Chapter 6). A more complex corridor-based example problem is used to illustrate application of the updated guidance. Finally, a complete end-to-end case study using a large microsimulation model for a hypothetical work zone alternatives analysis is included in an appendix. This case study illustrates the application of the detailed guidance on data collection and analysis, calibration and alternatives analysis. The goals of this update are to:

- Encourage comprehensive experimental design based a range of varying travel conditions, rather than a normative "average" day.
- Focus calibration and alternatives analysis on the representation of time-dynamic system performance measures including bottleneck formation and dissipation.
- Eliminate all subjective criteria, replace with criteria that are statistically valid and derived from observed data.
- Develop a calibration process that is data-driven, repeatable, and potentially automatable.

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FOREWORD REGARDING THE 2019 UPDATE

The purpose of the Guidelines for Applying Traffic Microsimulation Modeling Software is to provide a recommended process for using traffic microsimulation software in transportation operations analyses. The guidelines provide the reader with a seven-step process that begins with planning a microsimulation analysis for the project and ends with the final project report. The process is generic, in that it is independent of the specific software tool used in the analysis. In fact, the first step in the process involves picking the appropriate tool for the job at hand.

The 2004 version of this guide created a set of standard practices for effective application of microsimulation tools. The guide addressed the most critical need of the day, namely to provide a systematic process that began with project scoping, tool selection, data collection and input preparation, model testing and calibration, alternatives analysis, and project documentation.

When the 2019 update effort was initiated, the Federal Highway Administration (FHWA) engaged more than two dozen experts from around the world to provide their views on the current state of the microsimulation practice and how this document might be best improved. These experts responded to a structured set of questions to identify the most pressing current needs and to provide prioritization among competing needs.

Taken as a whole, the panel responses reinforced the concept of an increasingly complex and demanding landscape for microsimulation analyses. The experts noted a trend towards more complex applications of microsimulation tools on larger networks, the evaluation of increasingly complex alternatives, and the increasing importance of microsimulation studies in influencing both operational and investment decisionmaking.

Another crucial consensus observation among the experts was the rise of more comprehensive and detailed data sources available to the microsimulation analyst. Pre-2004, data were relatively scarce, and simulation analysts were often forced to rely on a set of vehicle count data limited to some larger facilities within the system. In this era, notions of microsimulation calibration were adapted from travel demand forecasting methods and targeted the accurate reflection of average vehicle counts at detector locations within the network. The panel pointed out that new forms of time-dynamic data were now available but often ignored or ineffectively incorporated within simulation studies.

IDENTIFIED HIGH-PRIORITY AREAS

The expert panel prioritization exercise identified four high-priority areas for the 2019 update:

- Fully Integrate Time-Dynamic Representation of Congestion. The panel indicated that current practice in microsimulation was too focused on fixed or average demand patterns and that congestion development and dissipation over time were often poorly reflected in tool application. This issue resulted in unrealistic analyses that failed to reflect accurately the performance of alternatives under congestion conditions. An identified need for an updated version of this document was to provide more emphasis on time-dynamic data in simulation development, calibration, and alternatives analysis.

- Require Better Representation of Recurrent and Non-Recurrent Conditions. Simply put, the panel indicated that many simulation analyses used to justify investments failed to represent adequately incidents, weather, and variations in travel demand. In some cases, the impact of particular alternatives (traveler information, incident management, road-weather applications) were not accounted for within the simulation study, and suffered relative to other alternatives (e.g., geometric improvements). The identified need was to provide guidance on how to integrate a variety of data sources to create meaningful and realistic models for these travel conditions. This guidance should also include the tailoring of driver behavioral model parameters (e.g., gap acceptance and car-following distance) to the specific conditions being modeled.
- Remove Subjective Calibration Criteria. Some elements of guidance presented as best-practice examples within the guidebook included subjective criteria (e.g., the phrase "to the analyst's satisfaction"). This resulted in two issues. First, these criteria often led to contention among stakeholders since "satisfaction" is highly subjective. Second, in the absence of clear FHWA guidance on calibration, examples used as illustrations within the document were misinterpreted as FHWA guidance. The identified need was to create and document FHWA guidelines on a data-driven calibration process based on statistically-derived and objective criteria.
- Emphasize Accurate Bottleneck Modeling. The accurate representation of the bottleneck location, onset time, and duration were identified as a critical aspect of modeling congested systems. The panel recommended more emphasis on modeling and calibrating bottleneck dynamics.

GOALS

From these recommendations, FHWA focused available resources for the 2019 update on the following goals:

- Encourage comprehensive experimental design based a range of varying travel conditions, rather than a normative "average" day.
- Focus calibration and alternatives analysis on the representation of time-dynamic system performance measures including bottleneck formation and dissipation.
- Eliminate all subjective criteria, to be replaced with criteria that are statistically valid and derived from observed data.
- Develop a calibration process that is data-driven, repeatable, and potentially automatable.

It is hoped that these guidelines will assist the transportation community in moving away from outdated practices that were developed in the relatively data-poor past dependent on the analysis of averages or the assumption that unrealistic "normal" conditions always prevail, and towards conducting data-driven, statistically-valid objective analyses.

FORMAT OF THE UPDATE

In order to meet the goals of the update, a complete rewrite of the document was neither feasible nor desirable. Instead, the 2019 update retains the general structure and intent of the main sections of the 2004 guidebook [1], with updated materials throughout the document. Significantly enhanced and detailed technical guidance has been included in chapters dealing with data collection and analysis (Chapter 2), model calibration (Chapter 5), and alternatives analysis (Chapter 6). A more complex corridor-based example problem is used to illustrate application of the updated guidance. A series of technical appendices from the 2004 document on ancillary topics have been either incorporated into the body of the document or removed. References have been updated, particularly with respect to the larger body of current and projected Traffic Analysis Tools volumes. Finally, a complete end-to-end case study using a large microsimulation model for a hypothetical work zone alternatives analysis is included in an appendix. This case study illustrates the application of the detailed guidance on data collection and analysis, calibration and alternatives analysis.

Aside from this section, for the purposes of clarity, the 2019 update is presented as a complete document without reference to original source (2004 or 2019). That is, the specific passages and updates introduced into this version are not identified separately from materials which appeared in the original version.

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

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INTRODUCTION

Microsimulation is the modeling of individual vehicle movements on a second or sub-second basis for the purpose of assessing the traffic performance of highway and street systems, transit, and pedestrians. Microsimulation analyses are increasingly visible and important – fostered both by the continued evolution of microsimulation software capability and increasing application within transportation engineering and planning practices. These guidelines provide practitioners with guidance on the appropriate application of microsimulation models to traffic analysis problems, with an overarching focus on existing and future alternatives analysis.

The use of these guidelines will aid in the consistent and reproducible application of microsimulation models. They are also intended to support further the accuracy and credibility of analyses using these tools. As a result, practitioners and decision makers will be equipped to make informed decisions that will account for current and evolving technology. It is hoped that these guidelines will assist the transportation community in moving away from outdated practices that were developed in the relatively data-poor past dependent on the analysis of averages or the assumption that unrealistic "normal" conditions always prevail, and towards conducting data-driven, statistically-valid objective analyses. Depending on the project-specific purpose, need, and scope, elements of the process described in these guidelines may be enhanced or adapted to support the analyst and the project team. It is strongly recommended that the respective stakeholders and partners be engaged prior to and throughout the application of any microsimulation model. This further supports the credibility of the results, recommendations, and conclusions, and minimizes the potential for unnecessary or unanticipated tasks.

GUIDING PRINCIPLES OF MICROSIMULATION

Microsimulation can provide the analyst with valuable information on the performance of the existing transportation system and potential improvements. However, microsimulation can also be a time-consuming and resource-intensive activity. The key to planning and conducting an effective (and cost-effective) microsimulation analysis revolves around a set of guiding principles:

- <u>Ensure the Analysis Has a Clear Objective, Hypotheses and Well-Defined Performance Measures</u>. Prior to embarking on the development of a microsimulation model, establish its scope among the partners, taking into consideration expectations, tasks, and an understanding of how the tool will support the engineering decision. Output of a microsimulation model is different from that of the *Highway Capacity Manual (HCM) (Transportation Research Board (TRB))*. Definitions of key terms, such as "delay" and "queues," are different at the microscopic level of microsimulation models than at the macroscopic level typical of the HCM. In addition, because well-defined performance measures may be different when applied to observed (field) data or standard simulation outputs, these differences must be reconciled for effective analysis. Additional Resources: Forthcoming FHWA guidance document *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* [2] and *Traffic Analysis Toolbox Volume VI* [10].

- Select an Appropriate Tool. Use of the appropriate tool is essential. Do not use microsimulation analysis when it is not appropriate. Understand the limitations of the tool and ensure that it accurately represents the traffic operations theory. Confirm that it can be applied to support the purpose, needs, and scope of work, and can address the question that is being asked. Additional Resources: *Traffic Analysis Toolbox Volume II* [25].
- Budget Sufficient Analytical Resources and Time. Do not use microsimulation if sufficient budget or schedule (time to conduct) are not available. A rushed or under-resourced analysis can result in faulty conclusions and lead to a loss of credibility in simulation analyses in general. Additional Resources: *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* [2].
- Obtain Sufficient Available Data. In particular, good data are critical for good microsimulation model results. Modeling without sufficient data either to determine operational conditions or to calibrate effectively can be risky, resulting in faulty conclusions and leading to a loss of credibility. Additional Resources: *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* [2].
- Use a Model that is Calibrated Specifically for the Study Purpose. It is critical that the analyst calibrate any microsimulation model to local conditions and prevailing travel conditions. Failure to calibrate a model sufficiently can lead to erroneous alternatives analysis and can be detrimental to effective transportation systems management.
- Engage Stakeholders Early and often Throughout. To minimize disagreements between partners, embed interim periodic reviews at prudent milestones in the model development and calibration processes. Maintain a *Methods and Assumptions* document to ensure there is a consistent and logbook of key decisions made throughout the simulation project.

OVERVIEW OF THE MICROSIMULATION ANALYTICAL PROCESS

The overall process for developing and applying a microsimulation model to a specific transportation analysis problem consists of seven major tasks. Each task is summarized below and described in more detail in subsequent chapters. A flow chart, complementing the overall process, is presented in Figure 1. This figure is intended to be a quick reference that will be traceable throughout the document.

Chapter 1 addresses the management, scope, and organization of microsimulation analyses. In this section, the guidebook describes key issues for the management of a microsimulation study. This includes defining the project purpose, identifying the project influence area and analytic time period(s), characterizing the alternatives to be evaluated, selecting performance measures, developing a general technical approach (including tool selection) and estimating staff time and other costs.

Chapter 2 discusses the steps necessary to collect and prepare input data for use in microsimulation models. This task involves the collection and preparation of all of the data necessary for the microsimulation analysis. Microsimulation models require extensive input data, including: roadway geometry, controls, travel demand, and calibration data, among others. Chapter 2 also includes guidance on analyzing contemporaneous data on traffic counts (demand), weather, incidents, and key performance measures (e.g., travel time) to characterize a set of operational and travel conditions.

Chapter 3 discusses the coding of input data to create a base model. The goal of base model development is a model that is verifiable, reproducible, and accurate. It is a complex and time-consuming task with steps that are specific to the software used to perform the microsimulation analysis. The details of model development are best covered in software-specific user's guides. For this reason, the development process may vary. This report provides a general outline of the model development task.

Chapter 4 presents error-checking methods. The error-checking task 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.

Chapter 5 provides guidance on a systematic calibration of the error-free base model developed in Step 4 to reproduce observed throughput and other performance measures for distinct travel conditions characterized in Step 2. First, individual bottleneck capacities are obtained from observed data. The analyst then performs systematic adjustment of relevant tool parameters to reproduce this throughput rate in model outputs. Second, aggregate demand crossing key strategic internal boundaries (screenlines) are characterized from observed data and are reproduced through alteration of travel demand flow rates. Third, a statistical analysis of observed data creates a series of time-dynamic ranges for key performance measures (e.g., bottleneck throughput and travel times) in each of the travel conditions identified in Chapter 2. One model variant for each travel condition is then calibrated to fall within these time dynamic statistical envelopes, passing four distinct calibration criteria. When these criteria are met for all operational condition model variants, calibration is complete and alternatives analysis may begin.

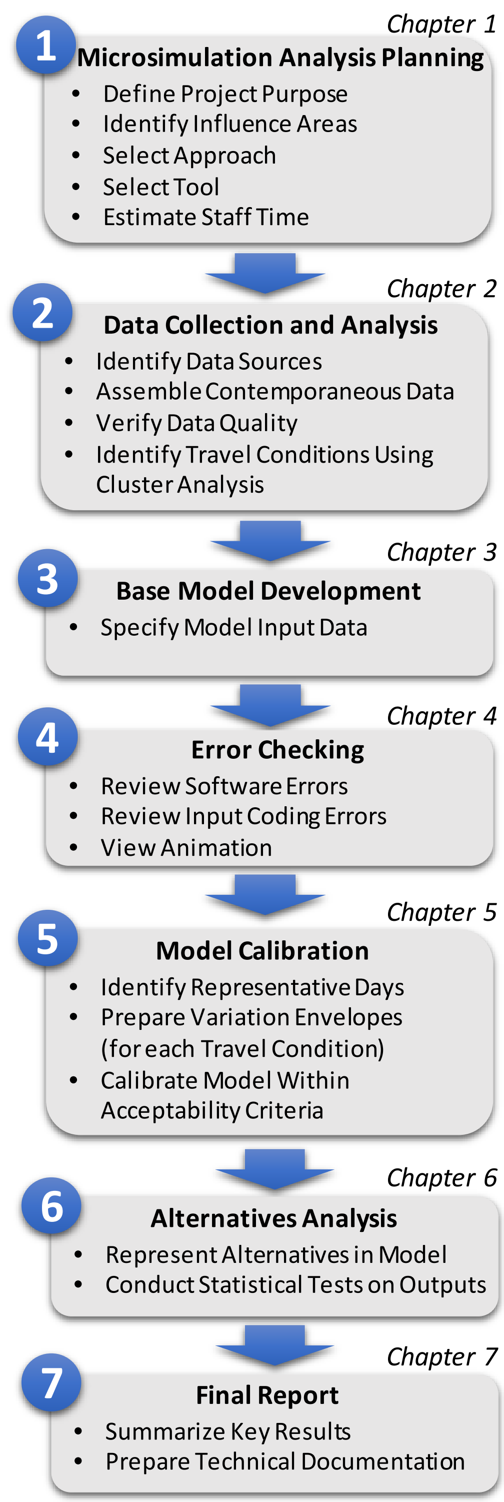

Figure 1. Diagram. The Microsimulation Analytical Process (Source: FHWA)

Chapter 6 explains how to use microsimulation models in a well-designed experiment to support an analysis of alternative improvements proposed for the modeled transportation system. The set of calibrated microsimulation model variants corresponding to the set of travel conditions are run several times to test various project alternatives. The first step is to develop a baseline demand pattern, potentially for a future year. Then the various improvement alternatives are coded into the simulation model representing each travel condition. Randomness in simulation outputs is analyzed to determine the required number of runs to assess statistical validity satisfactorily when comparing the impacts of competing alternatives. The analyst then runs each model variant for the required number of replications for each alternative to generate the necessary output to generate the key performance measures. A statistical test is then performed to determine whether differences between two alternatives are statistically significant, i.e., to determine if the test meets the minimum criteria bounding the risk that the differences are only related to randomness in model outputs.

Chapter 7 provides guidance on the documentation of microsimulation model analysis. This task involves summarizing the analytical results in a final report and documenting the analytical approach in a technical document. This task may also include presentation of study results to technical supervisors, elected officials, and the general public. The final report presents the analytical results in a form that is readily understandable by the decision makers for the project. The effort involved in summarizing the results for the final report should not be underestimated, since microsimulation models produce a wealth of numerical output that should be tabulated and summarized.

ORGANIZATION OF THIS DOCUMENT

- Introduction (this chapter) highlights the key guiding principles of microsimulation and provides an overview of these guidelines.
- Each chapter addresses one of the steps in the process. An example problem is used to illustrate specific aspects in selected steps within the process.
- Appendix A presents a hypothetical case study regarding the application of a microsimulation analysis to support cost-effective planning for a significant work zone project.

CHAPTER 1. MICROSIMULATION ANALYSIS PLANNING

Microsimulation can provide a wealth of information; however, it can also be a very time-consuming and resource-intensive effort. It is critical that the manager effectively coordinate the microsimulation effort to ensure a cost-effective outcome to the study (Figure 2). The primary component of an effective management plan is the study scope, which defines the objectives, hypotheses, performance measures, scope, technical approach, and an estimate of resources required for the study. The topic of effective analytic planning and scoping is a complex topic addressed in several FHWA guidance documents. Guidance drawn from these documents are referenced throughout this chapter**.** This chapter presents the key components of an overall management approach for planning a cost-effective microsimulation analysis.

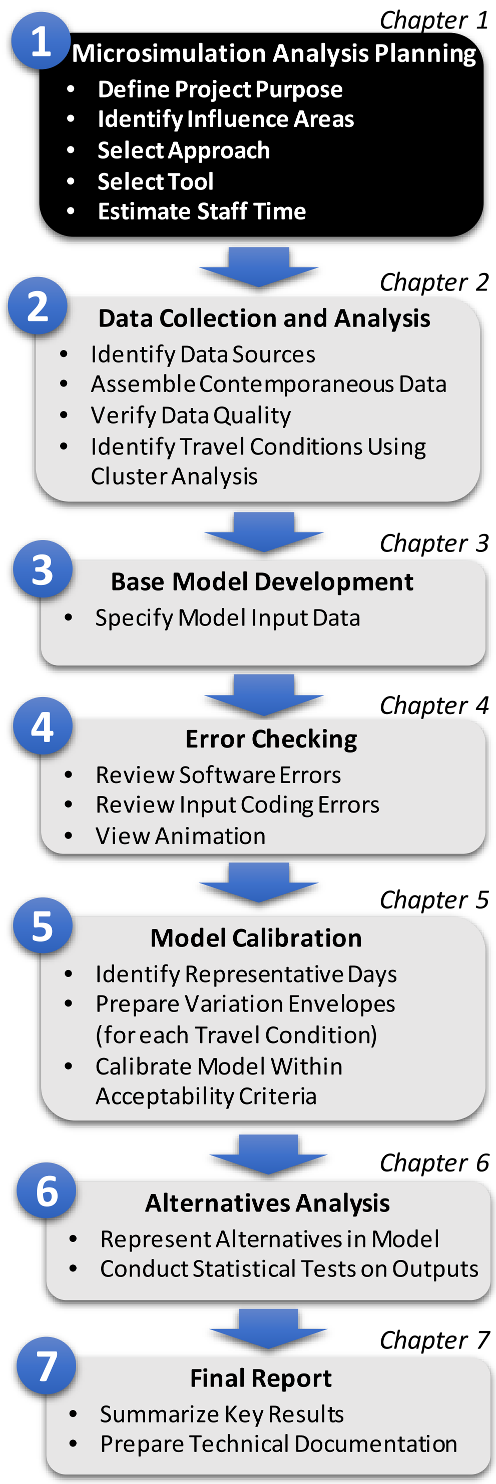

Figure 2. Diagram. Step 1: Microsimulation Analysis Planning (Source: FHWA)

ESTABLISH PROJECT PURPOSE

Before embarking on any major analytical effort, it is critical to establish a clear objective of the analysis among stakeholders. An analytical effort that has unclear objectives can often lead to avoidable negative outcomes such as failure to meet schedule or budget targets, weak or inconclusive findings, and a general loss of credibility in microsimulation analysis among decision-makers.

Ideas for analyses may arise from many potential sources. Competing concepts for new investments may require systematic analysis. Proposed changes to operational practice or system policy may warrant examination. Diagnostic analysis of system performance may reveal critical anomalies and potential mitigating actions. In each case there is an underlying hypothesis – that specific actions to be taken will result in improved system performance. It is useful to discuss ideas for analytical projects among the full range of stakeholders responsible for the performance of the transportation system as well as the stakeholders potentially impacted by the alternatives considered in the analysis.

To capture the purpose of the project clearly and succinctly, a prospective analysis should have a well-defined statement of objectives. A limit of 50-75 words for this statement (including all objectives) can be helpful in crafting a focused analytical project.
Study objectives should answer the following questions:

- What is the system performance problem being addressed?
- What are the alternatives that will be analyzed and associated hypotheses?
- Who are the intended decision makers for analytical results?

In some cases, there may be many competing ideas about how to improve the system, and multiple complementary concepts that together might be tested using microsimulation. The analyst can be helpful in leading stakeholders in crafting a statement of objectives that includes clearly identifying the alternatives to be considered. With some discussion, ideas often naturally group together into natural comprehensive solutions that can be represented and evaluated as alternatives within the analysis.

Try to avoid broad, all-encompassing study objectives. They are difficult to achieve with the limited resources normally available and they do not help focus the analysis on the top-priority needs. A great deal of study resources can be saved if the manager and the analyst can identify upfront what will not be achieved by the analysis. The objectives for the analysis should be realistic, recognizing the resources and time that may be available for their achievement.

The FHWA guidance document *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* [1] provides related guidance on integrating simulation analytics within an effective transportation systems management process. In the project conceptualization phase, a *portfolio prioritization process* is recommended that collects, integrates, and ranks project concepts to ensure that analytical resources are focused on the highest priorities.

SELECT KEY PERFORMANCE MEASURES

The objectives of the analytical effort should align with the overarching goals of organizations that manage the transportation system. For example, as a part of a system-wide performance management plan, there may be a focus on improving productivity, personal mobility, system safety, or environmental impact (or all of the above).

Just as it is not good practice to attempt to address a large number of objectives in a single analytical effort, it is also risky to attempt to examine a large number of performance measures within a single analysis. Simply put, as the number of key performance measures grows, the level of effort associated with the prospective effort grows exponentially. This exponential level of effort is related to the effort to obtain and analyze observed data for each measure, to calibrate simulation models to reflect each measure, to conduct an analysis of alternatives based on each measure, and to integrate each measure within an overall framework supporting decisionmaking.

Performance measures identified for an analytical project should focus on what will differentiate the alternatives identified in the objectives statement. Since these measures will directly inform decision makers, they are a critical element to focus on early in the project planning step. Key questions to consider when selecting performance measures:

- Can the performance measure be observed using field data?
- Can the performance measure be generated from simulation outputs?
- Can the performance measure effectively differentiate the alternatives?

If the answer to any of these questions is no, then the performance measure should not be used. A well-defined analytical project should have at least one (and preferably multiple) key performance measure that meet these criteria.

DEFINE SCOPE

Once the study objectives and performance measures have been identified, the next step is to identify the scope—both in terms of geographic and temporal limits. Several questions related to analytical scope should be considered:

- What is the nature of the alternatives to be analyzed?
  - How many of them are there?
  - How complex are they?
  - In what significant ways do they differ?
- What performance measures will be required to evaluate the alternatives?
  - Over what geographic area are observed data available to calculate these measures?
  - In what time periods are these data available?
  - At what intervals (e.g., 15 minutes) can these measures be characterized?
  - What types of simulation output (e.g., speed by lane) required?
- In what geographic locations are the alternatives expected to influence system performance?
- In what time periods (months of the year, days of the week, hours of the day) will alternatives influence system performance? For what year(s) and time period(s) will output data be needed for other analyses (e.g., environmental studies)?
- Will the resulting influence in system performance from the alternatives influence adjacent facilities or the time-dynamics travel demand patterns?
- What resources are available to the analyst?

<u>The geographic and temporal scopes of a microsimulation model should be sufficient to completely encompass all of the traffic congestion present in the primary influence area of the project during the target analysis period (current or future)</u>. What degree of precision in system performance will be required to differentiate alternatives? Are hourly averages satisfactory? Will the impact of the alternatives be very similar or very different from those of the proposed project? How disaggregate an analysis is required? Is the analysis likely to produce a set of alternatives where the decision makers should choose between varying levels of congestion (as opposed to a situation where one or more alternatives eliminate congestion, while others do not)?

The analyst should try to design the model to geographically and temporally encompass all resulting congestion to ensure that the model outputs provide a complete picture of impacts on system performance. However, given the extent of congestion in many urban areas and resource limitations, it may not always be possible to achieve this goal. If this goal cannot be achieved, then the analyst should attempt to encompass as much of the congestion as is feasible within the resource constraints and be prepared to estimate (by post-processing model outputs) to compensate for the portion of congestion not included in the model. Increasing the temporal simulation horizon may be helpful in projects where expanding geographic boundaries is highly impractical.

The model study area should include areas that might be impacted by the proposed improvement strategies. For example, if an analysis is to be conducted of incident management strategies, the model study area should include the area impacted by the diverted traffic. All potentially impacted areas should be included in the model network. For example, if queues are identified in the network boundary areas, the analyst might need to extend the network further upstream.

DEVELOP THE ANALYTICAL APPROACH

Microsimulation takes more effort than macroscopic simulation, and macroscopic simulation takes more effort than HCM-type analyses. The analyst should employ only the level of effort required by the problem being studied. Microsimulation models are data- intensive. They should only be used when sufficient resources can be made available and less data-intensive approaches cannot yield satisfactory results.

In some cases, a microsimulation can be used in combination with other tools in a multi-resolution modeling (MRM) approach. A compilation of MRM studies can be found in Traffic Analysis Toolbox Volume XIV [3]. MRM methods are relatively new and experimental in nature, and each application should be customized to the effort at hand. The guidance in this document is relevant to a microsimulation project performed in the absence of other tools or within a well-defined MRM effort.

Microsimulations have critical analytical strengths to be brought to bear. Some notable cases where these strengths are particularly useful include:

- Alternatives impacting lane-level capacities and throughput.
- Time-dynamic analyses detailing the onset, intensity, and duration of system congestion.
- System congestion dynamics that influence multiple intersections, interchanges and facilities over time.

Because they are sensitive to different vehicle performance characteristics and differing driver behavior characteristics, microsimulation models are useful for informing decision-makers on a wide range of potential investments, including:

- Signalized network systems analysis.
- Freeway operational studies.
- Managed lane deployments.

- Incident management projects.
- Integrated corridor management strategy assessments.
- Work zone planning.
- Studies of Intelligent Transportation System (ITS) technologies and applications.

The modern analyst has an increasingly wide selection of commercial microsimulation tools to consider for a particular analysis. Some of the key criteria to be considered in software selection are technical capabilities, input/output/interfaces, user training/support, and ongoing software enhancements. *Traffic Analysis Toolbox Volume II* [25] provides detailed guidance on the selection of an appropriate analytical approach that may include a microsimulation tool.

ESTIMATE REQUIRED RESOURCES

The resource requirements for the development, calibration, and application of microsimulation models will vary according to the complexity of the project, its geographic scope, temporal scope, number of alternatives, and the availability and quality of the data. Adequate time should also be allotted to conduct a successful analysis. Data collection, coding, error checking, and calibration are the critical tasks for completing a calibrated model. The alternatives analysis cannot be started until the calibrated model has been reviewed and accepted. The FHWA guidance document *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* [2] provides a useful reference for the estimation of required resources to conduct simulation studies, including an interactive tool for the rough estimation of total hours (by experience level).

PREPARE A PRELIMINARY ANALYSIS PLAN

Much of the management of a microsimulation study is the same as managing any other complex project: establish clear objectives, define a solid scope of work and schedule, monitor milestones, and review deliverables. One of the key attributes of project management includes documenting key assumptions early in the effort and socializing these assumptions with key stakeholders. The Analysis Plan should be updated as the project moves through the sequence of stages from planning to alternatives analysis. One key component of an Analysis Plan is a Methods and Assumptions document that summarizes key decision made between the simulation project management (e.g., the sponsoring agency and their staff) and the simulation analyst responsible for carrying out the project. The outline (or template) for how entries in the Methods and Assumptions document are expected be logged and described. Prior to moving to data collection and analysis, it is critical to document (and socialize) these key aspects of the proposed analysis discussed in this chapter in a first iteration of an Analysis Plan:

- Study Objective.
- Key Performance Measures.
- Study Scope.
- Analytical Approach.
- Methods and Assumptions (outline).
- Estimated Resources.

EXAMPLE PROBLEM: ALLIGATOR CITY

The example problem is a complex corridor analysis in a hypothetical location (Alligator City).

Background

Our example problem is set in Alligator City (Figure 3), a mid-sized hypothetical metropolitan area on the Gulf Coast. It has attributes combining three different Gulf Coast metro areas but is not intended to represent any specific location. Like most rapidly growing metropolitan areas, it has significant congestion and mobility issues.

Figure 3 presents the major geographic features in the region. Okanahatchee County spans the majority of the region, which features two high-ground locations. The first, Alligator City itself, located on an oval-shaped high-ground location adjacent to a deep-water harbor where the Chattacola River enters the Gulf of Mexico. Surrounding Alligator City is a series of wetlands and swampy grounds that include the slow-moving and shallow Chattacola.

Overland access from Alligator City has been built crossing the Chattacola to the west across the Great Gloomy Swamp. The Marine Causeway, Komodo Tunnel and Victory Island Bridge connect to the West Hills, the other high-ground location in the region. As the metro area has grown, much of the growth in the last 40 years has been in the West Hills, putting pressure on the limited capacity of the facilities crossing the swamps and wetlands on the east/west axis.

The Victory Island Bridge is an aging, toll-free facility that is the oldest east-west crossing of the Chattacola. In the 1970s, the Komodo Tunnel was constructed to supplement the bridge. The tunnel has three tubes. The center tube is reversible and is used as a carpool HOV-3 facility eastbound in the morning hours and westbound in the afternoon hours. Tolls are collected only on the inbound tunnel tube (all day) primarily through electronic toll tags.

AM peak period congestion is a key issue in the metropolitan area. Figure 3 highlights some of the locations of highest local concern about congestion. Egress from the bridge and tunnel are often made difficult by congestion on the arterial grid within Alligator City.

Access to the Victory Island Bridge from the Marine Causeway traverses some of the oldest infrastructure in the region. Traffic in these sections breaks down frequently in narrow lanes and some sections are subject to flooding.

Current congestion reduction programs include the use of the reversible tunnel tube for HOV and bus access. Bus and Carpool facilities have been established in the West Hills to encourage the use of the carpool lane(s).

Traveler information is provided primarily through commercial radio broadcast. At least one local media outlet uses fixed-wing aircraft to observe traffic conditions to support regular traffic reports. Finally, since there is almost no access between the two cities and very limited right-of-way, the County maintains and deploys a fleet of incident management trucks that patrol the Marine.

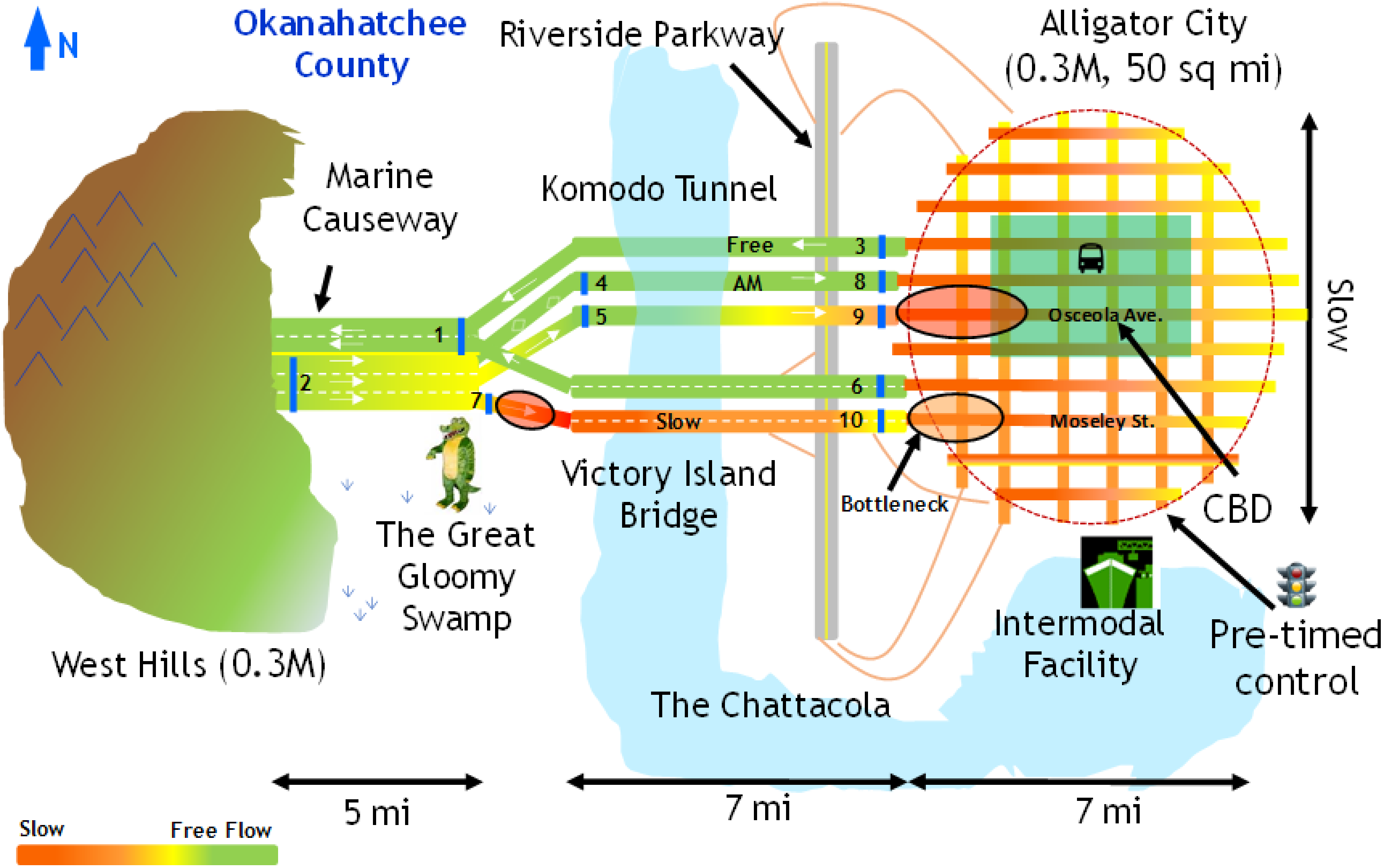

Figure 3. Map. Key Features of the Alligator City Example Problem (Source: FHWA)

Causeway and the Bridge to move and manage crashes and stalled vehicles. The tunnel authority operates a similar service within their jurisdiction. Collectively, the popular incident management program is known as CATTAIL (Congestion Alleviation Trucks Targeting Active Incident Locations).

Consistent public and stakeholder complaints regard the increasingly unreliable commute between the West Hills and Alligator City. Wait times to exit the bridge and tunnel have grown steadily over the last decade. Non-recurrent delays associated with poor visibility, flooding and incidents receive both public and media attention. The movement of freight to and from the intermodal facility in Alligator City is complicated both by unreliable access across the Chattacola and increasing congestion within the Alligator City arterial grid.

Potential actions in the region to alleviate congestion are complicated by multiple institutional factors. First, further expansion of facilities within the Great Gloomy Swamp and other marshlands in the County are no longer possible since its designation as a protected wetland.

