Guidance on the Level of Effort Required to Conduct Traffic Analysis Using Microsimulation

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Research, Development, and Technology
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FOREWORD

The Federal Highway Administration, in support of the Traffic Analysis and Simulation Pooled Fund Study, initiated this study to provide guidance for analysts and modeling managers on successfully applying traffic simulation analyses. Currently, State and local agencies face challenges to make proper decisions on transportation improvement projects. The traffic analysis and application of the analysis tools may be limited or improperly scoped, leading to conclusions and decisions that may be compromised. Projects may not be scoped properly due to the complexity of the traffic analysis tools. The level of effort to get the quality output may not be known. As a result, agencies may not sufficiently fund these projects. This report presents systematic ways to determine the appropriate scope and budget for traffic analysis efforts using microsimulation, resulting in better project and program decisions on transportation improvement projects. The target audience for this report includes modeling managers and analysts.

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Research and Development

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16. Abstract

The purpose of this report is to provide guidance for analysts and modeling managers on successfully applying traffic simulation analyses. This report presents systematic ways to determine the appropriate scope and budget for traffic analysis efforts using microsimulation, resulting in better project and program decisions on transportation improvement projects.

This report focuses on conducting traffic analysis for geometric and operation design projects during a typical day. This type of analysis is customarily performed during project development by State transportation departments and reviewed by U.S. Department of Transportation staff for interstate access and other related requirements. This report is consistent with the seven-step process outlined in *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1)

Considering that each transportation agency has unique needs and resources, this report can be used by any agency to develop its own framework for determining the level of effort. Putting into perspective the challenge of meeting the increasing needs of traffic analyses while keeping up with limited budgets, this report tackles different critical areas of those analyses by pinpointing best practices and identifying ways to tailor the level of effort invested to the analysis expectations.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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EXECUTIVE SUMMARY

PURPOSE OF THE GUIDE

The purpose of this report is to guide analysts and modeling managers on successfully applying traffic simulation analyses. This report presents systematic ways to determine the appropriate scope and budget for traffic analysis efforts using microsimulation, resulting in better project and program decisions for transportation improvement projects.

This report focuses on traffic analysis for geometric and operation design projects during a typical day (i.e., a day that avoids unusual traffic situations such as weekends, summer vacation, construction, etc.). This analysis is customarily performed during project development by State transportation departments and reviewed by U.S. Department of Transportation (USDOT) staff for interstate access and other related requirements. This report is consistent with the seven-step process outlined in the Federal Highway Administration (FHWA) report, *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1) It should be noted that this report is not intended to address traffic analysis for planning studies, regional analysis projects, different operational conditions (i.e., impacts of weather events, high travel demand, and incidents), or multiroute or multimodal projects where route or mode shift may occur.

Considering that each transportation agency has unique needs and resources, this report can be used by agencies to develop their own framework to determine their level of effort. Putting into perspective the challenge of meeting the increasing needs of traffic analyses while keeping up with limited budgets, this report tackles different critical areas of those analyses by pinpointing best practices and identifying ways to tailor the level of effort invested to the analysis.

Analysis and recommendations provided in this report are based on case studies that do not include parallel facilities to the freeway where route choice would need to be engaged or parallel transit facilities where mode shift would need to be taken into account. The introduction of parallel facilities, signalized intersections, and transit into the simulation makes model calibration and application a more complex exercise. The number of intersections and parallel arterials in the network has a major impact on the level of effort required for model calibration and application. It is not recommended to use the levels of effort presented in this report for simulation efforts including parallel arterials, multiple route choice, and mode choice.

The reported labor-hour estimates should be used as a point of reference and not as absolute numbers to apply to projects. Seemingly similar projects may require different levels of effort for many reasons including the following:

- Experience of project manager, analyst, and reviewers.
- The project purpose, objectives, and scope.
- The availability of sound data for model calibration.
- The number and complexity of the alternatives being analyzed.

- Performance measures used.
- Software used.
- The amount of documentation, number of meetings, and number of presentations required.
- The number and effectiveness of project reviews conducted.
- The amount of stakeholder involvement.

REPORT ORGANIZATION

This report has been organized around the traditional seven-step simulation modeling process as follows:

- **Chapter 1—Level-of-Effort Case Studies**: This chapter contains microsimulation level-of-effort information from four selected networks. Four case studies were reviewed, and the number of hours to complete the simulation analysis for these real projects is examined and discussed.
- **Chapter 2—Transportation Agency Experiences**: This chapter captures the major ideas and trends that were extracted from interviews conducted to gather information on the current state of the practice at different transportation agencies. It also identifies gaps and concerns related to guidance on the level of effort required for those analyses.
- **Chapter 3—Project Scope**: This chapter provides guidance on how to develop a traffic simulation project scope. It includes a sample template to develop microsimulation scope and provides guidance on how to develop an analysis plan. Interested agencies can use this information to develop requests for proposals (RFPs) for microsimulation analysis projects and analysis plans.
- **Chapter 4—Data Collection:** This chapter discusses data collection in terms of the types of data required for microsimulation model calibration and data sources including some of the new mobile source information from private vendors. This chapter also contains a discussion of common challenges in data collection including data quality, accuracy, and comprehensiveness, as well as how the margin of error on collected data affects the validity of simulation results. This chapter also provides guidance on how to develop a data collection plan.
- **Chapter 5—Base Model Building**: This chapter discusses base model building practices and includes suggestions on how to break down the base model building process into discrete steps to make the process more efficient. Information is also provided on developing origin-destination (O-D) matrices for microsimulation models and using different techniques for creating O-D inputs.

- **Chapter 6—Model Calibration**: In this chapter, the model calibration process is briefly discussed, which is consistent with the seven-step process outlined in the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1) This chapter provides new guidance on statistical techniques to determine the minimum number of model runs required and to determine if a model is calibrated well enough to replicate observed data within a required statistical confidence. A case study example is provided to illustrate these statistical methods.

- **Chapter 7—Alternatives Analysis**: The alternatives analysis process is discussed in this chapter, including the workflow of alternatives analysis and related requirements and principles. Suggestions are also provided on how to streamline the sequencing of alternatives analysis. There are also examples of how model results can be presented in different formats to help inform the decisionmaking process.

CHAPTER 1. LEVEL-OF-EFFORT CASE STUDIES

To provide analysts and modeling managers with a frame of reference on the level of effort required to complete a microsimulation analysis, a sample of completed projects was assembled and analyzed. This chapter presents a summary of four different microsimulation case studies that have been successfully completed. The cases range in size (small, medium, and large) and were completed with different simulation software packages.

For the purposes of this report, the model sizes were categorized into small, medium, and large models, which are defined as follows:

- **Small networks:** Includes 5–20 mi of freeway with three freeway interchanges and signalized intersections on either side the interchanges.
- **Medium networks:** Includes 10–20 mi of freeway with 4–15 freeway interchanges.
- **Large networks:** Includes 20–40 mi of freeway, 15–35 interchange, and 1–2 interstate systems.

The selected case studies were successfully completed projects that followed the seven-step modeling process as outlined in the FHWA report, *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1) The labor-hour estimates should be used as a point of reference and not as an absolute number to apply to projects. Seemingly similar projects can require different levels of effort for many reasons including the following:

- The project purpose, objectives, and scope.
- The availability of data (i.e., how much data have to be collected).
- The number and complexity of the alternatives being analyzed.
- Performance measures used.
- Software used.
- The amount of documentation required.
- Experience of project manager, analyst, and reviewers.
- Number and effectiveness of project reviews conducted.
- The amount of stakeholder involvement.

A summary of each of case study includes the following information:

- Project description.
- Size of the model.
- Software platform used.
- The level of effort by task in hours that were expended.
- Commentary on the level of effort.

The level of effort demonstrated in these case studies does not include the effort required to prepare traffic forecasts. Traffic forecasts were either prepared under a separate task or provided externally.

In all the cases provided, the number of model runs required was established externally by the performing agency. None of the projects conducted a statistical analysis of the data as a basis for the tolerance levels to be used for determining the minimum number of model runs required. Chapter 6 of this report provides a technique for conducting this exercise.

CASE STUDIES

Small Model: I-35 in Forest Lake, MN

Project Description

Improvements to the interchange of County State Aid Highway 2 (CSAH 2) with I-35 were proposed by Washington County in Minnesota. As part of the requirements for approving the access modification, a microsimulation model of the study area was prepared. The purpose of the modeling effort was to determine the impact that different interchange concepts would have on I-35 and to use this information to select a preferred alternative. Figure 1 shows a map of the study area.

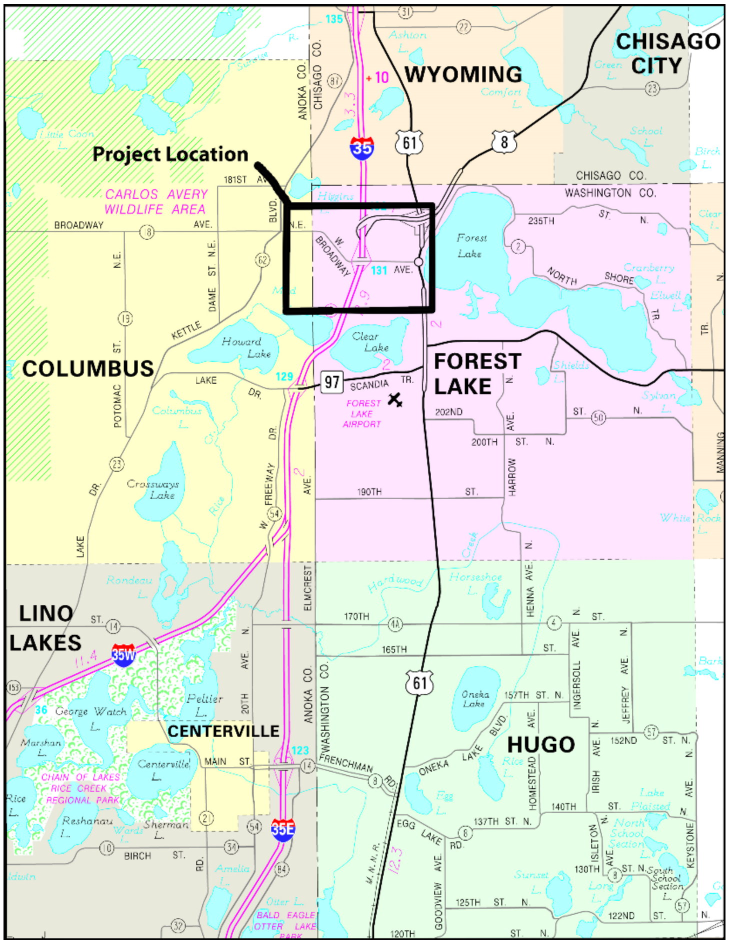

Figure 1. Illustration. I-35/CSAH 2 study area.

Model Size

The model consists of approximately 18 mi of freeway mainline, two local access interchanges, and one regional access interchange. The temporal extents of the model were 3 h in the morning and afternoon peaks, and the traffic flow data were broken down into 15-min intervals. The model has 154 nodes and 174 links.

The model included I-35 (north-south interstate) with three crossing arterials (interchanges) with ramp terminal intersections at each location (six intersections). There were no parallel arterials adjacent to I-35 included in the microsimulation model.

The traffic analysis for this project was one component of the overall planning, design, and construction of the CSAH 2 interchange. The total level of effort required to complete the analysis is summarized in table 1. The data collection involved a combination of manual counts and an assembly of available counts from the Minnesota Department of Transportation (MnDOT) Traffic Management Center.

Table 1. Small model I-35 level-of-effort summary.

Task Number	Task	Hours
1	Data collection	40
2	Simulation model development and calibration	140
3	Design year traffic analysis (four alternatives)	200
4	Opening year analysis	80
5	Documentation	40
6	Project management	40
Total		**540**

Medium Model: State Trunk Highway 100 in Saint Louis Park, MN

Project Description

The purpose of this project was to test proposed improvements on State Trunk Highway 100 (TH 100) between Excelsior Boulevard and Cedar Lake Road. The project was not the subject of a formal interstate access request for FHWA; however, due to the complexity of the interchanges and the levels of congestion (i.e., in excess of 8 h per day), MnDOT required that a microsimulation analysis be conducted. TH 100 was the first freeway built in Minnesota and was originally constructed in the 1930s as a four-lane freeway with interchange access every 0.5 mi. Over time, TH 100 was increased to a six-lane freeway north and south of the study area. The modeled area and the project limits are illustrated in figure 2.

The proposed improvements were intended to provide a full standard six-lane freeway with interchange access consolidated to approximately 1 mi. The access was consolidated through a series of a collector distributor roads and frontage roads. The original project scope entailed examining one design alternative; however, the analysis revealed there were operational challenges with the proposed design, and the alternatives analysis task was expanded to include the development of new design concepts.

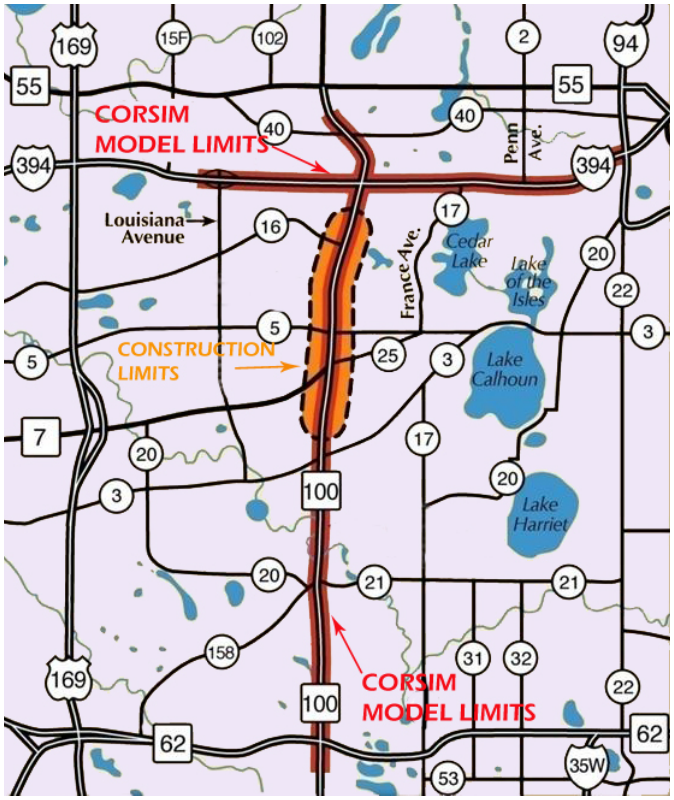

Figure 2. Illustration. TH 100 study area.

Model Size

The project area simulation limit was 13 mi. The I-394 freeway is immediately to the north of the project area and has an impact on operations within the project area. A portion of I-394 (east-west) was included to account for these traffic impacts. The model did not include parallel facilities, and there were eight signalized intersections included in the model. The model has 659 nodes and 646 links.

Level of Effort

The level effort involved directly supporting MnDOT staff who developed the preliminary plans, conducted public involvement meetings, and sought local approval of the project. Table 2 provides a summary of the level of effort expended to complete the analysis. The data collection portion of the project consisted of downloading traffic management center data, compiling the data, and smoothing the field observations. Intersection turning movement counts had previously been conducted by MnDOT; these costs are not reflected in the level of effort.

Table 2. Medium model TH 100 level-of-effort summary.

Task Number	Task	Hours
1	Data collection	262
2	Building of base model	339
3	Base model calibration	258
4	Design year traffic analysis	871
5	Opening year traffic analysis	185
6	Documentation	62
7	Project management	84
Total		**2,061**

Medium Model: I-5 in Tacoma, WA

Project Description

The purpose of this project and analysis was to obtain approval from FHWA to modify interchanges along I-5 in Tacoma, WA, to accommodate a new high-occupancy vehicle (HOV) lane. The modeled area and the project limits are illustrated in figure 3. The project had been studied previously, and the level of effort that is described in this guidebook represents a comprehensive update of the previous effort. The alternatives analysis considered only the alternative that had been previously selected.

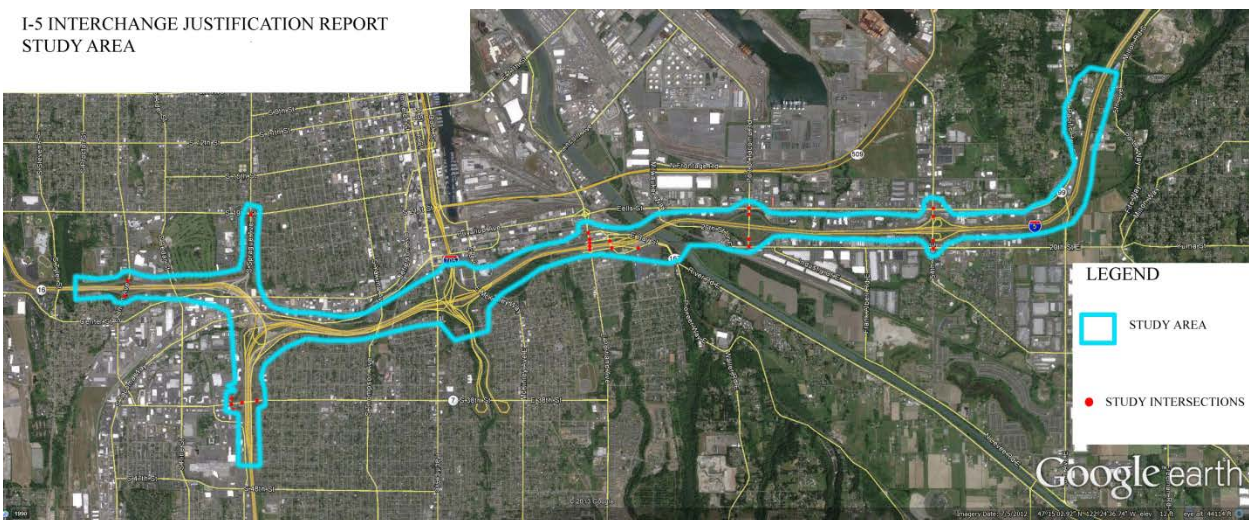

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Figure 3. Illustration. I-5 Tacoma study area.[(2)]

Model Size

The project area spanned 10 mi of I-5, and the simulation limits included a total of 10 mi. The project did not include parallel arterials, and there were 27 intersections included in the model. The model has 164 nodes and 203 links.