The reversible tube of the Komodo Tunnel is considered underutilized by some stakeholders as it is reserved for carpool and bus traffic only. There is building political pressure to open the tube up to general traffic but this is opposed by current transit and carpool users.

Transportation in the region is a hot political issue and there is significant media attention. Differing blocs of stakeholders have proposed independent solutions to regional concerns.

One alternative has been dubbed “Better Bridge and Tunnel”. This alternative has three components. Current mitigation programs continue unchanged. First, comprehensive detection is established along the Victory Island Bridge access and bridge span. Variable Speed Limits (VSL) are implemented along this segment of the facility to harmonize speed and flow.

In addition, the segments of the access road between the Marine Causeway and the bridge span will be re-striped to widen lanes and provide consistent markings along this critical stretch of older roadway.

Underutilized carpool lanes in the AM will be converted to a High-Occupancy-Toll (HOT) facility. Vehicles not meeting the occupancy requirements can pay an extra time-variant fee and traverse the lane in the AM period. This opportunity is extended only to vehicles equipped with electronic toll tags.

Another alternative has been dubbed “Adapt and Redirect”. This alternative also has three components. Some current mitigation programs are augmented in this alternative. This alternative also includes the deployment of new detection capabilities, but this time to explicitly support estimation of travel times along the Marine Causeway, Komodo Tunnel, and Victory Island Bridge. This level of detection is different than the VSL-supporting deployment planned in the other alternative.

Travel times estimated with data from the new detection system are provided to a new, large Variable Message Sign (VMS) erected over the Marine Causeway a short distance east of its western terminus in the inbound (eastbound) direction. Further, travel times are shared with commercial radio partners and provided via a new 511 telephone service.

Selected intersections within the Alligator City arterial grid are upgraded to allow new controllers and the capability to adapt signal timings on the fly from an existing County operations center.

Study Objectives

A study objective statement of fewer than 75 words for this example:
Support a pending decision on new investment to improve morning peak period east bound travel time reliability facilitating travel from West Hills to Alligator City, considering two competing alternatives. Alternative A implements adaptive signal timing, adds resources to incident management, and enhances traveler information. Alternative B implements managed lanes in the Komodo Tunnel, and deploys variable speed limits and some geometric improvements west of the Victory Island Bridge.

Key Performance Measures

Travel time (and travel time reliability) from West Hills to Alligator City along the two main routes (Komodo Tunnel and Victory Island Bridge). An existing system for estimating travel time on these facilities is in place, and travel time can be readily calculated from microsimulation outputs.

Study Scope

The geographic scope of the analysis comprises the corridor from West Hills to the Alligator City arterial grid. Much of the Alligator City Central Business District (CBD) should also be included in the influence area since congestion occurs within the arterial grid itself impacting the two main routes from the west. The temporal scope of the analysis regards the morning peak period, the exact timing of which will be determined after analyzing congestion onset and dissipation patterns when corridor data are further examined (Chapter 2). To differentiate the impact of the two alternatives, travel time profiles across the entire morning peak period at 15 minute intervals is required.

Analytical Approach

The complex alternatives include competing deployments of multiple ITS strategies, differences in lane-level control, and the need to accurately characterize congestion onset, duration, and intensity in the morning peak period. Given the requirement to model and differentiate these alternatives, a microsimulation approach is deemed superior to other analytical approaches. An existing microsimulation of the corridor will be updated and calibrated to support the alternatives analysis.

Estimated Resources

Given the complex nature of the alternatives and the size of the network to be analyzed, a preliminary estimate indicates that 800 - 1,200 staff hours of effort may be required to conduct the analysis. Assessing data availability, current model capability, and other factors, a 15-month analysis period is estimated spanning data collection, model development and testing, calibration, alternatives analysis, and documentation.

KEY POINTS

In summary, when planning a microsimulation study:

- Convene stakeholders to develop a clear objective.
- Identify alternatives to be analyzed.
- Define what performance measures will differentiate alternatives.
- Determine the scope of the effort (geographic and temporal).
- Prepare an appropriate technical approach.
- Estimate resources.

CHAPTER 2. DATA COLLECTION AND ANALYSIS

This chapter provides guidance on the identification, collection, and preparation of the data needed to develop a microsimulation model for a specific project analysis. This is Step 2 in the Microsimulation Analytical Process (Figure 4).

There are agency-specific techniques and guidance documents that focus on data collection, which should be used to support project-specific needs. These sources should be consulted regarding appropriate data collection methods. A selection of general guides on the collection of traffic data includes:

- Introduction to Traffic Engineering: A Manual for Data Collection and Analysis, T.R. Currin, Brooks/Cole, 2001, 140 pp., ISBN No. 0-534378-67-6.
- *Manual of Transportation Engineering Studies*, H. Douglas Robertson, Joseph E. Hummer, and Donna C. Nelson, Institute of Transportation Engineers, Washington, DC, 1994, ISBN No. 0-13-097569-9.
- *Highway Capacity Manual 2010*, TRB, 2010, ISBN No. 978-0-309-16077-3.
- Traffic Analysis Toolbox Volume VI - Definition, Interpretation, And Calculation of Measures of Effectiveness, R. Dowling, FHWA Report # FHWA-HOP-08-054, January 2007.
- *Traffic Monitoring Guide*, FHWA Report # FHWA-PL-13-015, September 2013.

Data collection can be one of the most costly components of an analytical study. It is thus essential to identify the key data that are needed for the study and budget resources accordingly. If there is limited funding, resources need to be spent judiciously so that sufficient, quality data are available for conducting a study that will inform decision makers of the potential implications of their transportation investments.

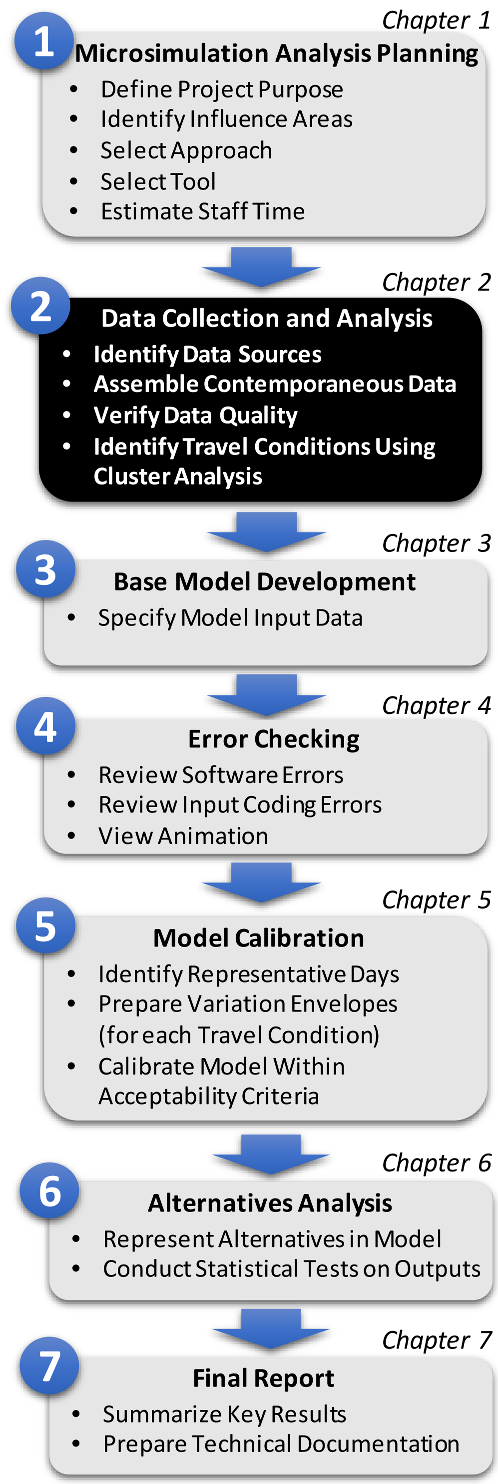

Figure 4. Diagram. Step 2: Data Collection and Analysis (Source: FHWA)

The following are the basic tenets of data collection and management for an effective analytical study using a microsimulation model:

- Use data that are measurable in the field.
- Quality and quantity of data influences analysis.
- Required analytical accuracy drives quantity collected.
- Use data that are relatively recent.
- Use data that are time variant.
- Use contemporaneous data.

An analytical study can represent the impacts of the decisionmaking process only if the model used for the study is calibrated to accurately replicate field conditions. This is feasible if data that are observable in the field are used for building and calibrating the model. Secondly, the type of analysis being conducted is dependent on the quantity and quality of data available. If the amount of available data does not adequately support the project objectives and scope identified in Task 1, then the project team should return to Task 1 and redefine the objectives and scope so that they will be sufficiently supported by the available data. The required accuracy should drive the quantity collected. Chapter 5 will discuss the approach for determining the amount of data required for a desired level of accuracy. Finally, the quality of the analysis and the resulting decisions will depend on the data that were used. Data that are relatively recent, capture the temporal variations in demand, and are concurrent should be used for a microsimulation analysis.

Until recently, due to insufficient data, analysts used a single, average day created from disparate sources and from data collected on different days. Outlier days that included incidents, weather and unusually high or low travel demand were removed from the analysis.

When making transportation investment decisions it is important to look at the cost-effectiveness of alternatives. If only a single “normal” day is used to compare the alternatives, as has been the norm for analytical studies, the effectiveness of each alternative will not be fully captured as driver behaviors vary significantly from normal to non-normal days. This makes it necessary to look at the causes and the size of the problem being addressed. For example, how many days in a year experience severe congestion? What proportion of the extreme delays can be attributed to inclement weather, such as snowstorms? What proportion of the extreme delays was caused by multi-vehicle crashes? Modeling all days, however, is not a practical approach. It is infeasible, cost-prohibitive, and unnecessary.

This version of the toolbox provides guidance on overcoming this limitation by including even the “outlier” days by assigning days into groups that experience similar travel conditions and modeling a representative day from each cluster, making it feasible cost-wise. Travel conditions are defined as a combination of operational conditions and resulting system performance. Operational conditions are identified by a combination of demand levels and patterns (e.g., low, medium or high demand), weather (e.g., clear, rain, snow, ice, fog, poor visibility), incident (e.g., no impact, medium impact, high impact), and other planned disruptions (e.g., work zones, special events) that impact system performance (e.g., travel times, bottleneck throughput).

To make wise, cost-effective investment decisions it is beneficial to identify and categorize days by travel conditions to better understand the sources of variability in the system and identify conditions when one alternative outperforms another or under what conditions an alternative is most effective. For example, to articulate the value of adaptive traffic signal control, it is critical to examine under what conditions the strategy will be most effective, and under what conditions it will not yield significant benefits. However, distinguishing between good and bad performance in a transportation system that is confounded by noise from factors such as adverse weather, incidents, etc., is challenging. Comparison of the average performance over all days in the baseline or the pre-implementation period with that in the post-implementation period will not reveal the true impacts (whether positive or negative). For example, an increase in corridor delays during the post-implementation period might be attributed to poor performance of the adaptive traffic signal control strategy. However, this might have been caused by some confounding factor, such as a series of severe weather events during the post-implementation period. Had the performance on days with severe weather events been compared, the strategy may have proved to be beneficial. Comparing the effectiveness of alternatives on similar travel conditions will help minimize the effect of confounding factors that may affect benefits analyses.

If the analyst doesn’t have data for multiple days in a year that represent the possible travel conditions that a traveler may experience, then the analyst is advised to either collect data for additional days or in the event of constrained resources or schedule, explore alternative solutions to microsimulation. In recent studies, analysts have identified travel conditions by categorizing (or binning) days into *pre-determined* groups based on demand, and key sources of congestion for the study area being modeled. Such approaches do not accurately represent system outcomes (e.g., travel times, travel speeds, bottleneck throughput). For example, a traveler’s experience on two days with identical demand and severity of incidents might not be similar if the locations of the incidents are not similar or if the number of incidents is not identical.

This chapter provides an alternate approach that makes use of cluster analysis to assign days into groups, where each group characterizes a specific travel condition. Cluster analysis helps to partition data into groups or clusters to minimize the variance within each cluster (so that days within each cluster are similar) and maximize the variance between clusters (so that days in different clusters are dissimilar). The groups are not pre-selected; instead clustering discovers natural groups that exist in the data. It should be noted that clustering does not yield a *right* answer. In fact, outcomes may or may not be deterministic depending on the clustering technique. Outcome of clustering is highly dependent on the pre-processing of data, selection of attributes, clustering technique, initial solution, and stopping criterion for identifying the final number of clusters.

The key steps for data collection for an analytical study include:

- Identify Data Sources.
- Assemble Contemporaneous Data.
- Verify Data Quality.
- Identify Travel Conditions Using Cluster Analysis.

IDENTIFY DATA SOURCES

The sections below discuss the three categories of data required by an analytical study and the corresponding sources:

- Data for base model development.
- Data for determining travel conditions.
- Data for calibration.

Data for Base Model Development

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 analytical studies will require the following types of input data:

- Road geometry (lengths, lanes, curvature).
- Traffic controls (signal timing, signs).
- Demand (entry volumes, turning volumes, O-D table).

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. Most microsimulation tools employ statistical distributions to represent the driver and vehicle characteristics. The statistical distributions employed to represent the variability of the driver and vehicle characteristics should be calibrated to reflect local conditions.

Each microsimulation model will also 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. The discussion below describes only the most basic data requirements shared by the majority of microsimulation model software.

Demand data will be discussed in the data for travel conditions section.

Geometric Data

The basic geometric data required for building a model are the number of lanes, length, and design speed. For intersections, the necessary geometric data may also include the designated turn lanes, their vehicle storage lengths, and curb turn radii. These data can usually be obtained from construction drawings, field surveys, geographic information system (GIS) files, Google Maps, or aerial photographs.

Some microsimulation modeling tools may allow (or require) the analyst to input additional geometric data, such as grade, horizontal curvature, load limits, height limits, shoulders, on street parking, pavement condition, etc.

Control Data

Control data consist of the locations of traffic control devices and signal-timing settings. These data can best be obtained from the files of the agencies operating the traffic control system or from field inspection. The analyst should obtain time-stamped signal-timings when possible. A best practice is to not just rely on the information provided by the public agency. Resources should be allocated to conduct a spot-check of the data through field inspection.

Some tools may allow the inclusion of advanced traffic control features. Some tools require the equivalent fixed-time input for traffic-actuated signals. Others can work with both fixed-time and actuated-controller settings.

Vehicle Characteristics

The vehicle characteristics typically include vehicle mix, vehicle dimensions, and vehicle performance characteristics (maximum acceleration, etc.). The software-supplied default vehicle mix, dimensions, and performance characteristics should be reviewed to ensure that they are representative of local vehicle fleet data, especially for simulation software developed outside the United States.

<u>Vehicle Mix</u> – The vehicle mix is defined by the analyst, often in terms of the percentage of total vehicles generated in the O-D (origin-destination) process. Typical vehicle types in the vehicle mix might be passenger cars, single-unit trucks, semi-trailer trucks, and buses.

Default percentages are usually included in most software programs; however, the vehicle mix is highly localized and national default values will rarely be valid for specific locations. For example, the percentage of trucks in the vehicle mix can vary from a low of 2 percent on urban streets during rush hour to a high of 40 percent of daily weekday traffic on an intercity interstate freeway.

It is recommended that the analyst obtain one or more vehicle classification studies for the study area for the time period being analyzed. Vehicle classification studies can often be obtained from a variety of sources, including truck weigh stations, Highway performance monitoring system (HPMS), etc.

<u>Vehicle Dimensions and Performance</u> – The analyst should attempt to obtain the vehicle fleet data (vehicle mix, dimensions, and performance) from the local/State DOT or air quality management agency. National data can be obtained from the Motor and Equipment Manufacturers Association (MEMA), various car manufacturers, FHWA, and the U.S. Environmental Protection Agency (EPA).

Driver Characteristics

Driver characteristics typically include driver aggressiveness, reaction time, desired speeds, and acceptable critical gaps (for lane changing, merging, crossing). In addition, some tools may also allow the analyst to specify driver cooperation, awareness, and compliance (to posted speeds limits, signs, etc.).

Driver aggressiveness characterizes how drivers respond to traffic flow conditions [4]. Driver cooperation characterizes the degree to which drivers will forgo individual advantage and modify their driving behavior to assist other drivers in the traffic stream [4]. Driver awareness characterizes how informed a driver is of the traffic conditions. What percentage of the drivers are habitual drivers or commuters versus tourists? What percentage of the drivers are aware of the traffic flow conditions (e.g., queue ahead, congestion, incidents) and feasible alternatives (e.g., route, mode) through traveler information or messages posted on VMS? Driver compliance characterizes how often a driver complies with the traffic control signs, mandatory messages posted on the VMS, etc.

As is done for vehicle characteristics inputs, the software-supplied defaults should be reviewed to ensure that they are representative of the local driving population.

Traffic Operations and Management Data

Traffic operations and management data can be categorized into driver warning data, regulatory data, information (guidance) data, and surveillance detectors. For all four categories, the analyst will need the type and location of the signs or the detectors.

For warning data, the analyst will need information on the type and location of warning signs. For example, are there signs for lane drops or exits? Where are they located? For regulatory data, the analyst will need the type and location of the signs, and the information posted (e.g., regulatory speed limit in a work zone). If there are HOV lanes, the analyst will need information on the High Occupancy Vehicle (HOV) lane requirement (e.g., HOV-2 versus HOV-3), the hours, the location of signs, and information on driver compliance. If there are High Occupancy Toll (HOT) lanes, the analyst will need information on the pricing strategy and HOT management procedures. For example, the analyst may need information on how the HOT lanes are managed in the event of an incident, when and how the HOT lane requirements are modified, what the criteria are for lifting the restrictions, etc. Information or guidance data include information posted on VMS. The analyst will need the type of information that is displayed, the location, and if possible, the actual messages that were displayed. This can be obtained from the local or State DOT. The analyst will also need information on the locations of surveillance detectors.

Most of the information, including messages posted on the VMS, can be obtained from the public agency responsible for the study area. Type of signs and locations can be obtained from GIS files, aerial photographs, and construction drawings.

Data for Determining Travel Conditions

This is the second category of data that should be collected and examined when conducting an analytical study. The Verify Data Quality Section will lay out the process for identifying travel conditions through cluster analysis.

Demand Data

Travel demand data is required for both base model development as well as for identifying travel conditions.

The basic travel demand data required for most models consist of entry volumes (traffic entering the study area) and turning movements at intersections within the study area. Some models require one or more vehicular O-D tables, which enable the modeling of route diversions. An O-D table includes the number of travelers moving between different zones of a region in a defined period of time. Procedures exist in many demand modeling software and some microsimulation software for estimating O-D tables from traffic counts.

Count Locations and Duration: Traffic counts should be conducted at key locations within the microsimulation model study area for the duration of the proposed simulation analytical period. The counts should ideally be aggregated to no longer than 15-minute time periods.

If congestion is present at or upstream of a count location, care should be taken to ensure that the count measures demand and not capacity. The count period should ideally start before the onset of congestion and end after the dissipation of all congestion to ensure that all queued demand is eventually included in the count.

The counts should be conducted simultaneously if resources permit so that all count information is consistent with a single simulation period. Often, resources do not permit this for the larger simulation areas, so the analyst should establish one or more control stations where a continuous count is maintained over the length of the data collection period. The analyst then uses the control station counts to adjust the counts collected over several days, preferably for a year, into a consistent set of counts.

Estimating O-D Trip Tables: For some simulation software, the counts should be converted into an estimate of existing O-D trip patterns. Other software programs can work with either turning-movement counts or an O-D table. An O-D table is required if it is desirable to model route choice shifts within the microsimulation model.

Local metropolitan planning organization (MPO) travel demand models can provide O-D data; however, these data sets are generally limited to the nearest decennial census year and the zone system is usually too macroscopic for microsimulation. The analyst should usually estimate the existing O-D table from the MPO O-D data in combination with other data sources, such as traffic counts. This process will require consideration of O-D pattern changes by time of day, especially for simulations that cover an extended period of time throughout the day. It might be necessary to generate separate O-D tables for trucks, especially if there is significant percentage of trucks in the study area. There are many references in the literature on the estimation of O-D volumes from traffic counts [5]. Most travel demand software and some microsimulation software have O-D estimation modules available.

There are more accurate methods for measuring O-D data, including use of license plate matching survey, wireless communication data (e.g., cellular phone positioning data, data from

GPS (global positioning system) enabled vehicles), etc. In the license plate matching method, the analyst establishes checkpoints within and on the periphery of the study area. License plate numbers of all vehicles passing by each checkpoint are noted either manually by the analyst or video surveillance. A matching program is then used to determine how many vehicles traveled between each pair of checkpoints. However, license plate matching surveys can be quite expensive.

In wireless communication-based methods, locations of cell phones can be derived directly from the GPS position if the phone is GPS-enabled or by tracking when a signal is received at a base station (signal tower). The locations of the cellular probes are matched to determine trip origins and destinations. To estimate the O-D matrix for a wider region, the probability of cell-phone ownership is applied. Cellular phone data can also help infer trip purpose (shopping, school, work, etc.) and mode (e.g., a slow-moving trajectory may be classified as a pedestrian).

If the study area has transit, High Occupancy Vehicles (HOV), and trucks in the vehicle mix, or if there is significant interaction with bicycles and pedestrians, the analyst will need the corresponding demand data. Even if only the peak periods are being examined, demand data should be collected before the onset of congestion and should continue until after the congestion is dissipated. To capture the temporal variations in demand it is best not to aggregate demand data to longer than 15 minutes.

For identifying travel conditions, average link flows should be calculated at two screen lines that bisect the study area. Average flows should be computed across all links that cross the screen lines. At a minimum, the average flows should be computed for the principal corridor(s) that is being modeled. Averages should be calculated for each day at 15-minute intervals; these may be averages for the entire day or just the peak periods, depending on the goals of the analysis.

Forecasting future travel demand is a challenging and difficult problem and is outside of the scope of the guidelines. Extensive literature already exists to conduct travel demand forecasts (For example, the *National Cooperative Highway Research Program (NCHRP) Report 765)*. Analysts should bring relevant forecasting into play when conducting operations analysis for the distant future. However, given the high level of uncertainty in future demand forecasts, it may behoove the analyst to conduct sensitivity analyses around the critical uncertainties.

Weather Data

If the study area modeled experiences inclement weather, then weather data, including precipitation, rain, wind speed, snow, visibility, etc., may be obtained from the National Weather Service (NWS) [6].

Average or maximum (worst case) precipitation levels, wind speeds, and visibility should be calculated for the entire study area as a whole for each day. These may be hourly averages, average for the entire day or just the peak periods, or the maximum for the entire day or just the peak periods, depending on the goals of the analysis. For a location that experiences inclement weather frequently or for an analysis that is specifically examining impacts of weather-related strategies, the analyst should use no greater than hourly averages, and if weather data are available more frequently at intervals that match the reporting intervals for demand (e.g., 15-minute intervals), then those data should be used. But for a location that has few such occurrences, a single average, maximum or minimum for the day or the peak period may suffice depending on the needs of the analysis.

Incident Data

Incident reports should be available for the study area from the site or location's State or local department of transportation. Incidents may be classified in the incident databases by day, location, time (notification, arrival, and clearance), type (e.g., debris, non-injury collision, injury collision, disabled, police activity), impacted lanes (e.g., single lane, multiple Lanes, shoulder, HOV, total closure), and time to system recovery from incident (if available).

Incident reports should be collected for each day; these may be for the entire day or just the peak periods, depending on the goals of the analysis.

Transit Data

If the analysis includes an assessment of transit-related strategies, then average transit ridership data should be calculated for each day for bus routes traversing the study area. These may be for the entire day or just the peak periods.

Freight Data

If the analysis includes an assessment of freight strategies, then average dray orders data should be obtained for each day for principal freight routes traversing the study area. These may be for the entire day or just the peak periods.

Bottleneck Throughput

Bottlenecks are defined as an area of diminished capacity that causes congestion. Bottlenecks can be the result of physical or operational characteristics, both of which can be latent when demand is low [7]. Active bottlenecks can be further classified as either moving or stationary. An interchange or an intersection can be classified as a stationary bottleneck, while a slow-moving truck can be classified as a moving bottleneck.

At least one stationary bottleneck should be identified for the study area. Bottleneck throughput (observed counts) should be measured either immediately upstream (within 0.5 miles and prior to any major intersection or interchange) or downstream of the bottleneck. Near downstream locations are preferred, prior to the next major intersection or interchange.

Maximum bottleneck throughputs should be calculated for each day at 15-minute (or more frequent) intervals. These may be maximum throughputs for the entire day or just the peak periods, depending on the goals of the analysis.

Travel Time

Numerous methods exist in literature for estimating travel times and these may be referred for a more in-depth treatment of travel time estimation [8, 9, 10]. Highlighted here are some excerpts from the literature [8]. There are two main categories of methods for estimating travel times - those that make use of spot measurements through use of detectors and video surveillance and those that make use of probe technology.

Spot measure data collection systems directly collect speeds from vehicles passing the device. Travel times are estimated by knowing the location of the devices and the distance to the next device.

Probe vehicle techniques involve direct measurement of travel time (along a route or point-to-point) using data from a portion of the vehicle stream. In license-plate, toll tags, and Bluetooth-based methods, vehicle identification data and time stamps of vehicles passing a roadside reader device are collected and checked against the last reader passed to determine the travel time between reader locations. In wireless communication-based methods, vehicles are tracked either through cell phone triangulation using cell towers or through GPS location tracking technology.

Travel times should be measured for each day for paths that traverse the study area and intersect at least one bottleneck location. Observed data should be available for these measures at 15-minute (or more frequent) intervals. More than one path may be required to capture the system dynamic. For example, for corridor analyses, the mainline and one alternative path are required. An interchange analysis may require only one path.

Data for Calibration

Additional data may be needed for calibrating the model. Calibration is the process of systematically adjusting model parameters so that the model emulates observed traffic conditions at the study area. To determine if the model represents the observed traffic conditions, the analyst will need to identify key calibration performance measures and the data needed for estimating these performance measures. The analyst should choose at least two key measures for an effective calibration.

Calibration performance measures fall into two broad categories: 1. Localized (i.e., segment-level or intersection-level) performance, 2. System (i.e., route-level, corridor level, or system-level) performance.

At a minimum, the analyst should calibrate to at least one localized performance measure and one system performance measure. The localized measure should capture bottleneck dynamics. Examples of such measures include, bottleneck throughput or duration, density, queuing. For system performance measure, the analyst may select travel time or speed profiles along one or more key routes on the roadway network. The analyst may also choose to calibrate to additional performance measures depending on the objective of the study and the need to differentiate between the alternatives being examined in the study. For example, for designing or evaluating a traffic signal system, queue lengths, intersection delays, and turning percentages may be selected as additional calibration performance measures.

ASSEMBLE CONTEMPORANEOUS DATA

For each category of data identified in the previous section, contemporaneous data should be collected for the entire study period (preferably a year). For example, if demand data are collected for year 2014, control data, incident and weather data should also be collected for year 2014. If all the data are not collected over the same time frame, there may be problems resolving data inconsistencies or in calibrating the model. For example, estimating freeway travel times during the AM peak, and demand and incident information during the PM peak will make calibration challenging.

VERIFY DATA QUALITY

Several methods for error checking have been cited in the literature and these should be consulted by the analyst [7, 11]. Resources should be allocated for the analyst to verify the data through field inspection and surveys. This section identifies some key data quality checks the analyst may perform:

Some examples of localized calibration performance measures are: bottleneck throughput, bottleneck duration, extent of queues at bottleneck, segment-level speed profiles, number of stops, intersection delays, turning percentages, etc.

Examples of system calibration performance measures are: travel times travel time index, planning index, travel time variance, network or route specific delays, etc.

There is comprehensive treatment of measurement of speeds, stops, queues, delays, density, travel time variance, etc., using field data in the literature [9] and hence will not be discussed in this section.

If using an existing model that was calibrated several years ago, the analyst will have to re-calibrate the model. In that case, the analyst will need to collect data not only for estimating calibration performance measures but also demand data. The analyst will need to further verify if geometric data, traffic control data and traffic operations and management data are still accurate and valid.

- Spot-check of geometric, control and traffic operations and management data should be done through field inspections to confirm if the files obtained match what is in the ground.
- Geometric and control data should be reviewed for apparent violations of design standards and/or traffic engineering practices. Sudden breaks in geometric continuity (such as a short block of a two-lane street sandwiched in between long stretches of a four-lane street) may also be worth checking with people who are knowledgeable about local conditions. Breaks in continuity and violations of design standards may be indicative of data collection errors.

- Internal consistency of counts should be reviewed. Upstream counts should be compared to downstream counts. Unexplained large jumps or drops in the counts should be reconciled. There is no guidance on precisely what constitutes a “large” difference in counts. The analyst might consider investigating any differences of greater than 10 percent between upstream and downstream counts for locations where no known traffic sources or sinks (such as driveways) exist between the count locations. Larger differences are acceptable where driveways and parking lots could potentially explain the count differences.
- Travel time and speed data obtained from probe vehicle techniques should be reviewed for realistic segment travel times and speeds.
- Discrepancies in counts resulting from counting errors or counts made on different days should be reconciled before proceeding to the model development task. Inconsistent counts make error checking and model calibration much more difficult. That is why it is critical to obtain concurrent or contemporaneous data.

IDENTIFY TRAVEL CONDITIONS USING CLUSTER ANALYSIS

This section describes the steps for conducting an effective cluster analysis to identify travel conditions that are revealed by the data.

Step 1: Identify Attributes

The goal of this step is to identify key attributes for defining the travel conditions experienced at the site. Travel conditions should be represented by demand, sources of congestion for the site, and key system outcomes or performance (e.g., bottleneck throughput, travel times). Later on, in Chapter 5, this characterization of system performance will be critical in assessing whether the simulation tool is calibrated enough to well represent the portfolio of travel conditions. Example attributes are listed below:

- Demand.
- Weather.
- Incident.
- Transit.
- Freight.
- Bottleneck Throughput.
- Travel Time.

Sources of data required for each attribute are discussed in the Data for Determining Travel Conditions Section. After collecting concurrent data and verifying the data quality, proceed to Step 2.

Step 2: Process Data

All qualitative data should be transformed into quantitative or numeric data. However, it is crucial to not over process the qualitative data so that there are only a couple of indices that fail to capture the relationship between the attribute and the key measure of interest. For example, incidents should not be reduced to just three levels, representing a no-incident situation, low severity incident, and high severity incident based on closure time and number of impacted lanes. Two days might be assigned a low severity index if the two days had an incident on one lane for less than 30 minutes. What if one of the days had multiple small incidents that together amounted to a closure of 30 minutes within the peak period, while the other had a single incident that lasted the entire 30 minutes? Alternately, what if the type of incident on one day is a fatality while on the other day is a non-injury multi-vehicle collision? Will the rubbernecking experienced on adjacent lanes be the same? That is why it is not recommended to do categorization up front without assessing the impact of these incidents – i.e., without including travel times and/or bottleneck throughput in the clustering. It is best to just transform the data onto a numeric scale and let the cluster analysis decide which cluster/group the day fits into. One approach for transforming qualitative data is by defining a numeric scale that is exhaustive (i.e., considers all combinations observed in the data). For example, the analyst may want to define a numeric scale that looks at all combinations of the following incident-related attributes:

- Type of incident.
- Number of impacted lanes.
- Location of incident: This can be done by specifying if the incident occurs upstream of the natural bottleneck, downstream of the bottleneck, or at the bottleneck. Alternately, the location can be specified as the distance from the natural bottleneck.
- Time of occurrence: Here the analyst can specify if the incident occurs prior to the peak period, during the peak period, or after the peak period. Alternately, the analyst can specify the time of occurrence as the difference in time expressed in hours (rounded up) from the start of the simulation period. For example, if the peak period is from 6 to 9 AM, the analyst might choose a simulation period of 5 to 10 AM. If an incident occurs at 8:30 AM, the time of occurrence can be expressed as 4, as the incident occurs in the 4th hour after the start of the simulation period.
- Clearance or closure time: This should be a factor of what is observed in the data. This may be expressed in increments of 5, 10, or 15 minutes. But if it typically takes 15 minutes or more for clearance, there is no need to define in increments of 5 or 10 minutes.

Numeric data should not be further reduced into bins or categories. So, if weather data includes precipitation, the analyst should use the precipitation levels without further reducing them into two levels to represent no rain (0 mm) and rain (> 0mm). If only qualitative information is available (e.g., snow, blowing snow, sleet, etc.), then the analyst should define a numeric scale that includes all observed data for that category. An alternate approach is to transform categorical data to a binary scale.

Note that some clustering tools have built-in solutions to deal with categorical variables.

Step 3: Normalize Data

Once qualitative data are transformed onto a numeric scale, all data (numeric as well as qualitative data that have been transformed) should be normalized. Data that are measured on different numeric scales are normalized or converted to a common scale so that no single attribute dominates the others. Normalization is done using the following equation:

$$x' = a + \frac{(x - x_{min})(b - a)}{x_{max} - x_{min}} \qquad (1)$$

where:

- x': normalized value of data x
- x_{min}: minimum value for the attribute (min over all x)
- x_{max}: maximum value for the attribute (max over all x)
- a: minimum value of common scale (e.g., 0 if normalizing to scale of 0 to 1)
- b: maximum value of common scale (e.g., 1 if normalizing to scale of 0 to 1)

It should be noted that some of the tools will do this for you.

Step 4: Down select Attributes

After data have been normalized, the analyst should filter out those attributes that are either redundant or have no impact on the key measure of interest (e.g., travel time, bottleneck throughput). It is best to use attributes that are highly correlated with the key measure of interest but have low correlation with each other. Highly correlated attributes effectively represent the same phenomenon. Hence, if highly correlated attributes are included, then that phenomenon will dominate the other attributes thereby skewing the cluster analysis. So, for example, if the incident attributes are highly correlated with each other, select the attribute from the set of correlated incident attributes, which has the most impact on travel times. Most clustering tools have a built-in capability or algorithm to filter out redundant attributes or reduce the dimensionality (i.e., if there are too many attributes). One commonly used algorithm for dimensionality reduction is Principal Component Analysis (PCA), which converts a set of possibly correlated observations into a set of linearly uncorrelated variables called principal components.

Step 5: Perform Clustering

There are several clustering techniques and heuristics for discrete and continuous data. Examples of statistical and data mining tools that offer clustering capability are the commercial tools such as, MATLAB [12], IBM SPSS [13], and SAS [14], or the open source software such as, WEKA [15] (Waikato Environment for Knowledge Analysis), GNU Octave [16], R [17], Apache Spark MLlib [18], H2O [19], and TensorFlow [20].

Examples of commonly used clustering techniques are K-means, hierarchical clustering, and expectation maximization. These have been well-documented in the literature and are not discussed here.

Step 6: Identify Stopping Criterion

Data mining tools have inbuilt stopping criterion. Some tools use cross-validation to determine the optimal cluster size. The analyst can also select one of the several heuristics from the literature for determining when to stop the clustering. Given below is one such simple heuristic for determining the stopping criterion.

1. Set the maximum cluster size as $2 \times \sqrt{n/2}$ where n is the number of days.
2. Set k= 3 (initial cluster size).
3. Perform clustering using k clusters.
4. Calculate either of the following functions for the key measure of interest (e.g., travel times, bottleneck throughput).
   Option 1:
   $$\text{Within Cluster Variance / Between Cluster Variance} \qquad (2)$$
   Option 2:
   $$\text{Coefficient of Variation Normalized over all clusters} \times \text{\# of Clusters Normalized between 3 and } 2 \times \sqrt{n/2} \qquad (3)$$
5. Repeat steps 3 and 4 by systematically incrementing k by 1 until the maximum cluster size is reached.
6. Select the optimal cluster size as the size of the cluster that minimizes the function in step 4.

This process can be extended to include a weighted combination of key measures of interest and locations.

EXAMPLE PROBLEM: DATA COLLECTION AND ANALYSIS

This section walks through the data collection and analysis process for the Alligator City example problem discussed in Chapter 1. The analyst should identify, collect, and clean the data for the Alligator City network for the AM peak.

Identify Data Sources

The AM peak period is designated to be from 6 to 9 AM. Data are collected from 5 to 10 AM to allow for congestion to build up and dissipate. Data are available from 10 detector stations and a cell-phone tracking study. Data have been archived for the past 1 year.

Geometric Data: GIS files, Google Maps, construction drawings, and field inspections are used to obtain the lengths and the number of lanes for each section of the Alligator City network, including the Marine Causeway, Victory Island Bridge, Komodo Tunnel, Riverside Parkway, and the Alligator City CBD (Central Business District). Turn lanes and pocket lengths are determined for each intersection in the CBD.

Transition lengths for lane drops and additions are determined. Lane widths are measured if they are not standard widths. Horizontal curvature and curb return radii are determined if the selected software tool is sensitive to these features of the road and freeway design. Free-flow speeds are estimated based on the posted speed limits for the freeway and the surface streets.

Control Data: Signal settings are obtained from Alligator City's records for an entire year, and verified in the field. The signals in Alligator City are fixed-time, having a cycle length of 90 s.

Vehicle Characteristics Data: As truck traffic is heavy, truck percentages are obtained from the Alligator City DOT. Truck performance and classifications are obtained from the Intermodal facility. For the rest of the vehicle characteristics defaults provided with the microsimulation software are used in this analysis.

Driver Characteristics Data: The default driver characteristics provided with the microsimulation software are used in this analysis.

Traffic Operations and Management Data: As there are HOV and HOT lanes, the lane requirement, hours when active, pricing strategy, and location of signs are obtained. As trucks are restricted on the ramp from Victory Island Bridge to the Riverside Parkway, truck restriction information including, location of signs, and hours when active are obtained. The location and content of the VMS posted on the Marine Causeway are obtained. All data are obtained from the Alligator City agency records.

Demand Data: Data from a cell-phone tracking study are available for the Alligator City Metropolitan area. The cell-phone location data are used to estimate 15-minute interval O-D trip tables for the region.

In addition, for identifying travel conditions a screen line is drawn across the Marine Causeway at detection station 2, which is located at the entrance of the Eastbound Marine Causeway. Average flows are calculated at 15-minute intervals for the AM peak period at detector station 2.

Weather Data: Precipitation levels and wind speeds are obtained from the NWS website for Alligator City. Visibility data was not available for the entire time period.

Incident Data: Incident type and the lanes blocked are available and these are collected for the entire year.

Bottleneck Throughput: Three bottlenecks are identified for the Alligator City network:

- Marine Causeway to Victory Island Bridge.
- Victory Island Bridge Exit at Moseley Street to the Alligator City CBD.
- Komodo Tunnel Exit at Osceola Avenue to the Alligator City CBD.

Counts are measured approximately 0.5 miles upstream of the bottlenecks at detector stations 7, 8, 9 and 10 at 15-minute intervals.

Travel Time: Travel times are estimated using the cell-phone tracking study data at 15-minute intervals for the following three paths:

- West Hills to the CBD via the Victory Island Bridge.
- West Hills to the CBD via the Tunnel using General Purpose Lanes.
- West Hills to the CBD via the Tunnel using HOV Lanes.

Calibration Data: The model will be calibrated against estimates of bottleneck throughput and travel times.

Assemble Contemporaneous Data and Verify Data Quality

The input data are reviewed by the analyst for consistency and accuracy prior to data entry. The turning, ramp, and freeway mainline counts are reconciled by the analyst to produce a set of consistent counts for the entire study area. After completion of the reconciliation, all volumes discharged from upstream locations are equal to the volumes arriving at the downstream location.

Example Cluster Analysis Using the K-Means Algorithm

Given below are the steps for conducting cluster analysis using the k-means clustering algorithm. The k-means algorithm is a widely used cluster analysis algorithm, which aims to partition n observations into k clusters such that each observation belongs to the cluster with the closest mean. The partitioning is done by minimizing the sum of squares of distances between the observations and the cluster centroids. The k-means algorithm is one of the simplest clustering algorithms, but it is computationally difficult. Several efficient heuristic algorithms that converge quickly have been developed to overcome this limitation. One of these heuristics is described below [20]. Despite being commonly used, the k-means algorithm has a few drawbacks:

- The number of clusters k is pre-defined. An inappropriate choice of k may yield poor results.
- Convergence to a local minimum may produce counterintuitive results.
- The clustering algorithm is such that all data, including outliers, are assigned to a cluster.

The k-means clustering algorithm is used here only for the purpose of introducing the cluster analysis concept. Other algorithms, such as Expectation Maximization (EM) and Hierarchical clustering, which address some of the weaknesses listed may be used in lieu of the k-means algorithm.

There are two types of hierarchical clustering algorithms – agglomerative and divisive. In agglomerative clustering, each observation starts in its own cluster and pairs of clusters that are similar are successively merged until all clusters have been merged into a single cluster. In divisive clustering, all observations start off in one cluster, and clusters are successively split until each cluster has only one observation. The advantage of the hierarchical clustering is that the number of clusters do not need to be pre-defined. The user can determine when to stop based on a pre-defined stopping criterion. The disadvantage is that it is time consuming. The EM algorithm is similar to k-means, but uses probabilities to assign data to clusters. The goal is to maximize the probability that the data falls into the clusters created. The main advantage of the EM algorithm is that it is robust to noisy data. It is able to cluster data even when incomplete. The main disadvantage is that it converges very slowly.

Each step is illustrated using the Alligator City hypothetical simulation study as an example. The guidance provided here is intended to give general advice on clustering using k-means. For simplicity, data for only a month is shown throughout the example. The tables show only a single entry for each attribute for each day. The analyst should collect data for a longer period of time, such as a year, and should include data at 15-minute or hourly intervals depending on the observed variation for that attribute. For example, if there is very little precipitation throughout the year, there is no need to include precipitation at 15-minute or hourly intervals. A single value corresponding to the maximum precipitation levels observed during the 24-hour period or the peak period may be used. But for localized and system performance measures, such as bottleneck throughput and travel times, it is essential to use time-variant measures to capture the variability in the data. Hence, for these “attributes” the analyst should use measures estimated at 15-minute (or more frequent) intervals for each day in the cluster analysis.

Step 1: Identify Attributes

Table 1 shows the data assembled for the AM Peak which extends from 6 AM to 9 AM.

Table 1. Data Assembled for Travel Conditions Identification (Step 1)

DAY	Day of Week	AM Peak (6-9 AM) Demand (vph)	AM Peak (6-9 AM) Weather		AM Peak (6-9 AM) Incident		AM Peak (6-9 AM) Travel Time (min)			AM Peak (6-9 AM) Bottleneck Throughput (vph)		
		Detector #2; Avg. Count (vph)	Precipitation (mm)	Wind Speed (mph)	Incident Type	Lanes Blocked	WH to CBD (VIB)	WH to CBD (Tunnel-GP)	WH to CBD (Tunnel-HOV)	Marine Causeway-V.I.Bridge Link	V. I. Bridge Exit at Moseley Street	Komodo Tunnel Exit at Osceola Ave
2-Jan-12	2	4650	0.034	4.54	Disabled	Single Lane	36	32	27	2525	1934	2042
3-Jan-12	3	4557	0.192	5.62	Non-Injury Collision	Single Lane	46	39	33	2015	1767	1652
4-Jan-12	4	4253	0.006	4.34	Debris	Multiple Lane	44	35	30	2478	1835	1760
5-Jan-12	5	5126	0.016	4.77	Non-Injury Collision	Shoulder/Median	26	24	21	2756	2105	2344
6-Jan-12	6	3529	0.04	6.18	Debris	Multiple Lane	43	36	32	2013	1843	1742
16-Jan-12	2	2875	0.07	1.55	Non-Injury Collision	HOV	49	40	36	1524	1690	1594
17-Jan-12	3	2783	0	3.08	Injury Collision	Single Lane	51	44	38	2183	1664	1418
18-Jan-12	4	3071	0.034	4.60	Disabled	Single Lane	35	32	28	1735	1956	2052
19-Jan-12	5	4348	0.298	6.13	Debris	Multiple Lane	44	36	32	1957	1820	1720
20-Jan-12	6	4119	0	3.39	Debris	Single Lane	30	27	22	2517	2084	2258
23-Jan-12	2	3799	0.37	10.23	Abandoned Vehicle	Shoulder/Median	60	53	42	2352	1550	1287
24-Jan-12	3	4872	0.076	1.70	Disabled	HOV	40	34	33	1753	1919	1943
25-Jan-12	4	3302	0	4.73	Disabled	Shoulder/Median	26	22	21	1586	2166	2431
26-Jan-12	5	3952	0	2.39	Non-Injury Collision	Single Lane	46	39	32	1957	1796	1681
27-Jan-12	6	3913	0	1.77	Abandoned Vehicle	Shoulder/Median	56	52	41	2722	1551	1272
30-Jan-12	2	4052	0.014	2.23	Debris	Multiple Lane	43	34	31	2723	1858	1795
31-Jan-12	3	4704	0	4.01	Disabled	Single Lane	35	32	28	1694	1940	2033

Step 2: Process Data

The next step is to transform qualitative attributes to a quantitative scale. In the example in Table 1, an incident is defined by type and impacted lanes. The two incident attributes are reduced to a numeric value that represents the incident severity (Table 2). Table 3 presents the data that have been transformed onto a quantitative scale. Similar such rules should be developed for transforming qualitative data into quantitative data.

Table 2. Example Transformation of Incident Qualitative Data into Numeric Data (Step 2)

Incident Type	Lanes Blocked	Severity Index
Abandoned	Shoulder/Median	1
Disabled	Shoulder/Median	2
Non-Injury Collision	Shoulder/Median	3
Debris	Single Lane	4
Debris	HOV	5
Disabled	Single Lane	6
Disabled	HOV	7
Debris	Multiple Lanes	8
Non-Injury Collision	Single Lane	9
Non-Injury Collision	HOV	10
Injury Collision	Single Lane	11
Injury Collision	HOV	12
Injury Collision	Multiple Lanes	13

Step 3: Normalize Data

Data are normalized onto a scale of 0 to 1 using equation 1. Table 4 presents the normalized data.

Step 4: Down Select Attributes

In the example, visibility data was not available for the entire period, and when available it was found to be highly correlated with the precipitation. So, visibility was eliminated from the analysis. The other attributes were not highly correlated.

Table 3. Transforming Qualitative Data onto Quantitative Scale (Step 2)

DAY	Day of Week	AM Peak (6-9 AM) Demand	AM Peak (6-9 AM) Weather		AM Peak (6-9 AM) Incident Severity	AM Peak (6-9 AM) Travel Time (min)			AM Peak (6-9 AM) Bottleneck Throughput (vph)		
		Detector #2; Avg. Count (vph)	Precipitation (mm)	Wind Speed (mph)		WH to CBD (VIB)	WH to CBD (Tunnel-GP)	WH to CBD (Tunnel-HOV)	Marine Causeway-V.I.Bridge Link	V. I. Bridge Exit at Moseley Street	Komodo Tunnel Exit at Osceola Ave
2-Jan-12	2	4,650	0.034	4.54	6	36	32	27	2525	1934	2042
3-Jan-12	3	4,557	0.192	5.62	9	46	39	33	2015	1767	1652
4-Jan-12	4	4,253	0.006	4.34	8	44	35	30	2478	1835	1760
5-Jan-12	5	5,126	0.016	4.77	3	26	24	21	2756	2105	2344
6-Jan-12	6	3,529	0.04	6.18	8	43	36	32	2013	1843	1742
16-Jan-12	2	2,875	0.07	1.55	10	49	40	36	1524	1690	1594
17-Jan-12	3	3,051	0	3.08	11	51	44	38	2183	1664	1418
18-Jan-12	4	3,029	0.034	4.60	6	35	32	28	1735	1956	2052
19-Jan-12	5	4,605	0.298	6.13	8	44	36	32	1957	1820	1720
20-Jan-12	6	4,737	0	3.39	4	30	27	22	2517	2084	2258
23-Jan-12	2	3,294	0.37	10.23	13	60	53	42	2352	1550	1287
24-Jan-12	3	4,492	0.076	1.70	7	40	34	33	1753	1919	1943
25-Jan-12	4	3,618	0	4.73	2	26	22	21	1586	2166	2431
26-Jan-12	5	4,772	0	2.39	9	46	39	32	1957	1796	1681
27-Jan-12	6	2,736	0	1.77	13	56	52	41	2722	1551	1272
30-Jan-12	2	3,494	0.014	2.23	8	43	34	31	2723	1858	1795
31-Jan-12	3	4,396	0	4.01	6	35	32	28	1694	1940	2033

Table 4. Normalizing Data (Step 3)

DAY	Day of Week	AM Peak (6-9 AM) Demand	AM Peak (6-9 AM) Weather		AM Peak (6-9 AM) Normalized Incident Severity	AM Peak (6-9 AM) Normalized Travel Time			AM Peak (6-9 AM) Normalized Bottleneck Throughput		
		Normalized Detector #2 Avg. Count	Normalized Precipitation	Normalized Wind Speed		WH to CBD (VIB)	WH to CBD (Tunnel-GP)	WH to CBD (Tunnel-HOV)	Marine Causeway-V.I.Bridge Link	V. I. Bridge Exit at Moseley Street	Komodo Tunnel Exit at Osceola Ave
2-Jan-12	2	0.80	0.09	0.34	0.36	0.29	0.32	0.29	0.81	0.62	0.66
3-Jan-12	3	0.76	0.52	0.47	0.64	0.59	0.55	0.57	0.40	0.35	0.33
4-Jan-12	4	0.63	0.02	0.32	0.55	0.53	0.42	0.43	0.77	0.46	0.42
5-Jan-12	5	1.00	0.04	0.37	0.09	0.00	0.06	0.00	1.00	0.90	0.92
6-Jan-12	6	0.33	0.11	0.53	0.55	0.50	0.45	0.52	0.40	0.48	0.41
16-Jan-12	2	0.06	0.19	0.00	0.73	0.68	0.58	0.71	0.00	0.23	0.28
17-Jan-12	3	0.13	0.00	0.18	0.82	0.74	0.71	0.81	0.53	0.19	0.13
18-Jan-12	4	0.12	0.09	0.35	0.36	0.26	0.32	0.33	0.17	0.66	0.67
19-Jan-12	5	0.78	0.81	0.53	0.55	0.53	0.45	0.52	0.35	0.44	0.39
20-Jan-12	6	0.84	0.00	0.21	0.18	0.12	0.16	0.05	0.81	0.87	0.85
23-Jan-12	2	0.23	1.00	1.00	1.00	1.00	1.00	1.00	0.67	0.00	0.01
24-Jan-12	3	0.73	0.21	0.02	0.45	0.41	0.39	0.57	0.19	0.60	0.58
25-Jan-12	4	0.37	0.00	0.37	0.00	0.00	0.00	0.00	0.05	1.00	1.00
26-Jan-12	5	0.85	0.00	0.10	0.64	0.59	0.55	0.52	0.35	0.40	0.35
27-Jan-12	6	0.00	0.00	0.02	1.00	0.88	0.97	0.95	0.97	0.00	0.00
30-Jan-12	2	0.32	0.04	0.08	0.55	0.50	0.39	0.48	0.97	0.50	0.45
31-Jan-12	3	0.69	0.00	0.28	0.36	0.26	0.32	0.33	0.14	0.63	0.66

Step 5: Perform Clustering

Step 5.1: Sort data by bottleneck throughput at any one critical location. In the example, the tunnel to the Osceola Ave. exit is used as the critical location. If desired, data may be sorted again over travel time for a critical trip. Sorting is done to reach convergence quickly in Step 5.6.

Step 5.2: Specify the initial number of clusters, k as 3.

Step 5.3: Divide the days systematically into k clusters with nearly equal number of days. In our example, the 17 days can be divided into three clusters, with two clusters having 6 days and one cluster having 5 days. Table 5 presents the data that have been sorted and partitioned into 3 clusters.

Step 5.4: Calculate the centroid or the mean of each cluster. Means are calculated for each attribute. In the example, we make the assumption that each attribute has the same weight. But this can be changed so that one attribute has a higher weight implying that it contributes to the grouping or clustering more than the others. Table 6 presents the centroids or means of each cluster for each attribute.

Step 5.5: Calculate the Euclidean distance of each data to the centroids of the k clusters. This is done using the following equation:

$$xdis_y = \sqrt{(x_1 - ymean_1)^2 + (x_2 - ymean_2)^2 + (x_3 - ymean_3)^2 + \cdots} \qquad (4)$$

where:

$xdis_y$:	distance of data *x* to mean of cluster *y*
x_1 :	value corresponding to attribute 1 for data *x*
$ymean_a$:	mean value for attribute *a* for cluster *y*

Step 5.6: Assign each day to the cluster which has the closest centroid. Table 7 shows the distances of each data to the cluster centroids and assigns them to a new cluster, which is the nearest cluster. As highlighted in Table 7, in Iteration 1, January 3rd and 26th were re-assigned from cluster 1 to cluster 2 and January 18th was re-assigned from cluster 3 to cluster 2 since they were closest to the cluster 2 centroid. All other days remained in their previous clusters.

Step 5.7: If there is no change in the cluster, stop and proceed to Step 6. Otherwise, repeat steps 5.4-5.7. In the example, since there was a change, we go back to Step 5.4 and continue the process.

Step 6: Identify Stopping Criterion: In the example, we apply option 1 (see Eq. 2).

1. Set the maximum cluster size as $2 \times \sqrt{n/2}$. In our example, we only used 17 days. So, the maximum size is 6.
2. Set k= 3 (initial cluster size).
3. Perform clustering using k clusters (which was done in Step 5).

4. The key measure of interest may be chosen as the bottleneck throughput at the Komodo tunnel to Osceola Ave exit. Calculate the function given in Eq. 2.
5. Repeat steps 6.3 and 6.4 by systematically incrementing k by 1 until the maximum cluster size (6 in the example) is reached.
6. Select the cluster size that minimizes the function calculated in step 6.5 across all cluster sizes.

KEY POINTS

The guidance leverages use of concurrent data for supporting the analysis. In areas, where these data are not available, it is recommended that either the necessary concurrent data be collected or an alternate analytical technique in lieu of microsimulation analysis be considered. In summary, when collecting data:

- Measure flows and estimate or forecast demand.
- Temporal and geographic scope will impact estimation of demand; so broaden scope to account for onset and dissipation of congestion.
- Ensure flow conservation since it influences analysis.
- Use up-to-date GIS files, maps and drawings.
- Collect contemporaneous data.
- Errors in data will make calibration challenging; so ensure data are accurate and verify with field inspection.

Table 5. Iteration 0 - Preliminary Assignment of Data into Clusters (Step 5.3)

DAY	Day of Week	AM Peak (6-9 AM) Demand (vph)	AM Peak (6-9 AM) Weather		AM Peak (6-9 AM) Normalized Incident Severity	AM Peak (6-9 AM) Normalized Travel Time			AM Peak (6-9 AM) Normalized Bottleneck Throughput			Cluster
		Normalized Detector #2 Avg. Count	Normalized Precipitation	Normalized Wind Speed		WH to CBD (VIB)	WH to CBD (Tunnel-GP)	WH to CBD (Tunnel-HOV)	Marine Causeway-V.I.Bridge Link	V. I. Bridge Exit at Moseley Street	Komodo Tunnel Exit at Osceola Ave	
27-Jan-12	6	0.00	0.00	0.02	1.00	0.88	0.97	0.95	0.97	0.00	0.00	1
23-Jan-12	2	0.23	1.00	1.00	1.00	1.00	1.00	1.00	0.67	0.00	0.01	1
17-Jan-12	3	0.13	0.00	0.18	0.82	0.74	0.71	0.81	0.53	0.19	0.13	1
16-Jan-12	2	0.06	0.19	0.00	0.73	0.68	0.58	0.71	0.00	0.23	0.28	1
3-Jan-12	3	0.76	0.52	0.47	0.64	0.59	0.55	0.57	0.40	0.35	0.33	1
26-Jan-12	5	0.85	0.00	0.10	0.64	0.59	0.55	0.52	0.35	0.40	0.35	1
19-Jan-12	5	0.78	0.81	0.53	0.55	0.53	0.45	0.52	0.35	0.44	0.39	2
6-Jan-12	6	0.33	0.11	0.53	0.55	0.50	0.45	0.52	0.40	0.48	0.41	2
4-Jan-12	4	0.63	0.02	0.32	0.55	0.53	0.42	0.43	0.77	0.46	0.42	2
30-Jan-12	2	0.32	0.04	0.08	0.55	0.50	0.39	0.48	0.97	0.50	0.45	2
24-Jan-12	3	0.73	0.21	0.02	0.45	0.41	0.39	0.57	0.19	0.60	0.58	2
31-Jan-12	3	0.69	0.00	0.28	0.36	0.26	0.32	0.33	0.14	0.63	0.66	2
2-Jan-12	2	0.80	0.09	0.34	0.36	0.29	0.32	0.29	0.81	0.62	0.66	3
18-Jan-12	4	0.12	0.09	0.35	0.36	0.26	0.32	0.33	0.17	0.66	0.67	3
20-Jan-12	6	0.84	0.00	0.21	0.18	0.12	0.16	0.05	0.81	0.87	0.85	3
5-Jan-12	5	1.00	0.04	0.37	0.09	0.00	0.06	0.00	1.00	0.90	0.92	3
25-Jan-12	4	0.37	0.00	0.37	0.00	0.00	0.00	0.00	0.05	1.00	1.00	3

Table 6. Calculating Cluster Means (Step 5.4)

Centroid	Demand	Precipitation	Wind Speed	Incident Type	Travel Time from WH to CBD (VIB)	Travel Time from WH to CBD (Tunnel-GP)	Travel Time from WH to CBD (Tunnel-HOV)	Throughput at Marine Causeway-V.I.Bridge Link	Throughput at V. I. Bridge Exit at Moseley Street	Throughput at Komodo Tunnel Exit at Osceola Ave
Cluster 1	0.34	0.28	0.29	0.80	0.75	0.73	0.76	0.49	0.19	0.18
Cluster 2	0.58	0.20	0.29	0.50	0.46	0.40	0.48	0.47	0.52	0.48
Cluster 3	0.63	0.05	0.33	0.20	0.14	0.17	0.13	0.57	0.81	0.82

Table 7. Calculating Distance to Cluster Centroids and Assigning to Nearest Cluster (Steps 5.5-5.6)

DAY	Day of Week	AM Peak (6-9 AM) Demand (vph)	AM Peak (6-9 AM) Weather		AM Peak (6-9 AM) Normalized Incident Severity	AM Peak (6-9 AM) Normalized Travel Time			AM Peak (6-9 AM) Normalized Bottleneck Throughput			Current Cluster	Distance to Cluster 1 Centroid	Distance to Cluster 2 Centroid	Distance to Cluster 3 Centroid	New Cluster
		Normalized Detector #2 Avg. Count	Normalized Precipitation	Normalized Wind Speed		WH to CBD (VIB)	WH to CBD (Tunnel-GP)	WH to CBD (Tunnel-HOV)	Marine Causeway-V.I.Bridge Link	V. I. Bridge Exit at Moseley Street	Komodo Tunnel Exit at Osceola Ave					
27-Jan-12	6	0.00	0.00	0.02	1.00	0.88	0.97	0.95	0.97	0.00	0.00	1	0.85	1.48	2.12	1
23-Jan-12	2	0.23	1.00	1.00	1.00	1.00	1.00	1.00	0.67	0.00	0.01	1	1.17	1.73	2.38	1
17-Jan-12	3	0.13	0.00	0.18	0.82	0.74	0.71	0.81	0.53	0.19	0.13	1	0.38	0.94	1.62	1
16-Jan-12	2	0.06	0.19	0.00	0.73	0.68	0.58	0.71	0.00	0.23	0.28	1	0.68	0.95	1.58	1
3-Jan-12	3	0.76	0.52	0.47	0.64	0.59	0.55	0.57	0.40	0.35	0.33	1	0.66	0.54	1.21	2
26-Jan-12	5	0.85	0.00	0.10	0.64	0.59	0.55	0.52	0.35	0.40	0.35	1	0.78	0.50	1.11	2
19-Jan-12	5	0.78	0.81	0.53	0.55	0.53	0.45	0.52	0.35	0.44	0.39	2	0.94	0.71	1.23	2
6-Jan-12	6	0.33	0.11	0.53	0.55	0.50	0.45	0.52	0.40	0.48	0.41	2	0.70	0.39	0.96	2
4-Jan-12	4	0.63	0.02	0.32	0.55	0.53	0.42	0.43	0.77	0.46	0.42	2	0.83	0.38	0.86	2
30-Jan-12	2	0.32	0.04	0.08	0.55	0.50	0.39	0.48	0.97	0.50	0.45	2	0.91	0.63	0.99	2
24-Jan-12	3	0.73	0.21	0.02	0.45	0.41	0.39	0.57	0.19	0.60	0.58	2	1.02	0.46	0.87	2
31-Jan-12	3	0.69	0.00	0.28	0.36	0.26	0.32	0.33	0.14	0.63	0.66	2	1.23	0.54	0.60	2
2-Jan-12	2	0.80	0.09	0.34	0.36	0.29	0.32	0.29	0.81	0.62	0.66	3	1.25	0.56	0.50	3
18-Jan-12	4	0.12	0.09	0.35	0.36	0.26	0.32	0.33	0.17	0.66	0.67	3	1.19	0.67	0.75	2
20-Jan-12	6	0.84	0.00	0.21	0.18	0.12	0.16	0.05	0.81	0.87	0.85	3	1.72	0.97	0.36	3
5-Jan-12	5	1.00	0.04	0.37	0.09	0.00	0.06	0.00	1.00	0.90	0.92	3	1.97	1.24	0.64	3
25-Jan-12	4	0.37	0.00	0.37	0.00	0.00	0.00	0.00	0.05	1.00	1.00	3	1.98	1.27	0.72	3

***Note**: In this iteration, January 3rd and 26th were re-assigned from cluster 1 to cluster 2 and January 18th was re-assigned from cluster 3 to cluster 2 since they were closest to the cluster 2 centroid.*

CHAPTER 3. BASE MODEL DEVELOPMENT

This chapter provides general guidance on the procedures for developing a microsimulation model. This is Step 3 in the Microsimulation Analytical Process (Figure 5). In this step, the analyst should develop base models for all travel conditions or clusters identified in Chapter 2. A complete operational analysis using a full year of data is a useful step to making effective investment decisions. However, when resources are constrained, it may not be cost effective to model every condition. The analyst may want to model only those travel conditions where alternatives are likely to have significant impacts. In fact, these subset of travel conditions may be further clustered to distinguish the nuances between the alternatives. For example, when assessing two weather-related alternatives, the analyst may want to further cluster the weather-related data and model only those clusters. There are many software tools for performing this task and each has its own unique method to build the model. The guidance provided here is intended to give general advice on model development; however, the analyst should consult the specific microsimulation software documentation for information on available data input tools and techniques.

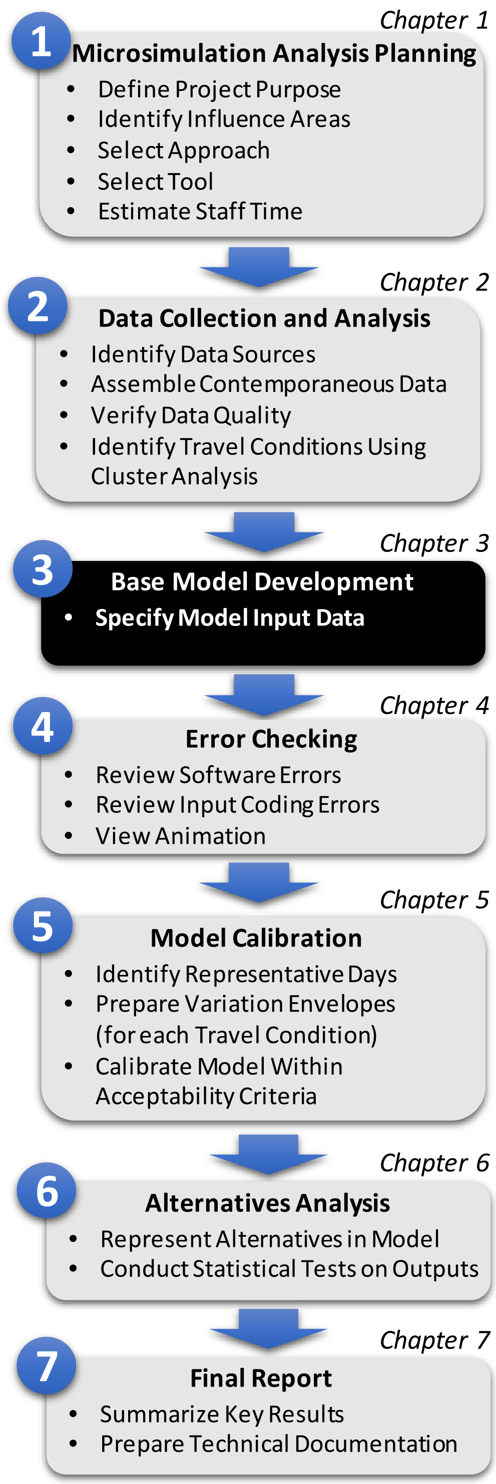

Figure 5. Diagram. Step 3: Base Model Development (Source: FHWA)

SPECIFY MODEL INPUT DATA

Building a model is analogous to building a house. You begin with a blueprint and then you build each element in sequence—the foundation, the frame, the roof, the utilities and drywall, and finally the interior details. The development of a successful simulation model is similar in that you should begin with a blueprint (the link- node diagram) and then you proceed to build the model in sequence—coding links and nodes, filling in the link geometries, adding traffic control data at appropriate nodes, coding travel demand data, adding traveler behavior data, and finally selecting the model run control parameters.

Any assumptions, default values or deviations from defaults values should be discussed and incorporated into the Methods and Assumptions document of the project for examination and cross-validation.

Link-Node Diagram: Model Blueprint

The link-node diagram is the blueprint for constructing the microsimulation model. The diagram identifies which streets and highways will be included in the model and how they will be represented. An example link-node diagram is shown in Figure 6. This step is especially useful when the network being modeled is complex.

The link-node diagram can be created directly in the microsimulation software or offline using GIS or other types of computer-aided design (CAD) software. If the diagram is created in the microsimulation software, then it is helpful to import a map, such as from Google Maps, into the software over which the link-node diagram can be overlaid. If the diagram is created offline using GID or CAD software, then it is helpful to import the map into the GIS or CAD software.

Nodes are the intersection of two or more links. Nodes are usually placed in the model using x-y coordinates and they can be at a place that represents an intersection or a location where there is a change in the link geometry. Some simulation software may also warrant consideration of a z coordinate. The node locations can be obtained from GIS or physical measurements.

Links represent the length of the roadway segment between the nodes and usually contain data about the geometric characteristics of the roadway segment. Ideally, a link represents a roadway segment with uniform geometry. Some software programs do not use a link-node scheme, while others allow the analyst to code both directions of travel with a single link. The two-way links coded by the user are then represented internally (inside the software) as two one-way links.

The analyst should consider establishing a node-numbering scheme to facilitate error checking and the aggregation of performance statistics for groups of links related to a specific facility or facility type (see Table 8 for an example of a node-numbering scheme designed to enable the rapid determination of the facility type in text output). Much of the output produced by microsimulation software is text, with the results identified by the node numbers at the beginning and end points of each link. A node-numbering convention can greatly facilitate the search for results in the massive text files commonly produced by simulation software. Some software programs provide analytical modules that assist the analyst in displaying and aggregating the results for specific groups of links. This feature reduces the necessity of adopting a node-numbering convention; however, a numbering convention can still result in a significant labor savings when reviewing text output or when importing text results into other software programs for analytical purposes.

If the link-node diagram was created offline (using some other software besides the microsimulation software), then the information in the diagram needs to be entered (or imported) into the microsimulation software. The x-y coordinates and identification numbers of the nodes (plus any feature points needed to represent link curvature) are entered. The nodes are then connected together to develop the link-node framework for the model.

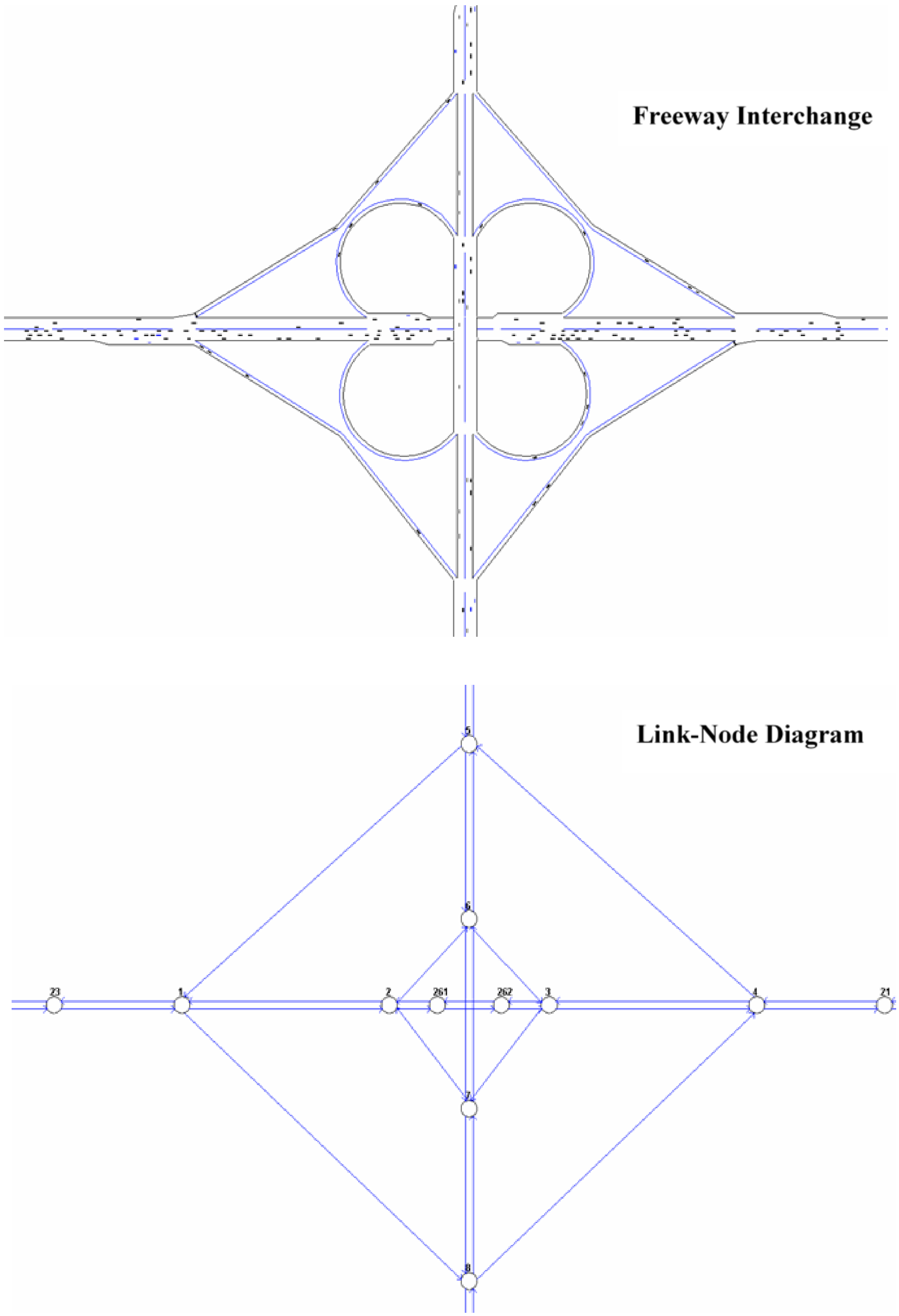

Figure 6. Diagram. Example of link node diagram (Source: FHWA)

Table 8. Example node numbering convention

Segment	From Range	To Range	Description
0’s	1	99	Miscellaneous
100’s	100	199	Northbound Freeway Mainline
200’s	200	299	Northbound Freeway Ramps
300’s	300	399	Southbound Freeway Mainline
400’s	400	499	Southbound Freeway Ramps
500’s	500	599	Eastbound Freeway Mainline
600’s	600	699	Eastbound Freeway Ramps
700’s	700	799	Westbound Freeway Mainline
800’s	800	899	Westbound Freeway Ramps
900’s	900	999	Arterials

Link Geometry Data

The analyst should input the physical and operational characteristics of the links or the roadway segments into the model.