Level of Effort

The level of effort to conduct the I-5 project in Tacoma, WA, is summarized in table 3. The level of effort for this project was streamlined due to previous work efforts related to the project. Washington State Department of Transportation (WSDOT) conducted the traffic data collection.

Table 3. Medium model I-5 Tacoma level-of-effort summary.

Task Number	Task	Hours
1	Data collection*	80
2	Building of base model	160
3	Base model calibration	400
4	Design year traffic analysis	320
5	Opening year traffic analysis	320
6	Documentation	240
7	Project management	80
Total		**1,600**

*Traffic count data were supplied by WSDOT.

Large Model: I-5 in San Diego, CA

Project Description

The purpose of this project was to prepare a Corridor System Management Plan (CSMP) for the California Department of Transportation (Caltrans) district 11 and the San Diego Association of Governments. The modeled area and the project limits are illustrated in figure 4.

Figure 4. Illustration. I-5 San Diego study area.

Model Size

The project includes 30 mi of freeway (27 mi on I-5 and 3 mi on I-805), 5 system-to-system freeway interchanges, and 26 service interchanges. The model has 659 nodes and 796 links.

Level of Effort

Table 4 provides a level-of-effort summary for the I-5 San Diego case study.

Table 4. Large model I-5 San Diego level-of-effort summary.

Task Number	Task	Hours
1	Select analysis tool	60
2	Collect data	2,000
3	Develop and calibrate baseline model	2,500
4	Develop future baseline model	860
5	Analyze alternatives	1,660
6	Finalize documentation	1,200
7	Develop and conduct presentations	650
8	Develop work plan and project management	1,150
Total		**10,080**

SUMMARY EVALUATION OF SAMPLE PROJECTS LEVELS OF EFFORT

The case studies are reflective of typical traffic analysis for geometric and operation design projects. This analysis is customarily performed during project development by State transportation departments and reviewed by USDOT staff for interstate access and other requirements. The case study projects were not intended to address traffic analysis for planning studies, regional analysis projects, different operational conditions (i.e., impacts of weather events, high travel demand, and incidents), or multimodal projects where mode shift may occur.

Each of the case study projects is unique in terms of alternatives being considered. A common factor among all the projects is the building of a microsimulation model following the basic seven-step procedures described in *Traffic Analysis Tool Box Volume III: Applying Microsimulation Model Software*.[(1)] All of the case studies ran the simulation models multiple times with different random number seeds and reported the averaged model results.

There are some similarities and differences between the four sample projects. The similarities include base model development and calibration and indicate that the modeling efforts are scalable to the network size (e.g., number of hours per interchange). The other tasks that are impacted by local and project specific factors include the number and type of alternatives being tested. Table 5 provides a composite comparison of the four case studies by major task category.

Table 5. Comparison of level of effort of sample projects.

	Model Size and Labor Hours			
Task	**Small**	**Medium**	**Medium**	**Large**
Data collection	40	262	80	2,000
Base model development and calibration	140	597	560	2,500
Alternatives analysis	280	1,056	640	2,520
Documentation/presentations	40	62	240	1,850
Project management	40	84	80	1,210
Total	**540**	**2,061**	**1,600**	**10,080**

Total Level of Effort Compared to Base Model and Calibration

Figure 5 provides a comparison of the total level of effort and the amount of effort expended specifically for building a base model and the calibration process. The only apparent trend is a consistent order of magnitude regarding the model building and calibration effort with the model size. Larger models require a disproportionately greater level of effort compared to smaller projects. This is attributed to the increased complexity of a larger simulation model as it relates to modeling travel demand and traffic operations in a larger geographic area and extensive project reporting, alternatives analysis, and presentation time expended.

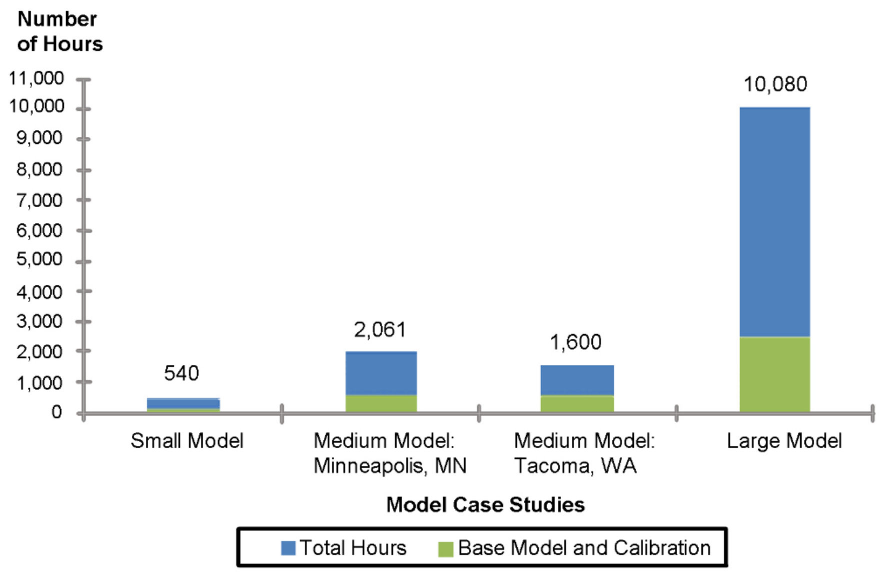

Figure 5. Graph. Total level of effort comparison.

Percentage Breakdown of Task Allocation

A further breakdown of the percent allocation of time was reviewed. Figure 6 shows the composite percentage of hours by task for all four case study projects. Figure 7 shows a composite percentage of hours by task for the three small/medium case study projects.

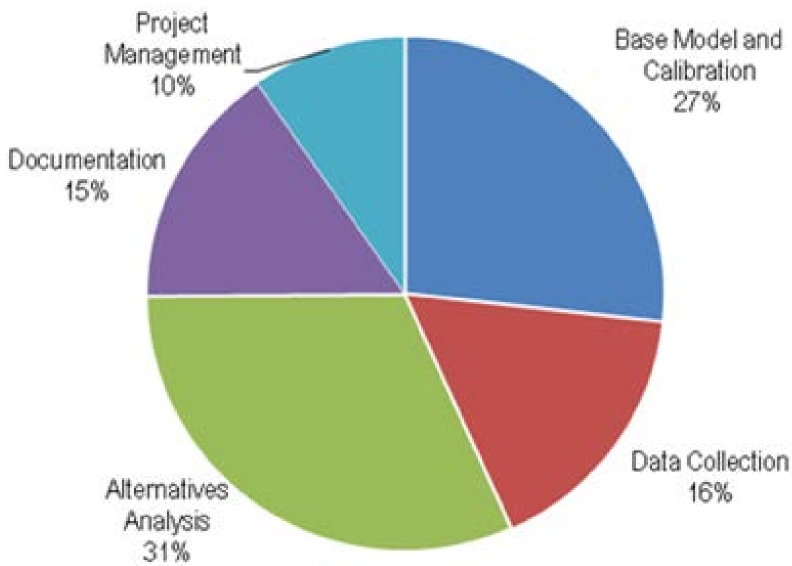

Figure 6. Graph. Composite effort percentage by major tasks for all four case studies.

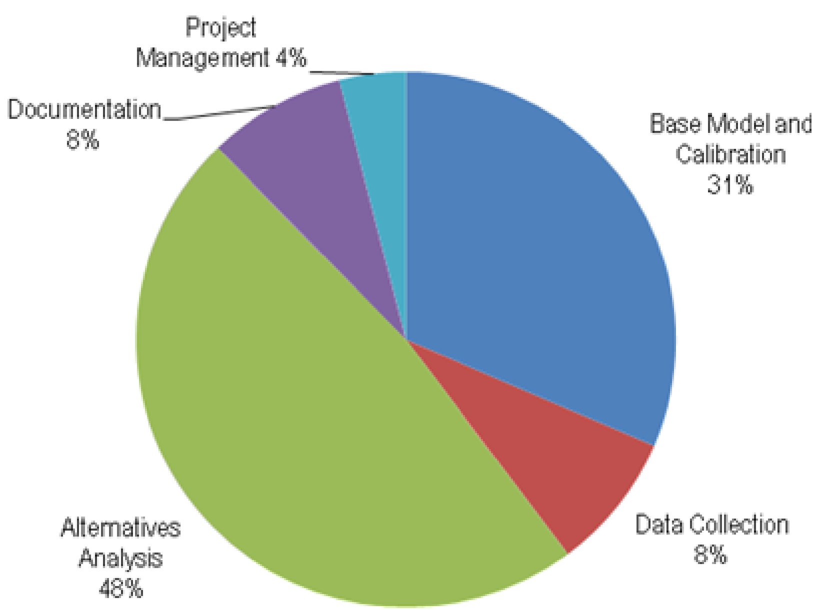

Figure 7. Graph. Composite effort percentage by major tasks for small- and medium-sized models only.

Comparison Conclusions

Larger models require a disproportionately greater level of effort compared to smaller projects. This is attributed to the increased complexity of a larger simulation model as it relates to modeling travel demand and traffic operations in a larger geographic area and extensive project reporting, alternatives analysis, and presentation time expended.

Roughly a third of the level of effort on the projects was allocated to the base model development and calibration. Model calibration is a critical activity in microsimulation and can drive the project level of effort to high levels. The experience level of project managers, analysts, and reviewers, as well as a robust quality assurance process can help control the risk of budget and time overruns.

Depending on the availability of data, the amount of time allocated to data collection varied from 8 to 16 percent of the total level of effort across the four case studies. As some of these locations had considerable existing instrumentation and resulting data available for their interstate system, these values may be lower than what other locations may experience. Anecdotal information from other non-instrumented regions indicates that up to 30 percent of the project effort may be devoted to data collection in the absence of archived data.

CHAPTER 2. TRANSPORTATION AGENCY AND PRACTITIONER EXPERIENCES

This chapter presents the major ideas and trends that were extracted from interviews conducted with transportation agency staff and consultants. A questionnaire was developed and sent out to targeted transportation agency representatives and consultants. Each questionnaire consisted of 30 questions spread across four categories: experience, building of the project's framework, model calibration, and beyond calibration. The terms "interviews," "surveys," and "questionnaires" are used interchangeably throughout the section.

The recipients of the interview were given the option to either fill out the questionnaire in writing or provide input during a phone interview. In total, 12 completed surveys were received—10 by agency representatives and 2 by consultants. Table 6 contains a list of the interviewees.

Table 6. Interviewee list.

Interviewee	Affiliation	Role
Derek Miura	Florida Department of Transportation (FDOT) District 4 Planning and Environmental Management System Planning Group	Senior system planning
Simon Eng and Chi Mai	Oregon Department of Transportation (ODOT) Region 1	Traffic engineers
Steve Hague	Caltrans	CSMP modeling oversight and task order development
Waddah Farah	FDOT District 7	Project development administrator, traffic engineer, traffic planner, project manager, project coordinator, and District Interchange Review Committee District Interchange Review Committee chairman for District 7
Doug McClanahan	WSDOT	State traffic analysis engineer
Dat Huynh	FDOT District 6	District project development engineer
Kenneth Jeffries	FDOT District 6	Transportation planner
John Shaw	Wisconsin Department of Transportation (WisDOT) Bureau of Traffic Operations	Development of technical guidelines for traffic analysis and organization of technical training for traffic engineers
Vladimir Livshits	Maricopa Association of Governments	System analysis program manager
James Young	Ohio Department of Transportation	Studies engineer
Jaimison Sloboden	Consultant	Traffic group leader
Loren Bloomberg	Consultant	Project manager and senior engineer

PROJECT EXPERIENCE

Analyses Conducted

The survey participants were involved in various traffic analysis studies in different roles. They conducted, managed, supervised, and provided support for analysis of construction projects, interchange operations studies, corridor studies, and planning studies. The surveyed individuals have ample experience in conducting/leading traffic and transportation studies involving simulation and/or traffic analysis tools.

Network Sizes Involved

The survey participants worked on a variety of network sizes ranging from a single intersection or interchange to several miles of interstate freeway, as well as a variety of analysis types including complex regional- and corridor-level analyses. While a typical project would include around 15 mi of freeway with crossing arterials, some projects involved freeway systems of more than 50 mi in addition to arterial network studies with several hundred intersections.

Project Type and Stage

Numerous projects, including local agency roadway operation improvement projects, safety projects, freeway modernization projects, and planning and corridor studies, were undertaken by the different surveyed agency representatives and consultants. Analysis included the entire process from early planning to final design stages.

Analysis Tools Used

Various analysis tools were used by the survey subjects. Those included deterministic tools as well as macroscopic and microscopic simulation analysis tools.

BUILDING OF THE ANALYSIS FRAMEWORK

Conducting the Analyses

Transportation agency representatives provided answers on who conducted the analyses, which is highlighted in figure 8. While some regularly resorted to consultants, others conducted in-house analyses (mix 1), and some used both in-house plus consultants (mix 2).

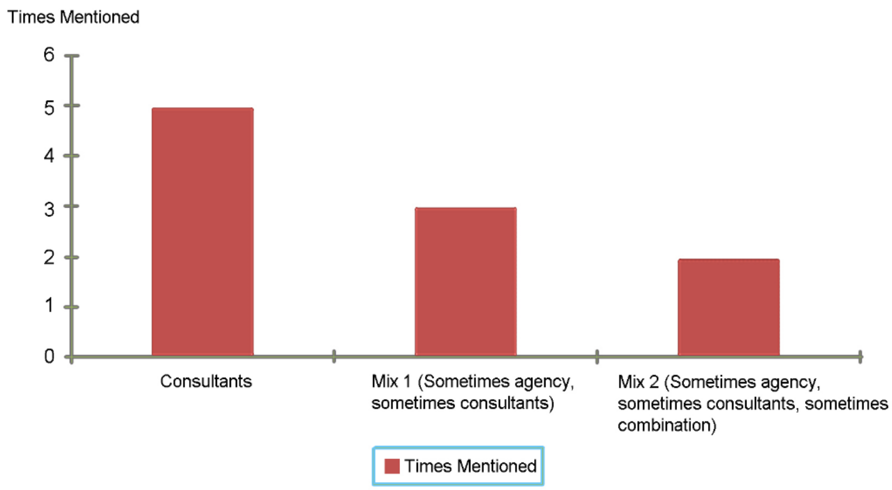

Figure 8. Graph. Agency responses of who conducted the analyses.

Developing RFPs

Some transportation agencies have in-house guidelines that are used to develop RFPs (such as FDOT's *Project Development and Environmental Studies*).[3] Others rely on RFPs for similar projects. Refinements to RFPs are made on a case-by-case basis depending on the unique nature, scope, type, size, and complexity of the project.

Identifying the Project Needs and Questions to Address

Respondents indicated that the needs and questions to be addressed by the analysis are based on field investigation and performance assessment. Studies are expected to address both existing and future needs. Any issues or challenges known in the study are recognized in the scope so they can be properly addressed in the analysis.

Scoping Projects

The interviewees were consistent in their indication that a planning and development team is formed within agencies for each project. The team consists of planning, traffic, and preliminary design staff. The team determines the initial scope and then works with a consultant to develop the refined scope of services.

The scope of work may be influenced by many factors such as funding availability, geographic homogeneity, influence of adjacent interchanges and intersections, or amount of time elapsed since the last study of any particular section. Study areas are typically extended beyond bottleneck extents so that the causes of congestion are reasonably replicated. Traffic patterns and the duration of congestion help determine the temporal extent of the analysis. Sufficient lead time prior to the beginning of congestion is included in the models.

Prior to specifying the scope of work, some agencies ask project managers to complete a scoping worksheet that describes the geographical limits, level of detail, any existing data or resources available for the project, and any previous models. Some agencies follow guides to develop their scoping documents.[4,5]

Determining the Level of Effort Required for the Analyses

At most transportation agencies surveyed, a labor-hour estimate is prepared by the consultant and reviewed by the project manager and the agency's program leader. A project schedule is developed, including anticipated documentation delivery dates and agency review times. The labor-hour estimate and project schedule are then submitted to the agency for review.

Analysis schedules are dependent on the availability of traffic counts, seasonal factors determining when to conduct the counts, availability of travel demand models (TDMs), funding constraints, and project phasing.

Consultants responding to the survey generally use a bottom-up approach to develop budget and schedule estimates by task. Half of the surveyed agencies and consultants (6 out of 12) do not use a guide to determine their budget and schedule.

Determining Data Requirements

Data requirements are based on the project's goals and scope and depend on the analysis tool used. The data requirements also are influenced by the amount of time and resources available to complete the work. Most surveyed agencies and consultants indicated that meeting data requirements is relatively challenging due to resource availability in terms of both time and budget. It was acknowledged that there is a conflict between the need for comprehensive model calibration data and limited data collection budgets.

Special methods have been developed by agencies such as WisDOT to resolve data discrepancies and maximize the use of existing data. Some State agencies mentioned O-D data as being the most challenging because they does not exist in a form that is ideal for model calibration. Furthermore, survey participants reported that there are no guidelines on the temporal consistency of collected data or the geographic coverage of freeway and arterial data collection. Most interviewees agreed that issues with data comprehensiveness, temporal consistency, geographic coverage, and overall resources are among the key reasons for schedule and budget overruns.

Determining Performance Measures

Performance measures are usually identified by agencies with input from consultants. They depend on the project type and the study objectives. Measures are reported by corridor subsections, direction, and facility type (i.e., mainline, on-ramps, off-ramps, and local streets). Typical performance measures used in the analysis include the following:

- Density.
- Volume.
- Speed.
- Level of service (LOS).

- Delay.
- Travel time.
- Queue length.

Performance measures such as travel time reliability, emissions, fuel consumption, and safety were not mentioned by the survey participants.

Selecting Analysis Tools

Most often, the tool that is used in the analysis is identified by the agency usually based on its staff/project experience. At times, consultants are asked to suggest the appropriate tool(s), and the assessment is then based on the type of analysis (scope and goals of the project) and the resources available (available data, schedule, and budget). Macrosimulation techniques are used for high-level screening of alternatives; however, most of the interviewees mentioned that they use microsimulation, especially for the analysis of traffic operations in congested environments.