The analyst should model a study area that is of sufficient geographic scope to capture the impacts of the alternatives. The network modeled should not only include the area of interest but also facilities that feed demand into the study area and facilities that might potentially be the real cause of the bottleneck or congestion in the study area.

Some key geometric data that the analyst might need to input include:

- Number of lanes.
- Lane width.
- Link length.
- Grade.
- Curvature.
- Pavement conditions (dry, wet, etc.).
- Sight distance.
- Bus stop locations.
- Crosswalks and other pedestrian facilities.
- Bicycle lanes/paths.
- Others.

The specific data to be coded for the links will vary according to the microsimulation software. Use defaults if values are unknown for specific inputs (e.g., sight distance).

Traffic Control Data

Most microsimulation uses a time-step simulation to describe traffic operations (which is usually 1 s or less). Vehicles are moved according to car-following logic in response to traffic control devices and in response to other demands. Traffic control devices for microsimulation models will vary. Listed below are some examples:

- No control.
- Yield signs.
- Stop signs.
- Signals (fixed timed, actuated, adaptive).
- Ramp metering.
- Roundabouts.

Traffic Operations and Management Data

Traffic operations and management data for links consist of the following:

- Warning data (incidents, work zones, lane drops, exits, etc.).
- Regulatory data (speed limits, variable speed limits, high-occupancy vehicles (HOVs), high-occupancy toll (HOT), detours, lane channelization, lane use, truck restrictions, weight restrictions, etc.).
- Information (guidance) data (VMS).
- Surveillance detectors (type and location).

Traffic Demand Data

Traffic demand is defined as the number of vehicles and the percentage of vehicles of each type that wish to traverse the study area during the simulation time period.

Furthermore, it may be necessary to reflect the variation in demand throughout the simulation time period. In most software programs, the traffic entering into the network is usually defined by some parameter, and traffic leaving the network is usually computed based on parameters internal to the network (turning movements, etc.). The analyst should code the traffic volume by first starting from the external nodes (this is where the traffic is put into the model). Once all of the entering traffic volumes at the external nodes are coded, the analyst will then go into the model and define the turning movements and any other parameter related to route choice. The key traffic demand data are:

- Entry volumes by vehicle type and turning fractions at all intersections or junctions (random walk simulators).
- O-D/path-specific and vehicle data (path-specific simulators).
- Bus operations (routes and headways/schedules).
- Bicycle and pedestrian demand data.

Driver Behavior Data

Driver behavior is typically difficult to observe and collect. In addition, these data may change in response to non-normal conditions. At the base model development step, it is not critical to specify these inputs. Default values for driver behavior data are usually provided with the microsimulation software. Defaults will suffice if driver behavior data that reflects the local conditions do not exist. However, it is during the calibration step that these parameters will have to be adjusted carefully so that model represents the observed traffic conditions. For example, if the study area sees significant truck flow, distribution of driver types may be adjusted to capture the interactions between trucks and passenger cars. During alternatives analysis, if the driver behavior parameters have not been chosen carefully, you might get erroneous results that underestimate or overestimate the benefits and impacts.

Users may override the default values of any driver behavior parameters if valid observed data are available (e.g., desired free-flow speed, discharge headway, startup lost time at intersections, etc.). These deviations should be included in the *Methods and Assumptions* document. Some examples of driver behavior data that analyst can specify include:

- Driver's aggressiveness (for minimum headway in car-following, gap acceptance for lane changing, response to yellow interval).
- Availability of (real-time) information for the driver.
- Driver's compliance or response to information, such as traveler information, route guidance, advisory/regulatory speeds posted on VMS, HOV/HOT lane restrictions, etc.

Not all driver behavior data are observable in the field. When data are not observable, defaults may be used in the base model development stage. If a specific driver behavior is observable in the field, the analyst should collect them if resources permit before resorting to use of defaults. Examples of observable driver behavior data include:

- Queue discharge and car-following headways.
- Gap acceptance.
- Start-up lost time.

Examples of unobservable driver behavior data include:

- Maximum speed and acceleration/deceleration rates.
- Lane change courtesy factor.
- Distribution of driver types (impacts aggressiveness).

Event Data

Event data are optional and will vary according to the specific application being developed by the analyst. Examples of event data inputs include:

- Blockages and incidents.
- Work zones.
- Parking activity in curb lane.

Some software allows the analyst to specify the location, time, and duration of the incident, the amount of rubbernecking, etc., while in others, incidents are not specified explicitly; rather these are modeled by specifying speed reduction zones. The analyst should refer the software's user guide for approaches to model events.

Simulation Run Control Data

All simulation software contains run control parameters to enable the analyst to customize the software operation for their specific modeling needs. These parameters will vary between software programs. They generally include:

- Length of simulation time.
- Selected MOEs or output (e.g., reports, animation files, or both).
- Resolution of simulation results (e.g., temporal and special resolution).
- Other system parameters to run the model.

The analyst should specify the length of the simulation time as the sum of the analysis period and the time needed for network loading, congestion build up, and congestion dissipation to capture demand and queuing accurately. If the analysis period is the AM peak period from 6 to 9 AM, we might have to specify a simulation period from 5 to 10 AM allowing for one hour for loading the network and congestion to build up, and one hour for congestion to dissipate. The additional time should be determined by examining the data.

Coding Techniques for Complex Situations

Microsimulation software allows the analyst to develop a model that represents the real-world situation. However, not all possible real-world situations were necessarily contemplated when the software was originally written. This is when the analyst, with a good understanding of the operation of the software, can "extend" the software to simulate conditions not originally incorporated into the microsimulation software. However, this should only be attempted after the tools, resources, and skills available are fully appreciated. This is because new tools continue to become available that account for selected real-world situations. These approaches should be discussed and agreed upon in the *Methods and Assumptions* document.

- A curb lane is heavily used for parking, loading, and unloading activities. As a result, this lane may be blocked virtually all the time. If the simulation software cannot correctly replicate the real situation, the analyst may consider removing this lane from the link. Alternately, the analyst may specify a speed reduction zone that extends the length of the loading zone, if the software has that capability, forcing vehicles to change lanes.
- Traffic regularly backs up on a freeway off-ramp, causing queuing on the freeway. However, instead of stopping on the freeway mainline lanes and blocking a lane, the queue forms on the shoulder of the freeway, keeping the right-hand lane open. If this is the case in the study area, the analyst may artificially extend the off-ramp length to realistically model the traffic in the field.

EXAMPLE PROBLEM: BASE MODEL DEVELOPMENT

Continuing with the Alligator City example problem from the previous chapters, the task is now to code the base model.

The first step is to code the link-node diagram. How this is best done can be determined from the software user's guide. Figure 7 shows the link-node diagram for the example problem. The next steps are to input:

- Link geometry data.
- Traffic control data for the Alligator City CBD (fixed-time control).
- Traffic operations and management data.
- Traffic demand data.
- Simulation run control data.

No driver behavior data have been collected for Alligator City and so, defaults are used.

KEY POINTS

In summary, when developing the base model, the analyst should be aware that:

- Geographic scope of study area will impact the alternatives; so, broaden scope to look at roadway segments that feed the demand and roadway segments that may be the real bottleneck.
- Temporal scope of the simulation will impact the alternatives; so, broaden the scope to allow congestion to build up and dissipate.
- Base model should reflect the observed field geometry; so, overlay the model on a map of the area.
- Assumptions made should be documented so that results can be justified, and sensitivity analyses can be conducted, where applicable.

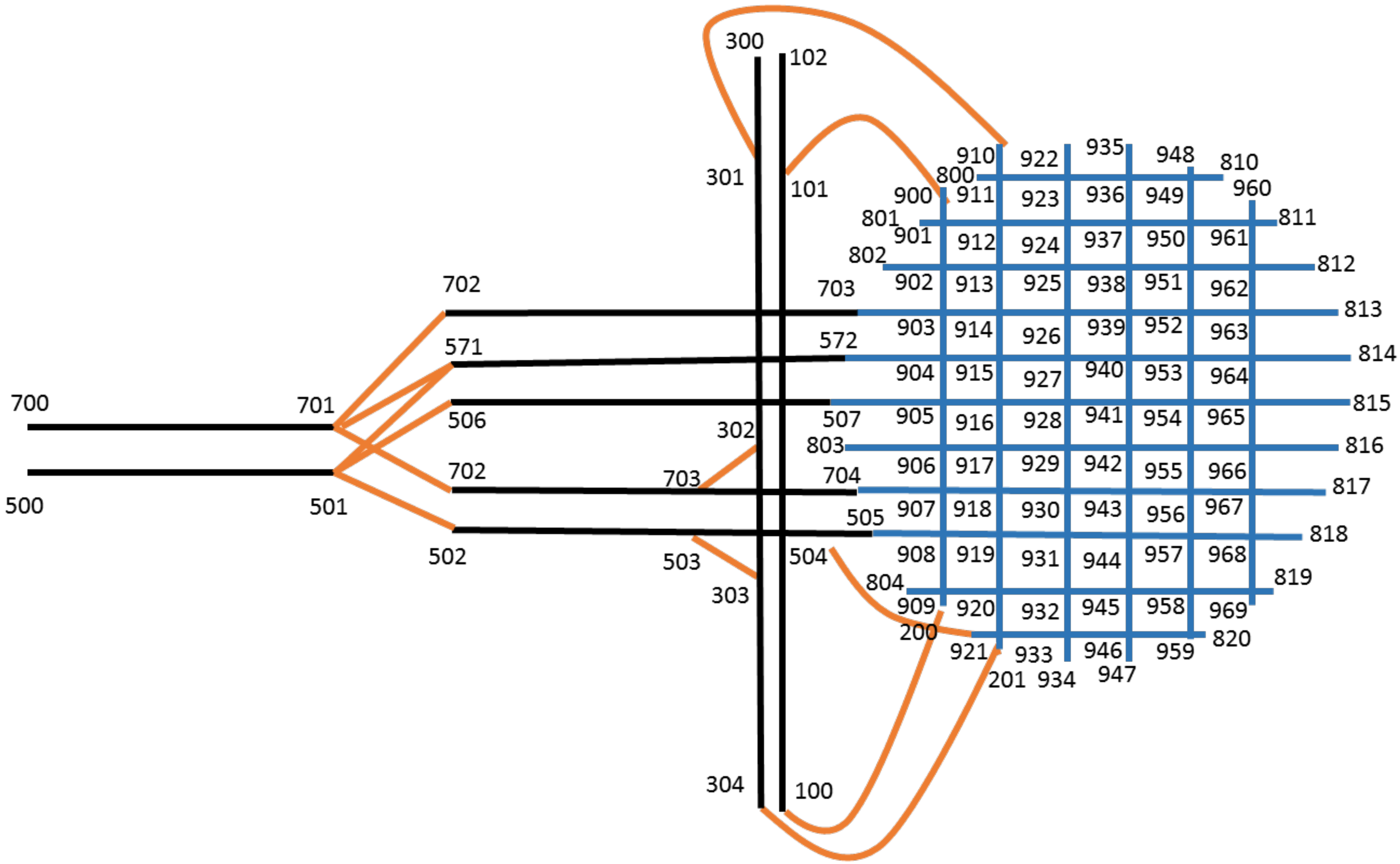

Figure 7. Diagram. Link-Node Diagram for Alligator City (Source: FHWA)

CHAPTER 4. ERROR CHECKING

The error correction step is essential in developing a working model so that the calibration process does not result in parameters that are distorted to compensate for overlooked coding errors. This is Step 4 in the Microsimulation Analytical Process (Figure 8). The calibration process relies on the elimination of all major errors in demand and network coding before calibration.

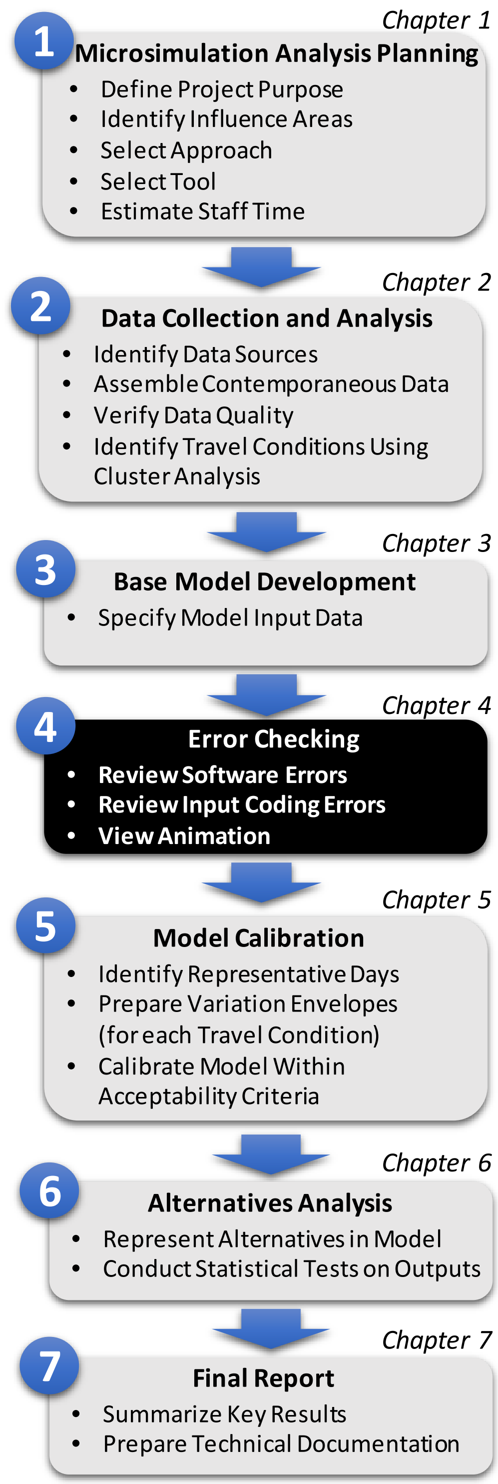

Figure 8. Diagram. Step 4: Error Checking (Source: FHWA)

Error checking involves various reviews of the coded network, coded demand, and default parameters. Error checking involves the following three stages:

1. Review software errors.
2. Review input coding errors.
3. View animation to spot less obvious errors.

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 version and “patch” of the software, if any.

REVIEW INPUT ERRORS

A checklist for verifying the accuracy of the coded input data is provided below:

Geometry:

- Check basic network connectivity (are all connections present?).
- Check link geometry (lengths, number of lanes, free-flow speed, facility type, etc.).

Control:

- Check intersection controls (control type, control data).
- Check for prohibited turns, lane closures, and lane restrictions at the intersections and on the links.

Demand:
- Check vehicle mix proportions at each entry node/gate/zone.
- Check identified sources and sinks (zones) for traffic.
- Verify zone volumes against traffic counts.
- Check vehicle occupancy distribution (if modeling HOVs).
- Check turn percentages (if appropriate).
- Check O-Ds of trips on the network.

Driver behavior and vehicle characteristics:
- Check and revise, as necessary, the default vehicle types and dimensions.
- Check and revise the default vehicle performance specifications.

The following techniques may be useful to increase the efficiency and effectiveness of the error-checking process:

- Overlay the coded network over a map of the study area to quickly verify the accuracy of the coded network geometry.
- If working with software that supports three-dimensional modeling, turn on the node numbers and look for superimposed numbers. They are an indication of unintentionally superimposed links and nodes. Two or more nodes placed in the same location will look like a single node when viewed in two dimensions. The links may connect to one of the nodes, but not to the other.
- For a large network, a report summarizing the link attributes should be created so that their values can be easily reviewed.
- Use color codes to identify links by the specific attribute being checked (e.g., links might be color-coded by free-flow speed range). Out-of-range attributes can be identified quickly if given a particular color. Breaks in continuity can also be spotted quickly (e.g., a series of 56-km/h (35-mi/h) links with one link coded as 40 km/h (25 mi/h)).

VIEW ANIMATION

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. The analyst inputs a very low level of demand and then follows individual vehicles through the network. Aberrant vehicle behavior (such as unexpected braking or stops) is a quick indicator of possible coding errors. At this stage, the analyst is not required to perform multiple runs of the model by changing the random number seeds; a single random-number-seed run will suffice.

A two-stage process can be followed in reviewing the animation output. Run the animation at an extremely low demand level (so low that there is no congestion). The analyst should then trace single vehicles through the network and see where they unexpectedly slow down. These will usually be locations of minor network coding errors that disturb the movement of vehicles over the link or through the node. This test should be repeated for several different O-D zone pairs.

Once the extremely low demand level tests have been completed, then run the simulation at 50 percent of the existing demand level. At this level, demand is usually not yet high enough to cause congestion. If congestion appears, it may be the result of some more subtle coding errors that affect the distribution of vehicles across lanes or their headways. Check entry and exit link flows to verify that all demands are being correctly loaded and moved through the network.

The animation should be observed in close detail at key bottleneck areas to determine if the animated vehicle behavior is realistic. If the observed vehicle behavior appears to be unrealistic, the analyst should explore the following potential causes of the unrealistic animation in the order shown below:

- Error in Analyst's Expectations: The analyst should first verify in the field the correct vehicle behavior for the location and time period being simulated before deciding that the animation is showing unrealistic vehicle behavior. Many times, the analyst's expectations of realistic vehicle behavior are not matched by actual behavior in the field. Analysts should not expect classic macroscopic traffic-flow concepts to apply at the microscopic individual-vehicle level. Macroscopic flow concepts (e.g., no variance in mean speed at low flow rates) do not apply to the behavior of an individual vehicle over the length of the highway. An individual vehicle's speed may vary over the length of the highway and between vehicles, even at low flow rates. Macroscopic flow theory refers to the average speed of all vehicles being relatively constant at low flow rates, not individual vehicles. Field inspection may also reveal the causes of vehicle behavior that are not apparent when coding the network from plans and maps. These causes need to be coded into the model if the model is expected to produce realistic behavior. Transportation Management Centers (TMC) with high-density camera spacing will be very helpful in reviewing the working model. Many TMCs are now providing workstations for traffic analysis/simulation staff.
- Error in Analyst's Data Coding: The analyst should check for data coding errors that may be causing the simulation model to represent travel behavior incorrectly. Subtle data coding errors are the most frequent cause of unrealistic vehicle behavior in commercial microsimulation models that have already been subjected to extensive validation. Subtle coding errors include apparently correctly coded input that is incorrect because of how it is used in the model to determine vehicle behavior. For example, it could be that the warning sign for an upcoming off-ramp is posted in the real world 0.40 km (0.25 mi) before the off-ramp; however, because the model uses warning signs to identify where people start positioning themselves for the exit ramps, the analyst may have to code the warning sign at a different location (the location where field observations indicate that the majority of the drivers start positioning themselves for the off-ramp).

A comparison of model animation to field design and operations is highly essential. Some of the things to look for include:

- Overlooked data values that require refinement.
- Aberrant vehicle operations (e.g., drivers using shoulders as turning or travel lanes, etc.).
- Previously unidentified points of major ingress or egress (these might be modeled as an intersecting street).

- Operations that the model cannot explicitly replicate (certain operations in certain tools/models), such as a two-way center turn lane (this might be modeled as an alternating short turn bay).
- Unusual parking configurations, such as median parking (this might be modeled operationally by reducing the free-flow speed to account for this friction).
- Average travel speeds that exceed posted or legal speeds (use the observed average speed in the calibration process).
- Turn bays that cannot be fully utilized because of being blocked by through traffic.
- In general, localized problems that can result in a system wide impact.

RESIDUAL ERRORS

If the analyst has field-verified his or her expectations of traffic performance and has exhausted all possible input errors, and the simulation still does not perform to the analyst's satisfaction, there are still a few possibilities. The desired performance may be beyond the capabilities of the software, or there may be a software error.

Software limitations can be identified through careful review of the software documentation. If software limitations are a problem, the analyst might seek an alternate software program without the limitations. Advanced analysts can also write their own software interface with the microsimulation software (called an "application program interface" (API)) to overcome the limitations and produce the desired performance. Any changes made to override the simulation software's capabilities should be documented in the *Methods and Assumptions* document.

Software errors can be tested by coding simple test problems (such as a single link or intersection) where the result (such as capacity or mean speed) can be computed manually and compared to the model. Software errors can only be resolved by working with the tool developer.

KEY DECISION POINT

The completion of error checking is a key decision point. The next task—model calibration—can be very time-consuming. Before embarking upon this task, the analyst should confirm that error checking has been completed, specifically:

- All input data are correct.
- Values of all initial parameters and default parameters are reasonable.
- Animated results look fine based on judgment or field inspection.

Once the error checking has been completed, the analyst has a working model (though it is still not calibrated).

EXAMPLE PROBLEM: ERROR CHECKING

Continuing with the Alligator City problem from the previous chapters, the task is now to error check the coded base model.

Software: The latest version of the software was used. Review of the model documentation and other material in the software and user groups' web sites indicated that that there were no known problems or bugs related to the network under study and the scenarios to be simulated.

Review of Input Data and Parameters: The coded input data were verified using the input files, the input data portion of the output files, static displays, and animation.

First, the basic network connectivity was checked, including its consistency with coded geometry and turning restrictions. All identified errors were corrected. For example, there was a fatal error that one of the SB Riverside Parkway links didn't exist. It was found that the link number had a typographical error.

Static network displays were used extensively to verify the number of lanes, lane use, lane alignment (i.e., lane number that feeds the downstream through link), and the location of lane drops. At this step, the consistency of link attributes was checked. For example, is the free-flow speed of ~90 km/h (55 mi/h) coded for all freeway links?

Next, the traffic demand data were checked. Input volumes at the network entrances were specified in four time slices. The input values were checked against the collected data.

Traffic signals coded at each intersection were reviewed. For fixed-time signals, the phasing and signal settings were checked. There was a fatal error that indicated Phase 1 at one of the intersections in Downtown Alligator City was incorrect. Phase 1 was defined as left-turns from the E-W street. But the cross street (N-S street) was coded as one-way. So, left turns are not allowed from the eastbound street. This was fixed.

Special attention was given to the traffic patterns at the interchange ramp terminals to avoid unrealistic movement. The software provisions (and options) were exercised to force the model not to assign movements to travel paths that were not feasible.

Vehicle characteristics were reviewed.

Review Animation: Following the checking of the input data, the model was run using very low demand volumes to verify that all of the vehicles travel the network without slowdowns. This step uncovered minor errors in the link alignments that needed adjusting.

Next, the traffic demands were specified to about 50 percent of the actual volumes and the simulation model was rerun. Animation was used to verify that all demands were properly loaded in the network links and the traffic signals were properly operating. The link and system performance measures (travel time, delay) were also checked for reasonableness (i.e., they should reflect free-flow conditions).

Careful checking of the animation revealed subtle coding problems. For example, the coded distance of a warning sign for exiting vehicles from the Victory Island Bridge affected the proper simulation of driver behavior. These problems were corrected.

Key Decision Point: The model, as revised throughout the error-checking process, was run with all the input data (actual demands) and the default model parameters. The output and animation were also reviewed and discussed with the Alligator City agency staff who were familiar with the study area. The conclusion was that the model is working properly.

KEY POINTS

In summary, when checking errors, the analyst should:

- Use structured/consistent processes.
- Check for “known” bugs and follow recommendations of the developer.
- Use graphical display and animation in the debugging process.
- Conduct an independent review to improve model quality.

CHAPTER 5. MODEL CALIBRATION

Upon completion of the error-checking task, the analyst has a working model of the transportation system. However, without calibration, the analyst has no assurance that the model will function as an accurate predictor of transportation system performance in alternatives analysis.

This is Step 5 in the Microsimulation Analytical Process (Figure 9). Calibration is the adjustment of model parameters to improve the model's ability to reproduce time-dynamic system performance observed under specific travel conditions. Note that variation in transportation system performance is primarily determined by external variations in travel conditions (e.g., variations in day-to-day travel demand, incident patterns, and weather conditions). Driver behavior (e.g., following distance, gap acceptance, and target maximum speed) and other model parameters are calibrated in each travel condition to create time-dynamic congestion patterns consistent with observed data.

Calibration is necessary because no single model can be expected to be equally accurate for all possible traffic conditions. Even the most detailed microsimulation model still contains only a portion of all of the variables that affect real-world traffic conditions. Since no single model can include the whole universe of variables, every model should be adapted to local conditions.

Every microsimulation software program comes with a set of user-adjustable parameters for the purpose of calibrating the model to local conditions. Therefore, the objective of calibration is to find the set of parameter values for the model that best reproduces observed measures of system performance.

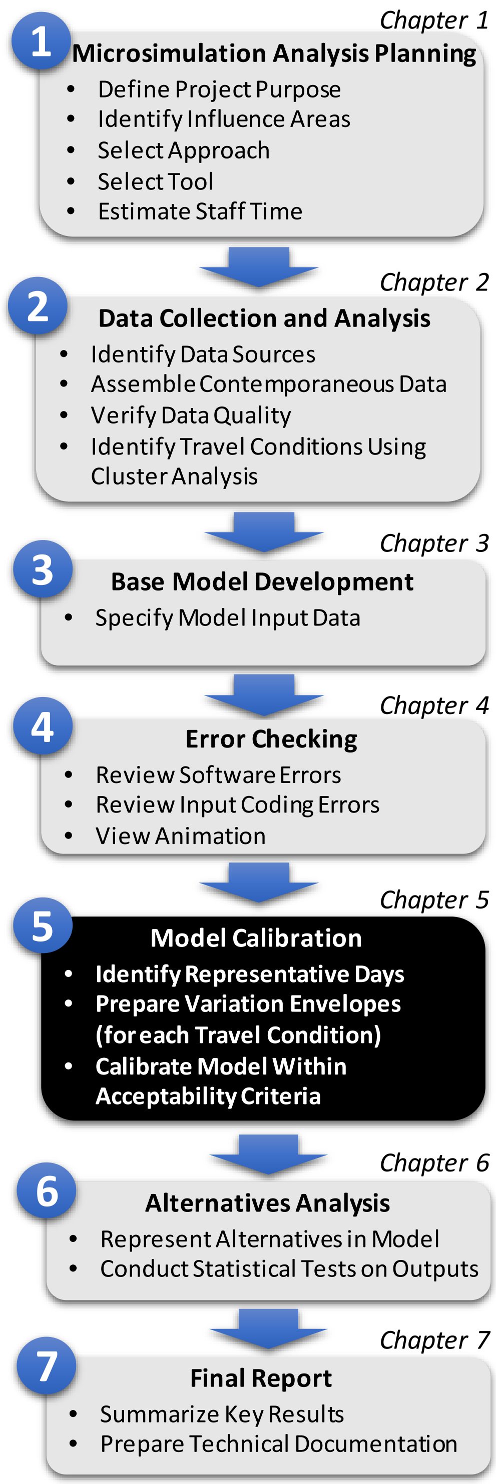

Figure 9. Diagram. Step 5: Model Calibration (Source: FHWA)

For the convenience of the analyst, the software developers provide suggested default values for the model parameters. These default parameters do not represent a calibrated model. The analyst should always perform model calibration and review the calibration criteria to ensure that the model accurately reproduces system performance by travel condition.

OVERVIEW OF THE CALIBRATION PROCESS

As shown in Figure 9, the calibration process has three steps:

1. Identify representative days. In this step, the analyst takes the data from the travel conditions identified using cluster analysis or other statistical methods (Chapter 2) and prepares them to support calibration. A key element of this preparation is the identification of one representative day for each travel condition.
2. Prepare variation envelopes. In this step, the analyst prepares the simulation inputs to model each representative day. For each representative day, the analyst creates a time-dynamic envelope consistent with variation in observed field data for all days in the cluster representing the travel condition. This envelope creates a data-driven calibration target for the calibration of an individual model variant consistent with each travel condition.
3. Calibrate model variants within acceptability criteria. The analyst then iteratively adjusts specific software parameters within a model variant until key performances measures derived from simulation outputs are acceptably close to the target variation envelope. Calibration of each model variant is complete when the simulation outputs meet four acceptability criteria.

The calibration process is applied to a single model run for each travel condition or cluster identified in Chapter 2. The analyst does not need to calibrate multiple model runs generated by varying the random number seeds. Variation demonstrated by varying random number seeds in microsimulation tools show differences in driver behaviors (e.g., gap acceptance, lane changing), and vehicles entering the system. These variations are markedly low compared to variation due to changes in travel condition attributes (e.g., demand, weather), which are not represented stochastically in microsimulation tools. If significant variations are seen between runs by changing the random number seeds, a possible reason might be errors in coding or gridlock conditions resulting from vehicles entering into unresolved contention in simulation (e.g., vehicles attempting conflicting parallel lane changes). An analyst should investigate if the network has been coded correctly and is operating realistically or if the model is unstable. The results from an unstable model run should not be used for calibration or alternatives analysis.

In the remainder of this section, we describe in detail each of the three steps, using the Alligator City hypothetical simulation study as an example.

IDENTIFY REPRESENTATIVE DAYS

In this step, we prepare and assemble observed data related to our key performance measures and network bottlenecks. Observed data are organized around the travel conditions identified in Chapter 2. Travel conditions and performance measures should be identified in the Analysis

Plan. Depending on an assessment of quality of data, there may be a need to adjust the selection of specific measures prior to calibration. Critical locations (bottlenecks) are identified for each travel condition, plus a super set of all bottlenecks maintained comprising all travel conditions.

It is important to focus calibration on a single observed day, since that day can be characterized in a microsimulation model with specific incident locations, travel times, and other performance data. Attempting to calibrate a model to a synthetic day created by the averaging together of multiple days is not recommended. Synthetic days based on averages create unrealistically smooth time dynamic performance measures like travel time and bottleneck throughput, creating targets that may be difficult for any model variant to replicate. For example, if one day has a major incident in one location and is then averaged with a day with no incident, then the result is the merging of two broadly dissimilar days. The analyst should now attempt to somehow induce a more minor incident in that location to produce a moderated congestion pattern. In fact, the resulting synthetic measures of system performance may not even be consistent with logically consistent traffic flow, and may be exceptionally difficult to reproduce in a valid modern microsimulation. In this case, the analyst wastes resources calibrating to a condition that never existed and will likely never exist.

For each travel condition, the analyst seeks to identify a single representative day. The representative day is used to typify system performance dynamics associated with the collection of days encompassing a single travel condition. More precisely, the representative day and has observed time-variant performance measures closest to mean time-dependent observed measures considering all days in the travel condition.

In order to identify the representative day, time-variant data related to the key performance measures are analyzed. For every day used in the analysis across all travel conditions, the analyst prepares a time-variant (15-minute profile) of the key measure. Multiple locations and routes may be required to characterize system performance. For example, in corridor networks with alternatives, travel time and speed measures may be needed on multiple routes. Likewise, there may be multiple bottleneck locations within the system. To identify a representative day:

1. For a particular key measure, establish necessary routes and locations.

   Let M be the set of measures, considered over J the set of routes and locations.
   Let $N_{cluster}$ be the number of days in cluster.
   Let $m_{i,j}(t)$ be the value of the measure on day i in time interval t at location or route j

2. For each measure, calculate the average time-variant value for each 15-minute time interval across all days in the travel condition for each location/route:

   $$\bar{m}_{t,j} = \frac{\sum_i m_{i,j}(t)}{N_{cluster}} \quad \forall m, t, j \qquad (5)$$

3. Calculate the difference between the average value and the value observed on a particular day, expressed as a percentage of the mean value:

$$\dot{m}_{i,j}(t) = \frac{\sqrt{(\bar{m}_{t,j} - \bar{m}_{i,j(t)})^2}}{\bar{m}_{t,j}} \qquad (6)$$

4. Find the individual day that minimizes the difference between the individual day and the average values considering all routes, locations, and measures:

$$i^* = min_i\left[\sum_m \sum_i \sum_t \dot{m}_{i,j}(t)\right] \qquad (7)$$

PREPARE VARIATION ENVELOPES

Select Calibration Performance Measures

An effective calibration requires at least two key performance measures. At least one measure should be related to travel time or speed profiles along one or more key paths in the roadway network. At least one other measure should be related to bottleneck dynamics, e.g., bottleneck throughput or duration. Other calibration measures can also be included that are critical to the purpose and needs of the project or in differentiating alternatives evaluated in the analysis. However, whatever measures are selected, the data required to calculate each measure for the purposes of calibration are required for every day included in the analysis of travel conditions. The ability to meet these data preparation guidelines for calibration should be documented in the accompanying project *Methods and Assumptions* document.

Travel time or speed measures. Travel times or speed profiles should be associated with paths that traverse the study area and intersect at least one bottleneck location on the representative day. Observed data should be available for these measures and paths at 15-minute (or more frequent) intervals. More than one path may be required to capture the system dynamic, or in corridor analyses, the mainline and one alternative path. An interchange analysis might require only one path.

Bottleneck measures. For every day across all travel conditions, identify the set of bottleneck locations. Bottleneck locations are defined as the set of network locations where transient demand exceeds facility capacity and resultant approach speeds drop below the bottleneck congestion speed threshold.

Data for the calculation of bottleneck measures are best derived from data obtained from at least one near upstream (within 0.5 miles and prior to any major intersection or interchange) or near downstream location for at least one bottleneck associated with the travel condition. Near downstream locations are preferred, prior to the next major intersection or interchange.

> *Congestion speed threshold*: For this threshold, the analyst requires a value lower than approximate speed-at-capacity and closer to speed-at-congestion, that is, a speed that indicates that the bottleneck has reached or exceeded its capacity. As a rule of thumb, a threshold of one third of observed free-flow speed can be used with visual inspection of time-variant speed and flow rates at the bottleneck for the representative day. However,

speed at capacity can be more precisely calculated using other data-driven approaches (For example, http://www.academia.edu/11327450/An_automated_statistically-principled_bottleneck_identification_algorithm_ASBIA). The goal of the analyst is selecting a threshold that is lower than speed-at-capacity and can be applied uniformly across all days in the travel condition.

For each bottleneck location, calculate bottleneck onset and duration. Onset and duration are identified at least within a 15-minute time intervals.

Congestion onset: Onset is defined as the 15-minute time period when a location immediately upstream of the bottleneck experiences observed speeds below the congestion speed threshold.

Congestion duration: Total time observed between congestion onset at the bottleneck location and the 15-minute period where average observed speeds exceed the congestion speed threshold.

For bottleneck attributes, it is imperative to focus on a specific observed representative day when conducting calibration. Aggregating bottleneck measures blurs distinctions among bottlenecks and often results in multiple “weak” bottlenecks with inconsistent time-dependent flow rates. These artificial conditions are never observed in a single day, and are difficult for a microsimulation to reproduce.

Onset and duration speed measurements should, if possible, be collected at a near upstream location. If not possible, document these as a deviation in the Methods and Assumptions document. Average mean space speed or mean point speed may be utilized whichever best characterizes the bottleneck performance. For example, a mean space speed may be preferable for a bottleneck upstream from a signalized intersection.

Creating Variation Envelopes

Our goal in calibration is to have the variation of results generated by the simulation fall within the range of variation seen in the observed data. In Chapter 2, we defined travel conditions. From the limited variation resulting from our travel condition analysis, in this step we create a practical range derived from the observed variation to act as a target for model variant calibration.

To create the time-variant *Variation Envelope* for our simulation results to fall within, we create a statistical region based on the standard deviation and an acceptable range of variation around both the time variant averages and the observed representative day value.

Let $c_r(t)$ be the observed travel times from the representative day. Let the standard deviation in travel time for each time interval be $\sigma(t)$.

First, we construct an envelope which describes 95% of the observed variation (the Z-statistic in this case is 1.96). In each time interval, this is expressed as:

~2 Sigma Band Maximum Value: $\hat{I}_{\sim 2}(t) = c_r(t) + Z_{95\%}(\sigma(t))$ (8)
~2 Sigma Band Minimum Value: $\check{I}_{\sim 2}(t) = c_r(t) - Z_{95\%}(\sigma(t))$ (9)

A narrower band is also constructed to describe roughly 2/3 of the observed variation based on a single standard deviation.

1 Sigma Band Maximum Value: $\hat{I}_1(t) = c_r(t) + \sigma(t)$ (10)
1 Sigma Band Minimum Value: $\check{I}_1(t) = c_r(t) - \sigma(t)$ (11)

These bands will play a crucial role in determining the acceptability of the model variants in our next step.

CALIBRATE MODEL VARIANT TO MEET ACCEPTABILITY CRITERIA

In this step, the analyst creates variants of the initial working model that has travel demand characteristics, incident patterns, and other features consistent with the each of the representative days. The analyst then conducts individual runs of each model variant and makes adjustments to the model variant input parameters until performance measures based on simulation outputs are *acceptably consistent* with observed data. Acceptably consistent is defined as meeting all four separate acceptability criteria defined in this chapter.

This step may be both time consuming and highly iterative. However, if quality data has been assembled for calibration, and the working model is free of major coding errors, this process can be straightforward. Self-calibration features or automated routines assisting calibration can be helpful in reducing analyst time in calibration. However, applying these routines does not replace this step; they merely support the completion of tasks leading up to testing for calibration acceptability.

The modern microsimulation analyst has several capable tools available to conduct effective analyses. Each of these tools has a specific set of parameters which influence simulated driver behavior. Therefore, we can provide no guidance on specific parameters (by tool) to select for calibration. However, example parameters are indicated in each step. Some helpful references are available regarding parameter sensitivities and calibration (For example, Volume XI: Weather and Traffic Analysis, Modeling and Simulation).

Calibration involves the review and adjustment of potentially hundreds of model parameters, each of which impacts the simulation results in a manner that is often highly correlated with that of the others. The analyst can easily get trapped in a never-ending circular process, fixing one problem only to find that a new one occurs somewhere else. Therefore, it is essential to break the calibration process into a series of logical, sequential steps—a strategy for calibration.

To make calibration practical, the parameters should be divided into categories and each category should be dealt with separately. The analyst should divide the available calibration parameters into the following two basic categories:

- Parameters that the analyst is certain about and does not wish to adjust. [e.g., incident location and number of lanes closed].
- Parameters that the analyst is less certain about and willing to adjust. [e.g., mean vehicle headway under low visibility conditions].

The analyst should attempt to keep the set of adjustable parameters as small as possible to minimize the effort required to calibrate the model to reflect local conditions characterized by observed data. However, the tradeoff is that more parameters allow the analyst more degrees of freedom to better fit the calibrated model to the specific representative day.

The set of adjustable parameters is then further subdivided into those that directly impact bottleneck throughput (such as mean headway) and those that directly impact the timing and location of travel demand (such as time-variant origin-destination demand profiles). Although the process will nearly always be iterative, one successful strategy is to calibrate bottleneck throughput parameters first, and then to make adjustments to travel demand inputs and other behavioral parameters related to trip timing and mode/route selection.

Each set of adjustable parameters can be further subdivided into those that affect the simulation on a *global* basis and those that affect the simulation on a more *localized* basis. The global parameters are initially adjusted first. Then local link-specific parameters are modified. This process, like all calibration processes, may be iterative in nature.

Adjust Parameters Influencing Bottleneck Throughput

Each representative day will have a bottleneck pattern comprising locations of recurrent demand in excess of localized capacity, as well as bottlenecks associated with incidents. The goal of this step is to adjust the model variant to produce bottleneck dynamics consistent with field data. Focus on the bottlenecks is critical because overall system performance will be largely defined based on these critical sections of the transportation network.

Some typical parameters influencing bottleneck throughput include:

- <u>Freeway Facilities</u>: Mean following headway, driver reaction time, and critical gap for lane changing, minimum separation under stop-and-go conditions.
- <u>Signalized Intersections</u>: Startup lost time, queue discharge headway, and gap acceptance for unprotected left turns.

An effective preliminary step in bottleneck throughput calibration is to ensure that maximum throughput rates obtained from the model variant are close to observed rates. For each bottleneck location, recover the maximum bottleneck throughput (over all of time-variant intervals) data from one representative day where the bottleneck appears. Also recover the same maximum throughput data for all of the days in the travel condition. The maximum time-variant bottleneck throughput from the simulation should be within the range of observed maximum bottleneck throughput rates for all days under this travel condition. This can be conducted as a visual test plotting the simulated data against the range of observed data. First adjust global parameters to bring simulated maximum throughput rates as close as possible to the observed range. Then adjust localized parameters so each bottleneck has a simulated maximum throughput rate as close as possible to the observed maximum throughput rate.

Modifying global parameters related to bottleneck throughput are often required to adjust for specific attributes of the representative day prevailing over the entire network, e.g., low visibility or wet pavement. Modifications of local parameters are often related to impacts or conditions near the bottleneck, e.g., shoulder activity, glare, or rubbernecking.

Adjust Parameters Affecting Dynamic Travel Demand and Assignment

Each representative day has an underlying travel demand pattern that is different from other days. Attributes of this travel demand pattern include the overall origin-destination demand, the timing of travel demand within the period studied, and how this travel demand is assigned to various alternative modes and routes. The goal of this step is to adjust the model variant to produce network volume data consistent with observed data. Representative travel demand, when combined with accurate bottleneck dynamics, is often the key to calibrating efficiently and effectively.

Some typical parameters influencing travel demand and assignment include:

- Travel Demand Rates: Overall origin-destination flow rates, the number of time steps introduced into a dynamic origin-destination flow rate profile, the number of trips in each time step for each origin-destination pair.
- Mode/Route Assignment: Mode choice parameter reflecting traveler preference (e.g., transfer penalties and time/cost valuations), parameters adjusting the method of assignment of travel demand (e.g., indifference thresholds or driver familiarity models).

An effective preliminary check in the adjustment of dynamic travel demand and assignment is to conduct an average screenline count check. First, identify average bi-directional link flows at two screen lines, one in a general upstream position relative to recurrent congestion and one generally downstream of recurrent congestion. This implies that the queues extending from recurrent bottlenecks do not cross these screenlines. A single screen line bisects the study area, and all links that traverse this screen line should have average flow estimates.

Run the simulation using the representative day to generate average flow rates to compare against the observed screenline counts. Adjust global travel demand parameters until simulated average flow rates should fall within the range of all observed days associated with expected conditions, close to the actual flow rate observed in this travel condition’s representative day. Some adjustment may be required to the simulated origin-destination demand pattern rates in order to bring the simulated model flow rates within the range of the observed data. Depending on the nature of the network and the number of alternative routes and modes, mode/route assignment parameter modifications may be required to bring screenline counts into the observed range.

In the Alligator City example problem, two useful screenlines might include a western screenline just east of the West Hills city limits intersecting the Marine Causeway and an eastern screenline at the eastern shore of the Chattacola River.

Perform Test Against Acceptability Criteria

The exact process and parameter adjustments required to calibrate a model variant is highly dependent on the simulation tool and the attributes of the representative day. Whatever the strategy used to calibrate the model variant, the model variant should meet four separate acceptability criteria related to the time-dynamic profiles developed for each measure and travel condition.

These criteria should all be satisfied individually for each key measure and travel condition in a single model run.

Criterion I: Control for Time-Variant Outliers

This criterion constrains the number of outliers in simulated results.

CRITERION I: 95% of simulated outputs fall within the ~2 Sigma Band, $c_r(t) \pm 1.96 \times \sigma(t)$. Note that if fewer than 20 time intervals are used to characterize time-dynamics, Criterion I is relaxed to allow for one simulated result outside the ~2 Sigma Band.

Criterion II: Control for Time-Variant "Inliers"

This criterion ensures the majority of time-variant simulated results fall close to the representative day, and that during the most congested time periods the simulated results are close to the observed data.

Two *critical time periods* are identified that reflect the ability of the model variant to reflect the most congested time periods in the dynamic range. These time periods are determined by examining the observed data profile for the representative day.

For travel time or speed profiles, the first-time period is the time interval with the highest observed travel time or lowest observed speed. The second critical time interval is the time period with the second highest observed travel time or lowest speed *in a non-adjacent time interval*. *Non-adjacent* means that the second-time interval should be more than one time interval earlier or later than the first critical time interval.

For bottleneck throughput, the critical time intervals are defined by the time of congestion onset (speed falls below the congestion threshold) and dissipation (when speed rises above the congestion threshold). Note that when congestion thresholds are not met, this location cannot be considered a bottleneck for this representative day. In the cases where a bottleneck dissipation threshold is not identified (speeds remain low) the best resolution is to extend the simulation horizon so that the congestion dissipation can be observed (and modeled).

CRITERION II: Two-thirds of the simulated results (and both critical time intervals) fall within the 1 Sigma Band for this travel condition.

Criterion III: Bounded Dynamic Absolute Error (BDAE)

This criterion ensures that, on average, simulated results are close to the observed representative day. The criterion involves a test to ensure that the average simulated absolute error from the representative day over all time intervals is less than or equal to differences from the representative day seen across all days in the travel condition. Let:

$c_r(t)$	Observed value of representative day during time interval *t*
$c_i(t)$	Observed value of non-representative day within the cluster during time interval *t*
$\tilde{c}_r(t)$	Simulated performance measure during time interval *t*
N_T	Number of time intervals
$N_{cluster}$	Number of days in the cluster representing this travel condition

Next, calculate the BDAE Threshold:

$$\text{BDAE Threshold} = \frac{\sum_{i \neq r} \sum_t \frac{|c_r(t) - c_i(t)|}{N_T}}{N_{cluster} - 1} \qquad (12)$$

CRITERION III is met when:

$$\frac{\sum_t |c_r(t) - \tilde{c}_i(t)|}{N_T} \leq \text{BDAE Threshold} \qquad (13)$$

Criterion IV: Bounded Dynamic Systematic Error

This criterion ensures that the simulated data are not excessive over- or under-estimators. In this case, the criterion utilizes a similar test to Criterion III but with respect to average simulated error (not absolute).

CRITERION IV is met when:

$$\left|\frac{\sum_t c_r(t) - \tilde{c}_i(t)}{N_T}\right| \leq \frac{1}{3} \times \text{BDAE Threshold} \qquad (14)$$

EXAMPLE PROBLEM: MODEL CALIBRATION

In the Alligator City example problem, travel time was identified as the key performance measure (Chapter 1), with emphasis on two routes: West Hills to the Alligator City via the Komodo Tunnel (General Purpose Lanes), and West Hills to Alligator City via the Victory Island Bridge. Further, we select two bottleneck locations: the Komodo Tunnel eastern exit at Osceola Avenue and the Victory Island Bridge where it crosses Moseley Street.

Identify Representative Days

In Table 9, consider observed time-variant travel times between West Hills and the Alligator City CBD using the Komodo Tunnel general purpose lanes observed in an travel condition composed of 12 AM peak periods. Note that our travel times represent the measured time to complete the trip to Alligator City based on time of departure from West Hills. Each peak period is shown in one column of the table, with the calculated average travel time over all periods in the last column.

We seek a representative day that minimizes the difference between the time-variant travel times from associated with the average of all peak periods in the travel condition. Table 10 shows the distance (difference) between each individual day time-variant travel time and the time-variant average travel time (last column of Table 9), expressed as a percentage of the time-variant average travel time.

Table 9. Time-Variant Travel Times, West Hills Eastbound to Alligator City

	Observed Travel Times, West Hills to CBD (Komodo GP), 12 Days												
Time of Trip Start	1	2	3	4	5	6	7	8	9	10	11	12	Average Travel Time
6:00 AM	15.3	14.7	15.6	15.0	15.8	16.3	15.8	16.5	15.5	15.4	14.9	16.1	15.6
6:15 AM	15.4	15.2	15.8	15.6	17.5	17.0	16.5	18.9	16.0	16.2	15.5	16.8	16.4
6:30 AM	20.5	18.5	25.5	19.8	28.6	28.1	25.5	23.6	22.5	20.7	21.6	22.8	23.1
6:45 AM	22.8	25.6	29.8	23.5	30.9	31.8	28.6	29.6	27.4	21.8	25.3	26.9	27.0
7:00 AM	27.6	30.5	36.5	28.3	33.5	36.1	34.5	32.1	30.6	25.3	29.8	31.2	31.3
7:15 AM	29.9	33.6	35.2	30.8	34.5	35.2	34.8	33.5	32.6	28.5	30.5	32.1	32.6
7:30 AM	30.8	30.4	34.2	31.2	31.5	33.6	33.8	32.2	30.6	28.5	31.5	31.4	31.6
7:45 AM	30.4	27.6	33.9	31.5	30.8	32.8	32.1	32.1	29.5	28.6	30.9	31.9	31.0
8:00 AM	30.1	28.5	30.8	31.6	29.3	30.6	31.5	31.8	29.1	28.3	29.9	30.6	30.2
8:15 AM	29.9	28.3	29.6	30.2	28.6	29.8	30.4	30.5	28.8	28.3	29.2	29.9	29.5
8:30 AM	27.6	27.3	28.5	29.1	27.9	28.6	30.3	30.5	28.5	25.3	26.6	28.3	28.2
8:45 AM	24.6	26.9	27.5	26.3	23.6	28.0	27.1	28.6	26.6	22.1	23.9	25.5	25.9
9:00 AM	23.6	22.9	27.4	25.5	21.6	27.6	26.6	24.5	22.7	18.9	22.5	23.4	23.9
9:15 AM	22.4	22.5	24.3	23.3	21.8	28.5	25.1	23.6	21.8	18.5	20.6	22.1	22.9
9:30 AM	21.1	20.8	21.6	22.6	22.8	25.3	24.3	21.3	21.5	20.1	19.2	19.9	21.7
9:45 AM	20.1	16.5	19.5	20.0	24.6	23.8	22.6	20.9	20.8	19.8	17.5	17.7	20.3
10:00 AM	18.8	16.8	17.6	18.0	23.6	22.8	21.6	19.3	20.5	17.5	17.2	17.1	19.2
PEAK AVG	24.2	23.9	26.7	24.8	26.3	28.0	27.1	26.4	25.0	22.6	23.9	24.9	25.3

For these travel time data, as highlighted in Table 10, Day 9 has the smallest absolute average difference from the average across all days in the travel condition, 2.8%. A similar analysis is conducted for an additional measure and potentially additional routes. For the Alligator City example problem, Day 9 has the smallest absolute average difference from the average when both the Komodo Tunnel and Victory Island Bridge routes are considered (although the VIB times are not shown here). Although Day 9 may be a good choice for travel times, the analyst should also take into consideration how well all the days in the travel condition reflect our other key measure relating to bottleneck dynamics, bottleneck duration.

Table 10. Differences Comparing Individual Days and the Average for the Travel Condition, Expressed as a Percentage of the Time Variant Averages

	Euclidean Distance Expressed as a Percentage of Average Travel Time, 12 Days											
Time of Trip Start	1	2	3	4	5	6	7	8	Rep Day (9)	10	11	12
6:00 AM	1.8%	5.6%	0.2%	3.7%	1.4%	4.7%	1.4%	5.9%	0.5%	1.1%	4.3%	3.4%
6:15 AM	5.9%	7.1%	3.5%	4.7%	6.9%	3.9%	0.8%	15.5%	2.2%	1.0%	5.3%	2.6%
6:30 AM	11.4%	20.1%	10.2%	14.4%	23.6%	21.4%	10.2%	2.0%	2.8%	10.6%	6.7%	1.5%
6:45 AM	15.6%	5.2%	10.4%	13.0%	14.4%	17.8%	5.9%	9.6%	1.5%	19.3%	6.3%	0.4%
7:00 AM	11.9%	2.7%	16.5%	9.7%	6.9%	15.2%	10.1%	2.4%	2.3%	19.3%	4.9%	0.4%
7:15 AM	8.3%	3.1%	8.0%	5.5%	5.8%	8.0%	6.7%	2.8%	0.0%	12.6%	6.4%	1.5%
7:30 AM	2.7%	3.9%	8.1%	1.4%	0.4%	6.2%	6.8%	1.8%	3.3%	9.9%	0.4%	0.8%
7:45 AM	2.0%	11.0%	9.3%	1.6%	0.7%	5.8%	3.5%	3.5%	4.9%	7.8%	0.3%	2.9%
8:00 AM	0.2%	5.6%	2.1%	4.7%	2.9%	1.4%	4.4%	5.4%	3.6%	6.2%	0.9%	1.4%
8:15 AM	1.5%	3.9%	0.5%	2.5%	2.9%	1.2%	3.2%	3.5%	2.2%	3.9%	0.9%	1.5%
8:30 AM	2.2%	3.2%	1.0%	3.2%	1.1%	1.4%	7.4%	8.1%	1.0%	10.3%	5.7%	0.3%
8:45 AM	5.0%	3.9%	6.2%	1.6%	8.9%	8.1%	4.7%	10.5%	2.7%	14.6%	7.7%	1.5%
9:00 AM	1.4%	4.3%	14.5%	6.5%	9.7%	15.3%	11.1%	2.4%	5.2%	21.0%	6.0%	2.2%
9:15 AM	2.1%	1.6%	6.2%	1.9%	4.7%	24.6%	9.7%	3.2%	4.7%	19.1%	9.9%	3.4%
9:30 AM	2.8%	4.2%	0.5%	4.1%	5.0%	16.5%	11.9%	1.9%	1.0%	7.4%	11.6%	8.3%
9:45 AM	1.1%	18.8%	4.0%	1.6%	21.1%	17.1%	11.2%	2.9%	2.4%	2.5%	13.9%	12.9%
10:00 AM	2.3%	12.7%	8.5%	6.4%	22.7%	18.5%	12.3%	0.3%	6.6%	9.0%	10.6%	11.1%
AVG	4.6%	6.9%	6.4%	5.1%	8.2%	11.0%	7.2%	4.8%	2.8%	10.3%	6.0%	3.3%

Note*: Day 9 has the smallest absolute average difference from the average across all days in the travel condition, 2.8%.*

Preparing Variation Envelopes

In the example of Alligator City, travel times from the West Hills to the CBD over the AM peak are shown below in Table 11, and plotted in Figure 10.

Table 11. Travel Time Variation Envelope Band Calculation, Alligator City

Time of Trip Start	Rep Day Travel Time	Standard Deviation (Sigma)	~2 Sigma Band (max)	~2 Sigma Band (min)	1 Sigma Band (max)	1 Sigma Band (min)
6:00 AM	15.5	0.53	16.5	14.5	16.0	15.0
6:15 AM	16.0	1.02	18.0	14.0	17.0	15.0
6:30 AM	22.5	3.09	28.5	16.5	25.6	19.4
6:45 AM	27.4	3.13	33.5	21.3	30.5	24.3
7:00 AM	30.6	3.26	37.0	24.2	33.9	27.3
7:15 AM	32.6	2.16	36.8	28.4	34.8	30.4
7:30 AM	30.6	1.55	33.6	27.6	32.2	29.0
7:45 AM	29.5	1.71	32.9	26.1	31.2	27.8
8:00 AM	29.1	1.14	31.3	26.9	30.2	28.0
8:15 AM	28.8	0.76	30.3	27.3	29.6	28.0
8:30 AM	28.5	1.39	31.2	25.8	29.9	27.1
8:45 AM	26.6	1.89	30.3	22.9	28.5	24.7
9:00 AM	22.7	2.44	27.5	17.9	25.1	20.3
9:15 AM	21.8	2.36	26.4	17.2	24.2	19.4
9:30 AM	21.5	1.71	24.9	18.1	23.2	19.8
9:45 AM	20.8	2.36	25.4	16.2	23.2	18.4
10:00 AM	20.5	2.25	24.9	16.1	22.8	18.2

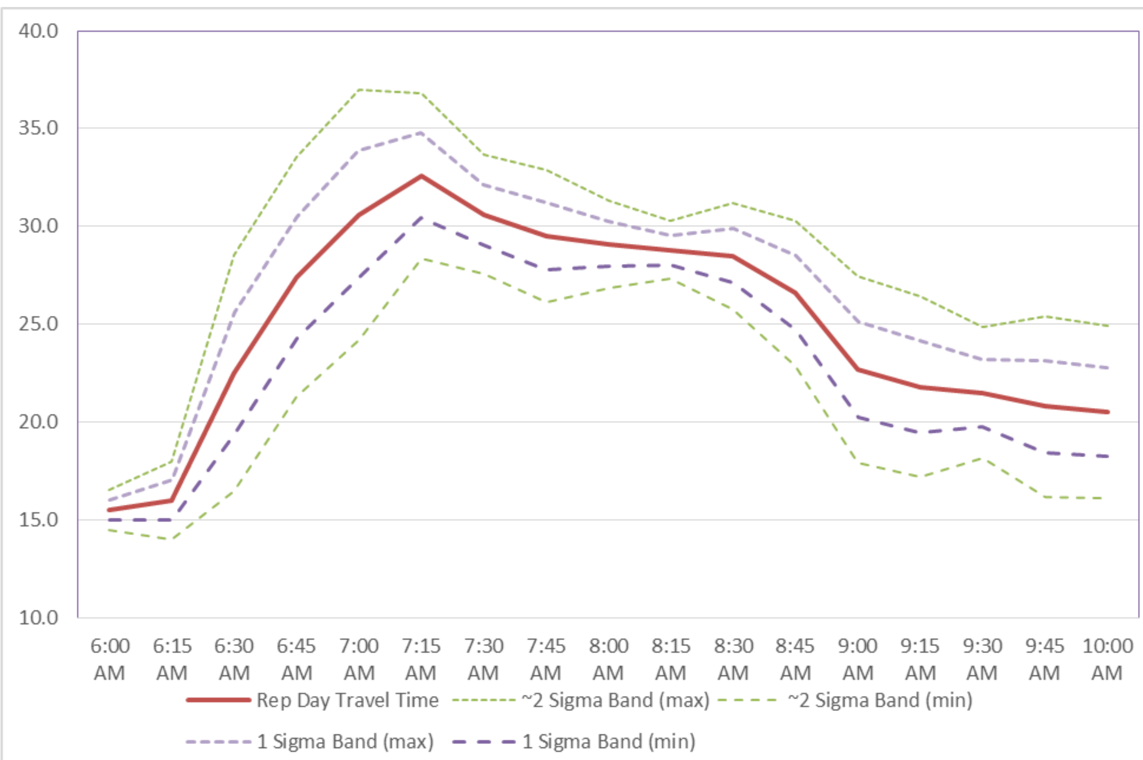

Figure 10. Chart. Plot of Variation Envelope for Eastbound AM Travel Times, West Hills to Alligator City (Source: FHWA)

Calibrate Model Variants within Acceptability Criteria

In the Alligator City example, consider the situation where an analyst is in the midst of calibrating the eastbound travel times from West Hills to Alligator City via the Komodo Tunnel. After a series of adjustments to the input parameters, the analyst calculates the simulated travel times for each of the 17 time intervals in the AM peak.

First, the analyst considers Criterion I to control for outliers (Figure 11). All of the points fall within the ~2 Sigma Band except for one point (8 AM). Given that there are 17 time intervals, at most one-time period can be outside the band. The model variant passes Criterion I.

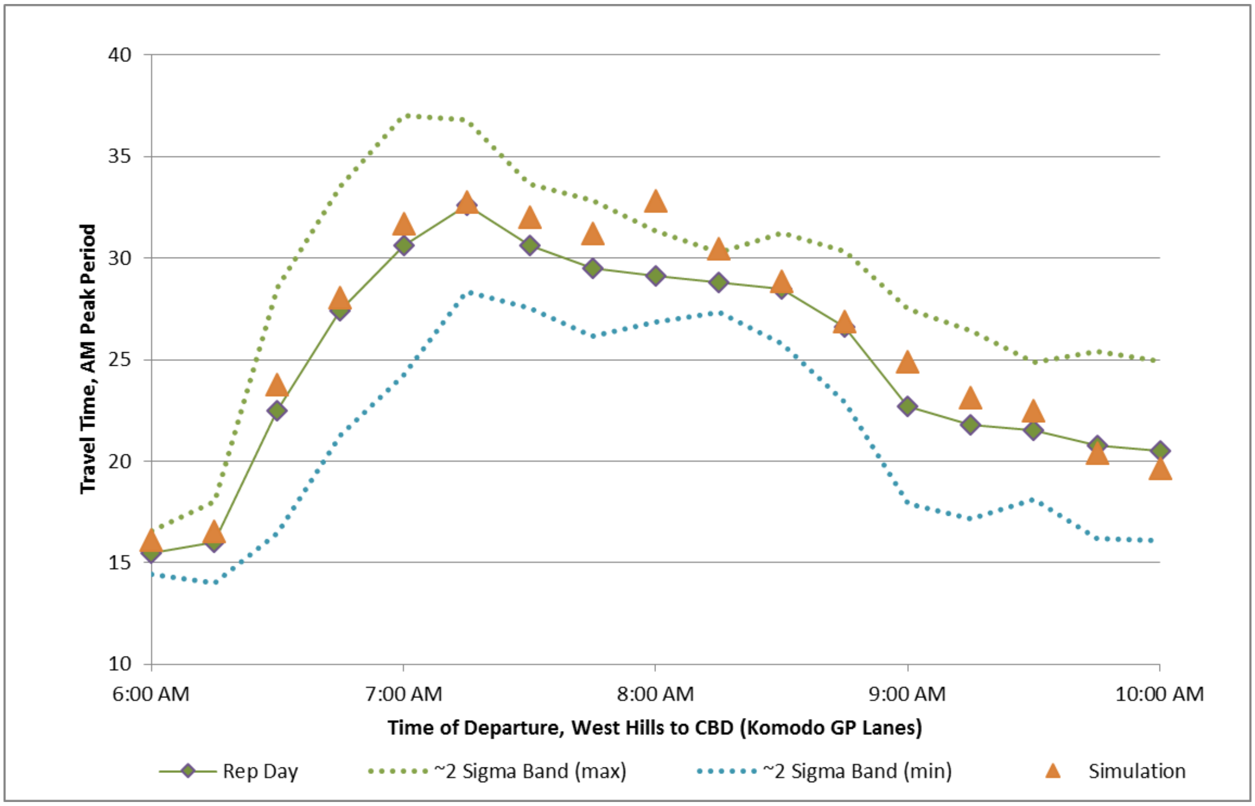

Figure 11. Chart. Assessing Criterion I, Alligator City (Source: FHWA)

Second, the analyst considers Criterion II to control for inliers (Figure 12). All of the points fall within the 1 Sigma Band except for three points (6:00 AM, 8:00 AM, 8:15 AM). The percentage of time periods within the 1 Sigma Band is 82% (14 of 17), higher than the 66.7% requirement. Critical time periods should also be considered. For this particular measure and representative day, the peak travel time occurs at 7:15 AM. The second highest non-adjacent travel time occurs at 7:45 AM. Both the 7:15 AM and 7:45 AM simulated travel times fall within the 1 Sigma Band. Therefore, the model variant passes Criterion II.

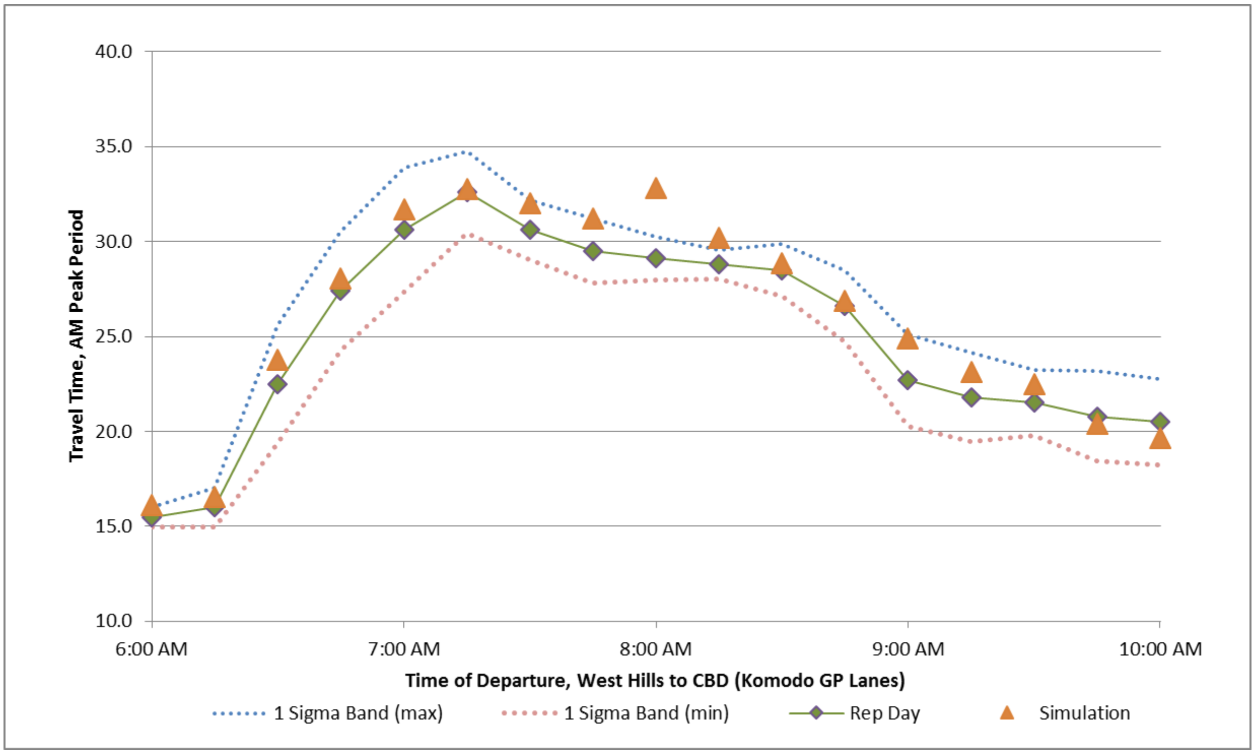

Figure 12. Chart. Assessing Criterion II, Alligator City (Source: FHWA)

Third, the analyst computes Bounded Dynamic Absolute Error threshold for this data set using the observed travel time data from each of the other days in the cluster and the representative day. These travel times were shown previously in Figure 11, above. The BDAE threshold for these data is 1.84 minutes. Differences between the simulated travel time and observed travel time are shown in Table 12. The average absolute difference between the simulated travel times and the representative day is 1.1 minutes, less than the BDAE Threshold of 1.84. Criterion III is met.

Fourth, the analyst considers the final criteria to determine if the simulation is an unacceptably large over or under estimator of the representative day. In this case, the threshold is set to one-third of the BDAE or 0.61 minutes. If the simulation does not, on average, overestimate travel times in excess of this threshold then the criterion is met. However, the simulation does indeed provide travel times that are on average 1.0 minutes longer than the representative day. Criterion IV is not met, because the current model is an unacceptably large over-estimator of travel time. The analyst will have to continue to alter model variant parameters to meet this criterion. For some simulation models, this may mean considering a slight reduction in target vehicle speeds, either globally or along the links of this specific route. This may influence other measures and locations, however. Note that the calibration criteria are only met when a single run meets all the calibration criteria for all measures and locations. Thus, the analyst should re-examine each criterion (I, II, and III) after making an adjustment to satisfy Criterion IV.

Table 12. Assessing Criteria III and IV, Alligator City

Time of Trip Start	Simulation	Rep. Day	Absolute Diff.	Diff.
6:00 AM	16.1	15.5	0.6	-0.6
6:15 AM	16.6	16.0	0.55	-0.5
6:30 AM	23.8	22.5	1.27	-1.3
6:45 AM	28.0	27.4	0.63	-0.6
7:00 AM	31.7	30.6	1.12	-1.1
7:15 AM	32.7	32.6	0.14	-0.1
7:30 AM	32.0	30.6	1.4	-1.4
7:45 AM	31.2	29.5	1.7	-1.7
8:00 AM	32.8	29.1	3.7	-3.7
8:15 AM	30.2	28.8	1.4	-1.4
8:30 AM	28.9	28.5	0.37	-0.4
8:45 AM	26.9	26.6	0.27	-0.3
9:00 AM	24.9	22.7	2.21	-2.2
9:15 AM	23.1	21.8	1.31	-1.3
9:30 AM	22.5	21.5	0.96	-1.0
9:45 AM	20.4	20.8	0.42	0.4
10:00 AM	19.7	20.5	0.84	0.8
		AVERAGE	1.1	-1.0

KEY POINTS

In summary, when calibrating a microsimulation study:

- Calibrate selectively, only for key performance measures.
- Performance measures for calibration should have good observed data.
- Calibrate a model variant for each travel condition.
- Use a representative day approach for calibration rather than a synthetic day combining multiple days.
- Calibration should be focused on bottleneck dynamics as well as time-variant performance measures.