MODEL CALIBRATION

Model Calibration Guidelines

A total of 7 out of the 12 interviewees (2 consultants and 5 agency representatives) indicated that they follow the FHWA model calibration guidelines, including volumes II, III, and IV of the *Traffic Analysis Toolbox*.(1,6,7) Some survey participants mentioned having encountered ambiguities and challenges while using the FHWA guidelines.

Ideas offered by the interviewees for guideline improvement include the following:

- Standards to limit the number of in-route removal of vehicles.
- Unreleased vehicles from zones.
- Logic check of demands between key O-D pairs.
- Path checks for key O-D pairs.
- A method to help select the typical day to simulate.

Several of the respondents developed their own set of policies and procedures. WisDOT has expanded its model calibration criteria and guidelines over time. ODOT is in the process of updating their *Protocol for Vissim Simulation*.(8) WSDOT has its own document that was developed specifically for each project involving Federal funds or Federal facilities in order to guide the requirements and expectations regarding model calibration. Florida and Minnesota also use their own model calibration guidelines.

Model Output Versus Real-World Data

A comparison between observed data and modeled output was performed via model calibration and validation. The data used in the comparison included volume, speed, travel time, queue length, and location of bottlenecks. Sources of observed data comprised field traffic volume and speed counts, applicable information from existing studies, and historical traffic counts. Survey participants suggested that models must also provide a qualitative look and feel that matches the way traffic operates in the real world.

Determination of Appropriate Number of Model Runs

Some interviewees acknowledged the usage of statistical methods to determine the appropriate number of model runs. (See references 1 and 6–8). The use of statistical methods to determine the appropriate number of model runs has emerged as an area where additional guidance is needed. Chapter 6 of this report contains an example on how to determine the appropriate number of model runs using statistical methods.

Documentation of Calibration Results

Interviewees consistently responded that the model calibration effort is usually documented via a report/memorandum. Calibration documentation contains the calibration method, including criteria, measures, and existing conditions as well as a summary of the calibration results documenting how performance measures from the baseline model relate to measured real-world data. Also, any parameters that are modified based on calibration results for the existing condition are documented in the report and carried forward to future alternatives. The model calibration report is considered a major milestone in the model development process.

The following assumptions were made concerning the consistency in analysis:

- **Microsimulation and externally developed forecasts**: Traffic volumes and/or O-D flows from externally developed forecasts are often used as inputs to microsimulation models. These inputs usually come from TDMs, which have different underlying assumptions and procedures than simulation models. Linking refined microsimulation zones to TDM traffic analysis zones is used as a means to maintain consistency between the two types of models.

- **Base models and future year models**: After baseline model calibration is complete for existing conditions, the calibrated model parameters are carried forward to future year models. This helps maintain consistency between baseline and future year models.

Documentation on the Level of Effort Required for Calibration

While some agencies document the level of effort (number of person-hours required) for model calibration in the scope of work, other agencies do not track the level of effort associated with model calibration. Consultants track their time through timesheets. Model calibration activities are usually tracked separately by task.

ANALYSIS AND RESULTS

Development of Analysis Scenarios

Respondents indicated that analysis scenarios are developed in close coordination with project stakeholders. Scenarios are usually driven by the planning needs of the project and by the availability of resources. The types and numbers of scenarios to be modeled are usually dependent on the geometric design and operational solutions being considered.

Analysis of Different Operational Conditions

Most interviewees' agencies conduct their analyses for the typical day. Some agencies use the 30th highest hour of the year to help establish morning and afternoon average day peak period analyses. It is not standard practice to model nonrecurring congestion (e.g., incidents, weather events, fluctuations in demand, and construction activities), and there are no model calibration criteria associated with these operational conditions.

Presentation of Analysis Results

Survey responses indicated that analysis results are presented through memoranda/reports, screen shots from the simulation, and video clips. Reports usually contain summary tables and charts for network measures, graphs, and maps for location-specific LOS. Reports also contain time-space diagrams for freeway corridor queues/congestion.

Decision Development from Analysis Results

Results of the analysis (including the comparison between performance measures for different analysis scenarios) provide useful information for decisionmaking on various projects and for prioritization and staging of programmed and planned projects. Interviewees stated that decisions are made based on a collaborative process involving the project development team, the management team, local jurisdictions, and stakeholders. In general, the charge of the analysts is to provide unbiased technical information for the clients/decisionmakers to review and take appropriate action.

Funding Level Specification

Specifying funding levels for the analysis is done on a project-by-project basis, and no general guidance is available. Microsimulation is recommended for facilities with significant congestion and/or operational problems, whereas simpler tools, such as deterministic methods and macrosimulation, are recommended for less complex projects. Factors influencing the project costs include the length of the corridor, presence/inclusion of parallel streets, existing level of congestion, time period of the simulation, routing assignment used, number and types of analysis scenarios desired, availability of existing data, and comprehensiveness and internal consistency of calibration data.

CONCLUSIONS

Through reviewing and summarizing agency and practitioner experience, this chapter highlighted current procedures and challenges in traffic simulation analyses. A number of key issues emerged from the survey findings where guidance is needed to assist in improving traffic analysis processes.

CHAPTER 3. PROJECT SCOPE

This chapter provides guidance on how to develop a traffic simulation project scope. It includes a sample template to develop a microsimulation scope and provides guidance on how to develop an analysis plan. Interested agencies can use this chapter to develop RFPs for microsimulation analysis projects and analysis plans.

The following signs indicate that a traffic analysis project is on track and likely to be successful:

- The purpose of the analysis is clear.
- Key stakeholders are engaged throughout the analysis.
- A detailed analysis plan is prepared that identifies appropriate tools, data required, performance measures, and people responsible for various parts of the analysis both at the agency and consultant levels.
- Tools used in the analysis can convincingly demonstrate their ability to replicate observed traffic conditions using quality checked, internally consistent observed data.
- Interim and final results can be independently reproduced.
- Analytical results can be clearly communicated relative to analytical objectives.

A clear scope helps to avoid problems such as the following:

- Misunderstandings or ambiguities regarding the goals of the modeling effort.
- Mission creep such as unplanned enlargement of the study area or implemented advanced model features that were not originally part of the scope.
- Misapplication of the model (i.e., attempting to use the model at a level of detail for which it was not intended).
- Inappropriate sequencing of activities (e.g., starting to model “build” scenarios before the base model has been properly calibrated).

GUIDANCE ON DEVELOPING MICROSIMULATION SCOPE

The purpose of this section is to provide guidance on how to develop a microsimulation scope including developing the purpose and need for the analysis, determining the analytical approach and tools to be utilized, identifying and communicating data needs, identifying the performance measures to evaluate alternatives, and informing decisionmakers on the parameters of the analysis (i.e., what the analysis will and will not answer).

Project Understanding and Purpose

The project understanding should describe the purpose of the project, provide the project background, and present the problems and issues that the microsimulation analysis is intended to address. The project understanding should include clear descriptions of the following:

- The transportation project purpose and need.
- Elements that relate to the transportation problem to be analyzed.
- The project study area.
- Affected communities and stakeholders.
- Traffic analysis objectives and hypotheses.

Technical Approach

This section outlines the technical tasks necessary to accomplish the analytical objectives of the project. The technical approach should provide detailed information on the requirements of the analysis, the alternatives to be analyzed, and the performance measures needed to evaluate the alternatives.

Analysis Requirements

This section includes the following components that help define the analysis:

- **Study area and facility types:** The spatial extent of the study area includes any intersections, highways, and other facilities that are analyzed. The study area must cover beyond the end of the full spatial extent of queues and congestion in the baseline and future years of analysis.
- **Analysis time period:** The project analysis time period should be defined (e.g., morning/afternoon peak hour and/or peak period, off-peak period, etc.). The analysis time period must cover the beginning and end of full temporal extent of queues and congestion in the baseline and future years of analysis. In some cases, the simulation analysis period must allow for vehicle loading and unloading time beyond the limits of the peak periods.
- **Scenario definition**: Scenarios should include geometric and operational alternatives that are analyzed and compared to the baselines. Chapter 7 in this report describes alternatives analysis.
- **Analytical tool selection**: Selection of the appropriate simulation tool is an important part of the study. The Analysis Plan section in this chapter provides specific guidance for this step.

Data Requirements

The data requirements for the development and calibration of a microsimulation model vary depending on the software package selected; however, they all require the following basic inputs:

- Roadway geometry.
- Traffic control data.
- Travel demand, traffic volumes, and intersection turning movements.
- Performance data (i.e., queue locations, queue lengths, travel times, and speeds).
- Data on vehicle characteristics (i.e., vehicle classification and vehicle mix).

Baseline Model Development

Most models are coded from georeferenced aerial photographs or as-built drawings. Reviewing previously developed models for the area is also a good starting point to determine a baseline. The following attributes are typically coded in the model:

- Number of lanes.
- Link/lane width and length.
- Grades.
- Curvature.
- Sight distances.
- Bus stop locations.
- Crosswalk and pedestrian facilities.

In coordination with the development of the base year microsimulation model, the TDM (if utilized) should be refined to reflect the zonal structure of the microsimulation model being developed. Most TDM software contains procedures for extracting or zooming in on a subarea for analysis. This procedure allows for the analyst to include all of the regional factors that may affect travel in the analysis area while working with a smaller subarea model. The subarea model zonal structure should be developed to correspond to the zonal structure of the microsimulation model. If the TDM has a 24-h O-D trip table in conjunction with a proper data collection program, the O-D table can be refined by developing factors to split the trip table into smaller time periods.

Baseline Model Calibration

Calibration of the baseline model is crucial to the validity of the model to replicate existing observed conditions as well as its stability to forecast future operations. Calibration requires two steps: (1) calibration for capacity and (2) calibration for route choice. This methodology is described in *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.[(1)] Prior to calibration, criteria must be developed for the models that are being calibrated. Model calibration targets should be set after taking into account the performance measures developed and the quality of field data. The performance measures should be measurable in terms of the field data collected and can be calculated for real-life conditions and compared to the model outputs.

Development of the Future Baseline Model

A future baseline microsimulation model (or future no-build alternative) is an essential part of the analysis process; it is the basis for comparison between alternatives. Many microsimulation models are used because the macroscopic deterministic analytical techniques do not fully capture the extent of congestion.

A common methodology for developing future demand forecasts is using a regional TDM. TDMs take into account regional growth due to land use, demographics, and socioeconomic activity. In cases where a TDM does not exist, it is acceptable to utilize a trend projection of travel demand. As with the development of the existing base-year model, the future baseline (i.e., no build) microsimulation model and future baseline subarea TDM should have zone and link/node structures that ensure correspondence between the models.

The amount of further refinement to the zonal layers within the demand and simulation models depends on the type of growth anticipated in the study area and the future no-build transportation system. The zones need to be refined if there is a large shift in land use within the study area or if transportation improvements cause a shift in land use or become barriers to access to the transportation system from certain zones. Otherwise, the future baseline scenario zones for the simulation model and the demand model can remain the same as the existing baseline zonal systems.

Alternatives Analysis

The alternatives analysis consists of the following steps:

- **Development of project alternatives for analysis:** Alternatives are usually developed by the project team and are shaped through the stakeholder involvement process.

- **Model application:** Microsimulation models operate based on randomly generated numbers, and results can often vary from model run to model run of the same scenario. Therefore, it is necessary to run each scenario multiple times with different random number seeds to determine mean, minimum, and maximum conditions. Multiple model runs are also useful in estimating the reliability of travel time associated with particular alternatives.

- **Tabulation of results:** The output of microsimulation models is usually in the form of animation and numerical outputs. These outputs are based on performance measures established at the beginning of the project and are used to compare system performance between alternatives and the baseline and across alternatives. Animation allows for visualization of the movement of individual vehicles through the network.

- **Analysis of alternatives:** The analysis of the alternatives is performed by analyzing the comparison of the no-build scenario results to the alternative scenario results.

Final Report and Presentations

The final report should summarize the efforts, methodologies, assumptions, and results of the study. The report's target audience is key decisionmakers and stakeholders who decide on the funding and implementation of the improvements put forth in the alternatives testing. Therefore, it is important to interpret the technical content and tabular results. The development of the model should not be the subject of the final report; this information can be presented in technical appendices to allow other analysts and modelers to view the technical information and technical analysis that went into the study.

A typical outline for the final report includes the following:

- Study objectives.
- Study methodology.
- Data collection.
- Model calibration.
- Forecasting procedures.
- Alternatives analysis.
- Summary of results.

Presentation of the final results of the study can be accompanied by the animations produced as an output of the model runs.

Project Deliverables

Clear project deliverables should be listed at the end of each task in the scope of work. Deliverables should include all meetings, project status reports, data to be compiled and delivered, models to be delivered, and reports including the number of copies.

Project Schedule

The project schedule should identify the expected duration of the overall project as well as the expected duration of individual interim tasks. The schedule should also provide milestones, meetings, and presentations.

Labor-Hour and Cost Estimate

In preparation for the RFP, the agency should consider developing a labor-hour and cost estimate for the project so adequate resources can be allocated to meet the project requirements. The estimate should contain enough detail not only to communicate the dollar value expenditure allocated for consulting services, but also the resources that will be needed by the agency to conduct and manage the project.

SAMPLE MICROSIMULATION SOLICITATION TEMPLATE OUTLINE

This section provides a sample microsimulation solicitation template outline.

I. RFP Cover Page

- **Agency title.**
- **Project title.**
- **Dated cover letter**. Provide a cover letter inviting the contractor firms to propose on the RFP.

II. Introduction/Overview

- **Project description and purpose**. Name the agency/agencies that will overlook the project. Provide a detailed description of the project and its purpose.

III. Submittal Information

- **Contact**. Provide the project manager's and contracts officer's names, telephone numbers, e-mail addresses, and mailing addresses.
- **Key action dates**. Provide dates for the pre-bid meeting, questions deadline, proposal deadline, interview, and decision.
- **Proposal format and content**. Provide the sections and format for the proposal.

IV. Scope of Work

- **Project definition and requirements.**
    - **Study area.** Define the spatial extent of the study area, including intersections, highways, and corridors.
    - **Analysis time period**. Define the analysis period and simulation period. For example, while the project analysis might be for the morning and afternoon 3-h peak periods of congestion, the simulation period used must provide for warm-up/initializing traffic and for processing residual queues resulting from the peak hour. The analysis time period must cover the full temporal extent of queues in the baseline and future years of analysis.
    - **Scenario definition (morning, afternoon, baseline, future year, etc.)**. Provide the time periods and scenarios that should be processed for the project. Scenarios should

include geometric and operational alternatives to be analyzed and whether they are to be analyzed independently or in packages.
    - **Simulation runs per scenario**. Provide/reference the methodology to determine the number of model runs for each scenario that the contractor must simulate.
    - **Modal impacts**. Provide travel modes that must be evaluated for the project. Examples include single-occupancy vehicle, HOV, bus, light rail, truck, etc.
    - **Performance measures**. Define the performance measures to be produced by the analysis. Typical performance measures include speed, travel time, reliability of travel time, volume, travel distance, vehicle miles traveled per passenger miles traveled, vehicle hours traveled per passenger hours traveled, delay, queue lengths, number of stops, crashes and their duration, emissions, fuel consumption, and benefit/cost. These should be produced for the whole study area and analysis period by facility type, region, mode, and scenario.
- **Work task description.**
    - **Project management.**
    - **Data collection.**
    - **Base model development and calibration criteria and requirements.**
    - **Future year forecast and future baseline scenario.**
    - **Alternatives analysis.**
    - **Deliverables (report and presentations).**
- **Project budget and schedule**. Provide the total budget and schedule for the project. RFPs should be submitted with a proposed budget for each task by person, including hourly labor rates, overhead, fee, and direct expenses. RFPs should include a detailed schedule outlining tasks, subtasks, milestones, deliverables, and meetings.

V. Evaluation Criteria

- **Qualifications of project manager, including experience/expertise.**
- **Management approach and quality assurance process.**
- **Project team qualifications.**
    - **Staff expertise.** Demonstrated ability based on firm's and team's experience to conduct the work.
    - **Staff resources.** Depth and breadth of staff resources.
    - **Location familiarity.** Familiarity of key staff with study area travel and congestion patterns, as well as agencies and organizations involved with transportation in the region.
    - **Presentation skills.** Ability to convey results of analyses in written form and present findings that are understandable to nontechnical audiences.

VI. Contract Requirements

- **Disadvantaged business enterprise policy.**
- **Insurance requirements.**
- **Selection dispute**. Provide a description of criteria, process, and date that a proposer must follow for disputing the selection.

VII. Addendums

THE ANALYSIS PLAN

Developing an analysis plan is an important first step in any transportation analysis project. This section discusses developing an analysis plan.

Determine Overall Project Scope

Confusion about the goals, objectives, or physical boundaries of a microsimulation project can cause delays and/or conflicts among stakeholders. At the beginning of a project, the analysis managers should develop an initial understanding of the analysis objectives. Several critical tasks need to be performed to gain this understanding prior to engaging stakeholders and moving forward with the analysis process. The outputs from this exploration should be considered preliminary and subject to change based on the input and feedback from stakeholders at the project kickoff meeting. These tasks include the following:

- **Develop an outline for the analysis plan.** The analysis managers should define an outline for the analysis plan early on in the analysis process. Elements to include in the outline vary depending on the input from the stakeholders and the needs of the analysis; however, several common elements should be included in all effective analysis plans including the following:
    - Introduction.
        - Project purpose.
        - Project background.
        - Study area overview.
        - Process for developing and applying the analysis plan.
    - Study area description, existing traffic conditions, and available data.
    - Analysis methodology and modeling approach.
    - Analysis scenarios and mitigation strategies.
    - Data requirements.
    - Output performance measures.
    - Criteria and data requirements for model calibration.
    - Analysis budget and resources.
    - Analysis schedule.
    - Allocation of responsibilities.

- **Determine project objectives and needs.** This task serves to clearly determine the "what" and "why" for conducting the analysis. The overall goals and objectives for the mitigation strategies should be assessed and used to shape the goals and objectives for the analysis effort. The analysis objectives should fully support and be consistent with the overall goals for the deployment project.

- **Identify stakeholders.** A broad set of stakeholders should be identified to fully represent the agencies and organizations impacted by the project.

- **Understand the study area, including major transportation issues and mitigation strategies to be considered.** Available documentation should be compiled and reviewed by project managers to familiarize themselves with the operating characteristics of the study area and identify substantial issues. Individual interviews with project partners also can be helpful in understanding study area conditions and the strategies being considered. Previous studies, archived data systems, and accident/incident data reports can all provide valuable insight into the current operational characteristics of the study area. The project managers should also seek out information on the mitigation strategies being considered and the impact these strategies have had in other regions.

- **Conduct a site visit.** The analysis managers should visit the study area to gain a better understanding of traffic conditions and characteristics. The site visit should include a comprehensive review of all the different facilities, modes of transportation, and major mode transfer locations throughout the study area. The site visit may also include visits to the regional traffic management center or toll authority, as appropriate. Also, depending on the characteristics of the mitigation strategies being considered, the project managers may want to plan to visit the site on multiple occasions (e.g., peak period versus off-peak or good weather versus inclement weather) to gain further insight into how traffic characteristics vary.

- **Schedule a technical kickoff meeting.** Once the project managers gain an initial understanding of the project and analysis needs, a technical kickoff meeting should be scheduled and conducted to discuss the analysis methods. Agency stakeholders should be encouraged to attend. The project managers should be prepared to provide a presentation documenting their initial understanding of the project and the analysis plan outline. The presentation will be used to solicit feedback from the stakeholders during the meeting in order to adjust the analysis managers' understanding to more closely match project expectations. Copies of this presentation should be provided to all stakeholders as initial documentation of project understanding. The intended outcomes of the kickoff meeting include the following:

    - **Confirm stakeholder perceptions of project needs.** The kickoff meeting provides an opportunity for the project managers to gain consensus on expectations for both the deployment as well as the necessary analysis.

- **Confirm analysis scope.** Scope issues to be explored with stakeholders include the following:
    - What is the appropriate geographic scope for the analysis?
    - What facility types need to be included in the analysis?
    - What travel modes need to be included in the analysis?
    - What are the possible mitigation strategies to be implemented?
    - What are the expected traveler responses to the mitigation strategies?
    - What performance measures need to be produced by the analysis and what are acceptable performance levels?
    - What is the approximate budget and schedule for the analysis work?
- **Confirm scenarios to be used in the analysis.** It is critical to understand precisely when (i.e., under what conditions) the mitigation strategies will be applied and how their application may vary under different conditions. The project managers and stakeholders need to identify the combinations of travel demand, incidents, special events, and weather events that comprise corridor operations.
- **Discuss data availability.** Analysis managers and stakeholders should explore potential data sources for the study. The quality and amount of data (sample sizes) for each performance measure to be utilized should also be evaluated. Chapters 4 and 6 of this report provide discussions on sample sizes of the field data needed. This discussion should include both traditional and nontraditional data sources in order to compile a comprehensive set of data that may be available for the project. For analysis needs, archived automated data sources (e.g., traffic detectors) are often more desirable sources of data than manually collected data. The long-term availability of automated data representing different operational conditions (e.g., varying demand, incident, and weather conditions) provides an opportunity to effectively assess multiple operating conditions. Data from multiple sources must also be for concurrent time periods. The data should be collected from all sources for the same period. For each data source, the analysis managers should ascertain the following:
    - Time periods when the data are available.
    - The format of the data.
    - Any lag time in data availability (e.g., is accident data available immediately or is time required to request, acquire, and record the data into a common database?).
    - Reliability of the data sources (e.g., are there significant gaps in the data?).

    - Any known data quality issues (e.g., are there any operating conditions that cause the data to be inconsistent?).

- **Update analysis plan**. Analysts should begin populating the analysis plan outline based on the information obtained during the kickoff meeting.

Select/Determine Analysis Methodology

Following the kickoff meeting, the analysis managers should begin to explore and select the appropriate analysis methodology to be applied. This is a critical step because the selection of the appropriate methodology and tools ensures that the analysis meets the needs of the study and streamlines the analysis process. Key steps in the evaluation and selection of the analysis methodology include the following:

- **Research and identify available analysis tools for the study area.** The analysis manager should research and compile information on models and analysis methodologies currently used in the region. This may include models that are used on a continual basis in the region (e.g., the regional TDM) as well as individual models that are used for specific one-time-only analysis in or near the study area. For each model or tool, the analysis manager should identify the following:

    - The analysis package or tool (i.e., name and version of the software).
    - The year of the analysis.
    - The year the data sources were collected along with type and location.
    - The time periods targeted for analysis.
    - The model geographic limits.
    - Facilities represented in the model.
    - Modes represented in the model.
    - Any special scenarios available in the model (e.g., incidents, special events, weather, etc.).
    - High-level assessment of model capabilities and limitations.

  The availability or popularity of a model or tool in a region should not be the sole determinant for selecting the models and methodologies used in the analysis. In subsequent steps, the analysis project managers will assess their individual needs and map these to an appropriate tool or combination of integrated tools. It may be determined that the capabilities of the existing tools in the region are not sufficient to meet the needs of the analysis and a new methodology must be developed. However, this information on available tools is useful in selecting the appropriate methodology and identifying potential data sources for the model development.

- **Identify factors for selecting methodology.** The analysis managers should perform a critical analysis of project factors to determine the required robustness of the analysis methodology selected. This information will be used in a subsequent step to map needs to an appropriate tool, or combination of tools, using a decision support tool developed by USDOT as part of the Traffic Analysis Tools initiative. To complete this process, the analysis managers should compile information related to the following factors:
  - Geographic scope.
  - Facility types impacted.
  - Travel modes impacted.
  - Any potential strategies considered.
  - Expected traveler responses.
  - Approximate budget and schedule.
- **Determine performance measures.** The last piece of information required to complete the selection of the methodology using the *Traffic Analysis Toolbox* is to identify required output performance measures.[1,6,7] The identified performance measures should be closely tied to the identified project goals/objectives and the expected traveler impacts. An effective way to identify appropriate performance measures is to develop one or more specific hypotheses to be tested for each objective. These hypotheses can either indicate a change in traffic conditions (e.g., the mitigation strategies will reduce travel time by 5 percent) or can be neutral in the prediction of an impact (e.g., the mitigation strategies will not result in a change in corridor accident rates). Performance measures that support the testing of each formulated hypothesis should then be identified. Use of this method ensures that the performance measures are appropriately mapped to the project goals and objectives.
- **Use FHWA criteria and methodology to select the appropriate traffic analysis tools.** FHWA has developed a useful guide to help practitioners select an appropriate analysis tool based on a number of input factors. This guidance includes a report and an automated decision support tool.[9] Figure 9 provides an overview of the basic factors to be considered using the FHWA guidance. In assessing the demanding needs of project analysis, it may be revealed that multiple tools are needed. A single tool may not be sufficiently robust to handle the analysis objectives, and the analysis managers may need to consider integrating the analysis capabilities from multiple tools to achieve the necessary abilities. Once appropriate tool categories have been selected by the decision support tool, the analysis manager can use the documentation provided in *Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools* to research the range and capabilities of individual software packages and tools within the selected category.[6] The FHWA documentation includes links to individual research organizations and vendors supporting the various packages that can provide even more information.

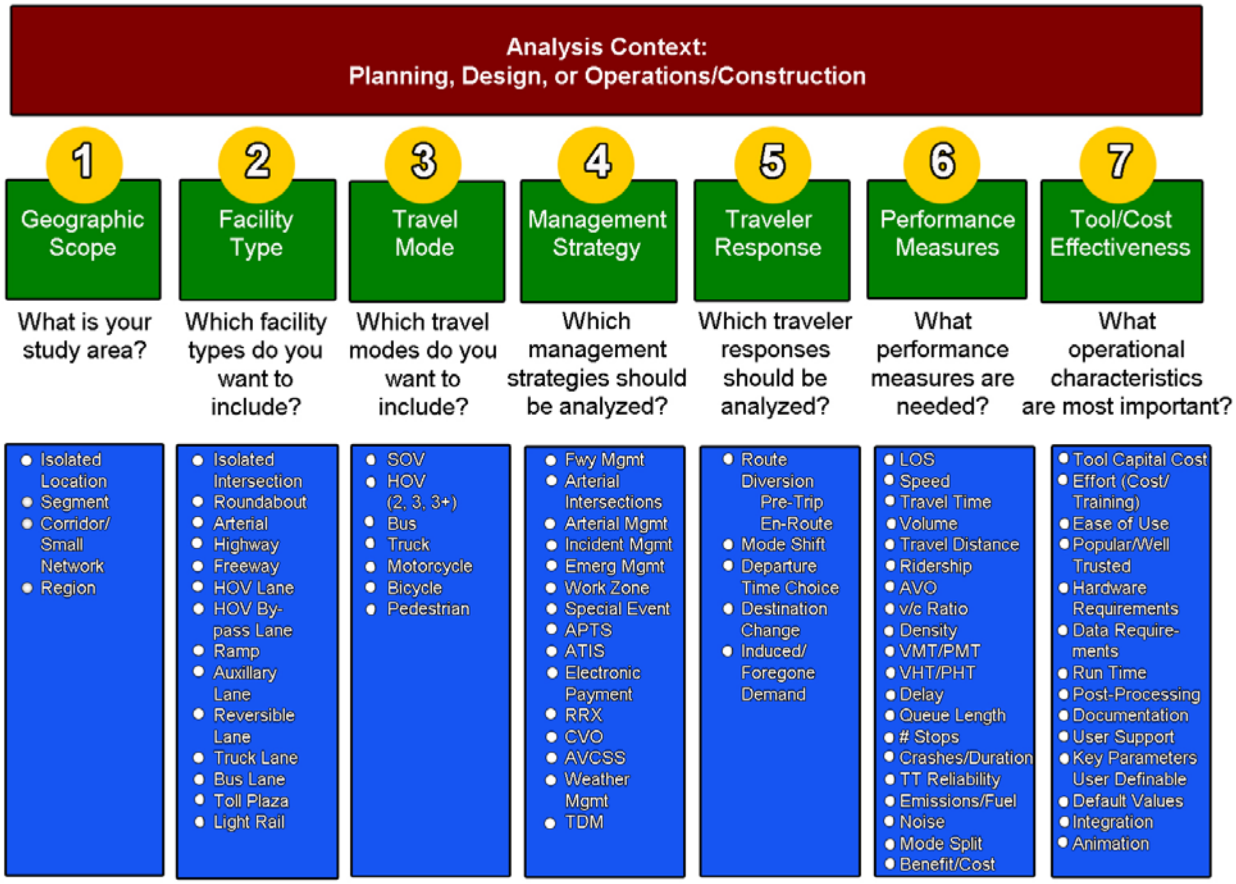

Figure 9. Flowchart. Overview of analysis factors to be considered in selecting an analysis methodology/tool.[(6)]

CHAPTER 4. DATA COLLECTION

The true validity of any model is dependent on the quality of the data that goes into it. The data requirements should be evaluated in the early inception stages of a project to get an early estimate of effort required. Quality/variability of existing data will impact sample sizes; therefore, early statistical evaluations of the data (margin of error) can prove highly valuable for subsequent development of effort required. Key calibration performance measures should be identified early to help determine the data needed to estimate these performance measures.

Often, it is possible to use existing data for data collection, but these data may be outdated or from different timeframes for different parts of the network. In that case, resources need to be allocated for new data collection. If there is limited funding, resources need to be spent judiciously to collect sufficient quality data. Table 7 lists example data required for simulation model calibration.

It also is important to plan for documentation of the information. The documentation methods should include a clear file-naming structure, an explanation of the sources of data, and a database structure that can be readily incorporated into model inputs and model reports. Efficiency of managing the data can be further enhanced through the development of automated procedures.

As part of the scope development process, a data plan needs to be developed. The data collection plan includes sources and types of data that will be needed to prepare and calibrate the model.

Table 7. Example data requirements for simulation.

Physical Geometry	**Traffic Control**	**Travel Demand**	**Intelligent Transportation Systems (ITS) Elements**
• Link distances • Free-flow speeds **Freeways** • Number of travel lanes • Presence of shoulders • HOV lanes (if any) and operational characteristics • Acceleration/ deceleration lanes • Grade • Curvature • Ramps **Arterials** • Number of lanes • Lane usage • Length of turn pockets • Grade • Turning restrictions • Parking	**Freeways** • Ramp metering • Type (local, system-wide) • Detectors • Metering rates • Algorithms (adaptive metering) • Lane use signals • Variable speed limits **Arterials** • Signal system description • Controller type • Phasing • Detector type and placement • Signal settings • Signal timing plans • Transit signal priority system	• Link volume • Traffic composition • On- and off-ramp volumes • Turning movement counts • Vehicle and person trip tables	• Traffic Management Center and surveillance system • Detector type • Detector spacing • Closed-circuit television • Information dissemination (changeable message signs) Highway advisory radio, 511 (traveler information telephone number), etc.) • Tolling system type and pricing mechanism (if any) • Data archival and dissemination • Incident detection and management characteristics

TYPES OF DATA

The types of data required can be categorized in four main areas: travel demand, traffic control, physical geometry, and ITS elements, as highlighted in table 7. Travel demand data include traffic counts, vehicle classification counts, speeds, travel times, congestion, and queuing observations. Travel demand data require the majority of the data collection effort. Traffic control data include signs, signal control, and timing plans. Physical geometry can be obtained from rectified aerial photography and base mapping files that may be prepared as part of the design effort for projects.

The four types of data can be further categorized into the following two areas:

- Data for model development.
- Additional data for model calibration.

The tenets of data collection and data management that are important for conducting an effective analytical study include the following:

- The type of analysis being conducted should dictate the quantity of data collected.
- The required accuracy should drive the quantity of data collected.
- It is important to utilize data that are recent, internally consistent, and relevant because the quality of the analysis and the resulting decisions depend on the data used.
- Collection of traffic data should capture the temporal variations in demand, and performance and should be finite enough to allow for an appropriate analysis to be conducted.

Helpful tips on data collection include the following:

- Do not solely rely on the veracity of historical data; allocate some resources to verify the data through current field inspection.
- Measure flows and estimate or forecast demand. Procedures for estimating demand are given in *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1)
- Check flow conservation; entry flows should match the exit flows.
- Always check for data quality. Use the most recent geographic information system (GIS) files, maps, and drawings.
- Use traffic counts from prior to the onset of congestion to after congestion dissipates.
- Broaden the geographic scope to cover bottlenecks and spatial and temporal extent of queues.

Key questions related to data collection include the following:

- Do you have the data you need to develop the base model?
- How old are the data?
- Have you statistically verified the data quality?
- Were there any field inspections conducted?
- Did you check the quality of the sensor data?
- If you need additional data collection, do you have the resources?
- What did you do to address missing data?

- Did you make use of data from other regions that have similar demand?

- Did you have to make any assumptions? What were they and how did you arrive at them? Have you documented the assumptions?

DATA SOURCES

Travel Demand

The basic demand data needed by most simulation software are the entry volumes (i.e., the travel demand entering the study area) at different points of the network. At intersections, the turning volumes or percentages should be specified.

O-D

O-D trips can be estimated from a combination of TDM trip tables and from traffic counts. O-D data can be acquired from the local metropolitan planning organization's (MPO) regional TDM, but these are generally 24-h estimates and, as such, need to be adjusted and refined to produce hourly or peak period estimates for use in simulation models. Typically, these estimates are further disaggregated to represent 5- or 15-min estimates required for simulation. License plate matching surveys can be used to estimate hourly trips, but this is resource-intensive. Depending on project complexity, a cost effective way of estimating O-D trips is to adjust the TDM O-D trip estimates based on field counts.

If the study area has transit, HOVs, and trucks or if there is significant interaction with bicycles and pedestrians, the corresponding demand data would be needed. In addition, vehicle dimensions and vehicle performance characteristics (e.g., maximum acceleration and deceleration) are required.

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 has dissipated. Also, to capture the temporal variations in demand, it is best not to aggregate demand data to intervals longer than 15 min.

Vehicle Characteristics

Vehicle characteristics data can be obtained from the State transportation departments or air quality management agencies. National data can be obtained from car manufacturers, the Environmental Protection Agency, and FHWA.

Traffic Control

Data from traffic control devices at intersections or junctions are required. Control data refers to the type of control device (e.g., traffic signal, stop sign, ramp meter, etc.), the locations of these control devices, and the signal timing plans. Traffic control data can be obtained from the agencies that operate the traffic control devices in the given study area.

Traffic operations and management data on links are also needed. These include location and type of warning signs. If there are HOV lanes, information on the HOV lane requirement (e.g., HOV-2 versus HOV-3), their hours of operation, and the location of signs are needed. If there are high-occupancy toll lanes, information on the pricing strategy is required.

Operational Conditions

If there are variable message signs (VMSs) in the study area, the type of information that is displayed, the location, and, if possible, the actual messages that were displayed are needed. Most of this information can be obtained from the public agencies that are responsible for operating the VMSs. The types of signs and locations can be obtained from GIS files, aerial photographs, and construction drawings.

Event data can be received from public agencies, such as traffic management center logs. Crash databases should be verified since data may not always be recent and may not be for the specific study area. The data should be from concurrent timeframes.

Transit Data

Transit data can be obtained from the local and regional transit operators. These data can include schedules and stop locations. Calibration data could include transit automatic vehicle locator data, boarding and alighting data, and dwell time at stops.

Mobile Source Data

Mobile source data include data derived from mobile phones, Bluetooth® devices, and other mobile sources. Mobile source data are relatively new sources of data that can be used to augment other data collected. The primary types of data obtained from mobile sources are speed and travel time. In most cases, the mobile source techniques use samples of vehicles in the traffic stream, but they may not be reliable sources for traffic counts and vehicle composition.

The mobile source data are typically obtained, stored, and sold by private vendors. Before purchasing these types of data, it is a good idea to have a demonstration of the data and a means to compare the data supplied by the vendor with a real observation of what is happening in the field. Consideration of how the data are provided (format, structure, and software) should be given and should take into account how they will be used for traffic modeling and other purposes.