CHAPTER 6. ALTERNATIVES ANALYSIS

Project alternatives analysis is Step 6 in the Microsimulation Analytical Process (Figure 13). It is the reason for developing and calibrating the microsimulation model. The lengthy model development process has been completed and now it is time to put the model to work. If the alternatives are to be evaluated in target future year, a future travel demand forecast will have to be incorporated to create future year model variant for each travel condition. The analyst should also create model sub-variants for each competing alternative for each travel condition. Alternatives analysis requires comparison between simulation runs that may have similar results. In these cases, there should be consideration of the impact of model variation. Even small variation resulting from simulation model stochasticity may impact the statistical validity observed in simulation outputs, which will in turn impact investment decisions. Hence, the analyst should consider multiple runs by varying random number seeds for alternatives analysis. As a first step, the analyst should run each model sub-variant four times under different random number seeds to assess variability in tactical driver behavior in the model sub-variant. Randomness in simulation outputs are analyzed to determine the required number of runs to satisfactorily assess statistical validity when comparing the impacts of competing alternatives. The analyst then runs each model sub-variant the required number of replication for each alternative to generate the necessary output to generate the key performance measures. A statistical test is then conducted to determine whether any differences between two alternatives are statistically significant, that is, these differences meet the minimum criteria that bounds the risk that differences are only related to randomness in model outputs.

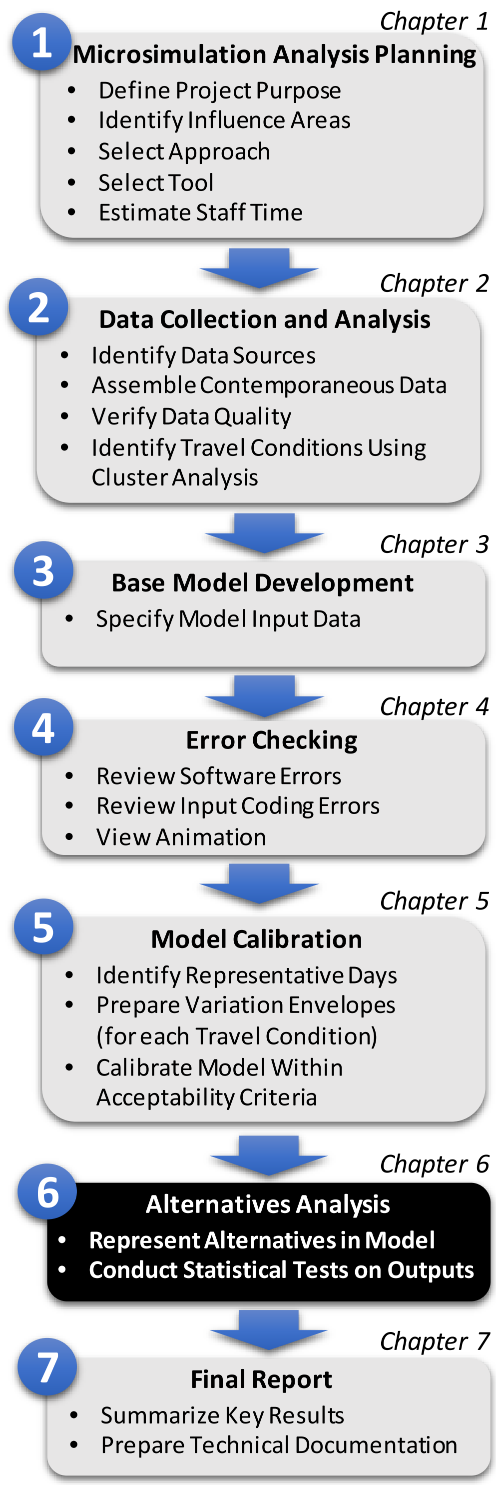

Figure 13. Diagram. Step 6: Alternative Analysis (Source: FHWA)

FORECAST FUTURE DEMANDS

Some analyses require the explicit consideration of system performance in future years. In these cases, the analyst should make a forecast of future year travel demand. Forecasts of future travel demand significantly different from current conditions are best obtained from a travel demand model, or from a multi-resolution modeling approach where the full range of dynamic travel demand attributes (including trip generation, distribution, mode choice, and trip start timing) can be considered collectively from the perspective of the complete transportation system.

These models require a great deal of effort and time to develop and calibrate. If one does not already exist, then the analyst (in conjunction with the simulation project management) may opt to develop demand forecasts based on historic growth rates. A trend-line forecast might be made, assuming that the recent percentage of growth in traffic will continue in the future. These trend-line forecasts are most reliable for relatively short periods of time (5 years or less). They do not take into account the potential of future capacity constraints to restrict the growth of future demand. Additional information and background regarding the development of traffic data for use in highway planning and design may be found in other resources (For example, the *National Cooperative Highway Research Program (NCHRP) Report 765*). Whatever the method selected, a description of the approach (and the rationale for the approach) should be captured within the *Methods and Assumptions* document.

Regardless of which method is used to estimate future demand (explicit travel demand modeling or simple trend line), care should be taken to ensure that the forecasts are a reasonable estimate of the actual amount of traffic that can arrive within the analytical period at the study area. Regional model forecasts are usually not well constrained to system capacity and trend-line forecasts are totally unconstrained. MRM approaches are generally more appropriate for future year demand estimation when travel demand is significantly larger than current travel demand.

All forecasts are subject to uncertainty. It is risky to assess competing alternatives to a precise future condition given the uncertainties in the forecasts. There are uncertainties in both the probable growth in demand and the available capacity that might be present in the future. Slight changes in the timing or design of planned or proposed capacity improvements outside of the study area can significantly change the amount of traffic delivered to the study area during the analytical period. Changes in future vehicle mix and the timing of travel demand can have a significant impact. Similarly, changes in economic development and public agency approvals of new development can significantly change the amount of future demand. Thus, it is good practice to plan for a certain amount of uncertainty explicitly in the analysis. This level of uncertainty is the purpose of sensitivity testing (explained in a separate section below).

REPRESENT ALTERNATIVES

In Step 1, competing alternatives are identified and detailed. Often times, however, the specificity required by the microsimulation to represent these alternatives is not evident until the travel conditions are defined. In this regard, the analyst can play a key role in working with stakeholders to further develop the concept in each alternative. For example, when considering a specific representative day with an incident, stakeholders may have to collectively make a decision as to whether this particular incident would trigger a response from the incident management system.

Detailed guidance on the accurate representation of elements of alternatives is highly dependent on the tool selected and is not in scope for this guidebook. However, several federal reports may be useful resources for specific types of alternatives. For example, TAT Volume XII is used for work zone alternatives, and TAT Volume XIII is used for integrated corridor alternatives. Both guides can be obtained from http://ops.fhwa.dot.gov/trafficanalysistools/.

DETERMINE REQUIRED NUMBER OF REPLICATIONS

Microsimulation models rely on random numbers to provide non-uniform elements of tactical driver behavior. These elements may include the type and sequencing of vehicles generated at origins, tactical decisions made regarding route and gap acceptance, and aggressiveness in lane changing behavior. The cluster analysis and calibration to specific travel conditions performed in the previous steps isolate the first order determinates of system variation (changes in travel demand patterns, incident patterns, and weather conditions). The inherent randomness in microsimulation models related to tactical driver behavior is second order compared to travel conditions. However, randomness from these stochastic processes within a microsimulation should still be accounted for within the alternatives analysis.

To generate an initial assessment of the impact of this randomness in support of alternatives analysis, run the model sub-variant associated with each alternative and travel condition four times using different random seeds. How random seeds are implemented in each simulation tool varies, but randomness is generally included in a default set of tactical driver behavioral models and vehicle generation processes. The minimum number of replications is calculated using the following equation:

$$N_{min} = \left(\frac{t_{n-1,95\%}s}{e\bar{x}}\right)^2 \qquad (15)$$

where:

N_{min}	:	Required number of model runs
n	:	Number of initial model runs (i.e., 4)
$\bar{x}, s$	:	Mean and standard deviation of the initial runs
$t_{n-1,95\%}$	:	*t* statistic for *n-1* degrees of freedom and 95% confidence level
e	:	Tolerance error

A confidence level of 95% is a traditional default to use. However, it may not always be the best value for every analysis. We need to identify an appropriate confidence level (a measure of accuracy when differentiating samples) and tolerance error (a measure of observed data precision).

Confidence Level should be determined by the decision-maker and not the analyst, prior to alternatives analysis. The choice of confidence level is typically associated with the required certainty for the decision-maker. In a broad sense, a higher confidence level is chosen when the consequences of being wrong are significant. For example, when analyzing safety critical systems, like airplane engine failures, the required confidence level might be 99.99%. However, the assessment of transportation alternatives may not be in the same category of down-side risk. Typical values are set between 80-95%, with 95% representing the highest confidence. A 95% confidence level is assumed unless otherwise set by project management (e.g., local agency policy) and logged in the *Methods and Assumptions* document.

Tolerance error, *e*, is calculated individually for each observed time-variant measure based on the two critical time periods, t_1 and t_2, identified for that measure. The expectation is that the most *within-cluster* variation is reflected at the critical time periods, when the dynamics of the system are in flux, transitioning from rise-to-fall (for travel time) or fall-to-rise (for throughput).

First, construct the confidence interval as follows:

$$\bar{x} \pm \left\{t_{n-1,95\%}\left(\frac{s}{\sqrt{n}}\right)\right\} \qquad (16)$$

where:

$\bar{x}, s$	:	Mean and standard deviation
n	:	Number of observations
$t_{n-1,95\%}$	:	t statistic for n-1 degrees of freedom and 95% confidence level

Tolerance error is computed as follows:

$$e = \frac{t_{n-1,95\%}\left(\frac{s}{\sqrt{n}}\right)}{\bar{x}} \qquad (17)$$

The numerator is also known as the margin of error.

Let $\bar{x}_1$, $s_1$and $\bar{x}_2$, s_2 be the mean and standard deviation of the measure at the two critical time periods for a given cluster, with n observations (or days). Calculate the tolerance error for the measure at the two critical time periods using the equations:

$$e_1 = \frac{t_{n-1,95\%}\left(\frac{s_1}{\sqrt{n}}\right)}{\bar{x}_1} \qquad (18)$$

$$e_2 = \frac{t_{n-1,95\%}\left(\frac{s_2}{\sqrt{n}}\right)}{\bar{x}_2} \qquad (19)$$

Set the tolerance error as the maximum of the two calculated tolerance errors at the two critical time intervals.

Run the model 4 times and compute the *simulated* average $\bar{x}$ and standard deviation s of the critical time-variant measures. Let $t_{3,95\%}$ be the t-statistic associated with a 95% confidence level and three degrees of freedom (3.182).

The required number of runs is calculated using the following formula, rounded up to the nearest whole number:

$$N_{min} = \left(\frac{t_{3,95\%}s}{e\bar{x}}\right)^2 \qquad (20)$$

The steps should be repeated for all key measures of interest and all clusters, and corresponding minimum number of runs should be calculated. The minimum number of model replications is then taken as the maximum of the minimum number of runs (N_{min}) computed for all key measures and all clusters.

In less congested conditions, there may be very little day to day variation resulting in very small tolerance errors. This can be problematic from a computational perspective since a small tolerance error will result in a large N_{min} with no gain in analytical insight as the result is many repetitions of essentially fixed near free-flow conditions. To guard against unreasonable N_{min} driven by small observed variation, we enforce a minimum floor for tolerance error of 5% as a practical guideline.

TEST DIFFERENCES IN ALTERNATIVES PERFORMANCE

When the microsimulation model is run several times for each alternative, the analyst may find that the variance in the results for each alternative is close to the difference in the mean results for each alternative. How is the analyst to determine if the alternatives are significantly different? To what degree of confidence can the analyst claim that the observed differences in the simulation results are caused by the differences in the alternatives and not just the result of using different random number seeds? This is the purpose of statistical hypothesis testing.

Perform Hypothesis Testing

In this step, we compare the results obtained examining two alternatives to see if the differences are statistically significant.

First, calculate the average performance measures for the two alternatives, x_1 and x_2, reflecting the frequency of each travel condition. For simpler measures like delay, this is a simple weighted sum using the frequency of each travel condition, as shown below:

$$\bar{x}_j = \frac{\sum_{i=1}^{C}(x_i \times n_i)}{\sum n_i} \qquad (21)$$

where:

- $\bar{x}_j$: Weighted average of measure for alternative *j*
- i : Cluster ID
- C : Total number of clusters
- x_i : Average performance measure estimate across all random number runs (i.e., N_{min}) for Cluster *i*
- n_i : Number of days in Cluster *i*

For other measures, like reliability, the individual results are combined in order to identify percentile-based statistics, such as 95th percentile planning time index.

Next, calculate the sample variance for the two alternatives as follows:

$$s_j^2 = \frac{\sum_{i=1}^{C}\left(x_i - \bar{x}_j\right)^2}{C} \qquad (22)$$

where:

s_j^2 : Variance of measure for alternative *j*

We assume population variances are unknown and equal. If variances are not equal, then Welch's t-test should be used. n_1 and n_2 are the number of simulation runs for the two alternatives. The pooled variance s_p^2 is the weighted average of the two sample variances, s_1^2 and s_2^2:

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)} \qquad (23)$$

Set up the hypotheses based on the evidence from the sample:

- Null Hypothesis, H_0: $\mu_1 \geq \mu_2$ OR $\mu_1 \leq \mu_2$
- Alternate Hypothesis, H_A: $\mu_1 < \mu_2$ OR $\mu_1 > \mu_2$

Calculate the test statistic:

$$t_{calculated} = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{s_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad (24)$$

Perform the hypothesis test:

- For H_0: $\mu_1 \geq \mu_2$, if $t_{calculated} \leq t_{n_1+n_2-2,\, 95\%}$, reject H_0 and accept H_A. Otherwise, we do not have enough evidence to reject H_0.

- For H_0: $\mu_1 \leq \mu_2$, if $t_{calculated} \geq t_{n_1+n_2-2,\, 95\%}$, reject H_0 and accept H_A. Otherwise, we do not have enough evidence to reject H_0.

Perform Sensitivity Testing

A sensitivity analysis is a targeted assessment of the reliability of the microsimulation results, given the uncertainty in the input or assumptions. The analyst identifies certain input or assumptions about which there is some uncertainty and varies them to see what their impact might be on the microsimulation results.

Additional model runs are made with changes in demand levels and key parameters to determine the robustness of the conclusions from the alternatives analysis. A sensitivity analysis of different demand levels is particularly valuable when evaluating future conditions. Demand forecasts are generally less precise than the ability of the microsimulation model to predict their impact on traffic operations. Additional runs may also be needed to address sensitivity to assumptions made in the analysis where the analyst may have little information, such as the percent of drivers listening to specific traveler information services.

EXAMPLE PROBLEM: ALTERNATIVE ANALYSIS

For the Alligator City travel time example, we examine the average and standard deviation of travel times at our two critical time periods, 7:15 AM and 7:45 AM. At 7:15 AM, the average travel time is 32.6 minutes, and the standard deviation is 2.2 minutes. At 7:45 AM, the average travel time is 31.0 minutes, and the standard deviation is 1.7 minutes. Raw tolerance error (excluding the 5% floor) at 7:15 AM is 0.97% and 0.81% at 7:45 AM. Since this falls below the 5% floor on tolerance error, a tolerance error of 5% is used.

Running the model variant 4 times for this condition produces an average travel time of 32.7 minutes with a standard deviation of 1.46 minutes. In this case the minimum number of runs is $(\frac{3.182\times1.46}{0.05\times32.7})^2 = 8.07$ runs. For this particular measure, alternative, and travel condition, 9 runs are required (8.07 rounded up to the nearest whole number).

A note regarding large N. In some cases where a model is not stable, a very large value of N (>20) may result. In these cases, it is not recommended to replicate 20 or more runs of the model sub-variant, but rather to investigate the reasons why a particular model sub-variant produces such a large variation in outputs. Sometimes it is an indicator that unrealistic gridlock conditions are being generated within the model, the results of which can skew model outputs. Model instability can also be symptomatic of model coding errors.

Table 13 provides a summary of aggregate statistics for the two competing Alligator City alternatives and a Do-Nothing case after a uniform number of random number seeds has been conducted (in this case, 5). Travel time is an aggregated value over the two major routes considering all time periods in the morning peak and weighted by each of the travel conditions. Throughput is a measure of average vehicles per hour exiting of all bridge and tunnel exits into Alligator City, considering all time periods in the morning peak period and weighted by travel condition. Planning time index is calculated as an origin-destination level measure from West Hills to Alligator City considering both potential routes and the variation in travel time over all time periods it the morning peak. The planning time index represents the ratio of the 95th percentile travel time to free-flow (uncongested) travel time from West Hills to Alligator City considering all travel conditions.

Table 13. Aggregate Results from Alligator City Alternative Analysis

Alternative	Performance Measures					
	Travel Time		Throughput		Plan Time Index	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Current Baseline	17.1	0.3	7463	189	2.02	0.25
Do Nothing	19.5	0.6	7209	369	2.15	0.35
Better Bridge and Tunnel	16.4	0.6	8337	450	2.65	0.36
Adapt and Redirect	16.6	0.8	8199	210	1.85	0.25

Examine a hypothesis considering the planning time index value for Adapt and Redirect (Alternative 1) compared to Better Bridge and Tunnel (Alternative 2). In this case, we seek to test whether the lower value for Adapt and Redirect when compared to that for Better Bridge and Tunnel is statistically significant. The hypotheses are set as follows: H$_0$: $\mu_1 \geq \mu_2$, H$_A$: $\mu_1 < \mu_2$.

The estimate for the pooled variance is:

$$s_p^2 = \frac{8 \times 0.36^2 + 8 \times 0.25^2}{9 + 9 - 2} = 0.096$$

$$t_{calculated} = \frac{1.85 - 2.65}{\sqrt{0.096 \times (\frac{1}{9} + \frac{1}{9})}} = -5.48$$

$t_{calculated} < \ t_{16,95\%}$ (-5.48 < 1.746), so we reject the null hypothesis that the planning time index for Alternative 1 is greater than or equal to that for Alternative 2, and conclude that the planning time index for Alternative 1 is statistically smaller. Similar comparisons of travel time and throughput can also be made. The overall result is that while the Adapt and Redirect (Alternative 1) generates a lower planning time index (i.e., higher reliability), for other measures the alternative is not clearly better (and for throughput worse). Similar comparisons should be made for the remaining alternatives.

KEY POINTS

In summary, when conducting alternatives analysis:

- Forecasting major shifts in future travel demand should be analyzed separately from the microsimulation.
- Every alternatives analysis requires multiple runs with different random seeds.
- Randomness in simulation outputs are related to variations in driver behavior models.
- Variation in results from different random seeds are not indicative of first order system variation, which are determined by travel conditions.
- Ensure models are stable and do not create unrealistic gridlock conditions, as this will create artificial (and dramatic) variation in outputs.

CHAPTER 7. FINAL REPORT

This chapter provides some guidance on preparing a short informative briefing on the analysis for stakeholders (Figure 14). In addition, this chapter discusses the documentation of the microsimulation analysis results in a final report and a technical appendix supporting the final report.

PREPARING THE RESULTS BRIEFING

Making a clear and concise presentation of analytical findings is a critical element of a successful microsimulation analysis. For some stakeholders, the presentation will be the most critical path to allowing the findings of the analysis to inform their decisionmaking. However, careful and thoughtful preparation for this vital presentation is often overlooked. In the whirl of activity when an analytical project is close to completion, there is a general tendency to focus on the most recent technical details, on difficulties with models, or with conflicting or unclear results obtained from the models. However, while technical issues may be fresh in mind, the presentation should not lose focus.

Remember your audience. Your stakeholders did not conduct the analysis. In fact, they may not have a clear recollection of what the study is and why it was performed. Therefore, the presentation should begin with the analytical objective and the context for the study. That is why the analytical effort was commissioned, so make sure there is a clear tie in all parts of the presentation to the motivations, objectives, and goals of the analysis.

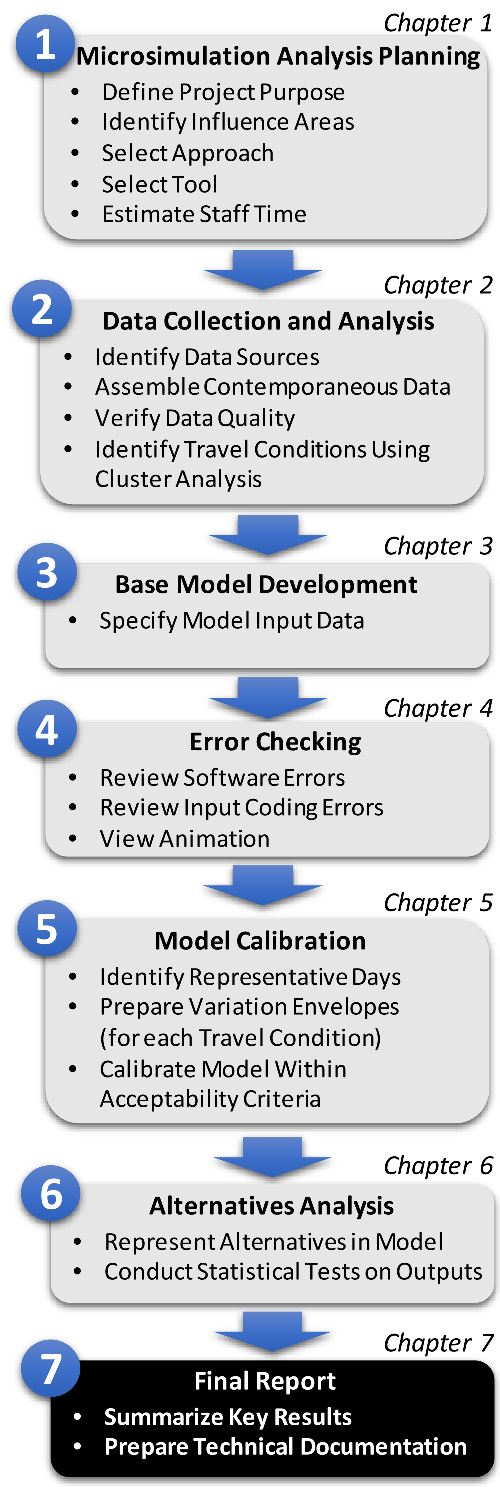

Figure 14. Diagram. Step 7: Final Report (Source: FHWA)

Clarify what was analyzed and not analyzed. Clearly describe the analysis plan and the travel conditions identified through the analysis of data. Clearly show how alternatives differ in both intent and in what specific model parameters or methods were used to capture those differences. Highlight insights gained regarding the performance of alternatives under various travel conditions and how this may influence how the underlying problem can be understood and resolved.

Inform stakeholders, but do not make their decisions for them. The presentation does not have to provide a simple yes/no answer for decision-makers, it provides insight that informs a broader decision. Don't forget to provide results, but keep them connected to supporting the decision. The story that you as the analyst can tell rapidly and effectively will be the most valuable part of any successful analysis to your stakeholders. In the case of a final presentation, graphics that capture a particularly important point, or an animation clip can be used to demonstrate certain aspects of system dynamics, for example, showing how coordinated diversion around an incident can reduce delay.

PREPARING THE FINAL REPORT

The final report presents the assumptions, analytical steps, and the results of the analysis in sufficient detail for decision makers to understand the basis for and implications of choosing among the project alternatives. The final report, however, will not usually contain sufficiently detailed information to enable other analysts to reproduce the results. That is the purpose of the technical report/appendix. The effort involved in summarization of the results should not be underestimated since microsimulation models produce a wealth of numerical output that should be tabulated and summarized. The final report should include the following:

- Study Objectives and Scope.
- Overview of Study Approach.
- Including Methods and Assumptions document entries.
- Data Collection.
- Travel Conditions.
- Calibration Tests and Results.
- Forecast Assumptions.
- Description of Alternatives.
- Results.
- Conclusions.

The technical report/appendix documents the microsimulation analysis in sufficient detail to enable an analyst to reproduce the results (the version or release of the software used is included). It may be an appendix to the final report or a separate document.

The technical report/appendix is a vital step in preserving the rationale for the various decisions that were made in the process of developing, calibrating, and operating a microsimulation model. The documentation should be sufficient so that given the same input files, another analyst can understand the calibration process and repeat the alternatives analysis.

KEY POINTS

In summary, when documenting and presenting analytic results:

- Step back and remember your stakeholders may require revisiting the objectives, alternatives, and assumptions to understand the implication of your results.
- Remember to inform decision makers, not try to make decisions for them.
- Present your “story” not all the details.
- Document in more detail and preserve analytical artifacts.

APPENDIX A. WORK ZONE CASE STUDY IN THE SEATTLE I-405 CORRIDOR

Appendix A presents a hypothetical case study in a large and realistic urban corridor to illustrate the updated 2019 guidelines of traffic microsimulation. In this case, the analytical project regards the application of a microsimulation analysis to support cost-effective planning for a significant work zone project. This case study was conducted using Washington State Department of Transportation (WSDOT) and University of Washington data archives and an existing WSDOT microsimulation model. However, the hypothetical situation described in this study (work zone repair in response to sinkhole damage from seismic activity) is neither based on actual events, nor do the alternatives analyzed here reflect WSDOT policies or contingency planning.

The Seattle I-405 Corridor

I-405 Corridor is a major commuter corridor in the Seattle area subject to periods of high travel demand and resultant congestion. In addition, the corridor experiences significant travel time variability as a result of dynamic incident patterns and frequent rain and fog. Figure 15 depicts the geographical coverage of the I-405 corridor in this case study, extending from a junction north of Lake Washington with I-5 to a junction rejoining I-5 south of Lake Washington. The length of the I-405 corridor is 29.5 miles.

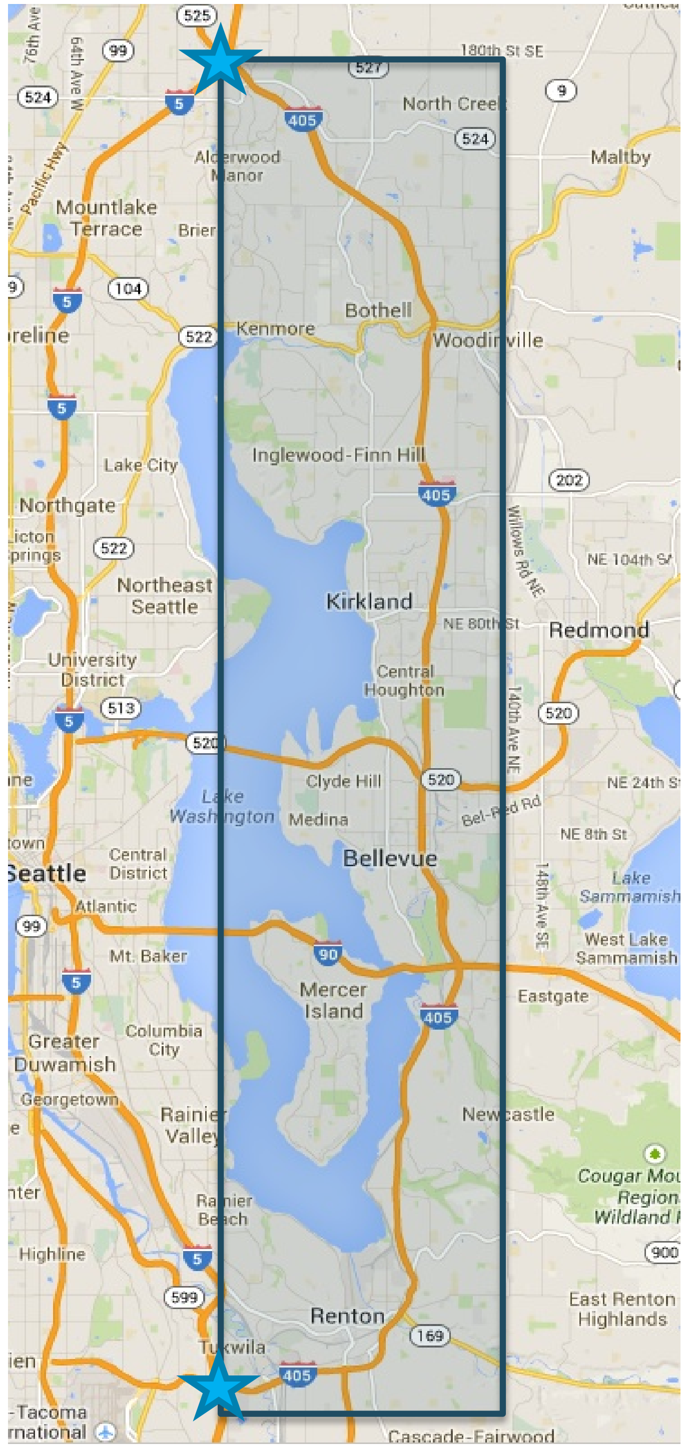

Figure 15. Map. I-405 Geographical Coverage (Source: Google Map/FHWA)

Purpose, Approach and Tool

In this hypothetical case study, the product of unanticipated seismic activity in the region has resulted in significant damage to the I-405 freeway facility. Two sinkholes have damaged segments of the I-405 roadway. The road is still passable and usable in all segments. However, significant rehabilitation is required within six months to the damaged sections. If these issues are not addressed within six months, there are risks of more substantial structural damage and the need for more expensive and complicated reconstruction. Repair work can and will be done on all available nights, weekends, and weekday midday periods. As a general policy, no work is planned for AM (6-10 AM) or PM peak (3-7 PM) periods because of expected congestion. However, completing the needed repair in six months with no peak period work will require expensive, expedited night and weekend work. Because of these high costs, there is interest in determining if *some* targeted peak period lane closures might be considered in this case to complete the work in the six-month window without incurring the additional expense of expedited off-peak work.

In order to inform this decision, alternatives analysis using microsimulation is selected for the project given a need for lane-level assessment of the precise alternative timing of potential lane closures. Total additional delays caused by a work zone is used as the primary measure differentiating alternatives, and travel time reliability is used as a supplemental measure of effectiveness. Two alternatives are proposed regarding the work zone schedule:

- *Alternative 1: Fixed Work Zone Schedule* – Work zone is inactive during both AM (6-10 AM) and PM (3-7 PM) peaks each weekday, i.e., work zone night work remains active from 7 PM until 6 AM and mid-day work begins from 10 AM to 3 PM each weekday. Work zone will always follow this simple schedule each weekday. This fixed schedule is consistent, direct and simple to explain. However, significant additional costs will be needed to expedite night and midday work to complete project within target period, or, alternatively, there are significant structural risks if project completion is delayed.

- *Alternative 2: Dynamic Work Zone Schedule with Supporting Traffic Management Strategies* – Road work continues from night session until the mid-day session under *Low Demand* travel conditions (20% of days), i.e., work zone remains active during AM peak on a set of anticipated low demand days. That allows four extra work hours to be logged for every low demand day. For other weekdays, work zone remains inactive during AM peak. To further reduce congestion, traffic management strategies with extra cost are added to this alternative:

  - Incident management: Dedicated incident response vehicles to reduce incident duration by 50%.
  - Detour/work zone warning: Additional buses and temporary parking lots combine to increase use of the alternate modes and routes during repair period, with an expected impact of reducing demand on selected north-south routes by 2%.

Available Data

The Washington Department of Transportation (WSDOT) regularly utilizes advanced data and simulation analytics to improve investments for operations. The agency has extensive experience in collecting traffic data, building and calibrating simulation models, and measuring system performance. At FHWA request, WSDOT provided 2012 traffic data, travel time information, incident data and weather information listed below. Data quality was checked/verified utilizing web-based capabilities provided by University of Washington.

- Vehicle count: 15-minute vehicle count and speed from permanent detector locations approximately every 1/2 mile along the I-405 mainline.
- Travel Times: five-minute estimated corridor travel times derived from speed data.
- Incident records that contain incident time, location, incident type, and lane closure information.
- Weather records (hourly) that contain temp, wind, snow, rain, visibility/fog.

As shown in Figure 16, two bottleneck locations were identified based on WSDOT Traffic Map Archive (http://www.wsdot.wa.gov/data/tools/traffic/maps/archive/?MapName=SysVert) and speed data. Note that these recurrent bottlenecks are characterized using the observed 2012 corridor data, and do not reflect the presence of the hypothetical sinkhole-related work zones.

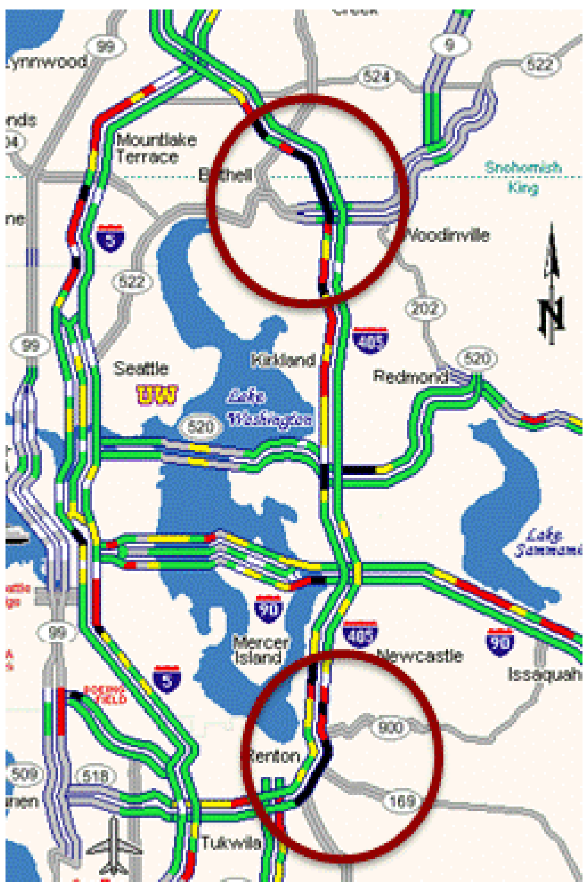

Figure 16. Map. Bottleneck Locations (Source: WSDOT)

- The northbound bottleneck is located at the interchange of SR-169 where the facility narrows by one lane.
- The southbound bottleneck is located just south of the SR-522 interchange due to a complex interchange with uphill and a large volume of merging traffic from SR-522 joining southbound I-405.

Cluster Analysis

This case study focuses on both northbound (NB) and southbound (SB) directions on the weekday morning peak, which is from 6:00 AM to 10:00 AM. Note that NB and SB facilities are analyzed together (not separately) in a single analysis. After removing weekends and holidays (not germane to our alternatives analysis), and the days where contemporaneous data were not available, a total of 196 weekdays were identified for cluster analysis. WEKA (Waikato Environment for Knowledge Analysis) is used in this case study for data normalization and analysis. The steps listed in Chapter 2 to identify travel conditions were followed and results obtained using the 196-day data archive, reported below.

<u>Steps 1 - 4: Identify and Select Attributes</u>

More than 30 potential attributes were initially considered for analysis. The following ten attributes were identified for each of the 196 days to represent variation in travel demand, underlying incident and weather-related impacts, and resulting aspects of system performance:

- Traffic Data: Average NB Entry flow rate, Average SB Entry flow rate, NB Bottleneck Duration and SB Bottleneck Duration (please refer to Chapter 5 for the definition of bottleneck duration).
- Travel Time Data: NB Maximum Travel Time and SB Maximum Travel Time. Note that this represents the “peak of the peak” travel time by direction based on 15-minute intervals.
- Incident Data: Total Number of Incidents on I-405 Corridor and Maximum Incident Duration during AM peaks.
- Weather Data: Rain and Visibility during AM peaks.