The following list provides a brief description of techniques and technologies that are all probe vehicle-based applications:

- **Toll tag readers:** Toll tags that are typically used for electronic toll collection can be used by toll tag readers deployed at various points on a roadway network to obtain average travel time and speed information. There are four components in a toll tag travel time system: electronic tags, antennas, readers, and a central computing and communication facility. As a vehicle with an electronic tag passes near a toll tag reader, the time and toll tag identification number are recorded. If the same vehicle passes the next reader location, the travel time and average speed between the two locations can be determined. The toll tag identification number can be encrypted to protect privacy.

- **Bluetooth® device matching:** Many computers, car radios, navigation devices, personal digital assistants, cell phones, headsets, and other personal devices are Bluetooth® enabled to allow wireless communication between devices. Generally, manufacturers assign unique median access control (MAC) addresses to Bluetooth® equipped devices. Bluetooth®-based travel time measurement involves identifying and matching the MAC address of Bluetooth®-enabled devices carried by motorists as they pass a detector location.

- **Wireless location technology:** Wireless location technology involves using signaling information from cell phones (i.e., cell tower handoffs) to anonymously track wireless devices as they traverse a roadway network. Cell tower handoffs occur when calls are transferred from one tower to another, during which the cellular phone is assigned a new frequency. By tracking the handoffs between towers, it is possible to determine which road a vehicle is traveling on and derive average travel time and speed information for that roadway segment.

- **Crowd sourcing:** Crowd sourcing involves obtaining real-time traffic congestion information from a driver's Global Positioning System-enabled mobile phone. Crowd sourcing relies on a large number of users and is primarily supported by personal navigation systems and mobile applications.

CHALLENGES WITH DATA

Systematically collecting the critical data, verifying data quality, and documenting any assumptions are important to justify the results of a study to decisionmakers and the public. A statistical analysis of collected and previously available data can be helpful to determine the statistical data variability and the margin of error contained in the data. Data variability can have a significant effect on the number of model runs required to represent the model's replication of observed traffic conditions. This report provides helpful suggestions on data types, sources, and challenges. Development of a more comprehensive data quality guide is under consideration by FHWA.

Data Comprehensiveness

Comprehensive data cover different performance measures (i.e., volumes, speeds, bottlenecks, queuing, and congestion data) across freeways and arterial streets, as well as transit data and incident data. Traffic counts should be taken at key locations in the study area. Key locations include major facilities (i.e., freeway segments, major intersections and interchanges, and major on- and off-ramps). If possible, this should be done simultaneously at all key locations. Otherwise, the counts should be taken during similar timeframes with similar demand patterns and weather conditions.

If a model that was calibrated several years ago is being used, it needs to be recalibrated to reflect more current field conditions. Therefore, not only would data be needed to estimate capacity and the calibration performance measures, but demand data need to be collected. Furthermore, the analyst must verify the accuracy of geometric data, traffic control data, traffic operations, and management data.

Challenges

Due to the innovative nature of many operational strategies, collecting relevant data to support such analyses includes the following challenges:

- Automated data sources are often best used for collecting long-term data necessary to develop and calibrate simulation models; however, many existing automated data collection systems lack the robustness or reliability to effectively compile relevant data sets. A thorough assessment of the data quality from all sources is recommended to identify any potential problems early on in the process and establish methods to address any deficiencies. Automated data availability can generally be classified in the following three categories:
    - **Fully automated**: Freeway and arterial data are available for the study area network.
    - **Semi-automated**: Only freeway mainline data are available.
    - **Manual**: There are no automated data for the study area network.
- Data quality from automated data sources (e.g., roadway loop detectors) may sometimes be insufficient for modeling purposes. Sample datasets should be obtained early in the data collection process and analyzed to assess data quality. The data collection plan should specify data quality procedures and minimum data quality requirements for this purpose. Further, the analysis manager should discuss any data quality issues with operations personnel familiar with the data source during the development of the data collection plan in order to understand and anticipate any problems with data source reliability, data accuracy, or other condition-specific issues (e.g., inaccurate speeds recorded during high-volume periods).
- *Accuracy* is defined as the measure of the degree of agreement between data values and a source assumed to be correct. It is also defined as a qualitative assessment of error. It is important to have accurate, internally consistent, and recent data. If information on future traffic conditions is not available, it could be helpful to study data from other regions that may have the bottlenecks and traffic patterns that are envisioned for the study area. This is critical since the goal of model calibration is to not only see if the model can represent observed conditions but also to examine if the model can handle future congestion. With respect to data filtering and fusion, it is crucial to adopt standard ways to accept or reject field data and to address data gaps and missing data.
- A small margin of error in the collected data is required to increase the validity of simulation results. It is necessary to collect multiple data points for each performance measure (i.e., volumes, speeds, etc.) so that the sample is an accurate representation of the mean and standard deviation of the performance measure. Depending on the mean to

standard deviation ratio and the desired margin of error, the required sample size may vary greatly. Table 8 shows different sample sizes based on different mean to standard deviation ratios and different margins of error.

Table 8. Margin of error for different standard deviation to mean ratios.

Sample Size (n)	$Z/\sqrt{n}$	Standard Deviation/Mean Ratio				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
2	1.385929291	13.85929	27.71859	41.57788	55.43717	69.29646
5	0.876538647	8.765386	17.53077	26.29616	35.06155	43.82693
10	0.619806421	6.198064	12.39613	18.59419	24.79226	30.99032
15	0.506069824	5.060698	10.1214	15.18209	20.24279	25.30349
20	0.438269324	4.382693	8.765386	13.14808	17.53077	21.91347
25	0.392	3.92	7.84	11.76	15.68	19.6
30	0.357845404	3.578454	7.156908	10.73536	14.31382	17.89227
35	0.331300468	3.313005	6.626009	9.939014	13.25202	16.56502
40	0.309903211	3.099032	6.198064	9.297096	12.39613	15.49516
45	0.292179549	2.921795	5.843591	8.765386	11.68718	14.60898
50	0.277185858	2.771859	5.543717	8.315576	11.08743	13.85929
55	0.264286346	2.642863	5.285727	7.92859	10.57145	13.21432
60	0.253034912	2.530349	5.060698	7.591047	10.1214	12.65175
65	0.24310808	2.431081	4.862162	7.293242	9.724323	12.1554
70	0.234264807	2.342648	4.685296	7.027944	9.370592	11.71324
75	0.226321306	2.263213	4.526426	6.789639	9.052852	11.31607
80	0.219134662	2.191347	4.382693	6.57404	8.765386	10.95673
85	0.212591849	2.125918	4.251837	6.377755	8.503674	10.62959
90	0.20660214	2.066021	4.132043	6.198064	8.264086	10.33011
95	0.201091757	2.010918	4.021835	6.032753	8.04367	10.05459
100	0.196	1.96	3.92	5.88	7.84	9.8
200	0.138592929	1.385929	2.771859	4.157788	5.543717	6.929646
300	0.113160653	1.131607	2.263213	3.39482	4.526426	5.658033
400	0.098	0.98	1.96	2.94	3.92	4.9
500	0.087653865	0.876539	1.753077	2.629616	3.506155	4.382693

Z = Value from the standard normal distribution for the selected confidence level.

DEVELOPMENT OF A DATA COLLECTION PLAN

This section describes a typical data collection plan for traffic analysis. The data collection plan will guide the collection, compilation, analysis, and archiving of data.

Approach and Work Steps

This section presents an overview of the subtasks and work steps related to the development and implementation of a data collection plan. The data collection plan should retain sufficient flexibility so that lessons learned in the compilation of data sources may be incorporated as part of the continuous improvement of the analysis effort.

Specific steps in the development of the data collection plan include the following:

1. **Research and identify available data for the study area**: Existing data sources and data requirements should be used to identify available data for the analysis area. The data collection plan should also identify those individuals/stakeholders responsible for compiling the data. The analysis manager should work closely with stakeholders to compile the data. If possible, the analysis manager should obtain samples of the datasets prior to full collection to view the content and format of the data and adjust collection plans as necessary.

2. **Identify information/data gaps and recommend an approach to filling those gaps**: Once available data sources have been investigated and dataset samples have been reviewed, the analysis manager should assess the appropriateness of the available data for use in the analysis and identify any critical gaps in data availability. Potential approaches to filling data gaps should be investigated, and recommended approaches should be documented in the data collection plan.

3. **Identify data management strategies**: Procedures for conducting data quality control and data archiving should be identified. Any required thresholds for minimum data quality should be identified as well as high-level descriptions of processes for addressing data shortcomings. Plans for archiving the data should also be identified. Responsibilities for data quality testing and data archiving should be clearly defined.

4. **Develop data collection plan**: The data collection plan should document all of the information listed in these steps and detail data elements to be obtained and their respective data sources. The data collection plan should outline data collection methodologies and contain budget and schedule estimates to fill data gaps.

An example outline for the data collection plan is as follows:

- Introduction and background.
- Data requirements.
- Available data.
- Data gaps.
- Data collection methodology.
- Data collection locations.
- Data collection budget and schedule.

Once the data collection plan is developed, the required data should be collected in accordance with the plan. Generally, implementing the plan includes the following activities:

- Assembling/collecting data on physical infrastructure and geometrics. Much of these data are likely to be available in existing models and regional GIS.
- Assembling/collecting existing traffic performance data within the study area.
- Gathering available information from existing studies. These studies include those currently underway as well as those that have been recently completed. Example studies include, but are not limited to, existing conditions analyses, environmental impact studies, and lists of projects and strategies that have been planned or programmed.
- Conducting field reviews within the study area.
- Collecting new data as specified in the data collection plan. All data collected in this effort should be analyzed and archived according to the data management procedures documented in the data collection plan. Any identified problems with data quality or the successful archiving of data should be immediately communicated to the analysis managers as part of the continual improvement process.

Deliverables

Major deliverables under this task include the data collection plan and the archived datasets.

Schedule

The time required to complete this task is dependent on the types, quantity, and quality of data required; the data collection methods; and the amount of readily available archived data from automated sources. The schedule for developing the data collection plan is estimated to be approximately 2–4 months. Completing the collection of data is extremely variable and may take approximately an additional 2–6 months depending on the data required.

CHAPTER 5. BASE MODEL DEVELOPMENT

BASE MODEL DEVELOPMENT OVERVIEW

A systematic process is required to build a successful base traffic simulation model. The process should include clear documentation of the model structure and calibration criteria. Documenting and following the process ensures that the actual building of the model is done in an orderly way, thereby minimizing coding errors and mistakes.

Experience shows that speeding through the model building in the traffic software interface and relying strictly on the error-checking process to find all of the problems is not a cost effective approach. Although it takes time to set up and carry out the model, utilizing systematic procedures can make a big difference in the timeliness of completing the entire modeling analysis. The time dedicated to building the initial model is fairly small when compared to the overall modeling process. Taking the time to plan the modeling building and executing the work carefully will greatly reduce having to repeat work.

The base model development processes includes the following areas:

- Network (nodes, links, and link connectors).
- Lane geometry (number of lanes, length of turn lanes, etc.).
- Traffic control information.
- Travel demand:
    - Entering volumes.
    - Turning percentages.
    - O-D information.
- Error checking for all areas.

Procedures for developing base models have been documented in other guidebooks, such as the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* and *Traffic Analysis Toolbox Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software*.[1,7] However, other guidebooks have not documented the development of O-D matrices for use in simulation. The use of O-D matrices in traffic simulation models has grown and become increasingly important to produce effective and detailed analysis. The following section discusses the development of O-D matrices.

There is a tradeoff in the level of effort required for preparing accurate O-D information and model quality and reliability. Generally, more complex networks and/or more complex geometric alternatives require more robust O-D efforts. These considerations must be taken into account while determining the scope of the project.

O-D MATRIX ESTIMATION

This section addresses the need to include O-D information into microsimulation tools and presents a number of methods for obtaining the O-D data.

Reasons to Use O-D Matrices

Historically, traffic simulation models were set up to have traffic demands entering from the exterior portions of the model study area and applying turning percentages at each junction. As a vehicle approached a junction, the stochastic assignment would use the turn percentages to assign a choice. This process would repeat until the vehicle left the network. The "look ahead" function (i.e., when a driver/vehicle becomes aware of an upcoming decision) varied by model. This function could have been defined by a particular distance or number of links. This approach is adequate in many but not all situations.

Figure 10 illustrates the path of vehicle A entering the system in the lower left corner and exiting the system in the upper right corner. At each junction, there is a turn percentage or volume that is used to determine the path the vehicle takes through the system. Note that in this figure, there are six decision points at which a vehicle gets assigned a path.

Traffic simulation models inherently cannot understand the conditions in the field. That is, vehicles do not know where to go unless the inputs are set up correctly in modeling terms. This is important, for instance, when a simulation model is intended to correctly evaluate weaving operations on a freeway.

In order for the model to correctly represent not only the traffic volume but also the patterns of movement, some type of O-D information is required. Using O-D matrices is particularly helpful in complex networks, especially when parallel facilities are included in the network. If the project purpose involves evaluating operational strategies and determining alternate paths based on congestion or other ITS-related information, then the use of O-D matrices makes the use of the model more efficient, especially when analyzing alternate geometric configurations in future networks. Once the O-Ds are established, it becomes easier to test design alternatives and other more complex strategies.

Every simulation software package has its own method for creating and inputting O-D information. Some software packages can do partial O-Ds, O-Ds on freeway facilities, or full zonal- or gate-based O-Ds. Figure 11 and figure 12 show full O-D-based models. The path of vehicle A is identified by the zone 3 to zone 10 O-D. (Note that the path of vehicle A is illustrated the same as vehicle A in figure 10.)

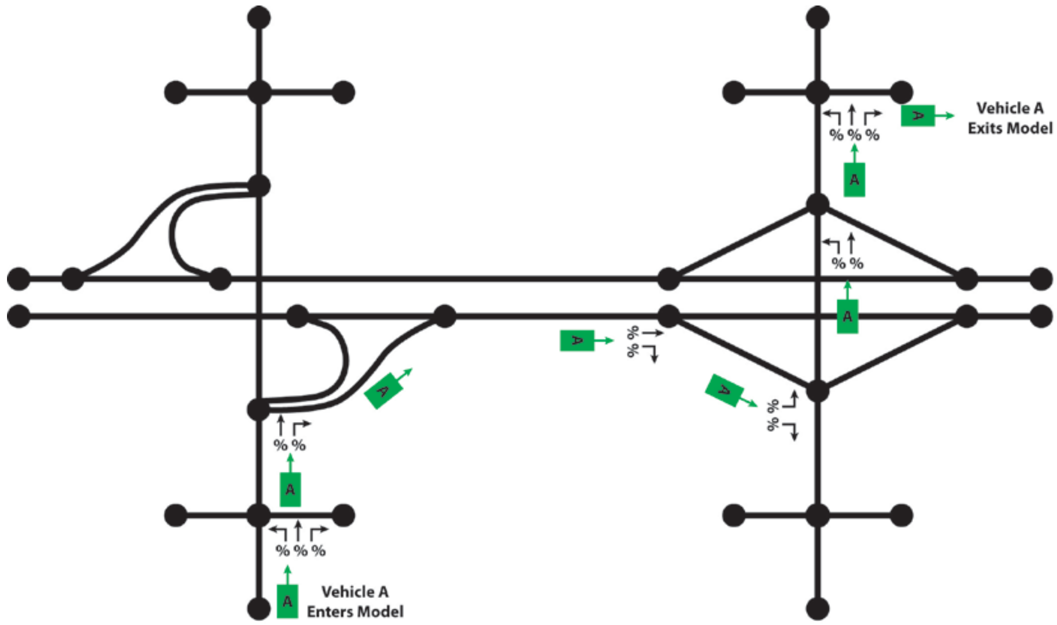

Figure 10. Illustration. Turn percentage O-D-based approach.

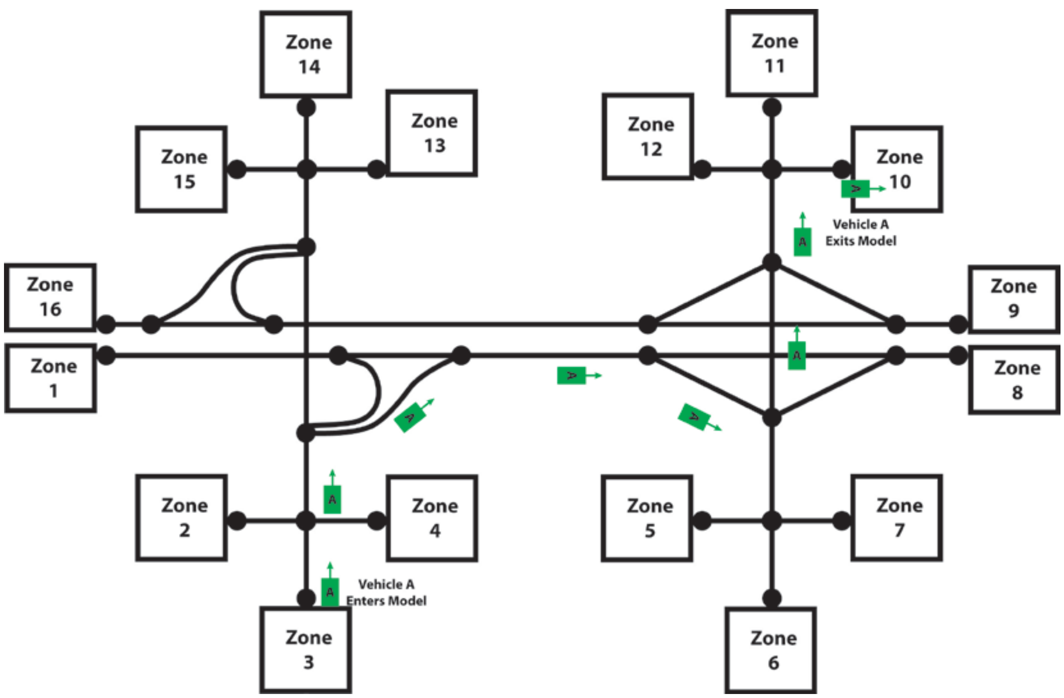

Figure 11. Illustration. Full O-D-based approach.