Since the selected attributes are numeric data, no further data processing is required. WEKA provides an automatic normalization function during cluster analysis process, so in this case study, data will be normalized through WEKA.

<u>Steps 5 - 6: Perform Clustering and Identify Stopping Criterion</u>

The WEKA K-Means option was used to perform cluster analysis. First, we calculated the maximum number of clusters to consider, $2\sqrt{n/2} = 2\sqrt{196/2} = 19.8$. Therefore, the maximum cluster size we considered was set to 20.

For the evaluation of the suitability of the WEKA-identified clusters by number of clusters, we first selected Option 2 (see Equation 3 of Chapter 2), heuristic assessment. Figure 17 plots the heuristic fitness index against the clusters obtained under a constraint of four clusters through 20 clusters. As a reminder, the heuristic index is obtained by multiplying the number of clusters by the average coefficient of variation among identified clusters. A cluster size of three was also considered but the obtained heuristic fitness value was too large to be included in this Figure 17. A five-cluster grouping generates the lowest heuristic index.

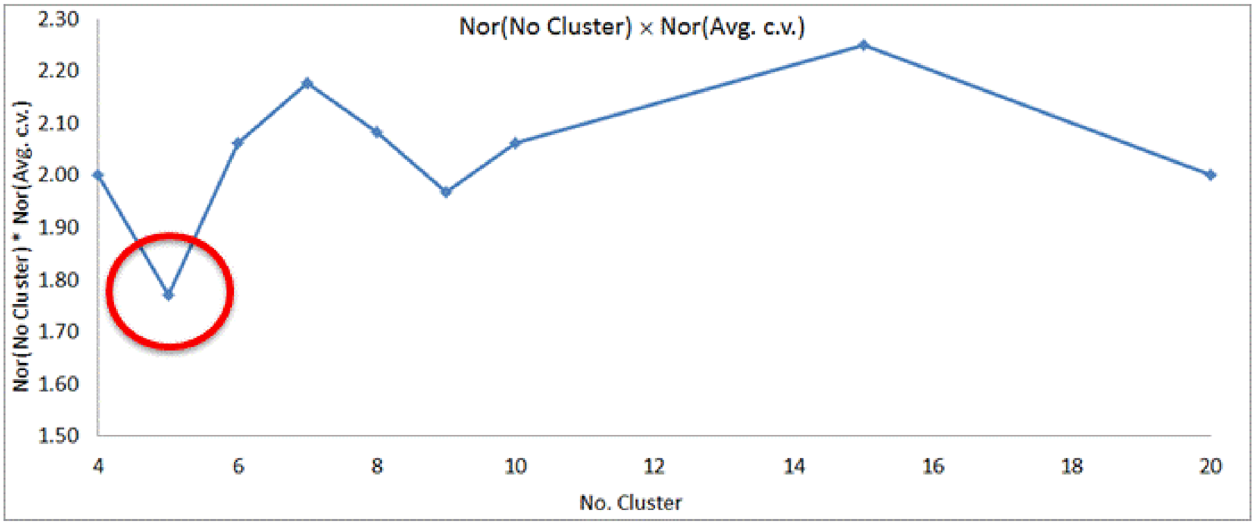

Figure 17. Chart. Plot of Heuristic Index Calculation Results (Source: FHWA)

For this study, we also examined the Sum of Squared Error (SSE), as another indicator of cluster performance. SSE is a measure of intra-cluster variation, essentially providing a measure of how close each of the days in the cluster are to the mean value for the ten critical attributes.

Table 14 and Table 15 present a comparison of the SSE for 4-cluster, 5-cluster and 6-cluster cases. In Table 14, the 5-cluster case has a lower average coefficient of variation and the 6-cluster case has the lowest SSE. In Table 15, the 5-cluster case has a high SSE in the Cluster 4 group, which indicates that there are potentially a large number of different days in this larger cluster. Adding one more cluster (i.e., the 6-cluster case) lowers the SSE significantly for this group. Therefore, a 6-cluster case is chosen for this case study.

Table 14. Sum of Squared Error and Average Coefficient of Variation for Different Number of Clusters

No Clusters	**4**	**5**	**6**
SSE	44.79	40.12	37.42
Avg. c.v.	0.26	0.24	0.25

Table 15. Sum of Squared Error for Each Cluster Group

SSE	Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
5 Clusters	9.67	8.47	1.77	6.61	**13.59**	n/a	n/a
6 Clusters	7.57	7.44	1.77	8.22	**4.45**	**7.96**	n/a

After running WEKA using the K-Mean approach with the number of clusters as six, Table 16 summarizes the cluster analysis results. As shown in Table 16, each cluster (or travel condition) is given a descriptive name based on the values of the attributes. Figure 18 is the travel condition dartboard, which provides a graphical view of the six identified travel conditions.

Table 16. A Summary of Cluster Analysis Results

Attributes	All	Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
No. Days	**196**	**40** (20%)	**25** (13%)	**6** (3%)	**41** (21%)	**28** (14%)	**56** (29%)
Cluster Description		Low Demand	Low Visibility	Weather + Incidents	Many Incidents	Bottleneck Trouble	Few Incidents
NB Entry Flow Rate	4451	4438	4353	4185	4417	4507	4528
SB Entry Flow Rate	3288	3584	3152	2726	3169	3101	3379
NB Bottleneck Duration	74.46	21.0	71.4	55.0	69.1	128.0	93.2
SB Bottleneck Duration	113.6	39.4	127.2	112.5	149.3	190.7	95.9
NB Max. Travel Time	54.9	48.8	57.0	69.2	58.7	57.5	52.6
SB Max. Travel Time	63.2	45.5	69.7	90.3	67.6	74.7	61.0
No. Incidents	1.64	1.63	1.60	2.67	2.98	1.21	0.79
Max. Incident Duration	22.8	27.7	21.1	62.3	28.5	20.0	13.2
Visibility	8.45	9.53	2.25	3.33	9.48	9.03	9.96
Rain	0.013	0.008	0.032	0.135	0.008	0.008	0.002

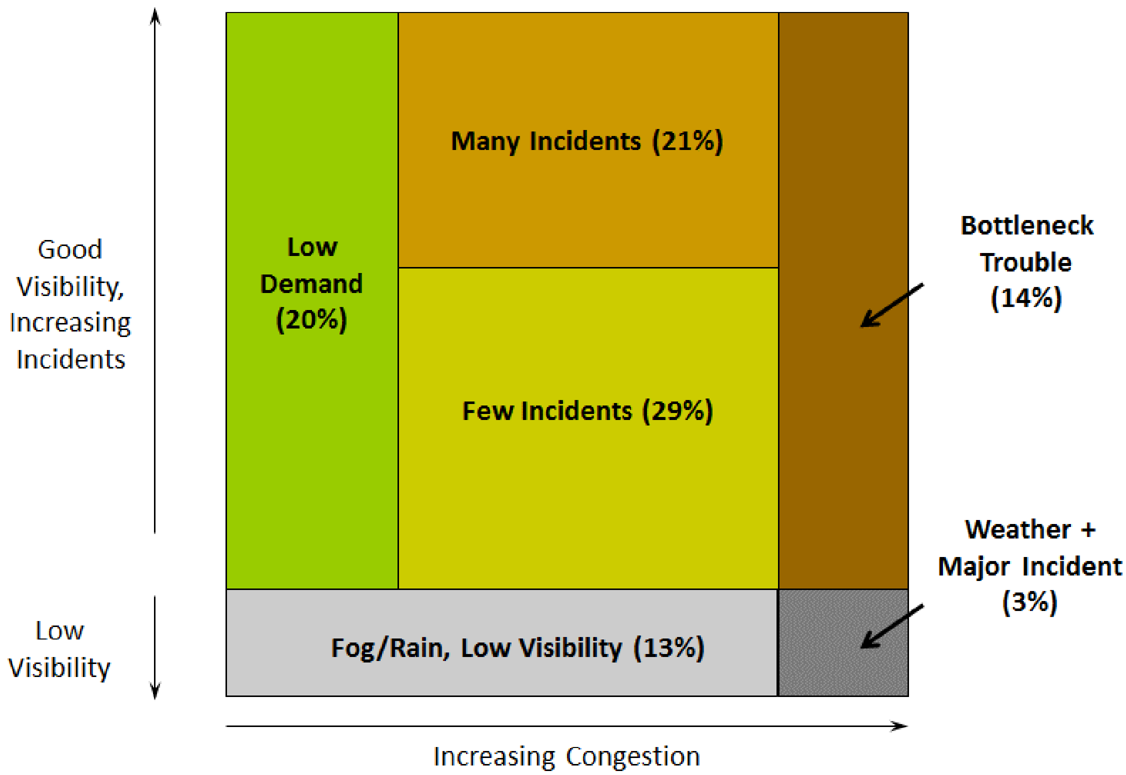

Figure 18. Diagram. I-405 Travel Condition Dartboard (Source: FHWA)

Model Calibration

WSDOT provided an I-405 VISSIM [26] model previously calibrated for a "nominal average day" for the purposes of an earlier study. This network is used as the initial working base model to perform calibration for the six identified travel conditions. In this model, calibration process, travel time and bottleneck throughout are selected as the key performance measures.

Step 1: Identify Representative Days

Based on the guidance in Chapter 5, a single representative day for each travel condition is selected that minimizes the average Euclidean distance. Figure 19 depicts the travel time and bottleneck throughput profiles of all the clusters compared to the "nominal average day" for both NB and SB directions. From the figures, one may observe that the profiles of the six travel conditions are different from each other and the "nominal average day" only has a good match for the *Few Incidents* travel condition (Cluster 5).

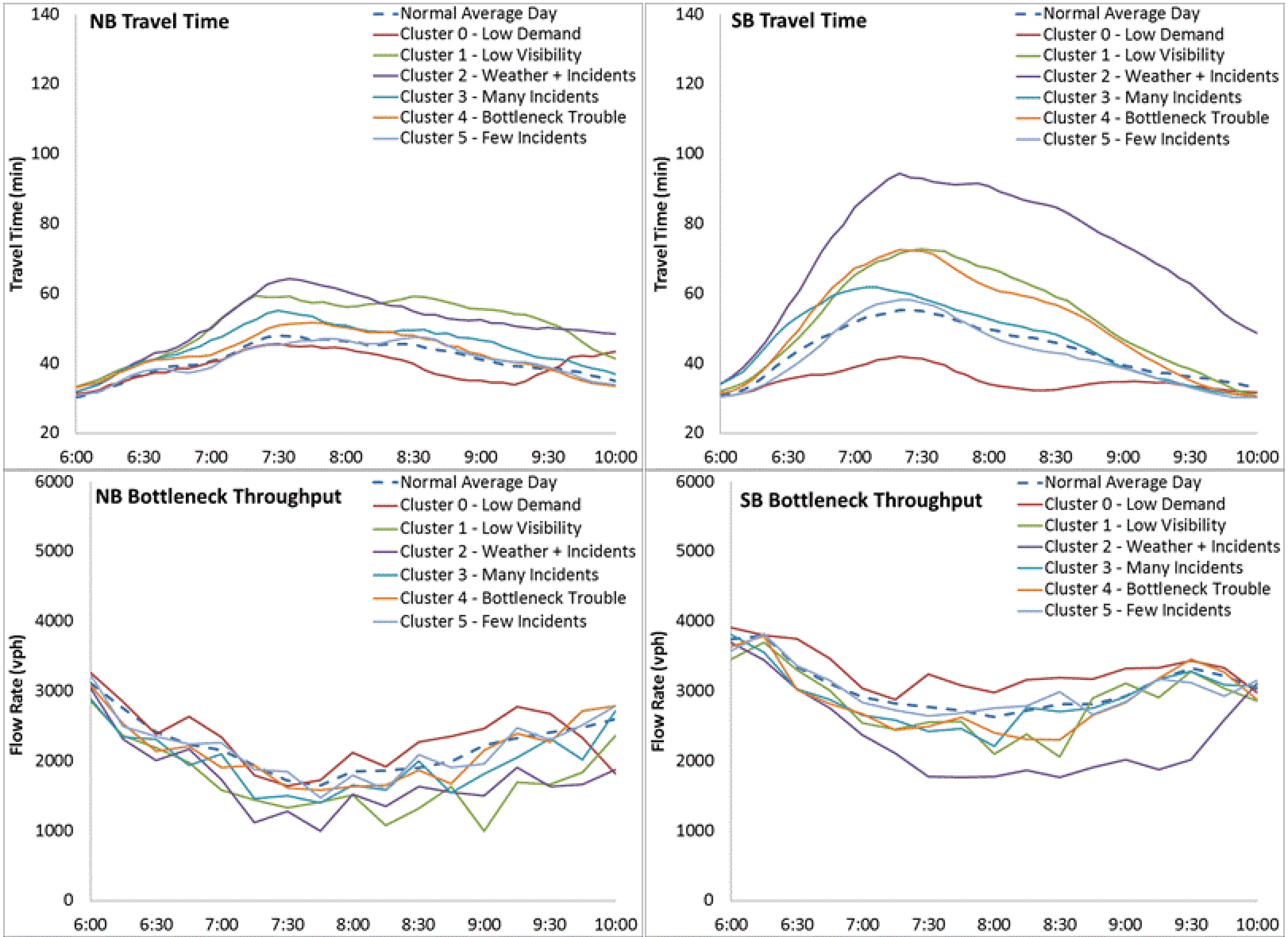

Figure 19. Chart. Travel Time and Bottleneck Throughput Profiles for Each Travel Condition (Source: FHWA)

Steps 2-3: Prepare Variation Envelopes and Calibrate Model Variants

In this case study, corridor travel time and bottleneck throughput at 15-min. time intervals are selected as calibration performance measures. The selection of the two bottleneck locations is described previously. The variation envelopes for all the travel conditions are created based on the guidance in Chapter 5. Figure 20 shows a subset of travel demand origins that were the focus of demand adjustment (both total flow and temporal profile) during the calibration process. The AM peak period extends from 6:00 AM to 10:00 AM. The simulation is set to start at 5:30 AM to provide a 30-min. warm up time and end at 10:30 AM to make sure the vehicles starting at 10:00 AM can complete the trip and be included into calculation. It is noteworthy that the 5-hour (5:30 to 10:30 am) simulation running time is about 3 hours of actual time. In this case study, demand, speed distribution, and car-following headways are used as adjustable parameters.

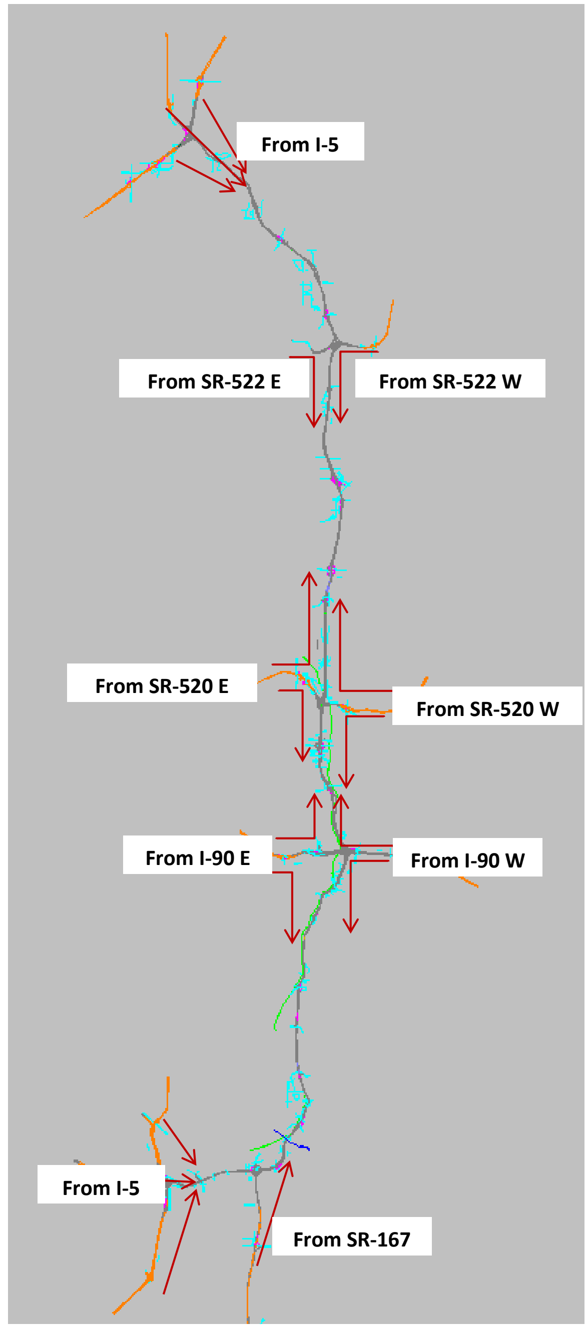

Figure 20. Map. Locations for Demand Adjustment (Source: FHWA)

Figure 21 through Figure 26 illustrate the variation envelopes and calibration results for each travel condition. In each figure, the orange line represents the selected representative day, the pink and light green dashed lines are the 1 sigma and ~2 sigma bands, and the green triangles are the simulation results. The two critical time intervals are selected based on the guidance listed in Chapter 5. The critical time intervals for travel time are marked with red dots along the representative day line. The critical time intervals for bottleneck throughput are indicated with red circles. Table 17 summarizes the calculation results of the acceptability criteria listed in Chapter 5.

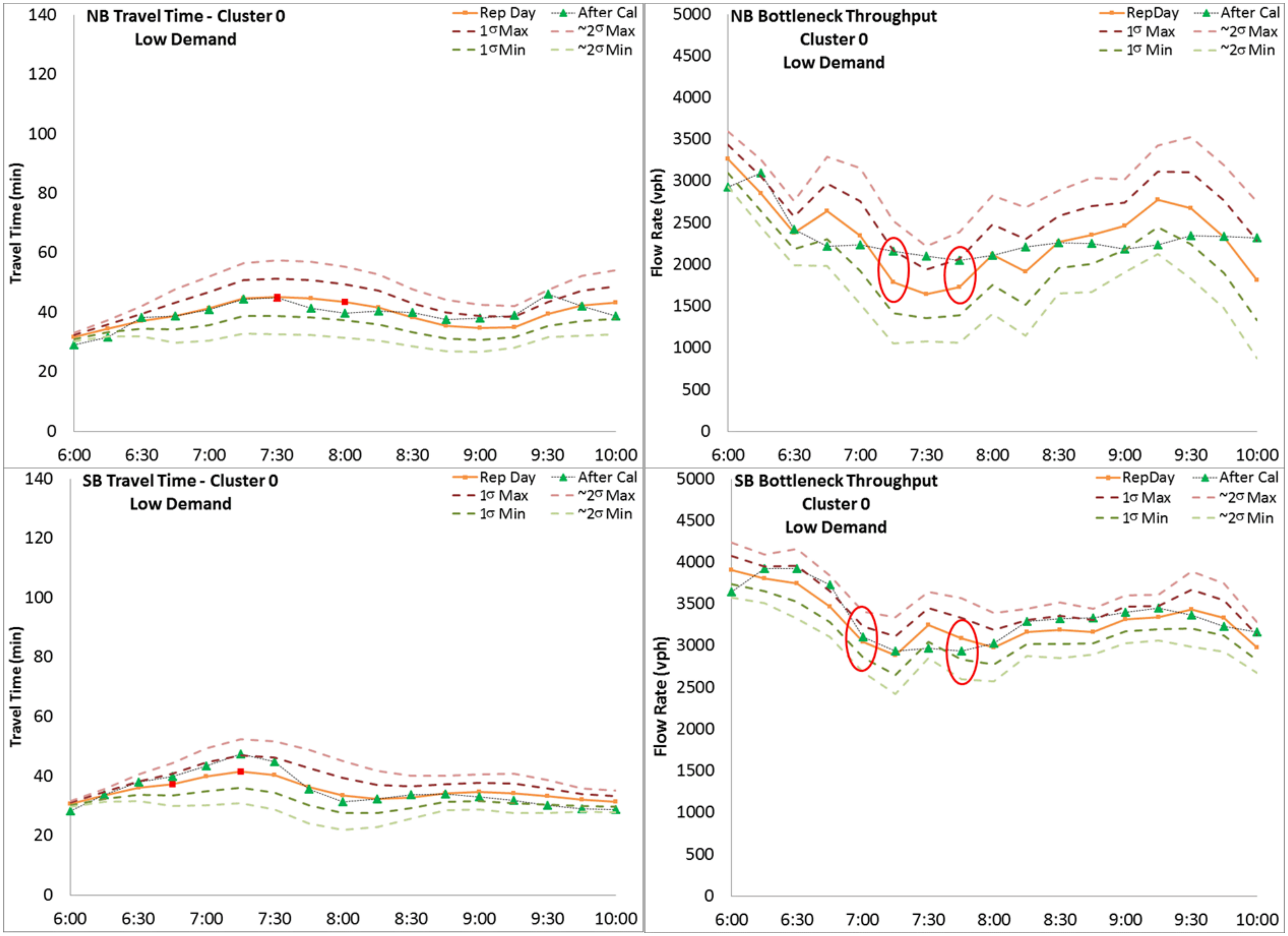

Figure 21. Chart. Variation Envelope and Calibration Results for Low Demand Travel Condition (Source: FHWA)

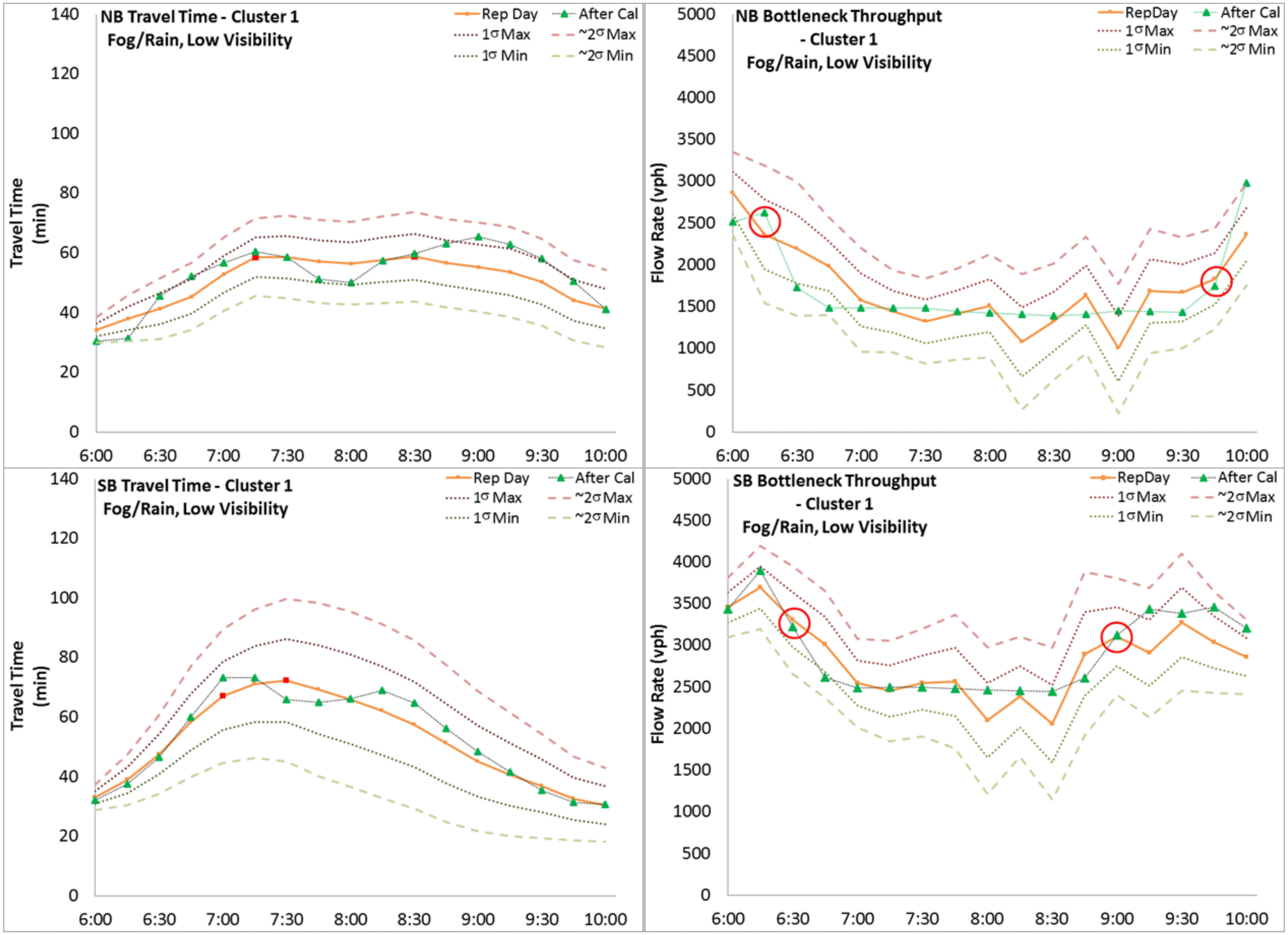

Figure 22. Chart. Variation Envelope and Calibration Results for Low Visibility Travel Condition (Source: FHWA)

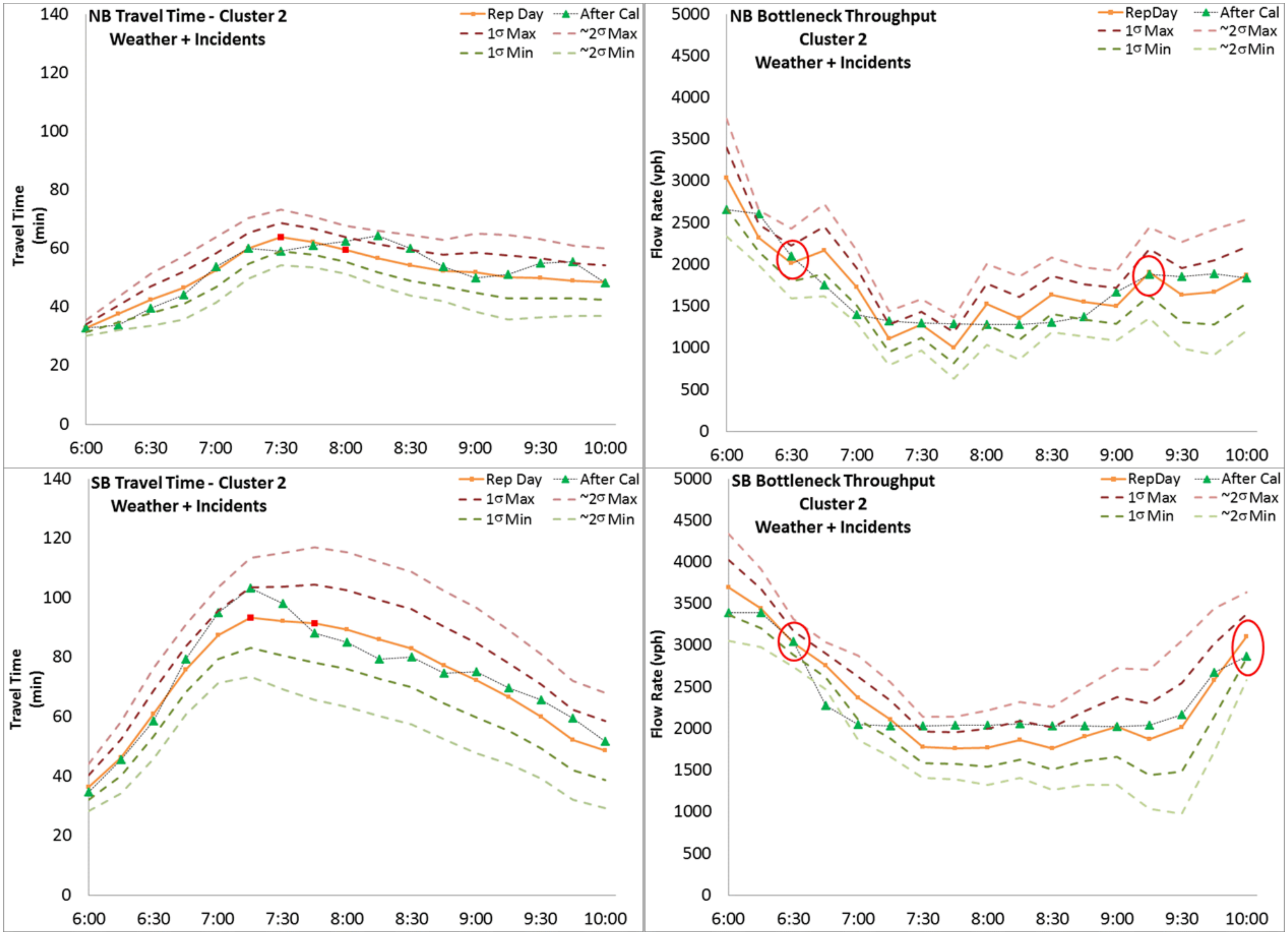

Figure 23. Chart. Variation Envelope and Calibration Results for Weather + Incidents Travel Condition (Source: FHWA)

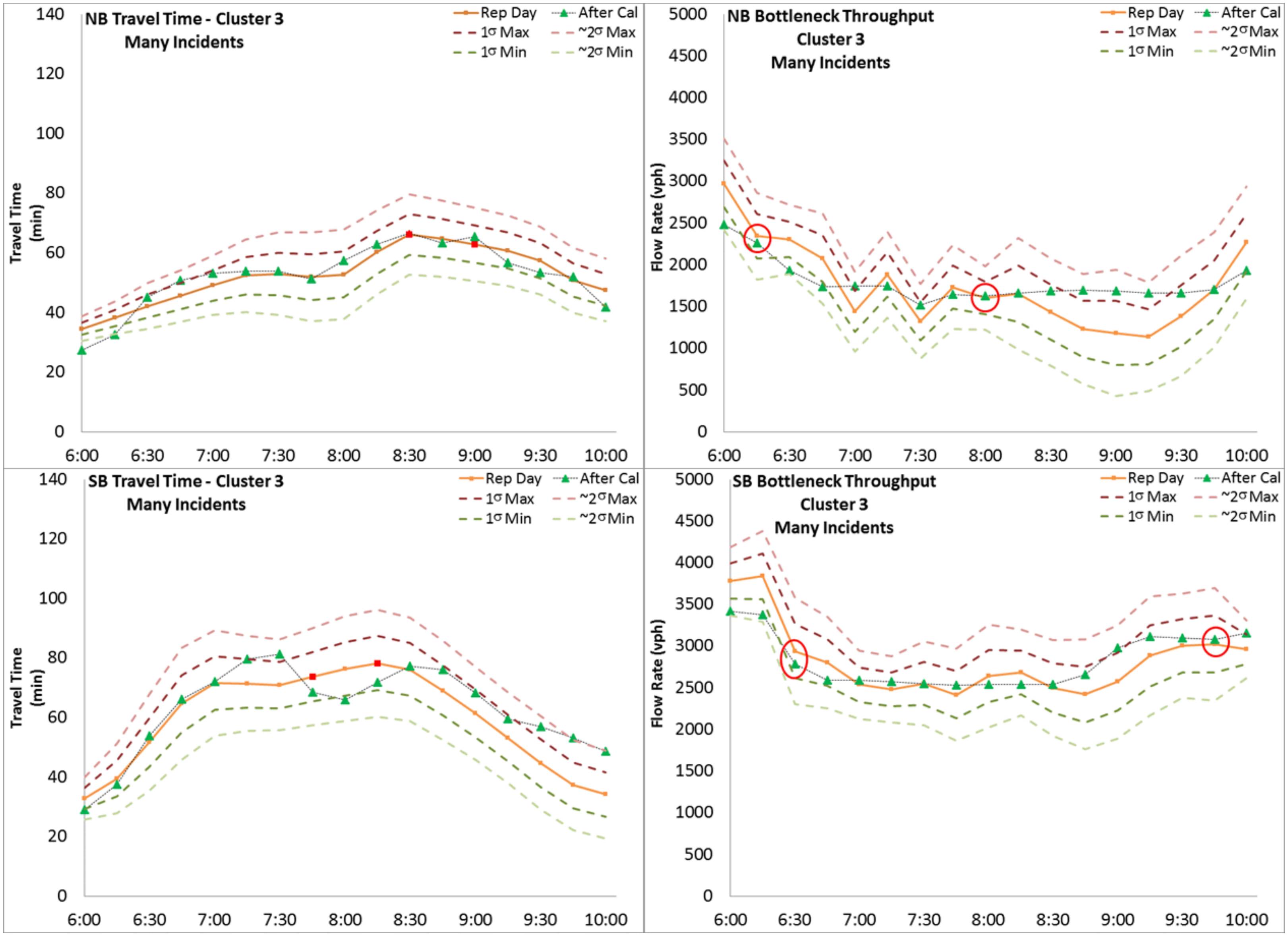

Figure 24. Chart. Variation Envelope and Calibration Results for Many Incidents Travel Condition (Source: FHWA)

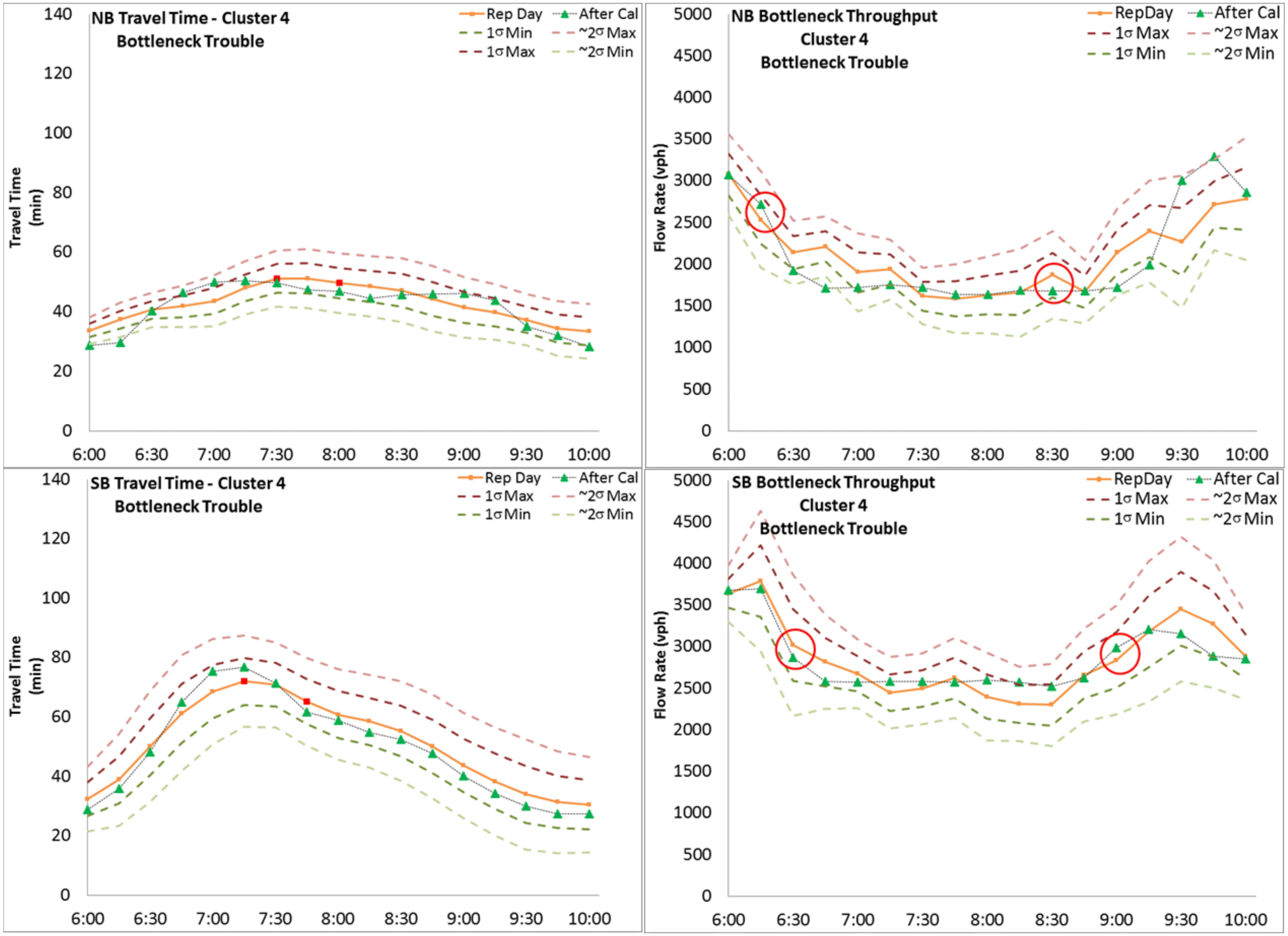

Figure 25. Chart. Variation Envelope and Calibration Results for Bottleneck Trouble Travel Condition (Source: FHWA)