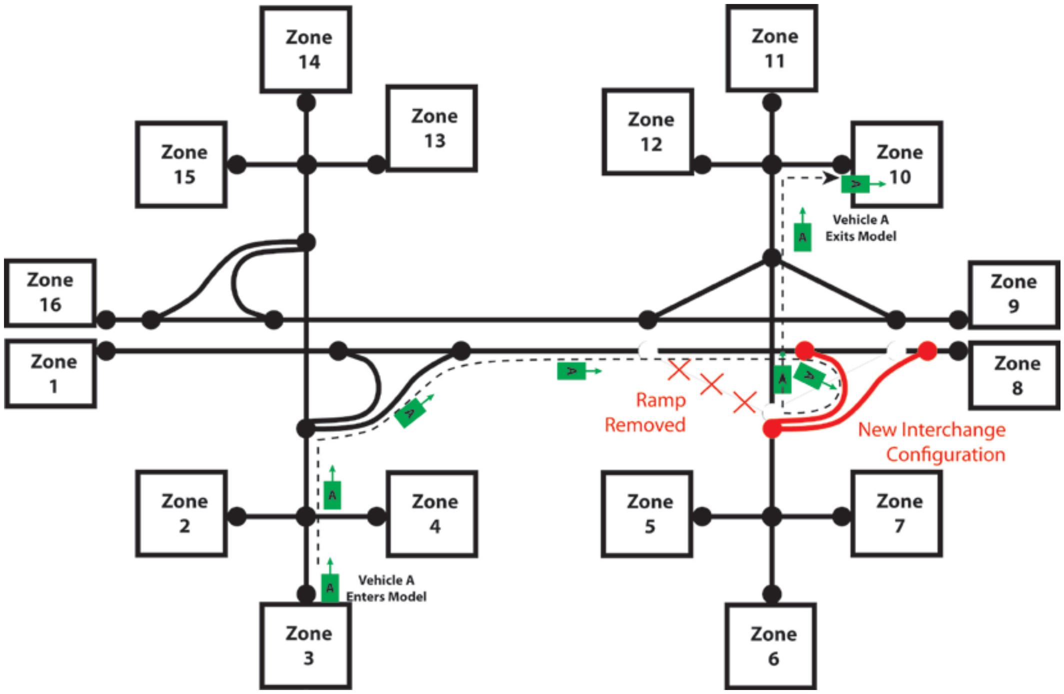

Figure 12. Illustration. Alternate full O-D-based network configuration.

Advantages of Using Full O-D Matrices in Simulation

The process and procedures for developing a sound O-D matrix can be time consuming and complex. The collected field data, license plate surveys (if available), and a trip table available from the local MPO are used to develop an O-D matrix for use in simulation. Approaches and techniques for developing O-D matrices, known as O-D matrix estimation (ODME), are discussed in this section.

Once the O-Ds are established, the ability to test design alternatives and other more complex strategies becomes easier. For example, in figure 12, the previously illustrated freeway system is altered. The diamond interchange on the right is changed to a partial cloverleaf interchange. If the O-D-based system of entering traffic demands is used, then the model only needs be altered geometrically and at the signal controls. The new assignment of trips automatically occurs, and the drivers/vehicles select the appropriate link leading to their destinations.

The advantages of using O-D matrices become even more evident in complex networks, especially when parallel facilities are included in the network. If the project purpose involves evaluating operational strategies and determining alternate paths based on congestion or other ITS-related information, then the full O-D matrix method is even more efficient. Figure 13 shows the same network (as shown in figure 11) with a parallel arterial north of the freeway. These types of complex models are not the focus of this report; however, this case illustrates additional advantages that can be gained in a microsimulation process when ODME techniques are used.

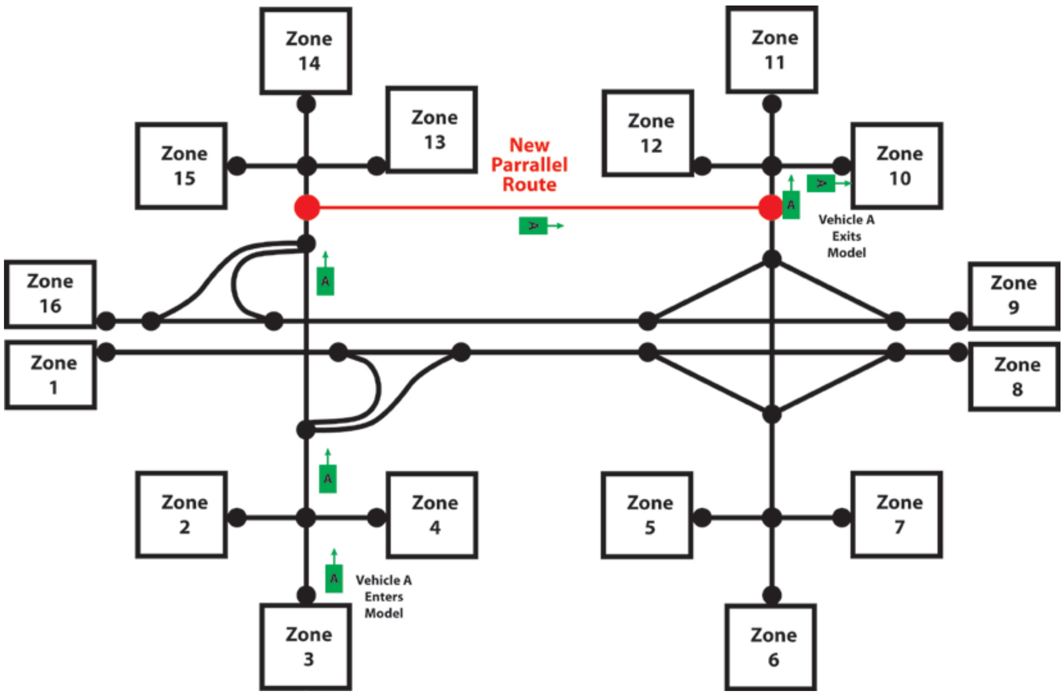

Figure 13. Illustration. O-D parallel facilities.

ODME Approaches

There are multiple methods for developing O-D inputs into microsimulation models. This is largely dependent on the software, which may have no O-D inputs, partial O-D inputs, or full O-D inputs. Depending on the size, complexity, available data, and software platform selected for the project, the ODME technique may include one or a combination of the following techniques:

- Traffic counts.
- Surveys (license plate or roadside).
- TDMs.

ODME by Traffic Counts

For a small freeway segment or for basic freeway operations (e.g., ramp-to-ramp O-Ds), developing O-D matrices for simulation from traffic counts alone is a straightforward method that can be accomplished with a spreadsheet tool similar to what is typically used to reduce and balance traffic count data. Traffic counts at each on- and off-ramp are required, and mainline volumes between interchanges are required to account for possible errors in ramp counts or at locations where ramp counts are performed on different days.

The primary advantage of this methodology is that it is relatively quick and simple. One disadvantage comes to light when performing an analysis on future scenarios where the growth in traffic is determined in the form of growth percentage and applied to the existing counts. This method has become less desirable in the current state of the practice as it can either overestimate traffic in areas not expected to have growth trends in land use or it can underestimate growth in traffic by not taking into account regional growth and through traffic that may be attracted to the corridor when improvements are made.

Another disadvantage is that the zones for the O-D matrices are in the form of ramp termini or entry points, not true transportation analysis zones (TAZs). This means that for any future scenarios that have interchange or ramp reconfigurations, the O-D matrices will have to be modified by hand to reflect the new ramp termini or interchange reconfiguration. This introduces the potential for errors, and depending on the size of the system, it can be labor intensive.

ODME by Surveys

ODME for simulation can also be developed by conducting O-D surveys through license plate matching, driver intercept surveys, and newer technologies utilizing mobile source data. These procedures provide O-D data by matching a vehicle's entry and exit points within the system (usually entry and exit ramps to a freeway). Since this methodology is a sample of the traffic within the system, a sampling plan must be prepared containing control counts at key locations within the study area to verify the level of traffic and to ensure that the vehicles included represent a statistically significant sample of the vehicles in the system. In addition to the survey, traffic counts are needed to develop expansion factors to expand the O-D survey data to match the traffic levels in the study area.

The advantage of using this method compared to traffic counts alone is that the O-D matrices for the analysis area are more accurate. The disadvantages are similar to those of the ODME by traffic counts mentioned in this section. An additional disadvantage is that this methodology typically includes only a sampling of the total traffic and may not provide information on through traffic on freeway segments.

ODME by TDMs

ODME for traffic analysis and microsimulation from existing TDMs has become popular as a result of the increased capabilities in software and computing power. However, O-D matrices cannot simply or directly be taken from a TDM and utilized in a microsimulation model. TDMs, however, can serve as the base platform for developing O-D matrices in terms of the network to be analyzed and TAZs to serve as O-D zones. This methodology offers several advantages, including the following:

- A larger study area can be considered beyond just the freeway segments and on- and off-ramps. This could include the local arterial system adjacent to the freeway and/or potential alternative routes to the freeway.

- The traffic analysis tool will be O-D based on true TAZs, not just entry and exit points to the freeway. This provides for a true dynamic assignment of traffic, which eliminates the need to manually reassign traffic for each network change/alternative as well as for future forecasts.

- Future forecasts can be derived at the TAZ level from accepted forecasts developed by the MPO and contained in the regional TDM at the TAZ level.

Disadvantages of this methodology include the following:

- ODME using TDMs requires an extensive data collection and calibration investment. Often, the TDM O-Ds are derived from regional surveys and estimates of local O-Ds for localized analysis of freeway sections. The process to derive the O-Ds in a TDM typically requires the same type of data that would be collected for the techniques of ODME by traffic counts and ODME by surveys. ODME can be calculated manually; however, it is typically more efficient to compute ODME using software. The level of effort and procedures can vary depending on the traffic analysis tool selected and the software platform of the regional model.

- Regional TDMs are validated to perform analyses of regional transportation plans and air quality conformity. This is usually done at the annual average daily traffic level (24-h assignment). This results in the need to process the ODME into at least hourly O-D matrices, which may require a factoring process for peak spreading in congested regions for hourly, 30-min, and 15-min time intervals.

ODME Overview

There are several methods and approaches used to develop O-D matrices. Depending on network and study complexity, there are advantages and disadvantages to all of the methods, including the following:

- The direct measurement method may be simpler; however, data collection costs may be prohibitive and may limit the size of the data collection area. Additionally, the direct measurement method is not accurate for complex networks and for new geometric configurations.

- TDM-based techniques provide larger coverage and better traffic estimation in new geometric configurations; however, the accuracy may be reduced because of the coarse estimation techniques that are used to develop regional trip estimations.

CHAPTER 6. MODEL CALIBRATION

OVERVIEW

Model calibration is an important step in the traffic simulation modeling process. The goal of this report is to provide practitioners with a statistical model calibration approach that provides a stronger link to field data and helps increase confidence in the model calibration results while remaining consistent with guidance provided in *Traffic Analysis Tools*.[9]

The objectives of this chapter are as follows:

- To provide a step-by-step model calibration process and framework.
- To provide a recommended statistical method for calibration (based on using field data from different days as a basis for determining tolerance).
- To provide an example of this statistical method using a real case study.

This chapter also provides guidance on the model calibration methodology to perform the following:

- Determine the minimum required number of model runs.
- Determine whether the model data replicate the performance measures observed in the field.

Model Calibration Definition

Calibration is the process of systematically adjusting model parameters so that the model is able to reproduce the observed traffic conditions. The process is continued until the error between the performance measures taken from the field data and the performance measures calculated in the simulation is less than a predetermined margin of error. Once it is determined that the model does reproduce observed conditions, model calibration can focus on specific performance measures such as volume, speed, travel time, and bottleneck. It is important to note that in the model calibration process, there needs to be a tradeoff between the required precision and the available resources to collect data and conduct modeling.

Calibration Challenges

The goal of calibration is to make the model represent locally observed traffic conditions. However, since traffic may vary greatly day to day, it is not possible for one model to accurately represent all possible traffic conditions. Most simulation software are developed using a limited amount of data. The model parameter values are estimated using the limited data.

Driver behavior differs by region, and it may differ significantly from normal to non-typical days. For example, poor visibility, severe weather, incidents, presence of trucks, and pavement conditions all impact driver behavior. As a result, it is not recommended to use a model developed using data from one region to represent future traffic conditions in another region. Investment decisions made using a model that has not been calibrated to local field conditions will be flawed.

Simulation software tries to mimic driver behavior using the limited data to which the analysts have access. Given that fact, if the model is not properly calibrated, any flaws in the model will be magnified.

Calculations and procedures presented in this chapter assume the following conditions:

- Traffic volume and speed data have been adequately scrubbed, and there are no internal inconsistencies.
- There is adequate spatial coverage and consistency in detector data.
- There is adequate and accurate sampling of speed data.
- Speed performance measures are calculated in consistent ways in the field and in the model.

CALIBRATION PROCESS

Guidance on the overall model calibration process is presented in *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.[1] The overall model calibration process can be divided into the following four main steps:

1. Identify the performance measures and critical locations for the models to be calibrated against.
2. Determine the strategy for calibration, consistent with *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.[1]
3. Determine the statistical methodology to be used to compare modeled results to the field data. Identify tolerance (measure of precision) and confidence levels (measure of accuracy or variability among samples).
4. Conduct model calibration runs following the strategy and conduct statistical checks. When statistical analysis falls within acceptable ranges, then the model is calibrated.

Performance Measure and Critical Location Identification

During the model scoping process and the development of the data collection plan, the field measurements are determined, including speed, volume, queuing, and other congestion observations at different locations in the network. Since traffic conditions fluctuate daily, it is important to obtain field data from multiple days. The data from multiple days serve as a base in which field variations are used to determine the tolerance of error in the simulated results. For simulation of a typical day, it is preferred that data exclude incident days as well as Mondays, Fridays, and weekend days.

During model development, it is recommended that the spatial and temporal model limits extend beyond where and when the congestion in the field occurs. The statistical calibration should not necessarily include every link in the model but should focus on the critical design elements within the primary study area in the model. This report focuses on capacity and operational interchange modifications on the interstate system. Therefore, the critical elements include the mainline freeway, ramp roadways, and the crossing arterials. Priority should be given to the higher-volume roadway elements.

The number of locations selected for comparing the performance measures in field data against model outputs needs to be balanced against the quality and location of the available data, the desired level of statistical confidence, and the availability of resources. The model outputs and reporting for these statistical tests should be similar to the performance measures that will be used later on in the analysis.

The selection of the number of data days to be used should be based on an analysis of available data in terms of what data are available and cost effective to collect. In an urban area where freeway sensor data are archived and readily available, more days of data can be used. In areas where there is no surveillance and where manual or temporary data collection devices are used, the amount of data to be collected would be more resource intensive.

The use of speed data can be more of a challenge. If the speed profile is constructed from freeway sensor data, then the reliability and available days of data will be similar to the volume discussion. If the speed data are based on probe vehicle information, then the reliability will be reduced because the probe vehicle data will only be a sample of the actual traffic stream.

Determination of Strategy for Calibration

The strategy for calibration is related to the steps and model parameters that the modeler chooses to modify in order to achieve calibration. Different simulation software have their own parameters and recommended practices for adjusting the models to get the performance to match the field data.

In order for the modeler to be cost effective, there should be a strategy for approaching the model adjustments. *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* highlights the following three-step strategy for calibration:[(1)]

1. Calibrate to capacity.

2. Calibrate route choice.

3. Calibrate system performance.

These strategies are still applicable, and this report focuses on refined statistical methods.

STATISTICAL METHODOLOGY

The purpose of conducting a statistical test on stochastic traffic simulation models is to ensure that the performance measure means across different simulation model runs differ significantly from the means of the data in the field. This statistical check requires two primary items. First, there must be a sufficient amount of field data from different days so that an acceptable margin of error in data can be determined. Second, there must be an error-free traffic simulation model that has been built to reflect the conditions in the field (i.e., the model reflects adequate spatial and temporal boundary conditions). With these two components, the following general statistical procedure can be conducted:

1. Select locations for statistical tests.

2. Analyze field data.

    - Calculate sampling error (margin of error) of field data from multiple days of data.

    - Calculate tolerance (margin of error in percent of the mean). This percentage value will be used to determine the minimum number of model runs to perform.

3. Analyze traffic model output.

    - Run traffic models 5–10 times with different random number seeds and conduct statistical tests on model results.

    - Conduct statistical test 1 to determine the minimum required number of model runs.

4. Compare field data to traffic model results.

    - Conduct statistical test 2 to compare field data to traffic model results using a *Z*-test.

    - If the statistical relationship between modeled output and field data does not indicate a significant difference, then proceed with measures of effectiveness (MOE) comparisons, including volumes, speeds, travel times, and bottlenecks.

    - If the statistical relationships between field data and modeled output indicate a significant difference, adjust calibration parameters, rerun models, and repeat statistical test 2.

Analyze Field Data

Field data must be collected for multiple days. These data are initially used to establish model inputs and are then used in statistical tests. The first set of analyses is used to understand the variability in the data. The variability is addressed by calculating the margin of error, E, among different representative days, as shown in figure 14.

$$E = Z_{critical}\left(\frac{\sigma}{\sqrt{n}}\right)$$

Figure 14. Equation. Margin of error.

Where:

E = Margin of error.
$Z_{critical}$ = Critical Z statistic (for a 95 percent confidence interval, Z = 1.96).
σ = Standard deviation.
n = Sample size (number of observations).

The tolerance error percentage is calculated by dividing E by the mean of the field data, as shown in figure 15.

$$e = \frac{E}{\overline{X}_{field}}$$

Figure 15. Equation. Tolerance error percentage.

Where:

e = Tolerance error percentage.
$\overline{X}_{field}$ = Mean of the field data.

Table 9 demonstrates how these two calculations are performed.

Table 9. Variability analysis of field data.

Day Number	Hourly Volume
1	2,980
2	2,682
3	3,063
4	2,594
5	3,193
6	2,675
7	3,230
8	2,562
9	3,034

Based on the field data in table 9, the calculations are as follows:

- $\overline{X}_{field}$ = 2,890.
- σ = 262.4.
- n = 9.
- $Z_{critical}$ = 1.96.
- E = 172.
- e = 6 percent.

Statistical Test 1—Determine the Minimum Required Number of Model Runs

Statistical test 1 is used to determine the minimum required number of model runs based on an error rate calculated using the procedure described in the previous subsection. For a given target level of tolerance (tolerable error determined using variability in field observations) and a given confidence level (usually a confidence level of 95 percent is selected), a minimum number of model runs is required using different random number seeds. The minimum required number of model runs is computed using the equation in figure 16.

$$n = \frac{(Z)^2(\sigma)^2}{(e\overline{X}_{model})^2}$$

Figure 16. Equation. Minimum number of model runs.

Where:

n = Minimum number of model runs required.
Z = Critical Z statistic (for a 95-percent confidence Interval, Z = 1.96).
σ = Standard deviation.
e = Tolerance error percentage.
$\overline{X}_{model}$ = Mean calculated on the basis of the performed model runs for the given MOE.

The minimum number of model runs should be calculated using two different performance measures, typically volume and speed, and for multiple locations. The highest resulting number of model runs should be used as the minimum required number of model runs. The example calculations show one performance measure (volume) for one location to demonstrate the statistical calculations and process. These same techniques should be performed at multiple locations and for different measures.

An example of how to calculate the minimum required number of model runs is shown in table 10. In this example, five model runs were conducted, and the results were used to perform the minimum number of runs required. The tolerance error, e, for this example was 6 percent as derived from the field data and calculation in table 9.

Table 10. Sample statistical calculation to determine the minimum number of runs.

Model Run Number	Hourly Volume
1	3,591
2	3,000
3	2,655
4	3,680
5	2,720

Based on the field data in table 10, the calculations are as follows:

- $\overline{X}_{model}$ = 3,129.
- σ = 481.1.

- $n = 5$.
- $Z_{critical} = 1.96$.
- $E = 172$.
- $e = 6$ percent.
- Number of model runs = 26, as calculated using the equation in figure 17.

$$26 \text{ model runs} = \frac{(1.96)^2(481.1)^2}{(0.06 \times 3{,}129)^2}$$

Figure 17. Equation. Number of model runs example.

The results of statistical test 1 indicate that the minimum number of model runs should be 26. As a result, 21 more model runs should be conducted before proceeding to the next step of comparing field data to model output.

Statistical Test 2—Compare Field Data to Model Output

The next statistical step is to compare the two populations (i.e., field data volume mean versus model output volume mean) by testing the following hypothesis:

$$H_0: \overline{x}_{field} = \overline{x}_{model}$$

$$H_1: \overline{x}_{field} \neq \overline{x}_{model}$$

$$Z_{Calculated} = \frac{\overline{x}_{field} - \overline{x}_{model}}{\sqrt{\frac{\sigma_{field}{}^2}{n_{field}} + \frac{\sigma_{model}{}^2}{n_{model}}}}$$

Figure 18. Equation. Compare field data to model output.

Where:

$\overline{X}_{field}$ = Average (mean) of the field observations.
$\overline{X}_{model}$ = Average (mean) of output from different model runs.
σ_{field} = Standard deviation from field observations.
σ_{model} = Standard deviation from the model runs.
n_{field} = Sample size of the field observations.
n_{model} = Number of model runs with different random number seeds.
$Z_{calculated}$ = Z-test of the field data and modeled data.

If $Z_{calculated} \geq Z_{critical}$ (1.96 for a 95 percent confidence level) or $\leq -Z_{critical}$, reject H_0.

The hypothesis test is a two-tailed Z-test based on a normal distribution. Figure 19 is a graph of the normal distribution. The area between $Z_{critical}$ of ±1.96 is the do-not-reject range.

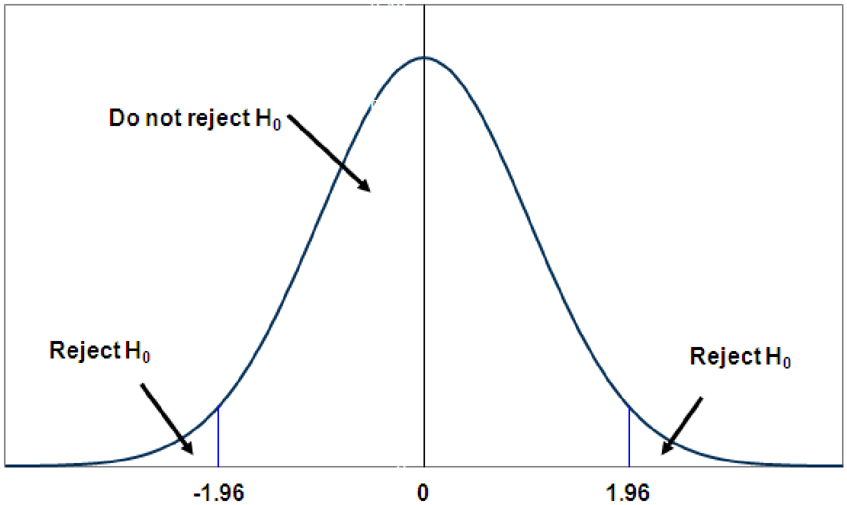

Figure 19. Graph. Normal distribution curve.

Using the same example as statistical test 1, the field data and 26 model runs are summarized in table 11 and table 12. Once all 26 model runs are conducted, the computation of the tolerance error is repeated to ensure that the margin of error is less than or equal to the desired tolerance error. The new tolerance error is 3.9 percent, which is lower than the desired 6.0 percent. Therefore, conducting 26 model runs was sufficient to satisfy the 95 percent confidence level and the 6.0 percent tolerance error.

Table 11. Sample calculation of field data.

Day Number	Hourly Volume
1	2,980
2	2,682
3	3,063
4	2,594
5	3,193
6	2,675
7	3,230
8	2,562
9	3,034

Where:

$\overline{X}_{field}$ = 2,890.
σ = 262.4.
n = 9.
$Z_{critical}$ = 1.96.
E = 172.

Table 12. Sample calculation of model statistics.

Run Number	Modeled Data
1	3,591
2	3,000
3	2,655
4	3,680
5	2,720
6	2,976
7	3,270
8	3,027
9	2,657
10	2,956
11	3,450
12	3,267
13	2,870
14	2,680
15	3,240
16	3,575
17	3,050
18	2,840
19	3,450
20	3,120
21	2,680
22	2,980
23	3,355
24	3,090
25	2,675
26	3,070

Where:

$\overline{X}_{model}$ = 3,074.
σ = 312.0.
n = 26.
$Z_{critical}$ = 1.96.
E = 120.

Based on a comparison of the data in table 11 and table 12, $Z_{calculated}$ can be determined, as shown in figure 20.

$$Z_{Calculated} = \frac{2{,}890 - 3{,}074}{\sqrt{\frac{262.4^2}{9} + \frac{312.0^2}{26}}} = -1.72$$

Figure 20. Equation Sample calculation of $Z_{Calculated}$.

Because $Z_{calculated}$ (-1.72) is not less than or equal to $Z_{critical}$ (-1.96), H_0 should not be rejected.

In this example, comparison of field data to the model output leads to not rejecting the null hypothesis. This means that there is insufficient evidence to conclude that the model output is significantly different than the field data. If the conclusion of the hypothesis was reject, then additional model trials using different calibration parameters would be required, along with a repeat of the hypothesis test. A complete iterative hypothesis test case study is presented in the next section.

STATISTICAL METHOD EXAMPLE CASE STUDY

The purpose of the case study was to test interchange improvements.

Data Collection

The field data were collected using freeway detection sensors. For the purposes of this exercise, nine different weekdays of data were selected to conduct the statistical tests. Of these 9 days of data, 1 day was selected as the typical day to build the base model. The data selected were free of any major incidents or crashes.

Build Base Model

The base model was developed according to the scope development process that identified spatial and temporal boundary limits. The model was constructed according to the procedures in the seven-step modeling process specified in *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.(1) The model was checked for errors and was found to be free of any errors.

After the base model was completed, an initial number of model runs with different random number seeds was conducted to come up with an initial set of output MOEs. These MOEs were used to determine the minimum number of model runs.

Select Locations and Time Periods for Statistical Tests

The selection of locations and time periods for a statistical test should be based on the primary study area within the model limits and the peak periods. Within the study area, the key features that are being analyzed should be selected such as the mainline freeway and ramps. It is neither practical nor necessary to perform these rigorous statistical checks on every component of the model. For example, it is possible to select an unimportant location and have that selection drive the number of model runs too high. The goal is to ensure that there is a statistical confidence in the desired results from the models.

Analyze Field Data

The first step was a field data analysis to determine the corresponding sampling error, E. Nine days were selected for data collection, and the corresponding data were obtained. Table 13 and table 14 present the corresponding error computations.

Table 13. Error calculation of field data hourly volumes from 7:45 to 8:45 a.m.

Day	Field Volume Data	
	Mainline	**Ramp**
1	2,980	1,030
2	2,682	1,266
3	3,063	975
4	2,594	1,239
5	3,193	920
6	2,675	1,319
7	3,230	890
8	2,562	1,271
9	3,034	1,026

The calculations for mainline and ramp, respectively, are shown as follows:

- $\overline{X}_{field}$ = 2,890 and 1,104.
- σ = 262.4 and 168.2.
- n = 9 and 9.
- $Z_{critical}$ = 1.96 and 1.96.
- E = 172 and 110.
- e = 6 and 10 percent.

Table 14. Calculation of modeled speed data error and variation from 7:45 to 8:45 a.m.

Day	Mainline Speed (mi/h)
1	25.5
2	35.2
3	35.1
4	35.1
5	30.7
6	32.0
7	27.7
8	34.7
9	34.2

The calculations for mainline speeds are as follows:

- $\overline{X}_{model}$ = 32.2.
- σ = 3.6.
- n = 9.

- $Z_{critical}$ = 1.96.
- E = 2.35.
- e = 7.3 percent.

Analyze Model Output

After the error-free base model was developed, it was run five times with different random number seeds. The initial output was used to determine if there was an adequate number of runs.

Statistical Test 1: Determination of the Minimum Required Number of Runs

The first statistical test was used to determine whether the minimum number of model runs with different random number seeds have been satisfied. In order to conduct this test, an initial set of five runs was conducted on the error-free base model. The formula for determining the minimum number of runs as discussed in the previous section was used assuming a 95 percent confidence interval and a tolerance level determined by using the variability in the field data.

Table 15 is a summary of the data and calculations based on hourly volumes for the two locations (i.e., mainline and ramp) and speeds for the mainline location that were identified previously. Based on the analysis, it was determined that 16 model runs would be required.

Table 15. Summary table for minimum required number of model runs.

Model Run Number	Modeled Volume Data (Vehicles/h)		Modeled Speed Data (mi/h)
	Mainline	Ramp	Mainline
1	2,980	1,051	29.1
2	3,333	923	19.6
3	2,782	1,265	23.8
4	3,273	875	23.0
5	3,583	935	25.3

The calculations for mainline volume, ramp volume, and mainline speed, respectively, are shown as follows:

- Mean = 3,110, 1,010, and 24.2.
- σ = 227.0, 156.6, and 3.5.
- n = 5, 5, and 5.
- $Z_{critical}$ = 1.96, 1.96, and 1.96.
- e = 6, 10, and 7.3 percent.
- Minimum number of runs = 6, 10, and 16.

Compare Field Data to Model Results—Trial 1

The results of the statistical test 1 (see table 15) indicate that the minimum number of model runs required for both locations and performance measurements is 16. Eleven more model runs should be conducted before proceeding to statistical test 2 to compare field data to model output. The 16 model runs are summarized in table 16. Once all 16 model runs were conducted, the computation of the tolerance error was repeated for each of the three data to ensure that the margin of error was less than or equal to the desired tolerance error. The new tolerance errors for the mainline volume, the ramp volume, and the mainline speed were 4.1 percent (desired was 6.0 percent), 6.8 percent (desired was 10.0 percent), and 7.2 percent (desired was 7.3 percent), respectively. All three tolerance errors were less than the desired. Therefore, 16 model runs were sufficient to satisfy the 95 percent confidence level and the desired tolerance errors.

Table 16. Trial 1 summary table for minimum required number of model runs.

Model Run Number	Modeled Volume Data (vehicles/h)		Modeled Speed Data (mi/h)
	Mainline	Ramp	Mainline
1	2,980	1,051	29.1
2	3,333	923	19.6
3	2,782	1,265	23.8
4	3,273	875	23.0
5	3,583	935	25.3
6	3,122	1,023	28.6
7	3,465	902	22.8
8	2,879	1,155	20.8
9	2,865	879	26.5
10	3,045	978	18.0
11	2,765	925	23.8
12	3,346	1,235	28.7
13	2,870	931	26.7
14	2,989	1,010	23.8
15	3,455	1,312	18.9
16	3,198	1,102	22.3

The calculations for mainline volume, ramp volume, and mainline speed, respectively, are shown as follows:

- Mean = 3,122, 1,031, and 23.9.
- σ = 263.3, 1,427, and 3.5.
- n = 16, 16, and 16.
- $Z_{critical}$ = 1.96, 1.96, and 1.96.
- e = 4.1, 6.8, and 7.2 percent.

Statistical Test 2: Hypothesis Test

The hypothesis test should be conducted on multiple locations. In order to illustrate the procedures, two locations were analyzed in the case study. Hypothesis testing is typically an iterative process involving trial and error. The following section illustrates that the initial base model results did not satisfy the hypothesis test. For the second trial, the calibration parameters were modified, and the results satisfied the second hypothesis test.

The previously selected mainline location was analyzed using the hypothesis test for hourly traffic volumes for the peak hour from 7:45 to 8:45 a.m. In table 17, the hypothesis test was rejected for model trial 1.

A second model iteration was conducted by adjusting the calibration parameters in the model. The random number seeds from model trial 1 were reused. In model trial 2, the null hypothesis was not rejected, and the results of this analysis are shown in table 18.

Table 17. Hypothesis test trial 1.

	Field Data			Model Results			Statistics	
Description	**Mean**	σ_f	n_f	**Mean**	σ_m	n_m	$Z_{calculated}$	**Null Hypothesis**
Mainline volume	2,890	262.4	9	3,122	263.3	16	-2.12	Rejected
Ramp volume	1,104	168.2	9	1,031	142.7	16	1.10	Cannot reject
Mainline speed	32.2	3.6	9	23.9	3.5	16	5.59	Rejected

σ_f = Standard deviation of field data.
n_f = Number of days field data were collected.
σ_m = Standard deviation of model runs.
n_m = Number of model runs.

Compare Field Data to Model Results—Trial 2

Since the first hypothesis test resulted in a reject conclusion for the mainline volume and speed results, a second trial was conducted. In this trial, calibration parameters were adjusted to attempt to closer match the results.

The calibration parameters that were adjusted include the following:

- Car-following sensitivity factors were adjusted on key mainline locations.
- Warning signs for exits and major ramp locations were adjusted (where drivers begin to consider changing lanes to achieve a desired destination).
- Free-flow speeds were increased at the boundary locations where traffic is free flow and uncongested.

After these parameters were adjusted in a number of locations, the models were rerun five times, and the hypothesis test was conducted again. Table 18 is a summary of the second trial.

Table 18. Hypothesis test mainline location trial 2.

	Field Data			Model Results			Statistics	
Description	**Mean**	σ_f	n_f	**Mean**	σ_m	n_m	$Z_{calculated}$	**Null Hypothesis**
Mainline volume	2,890	262.4	9	3,088	222.8	16	-1.91	Cannot reject
Ramp volume	1,104	168.2	9	1,200	121.2	16	-1.51	Cannot reject
Mainline speed	32.2	3.6	9	29.2	4.5	16	1.82	Cannot reject

σ_f = Standard deviation of field data.
n_f = Number of days field data were collected.
σ_m = Standard deviation of model runs.
n_m = Number of model runs.

CHAPTER 7. ALTERNATIVES ANALYSIS

OVERVIEW

The primary purpose of building models is to evaluate alternatives in support of the decisionmaking process. The alternatives analysis process has two fundamental parts: the simulation modeling of alternatives and the sequencing of the alternatives to analyze. From an overall workflow perspective, the alternatives analysis step is similar for all projects in terms of how the modeling steps are conducted. However, the number of alternatives and workflow for what is being analyzed and reported can be very different and therefore needs to be customized based on the issues and the nature of the proposed project and improvements.

There are three main areas of consideration for an alternatives analysis, as shown in figure 21. There is the simulation modeling work itself, which includes carrying forward relevant calibration parameters, satisfying the required number of model runs, forecasting traffic, and ensuring that error checking has been conducted. The second area is the sequencing of alternatives and timeframes that are to be simulated. Time should be invested up front to investigate and lay out an optimal approach for the sequencing of the simulation analysis to reduce the overall level of effort. The third area is the presentation of modeled results, where the report summaries must be designed to be illustrative and effective at communicating differences.

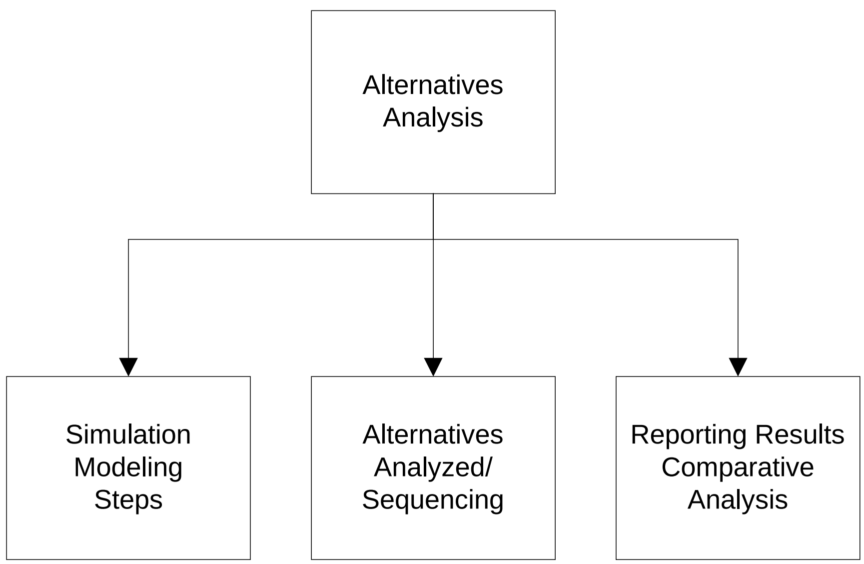

Figure 21. Flowchart. Alternatives analysis workflow.