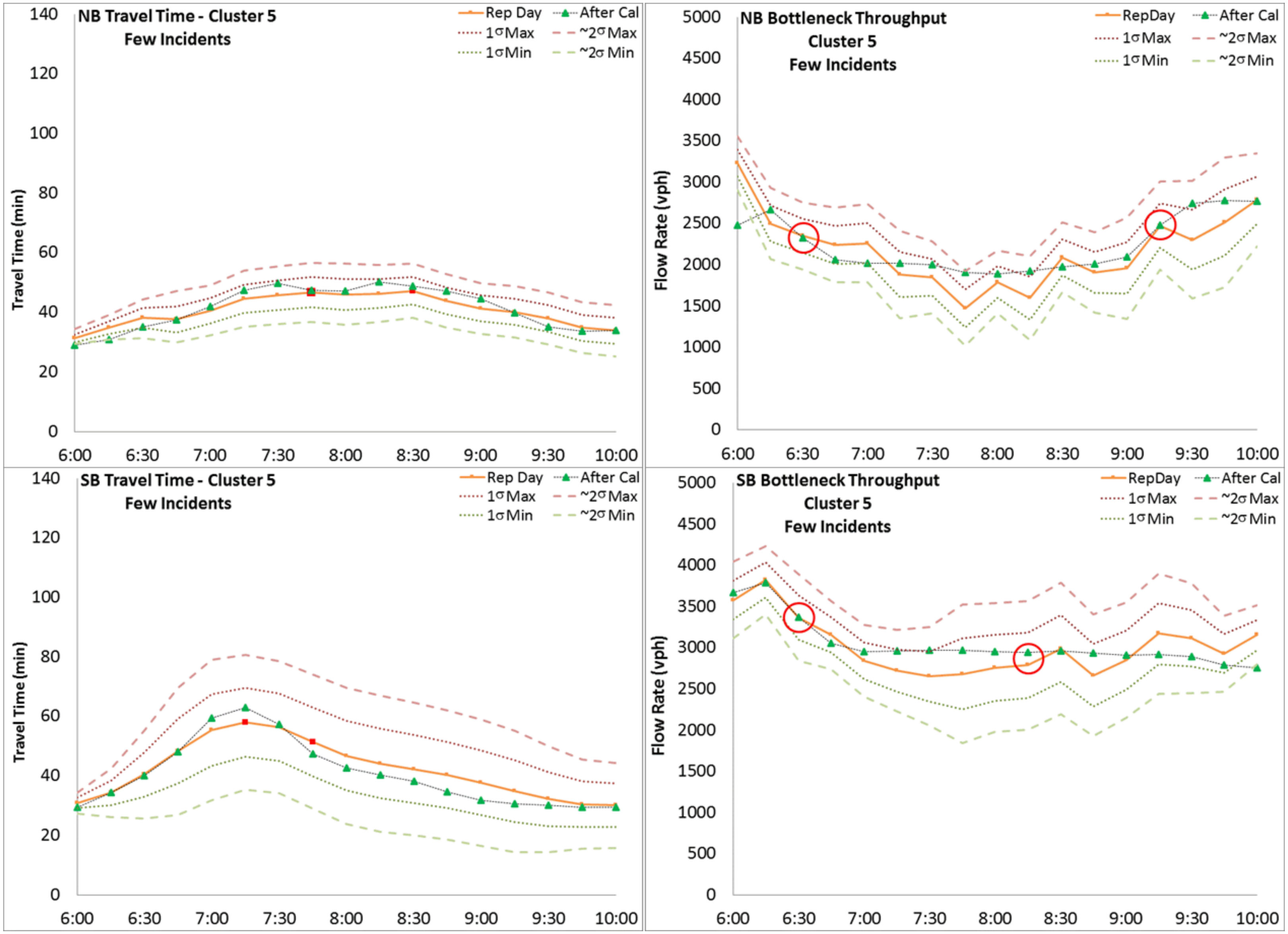

Figure 26. Chart. Variation Envelope and Calibration Results for Few Incidents Travel Condition (Source: FHWA)

Table 17. Summary of Acceptability Criteria Calculation Results

Travel Conditions	**Direction**	**Key Measures**	**Criterion I:** Control for Time-Variant Outliers	**Criterion II:** Control for Time-Variant "Inliers"		**Criterion III:** $\frac{\sum_t \lvert c_r(t)-\tilde{c}_r(t)\rvert}{N_T} \le$ ***BDAE Threshold***	**Criterion IV:** $\frac{\lvert\sum_t c_r(t)-\tilde{c}_r(t)\rvert}{N_T} \le \frac{1}{3}\times$ ***BDAE Threshold***	**All Criteria Met**
				2/3 Results	Critical Time Intervals			
Low Demand	NB	Travel Time	94%	82%	✓	2.24 < 4.62	0.04 < 1.54	✔
		Throughput	100%	71%	✓	272.3 < 326.2	22.6 < 108.7	
	SB	Travel Time	94%	82%	✓	2.22 < 3.11	0.06 < 1.04	
		Throughput	100%	82%	✓	140.4 < 175.3	39.8 < 58.4	
Low Visibility	NB	Travel Time	100%	76%	✓	4.75 < 7.53	2.01 < 2.51	✔
		Throughput	94%	76%	✓	248.8 < 374.3	19.7 < 124.8	
	SB	Travel Time	100%	100%	✓	6.00 < 9.21	0.98 < 3.07	
		Throughput	100%	76%	✓	205.5 < 313.3	88.3 < 104.4	
Weather + Incidents	NB	Travel Time	100%	88%	✓	2.90 < 5.20	0.86 < 1.73	✔
		Throughput	100%	71%	✓	206.5 < 261.6	30.5 < 87.2	
	SB	Travel Time	100%	100%	✓	4.31 < 10.48	1.44 < 3.49	
		Throughput	94%	71%	✓	193.4 < 291.4	20.8 < 97.2	
Many Incidents	NB	Travel Time	94%	88%	✓	3.23 < 9.07	0.17 < 3.02	✔
		Throughput	100%	71%	✓	258.2 < 412.0	42.2 < 137.3	
	SB	Travel Time	100%	71%	✓	6.74 < 12.22	3.48 < 4.07	
		Throughput	100%	88%	✓	174.0 < 255.3	4.1 < 85.1	
Bottleneck Trouble	NB	Travel Time	94%	82%	✓	3.54 < 4.71	0.75 < 1.57	✔
		Throughput	100%	71%	✓	228.2 < 262.6	19.2 < 87.5	
	SB	Travel Time	100%	100%	✓	3.36 < 8.63	1.48 < 2.88	
		Throughput	100%	100%	✓	146.7 < 288.9	14.9 < 96.3	
Few Incidents	NB	Travel Time	100%	88%	✓	2.14 < 3.40	0.52 < 1.13	✔
		Throughput	94%	92%	✓	211.9 < 235.1	55.1 < 78.4	
	SB	Travel Time	100%	100%	✓	2.80 < 5.96	1.60 < 1.99	
		Throughput	94%	94%	✓	171.7 < 259.7	32.9 < 86.6	

As noted in the guidance in Chapter 5, since only 17 time intervals are used to characterize time-dynamics in this case study, one simulated result is allowed to fall outside the ~2 Sigma Band for Criterion I. Therefore, in Table 17, 94% still meets Criterion I. The simulation models for all the identified travel conditions are now well-calibrated for work zone alternatives analysis.

Work Zone Alternative Analysis

When modeling hypothetical active and inactive work zone conditions, several assumptions were made and logged in the Methods and Assumptions document:

- When the work zone is not active, there are no lanes taken away but speed must be reduced for safety and to reduce roadway structural impacts. Capacity and speed impacts within work zone areas are:
  - 5% loss in capacity for all lanes (squeezed lanes, equipment on shoulders).
  - Speed reduced by 10 mph [22].
- When the work zone is active, one lane must be taken away and speeds reduced. Capacity and speed impacts within work zone areas are:
  - 33% capacity drop per lane for other lanes because lanes are narrowed [23].
  - Speed in the active work zone area reduced by 20 mph [24].

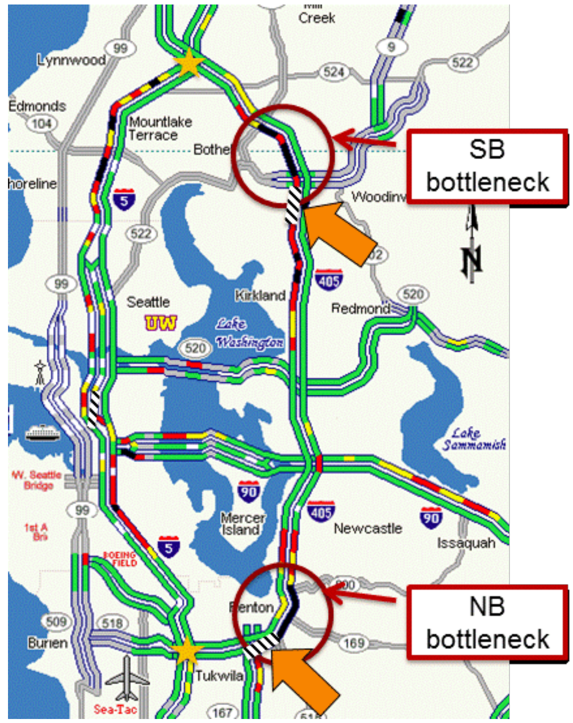

Figure 27. Map. Sinkhole Damaged Sections (Source: WSDOT)

Figure 27 illustrates the damaged sections that require repair: one on the SB direction right after the SB bottleneck location and one on the NB direction prior to the NB bottleneck location. Each work zone length is about 2000 feet.

Traditional Alternatives Analysis (Does Not Follow Updated Guidance)

Alternatives analysis was conducted using both a traditional "average day" method and with the updated "travel conditions" method with the following hypotheses:

- Using the traditional "average day" analysis, the effect of the two alternatives cannot be effectively differentiated.
- Using the "travel conditions" analysis, the effect of the two alternatives can be more effectively differentiated and will yield a statistically significant conclusion.

Traditionally, only one single "average day" would be identified after removing outlier data and averaging the remaining data ignoring impacts from incidents and weather. Figure 28 shows the SB direction travel time profiles of the two alternatives. In this figure illustrating the traditional approach of a single "average day", there is little differentiation of the effects of traffic management strategies (Alternative 1 vs. Alternative 2 with inactive work zones). The red line, with work zone active, represents the 20% of weekdays when a lane closure would be extended through the AM peak. As expected, on the SB direction, the travel times are relatively high in when a lane closure is introduced in the peak period.

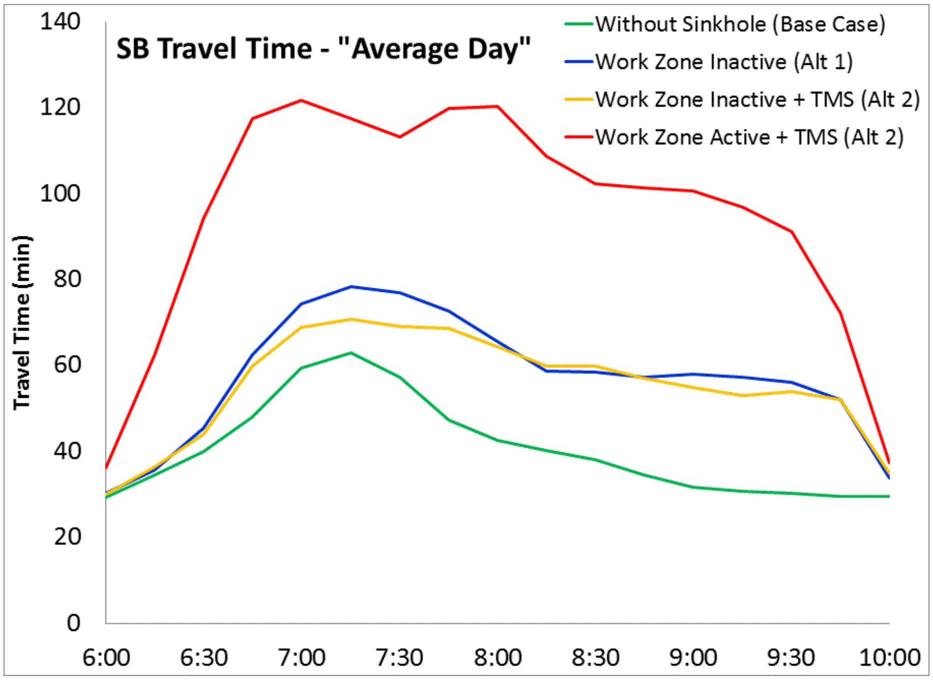

Figure 28. Chart. Travel Time Profiles of Alternatives (Source: FHWA)

Total additional delays due to work zones was used as the key performance measure in this alternatives analysis. The total additional delay for Alternative 1 is calculated directly from the work zones inactive condition, i.e., the blue line in Figure 28. The total additional delay for Alternative 2 is calculated from the combination of the two work zone conditions: eighty percent of the delay from work zones inactive with traffic management strategies (yellow line) plus twenty percent of the delay from work zones active with traffic management strategies (red line).

The required number of simulation runs for the "average day" case is obtained using the equations provided in Chapter 6. Using four pre-simulation runs yields a result that fewer than four runs are required, therefore four simulation runs will be used. After running simulation four times for both alternatives, Table 18 summarizes the total additional delay calculation during AM peak for the entire work zone period.

Table 18. Total Additional Delay Calculation using Traditional Approach

Alt	No. Weekdays	Total Additional Delay (hours)	Standard Deviation
Alt 1 (X1)	130	2,567,483	83,973
Alt 2 (X2)	112	2,588,419	85,253

The Null Hypothesis is set as H_0: $\mu_1 \leq \mu_2$. Using t-test listed in Chapter 6, we do not have enough evidence to reject H_0. This implies that when using the traditional "average day" analysis, we cannot statistically determine that Alternative 1 results in lower total additional delay than Alternative 2.

Travel Conditions Alternatives Analysis (Follows Updated Guidance)

The updated approach gives each travel condition a weight based on how frequently that condition occurs. Therefore, total additional delay is calculated as a weighted sum of delay observed in each travel condition. This allows the analyst to avoid gross generalizations incurred in the "average day" approach when estimating delay. Table 19 presents how delay is calculated in each travel condition. For Alternative 1, the work zone is inactive during the AM peak all the time, while for Alternative 2, the work zone is active under the *Low Demand* travel condition and the traffic management strategies are applied throughout the entire construction period.

Table 19. Delay Estimation Method in Travel Conditions Alternatives Analysis

	Low Demand	Low Visibility	Weather + Incident	Many Incidents	Bottleneck Trouble	Few Incidents
Alter 1	Inactive (20%)	Inactive (13%)	Inactive (3%)	Inactive (21%)	Inactive (14%)	Inactive (29%)
Alter 2	Active + TMS (20%)	Inactive + TMS (13%)	Inactive + TMS (3%)	Inactive + TMS (21%)	Inactive + TMS (14%)	Inactive + TMS (29%)

Figure 29 and Figure 30 illustrate travel time profiles of different travel conditions. Figure 29 is the SB travel time profile of *Low Demand* travel condition, where the work zone is inactive in Alternative 1 and active with traffic management strategies in Alternative 2. As expected, activating the work zone on low demand days during AM peak traffic management strategies causes extra delay. Figure 30 is the SB travel time profile of *Many Incidents* travel condition, where the work zone is inactive in both alternatives and with traffic management strategies applied to Alternative 2. The incident management strategy and demand management strategy in Alternative 2 improve corridor travel time compared to Alternative 1.

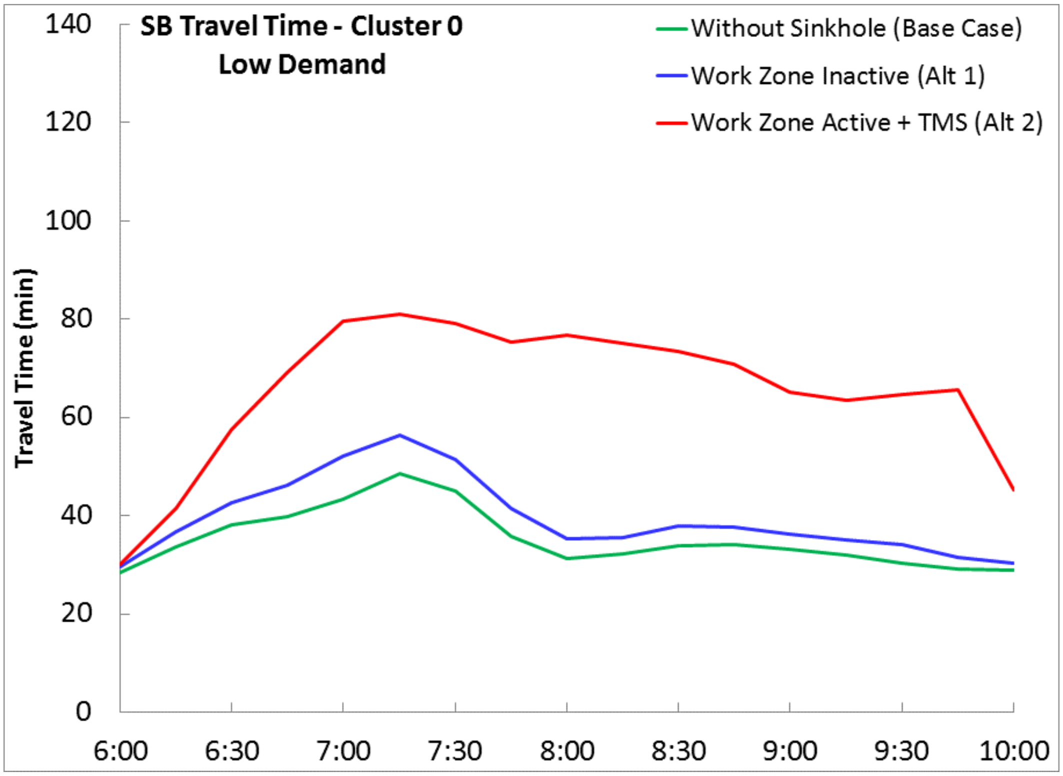

Figure 29. Chart. South Bound Travel Time Profile for Low Demand Travel Condition (Source: FHWA)

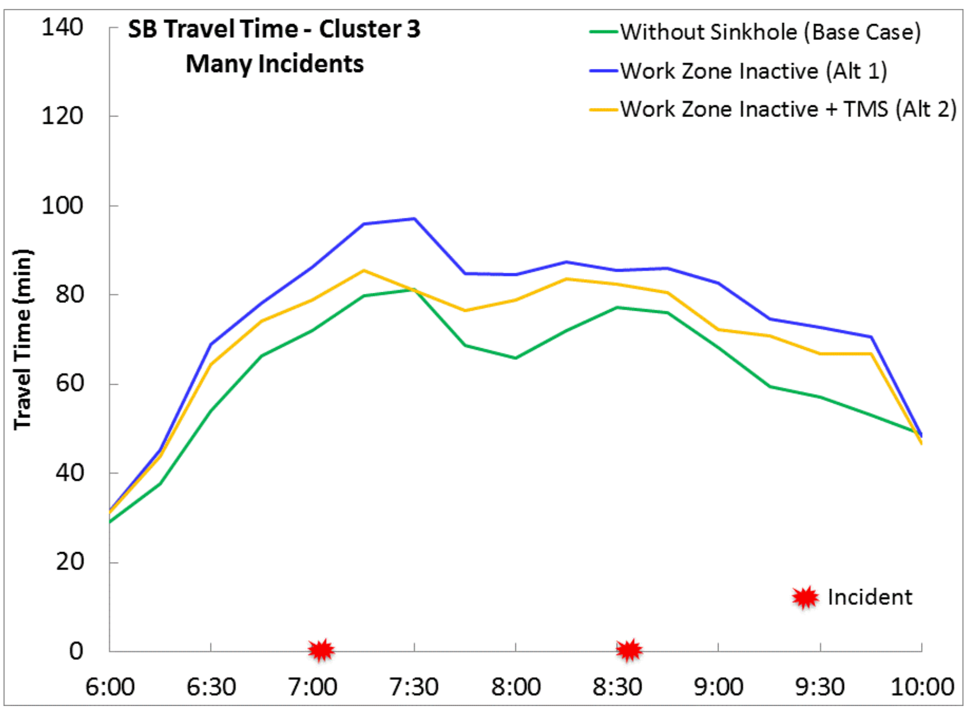

Figure 30. Chart. South Bound Travel Time Profile for Many Incidents Travel Condition (Source: FHWA)

Similar to the traditional approach (above), for the travel conditions approach, a calculation should be made to identify the required number of replication. Four simulation runs were found to be sufficient to perform a statistical test in this case. After running the simulation 4 times for each work zone scenario, Table 20 summarizes the total additional delay calculation using the travel conditions approach. In the table, with the additional four work hours logged on low demand days and the time saved to take away and/or setup the work zone, the number of weekdays for Alternative 2 is reduced.

Table 20. Total Additional Delay Calculation using Travel Conditions Approach

Alt	No. Weekdays	Total Additional Delay (hours)	Standard Deviation
Alt 1 (X1)	130	1,992,057	69,368
Alt 2 (X2)	112	1,832,387	57,592

The Null Hypothesis is set as H_0: $\mu_1 \geq \mu_2$. Using the t-test listed in Chapter 6, we reject H_0. This implies that the total additional delays generated for Alternative 2 is statistically lower than that for Alternative 1.

Total Cost Comparison

Since Alternative 2 includes the cost of additional traffic management strategies, a further comparison is performed to include both hard and soft costs. Soft cost is the cost due to extra delay; $20/hour is used in this calculation. Hard cost includes both work zone and traffic management strategies costs [1]:

- Work Zone Cost: Fixed cost: $500,000, daily cost: $15,000/day and setup cost: $1,500/day when work zone inactive during AM peak.
- Traffic Management Costs: incident management cost: $1,000/day and demand management cost: $3,000/day.

Figure 31 depicts the monetized comparison of the two alternatives using different approaches. When considering both hard cost and soft cost with the travel conditions approach, Alternative 2 is still more cost-effective than Alternative 1.

[1] http://www.ops.fhwa.dot.gov/wz/contracting/index.htm

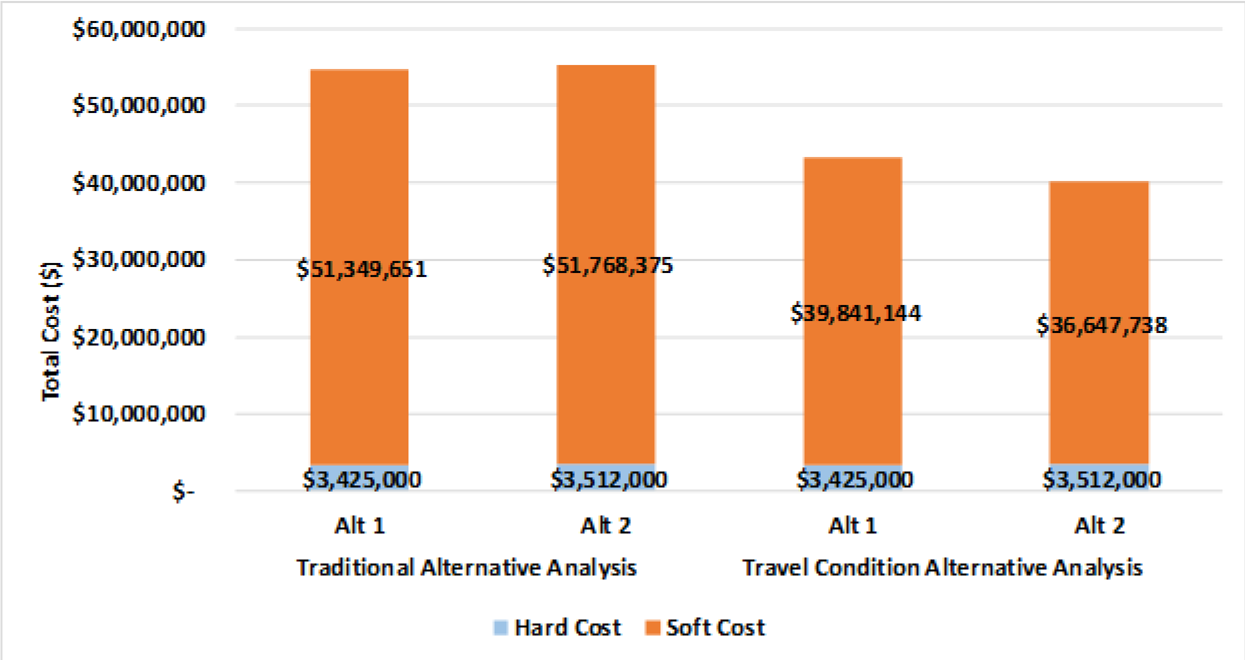

Figure 31. Chart. Total Cost (Hard Cost and Soft Cost) Computation (Source: FHWA)

Travel Time Reliability

The travel time reliability calculation process is available at the FHWA Office of Operations website: http://ops.fhwa.dot.gov/publications/tt_reliability/. One can calculate travel time reliability with an travel conditions approach. Planning time index is chosen in this case study; that is the 95th percentile travel time divided by the free-flow travel time for each time interval. Figure 32 shows the planning time index plot for NB and SB direction.

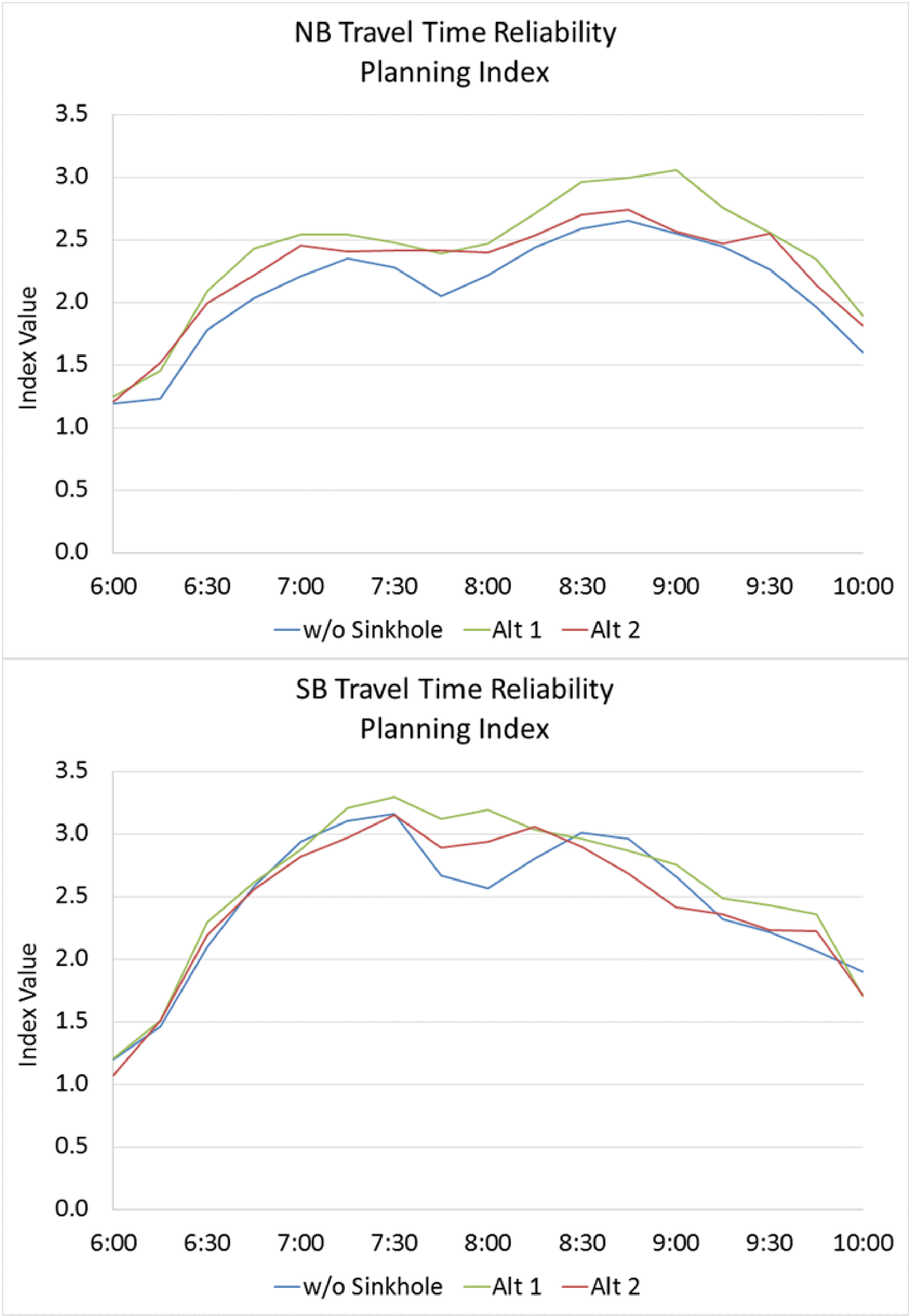

Figure 32. Chart. Planning Time Index (Source: FHWA)

In the figures, Alternative 2 has better travel time reliability compared to Alternative 1 in NB direction and Alternative 2 travel time reliability remains at roughly the same level compared to Alternative 1 in SB direction. Therefore, having the work zone active on low demand days does not negatively impact travel time reliability.

Conclusion of Alternatives Analysis

In summary, Alternative 2 causes more delay in the *Low Demand* travel condition but this is marginal, and travel time reliability remains at the same level. Alternative 2 also reduces delay under other travel conditions because the traffic management strategies improve overall travel time distributions. When considering both hard and soft costs, using travel conditions approach reveals that the dynamic work zone schedule with supporting traffic management strategies in Alternative 2 is more cost-effective than the fixed work zone schedule in Alternative 1. Furthermore, Alternative 2 shortens the entire construction period by adding more working hours to AM peaks on low-demand workdays.

Value of Cluster Analysis

A traditional analytical approach focuses on average demand patterns, so the congestion development and dissipation across the full range of observed conditions are not modeled well. That results in unrealistic analyses focused too much on average demand. Cluster analysis provides an approach to focus on time-dynamic data and travel demand in simulation model development and calibration, and thus can provide more accurate assessments to inform decisions. Using cluster analysis to identify travel conditions gives a better representation of system dynamics and underlying causes of congestion and unreliability, while the traditional average day approach only captures “recurrent” conditions that may only rarely occur (less than 30% of days in this case study).

In this case study, we demonstrate that without doing the full travel conditions analysis, these case study alternatives cannot be effectively differentiated. This may lead to incorrect information reaching decision-makers. With the full travel conditions analysis, modeling yields a stronger and statistically significant observation to inform decision-makers, i.e., Alternative 2 has lower soft and hard costs, while maintaining system travel time reliability.

Overall, considering the results from this case study, the value of the updated guidance on microsimulation may be described as follows:

- Identification of data-driven travel conditions through cluster analysis is technically sound and practical, even for large and complex systems.
- Calibration of simulation models to individual representative days is technically sound and practical, with the benefit of effectively capturing a wide range of conditions observed related to changes in demand patterns, incident patterns, and weather effects; and.
- Alternatives analysis utilizing travel conditions analysis provides more accurate results and critical insights are obtained, resulting in more informed decisionmaking.

APPENDIX B. GLOSSARY

Alternative: A precise set of specific operational practices or transportation system enhancements represented and evaluated within a microsimulation analysis. The impact of each alternative is compared to other alternatives in the analysis based on key performance measures to inform transportation management decisions.

Base Model: An initial working version of the model prior to calibration.

Calibration: Process where the analyst selects the model parameters that cause the model to reproduce field-measured local traffic operations conditions the best.

Key Performance Measure: A measure of transportation system performance identified during the project scoping step and utilized in the alternatives analysis step to differentiate competing alternatives.

Methods and Assumptions Document. A key element of simulation analysis planning and management that documents key decisions coordinating analyst actions and project management.

Microsimulation: Modeling of individual vehicle movements on a second or sub-second basis for the purpose of assessing the traffic performance of highway and street systems. Microsimulation may also include the modeling of individual pedestrian movement.

Model: Specific combination of modeling software and analyst-developed input/ parameters used in analysis to represent the transportation system.

Model Variant: A variant of a base model altered to represent a specific travel condition in the transportation system.

Travel Condition: A combination of operational conditions and resulting system performance. Operational conditions are identified by a combination of demand levels and patterns (e.g., low, medium or high demand), weather (e.g., clear, rain, snow, ice, fog, poor visibility), incident (e.g., no impact, medium impact, high impact), and other planned disruptions (e.g., work zones, special events) that impact system performance (e.g., travel times, bottleneck throughput).

Software: The simulation tool used by the analyst in the development and application of a specific microsimulation model. Several models can be developed using a single software program. These models will share the same basic computational algorithms embedded in the software; however, they will employ different input and parameter values.

Tool: See *Software*.

Travel Time Reliability. Travel time reliability reflects the range of variation in travel times for trips taken between two locations at the same time of day over time. The lower the variation, the higher the travel time reliability. Travel time reliability is a key measure for travelers and transportation system users because a lack of travel time reliability implies that system users should budget significant amounts of additional time to ensure on-time arrival at trip destinations.

Validation: Process under which intrinsic tool-predicted traffic performance for a transportation system is compared against field measurements of traffic performance, such as traffic volumes, travel times, average speeds, and average delays. This report presumes that the software developer has already completed this validation of the software and its underlying algorithms in a number of research and practical applications.

Verification: Process where the software developer and other researchers check the accuracy of the software implementation of traffic operations theory. This report provides no information on software verification procedures.

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