Key considerations for the alternative analysis step include the following:

- The purpose of the analysis is clear.
- The base model is error-free and properly calibrated.
- The determination of how the traffic forecasts are developed and incorporated into the simulation.

- There is an understanding of what alternatives should be simulated.

- The determination of whether the number of alternatives being simulated can be reduced by some other screening or analysis technique.

- The MOEs that are important in making a decisions are included.

- The MOEs are presented clearly to make the results transparent and easy to understand.

In some occasions, the simulation analysis may not be sensitive enough to distinguish between subtle nuances between similar alternatives. For example, simulation models cannot really distinguish between operational characteristics of two alternatives featuring a difference of 20 ft in the length of a storage lane. Similarly, simulation tools may not adequately analyze the differences between other design features such as shoulder widths, lane widths, and taper rates of acceleration and deceleration lanes. It is important that parameters are identified upfront about the realistic capabilities of what the simulation can and cannot be used to evaluate.

ALTERNATIVE ANALYSIS REQUIREMENTS

The requirements for an alternatives analysis depend on the type of project. The focus of this report is interstate freeway improvement projects. The level-of-effort case studies presented in chapter 1 include two projects requiring FHWA approval for interstate access requests. One project was a national highway system freeway (TH 100) that does not require the same FHWA approval as an interstate project, and the other was a comprehensive system plan (I-5 in San Diego, CA). The national highway system project mostly followed the interstate access request process.

The interstate access request process is fairly strict and requires a number of analyses, including the existing conditions, year opening, and design year. Depending on the sequence of construction and project phasing, additional interim year analyses may be required. This workflow is illustrated in figure 22. The interstate access request process is described in FHWA's *Interstate System Access Informational Guide*.[10]

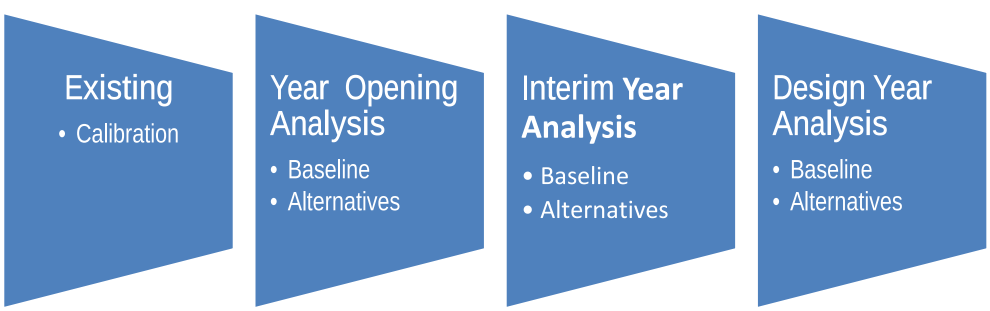

Figure 22. Illustration. Interstate access analysis requirements—analysis years.

Baseline Condition

In all of types of projects, it is important to have a baseline for comparison. The baseline condition generally reflects some of the current planned geometric and operational conditions with future year traffic. When future planned/approved projects are coded into the model, the baseline condition is representative of the no-build condition.

Depending on the complexity of the network and of the alternatives analyzed, it is beneficial to use the ODME process (described in chapter 5) to analyze future alternatives that have interchange or ramp reconfigurations. Constructing O-D matrices by hand (to reflect the new ramp termini or interchange reconfiguration) introduces the potential for errors, and, depending on the size of the system, it can be labor intensive.

SIMULATION OF ALTERNATIVES

The actual simulation of alternatives must follow the same principles and guidelines for base development and error checking. However, there are some specific considerations for the alternatives analysis that are captured in this section as follows:

- **Traffic forecasting**: Preparing traffic forecasts is part of the analysis process. This report does not include the costs and processes involved in the forecasting effort because the case study projects that were used had forecasts available through local agencies.

- **Number of model runs:** The procedure described in chapter 6 should be followed in the alternatives analysis. It is important to confirm that the selected tolerance in variation between model runs is satisfied. It is likely that the required number of runs in the alternatives model will be similar to the base model. Therefore, starting with the same number of runs would potentially save time.

- **Calibration parameters:** It is important to maintain the calibration parameters from the calibrated model as a basis to conduct the alternatives analysis.

SEQUENCING OF ANALYSIS

Managing the number of alternatives to be simulated in an alternatives analysis must be given careful consideration. If there are too few analyses, the process will have little credibility. Conversely, if there are too many analyses, the process can become bogged down with information overload, and it will become costly.

Simulation analysis is a powerful tool that allows for an effective and comprehensive analysis of an alternative. However, depending on the size and complexity of the model, it can also be a costly resource to deploy. It is essential to strike a balance between using the modeling process correctly and using the modeling process too much.

There are three different sequencing approaches, which are discussed in the following subsections. This is an illustrative exercise only and is provided to demonstrate how planning the alternatives analysis can be accomplished, potentially in a streamlined fashion. The disclaimer on this exercise is that there is no “one size fits all” solution; each project must consider the requirements and the best approach to satisfy the project. These examples demonstrate alternative methods that can reduce the amount of effort expended and improve the effectiveness of the analysis.

Incomplete Analysis

At times, particularly when resources are limited, there is a strong desire to skip the entire seven-step simulation process and go straight to the analysis of the alternative that is thought to be the best. This approach is incomplete and unacceptable for many reasons. For example, bypassing the model calibration step works against the credibility of the analysis. Also, the comparison between the baseline results and the alternative is most useful when focused on the differences in performance measures values rather than the absolute values.

An example analysis workflow of incomplete analysis is illustrated in figure 23. In this extreme case, the model calibration is not conducted, there is no baseline (no-build) for comparison, and there is only one alternative analyzed.

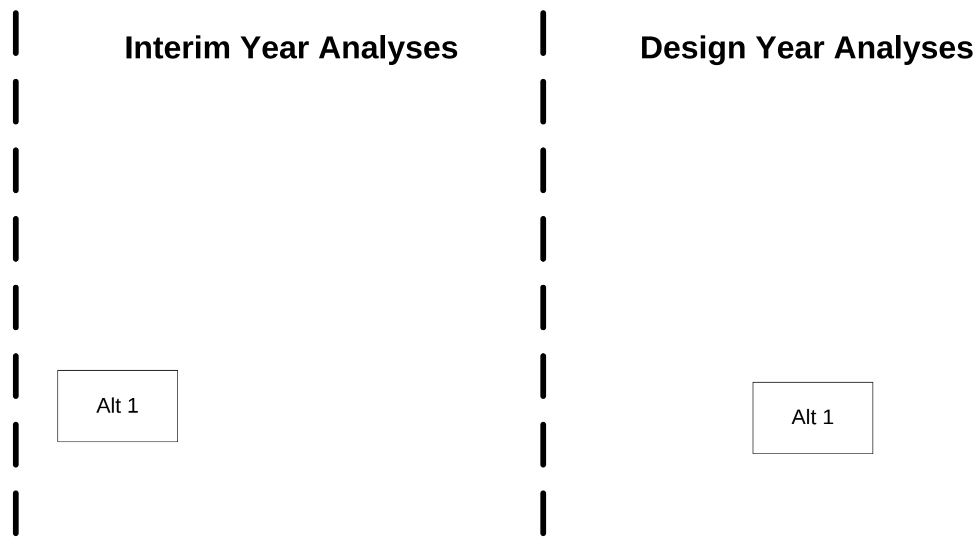

Figure 23. Illustration. Incomplete alternatives analysis approach.

Excessive Alternatives Analysis

The opposite of an incomplete alternatives analysis approach is one that is too excessive. In dealing with multiple stakeholders, there is a temptation to satisfy every request to analyze solutions in the microsimulation tool. At the beginning of the process, this may seem reasonable; however, as controversy occurs on a project and more ideas begin to be voiced, there is pressure to simulate more and more ideas.

One advantage of simulation is that when an alternative is modeled, the results provide useful information as to how to refine a design concept. If the initial/core set of alternatives is not managed to a reasonable number, then it is possible that the proliferation of subalternatives can add another layer of excessive alternatives analysis.

The last consideration is how the analysis years are sequenced. If the design year is the decisionmaking timeframe on the final solution, then it is advantageous to start with that timeframe to make a decision, reduce the number of alternatives, and then focus the analysis on the interim years on fewer alternatives. If not and the analysis proceeds in a linear fashion from existing to year opening to interim and then design year, then the modeler becomes obligated to carry forward all the alternatives (and sub-alternatives) forward without making a decision until all the analyses are completed.

A diagram of the number of alternatives and sub-alternatives that could easily occur as a result of the aforementioned issues is illustrated in figure 24.

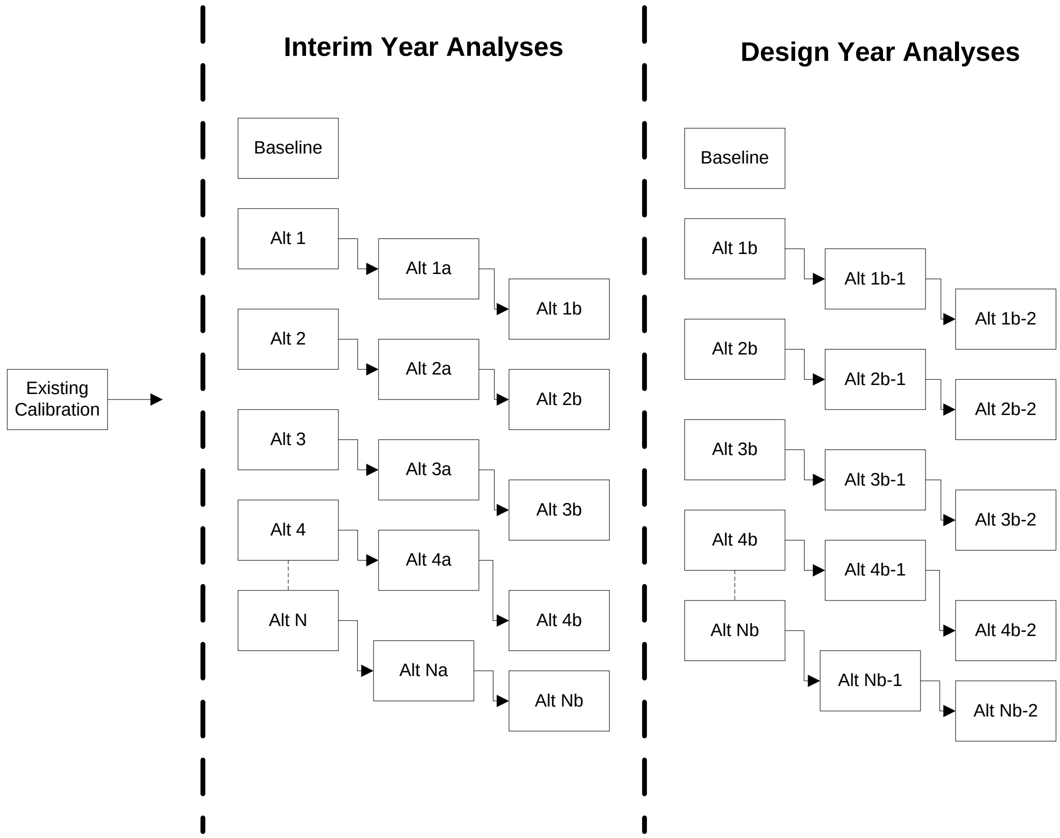

Figure 24. Illustration. Excessive alternative analysis.

Streamlined Sequencing

There are many ways to approach an alternatives analysis that can satisfy the requirements and be time effective. Some simple streamlining techniques include the following:

- Screening down the number of alternatives, thereby reducing the number of alternatives simulated.
- Rearranging the sequence of analysis years.

An example is shown in figure 25. In addition to the simulation time, it is important to consider the stakeholders that must absorb the model information and make a decision. These techniques can be effective in managing stakeholders’ needs, requests, and expectations.

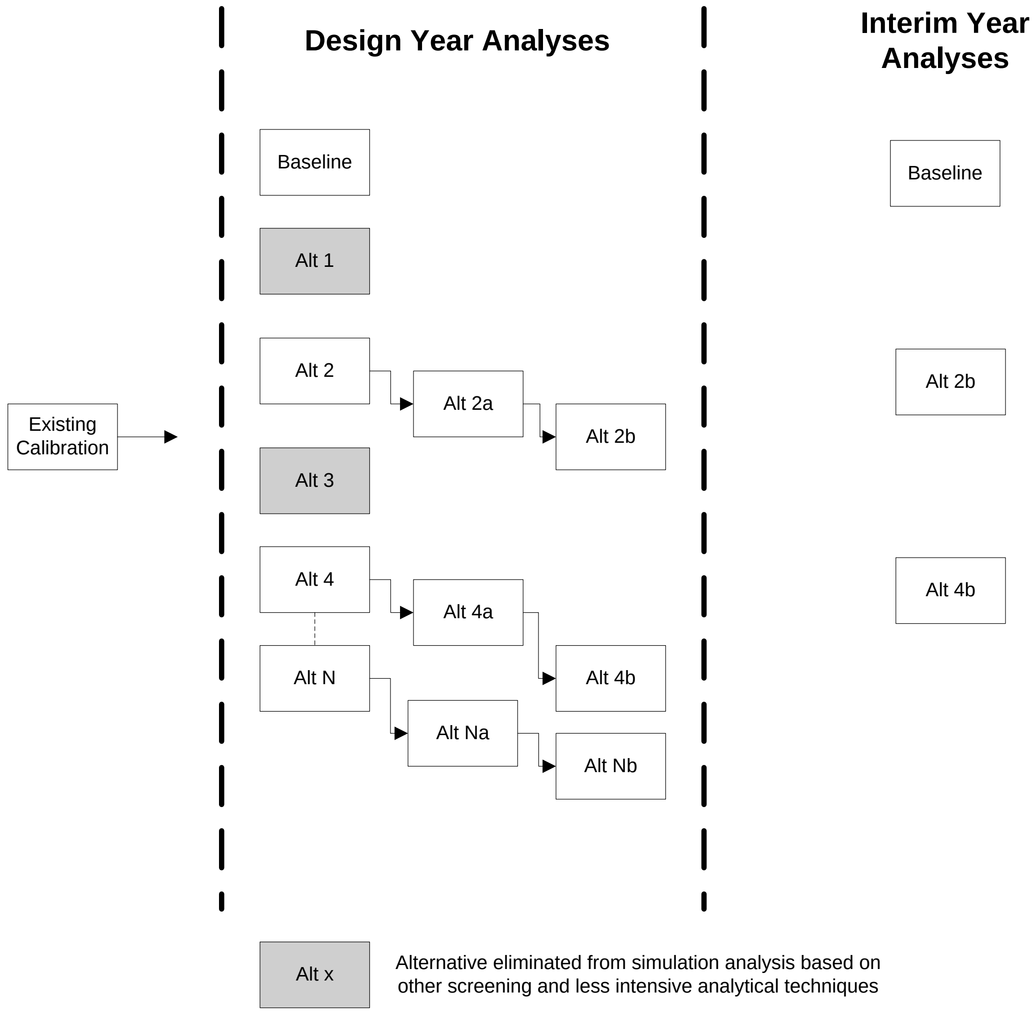

Figure 25. Illustration. Streamlined alternatives analysis method.

Sample Relative Level-of-Effort Approaches

The previous sample alternative analysis workflows are generic cases to illustrate the issues with too little analysis, too much analysis, and a modified approach. Assigning a value of 100 h for each analysis box in the preceding figures, the results depicted in figure 26 make a strong argument for planning a streamlined analysis before the modeling work is to begin.

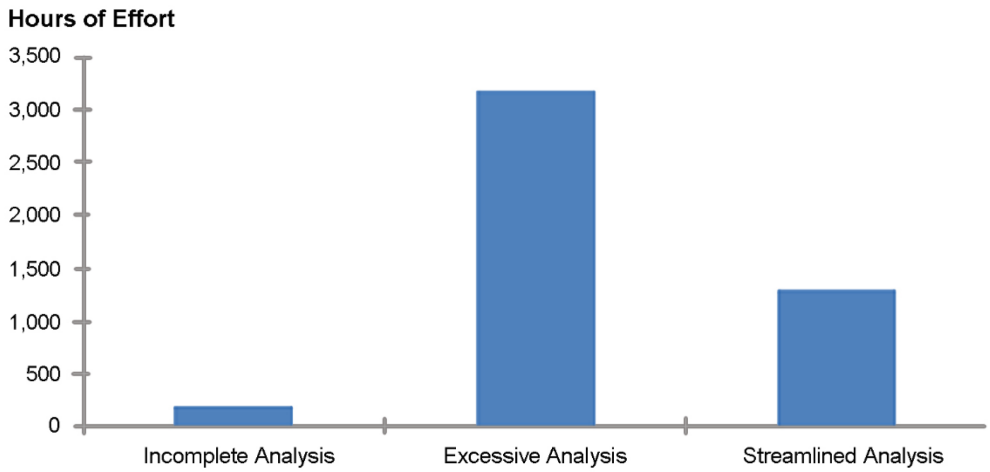

Figure 26. Graph. Comparison of the effort for different alternative analysis approaches.

EXAMPLES ON REPORTING RESULTS OF THE COMPARATIVE ANALYSIS

Tabular Methods

Simulation models produce excellent MOEs that help provide a quantitative assessment of alternatives. The models have the capacity to produce a lot of data. Reducing these data down to a few core tables of essential information is needed for an effective decisionmaking process. Table 19, table 20, and figure 27 are examples of data summaries. The color code in figure 27 indicates the following speeds:

- Green = 65+ mi/h.
- Medium green = 63–64 mi/h.
- Yellow green = 61–62 mi/h.
- Yellow = 55–60 mi/h.
- Yellow red = 50–54 mi/h.
- Light red = 40–49 mi/h.
- Red = 21–39 mi/h.
- Red with red numbering = Less than 21 mi/h.

Table 19. Sample MOE summary table.[7]

Analysis Segment	Design Year							
	2005		2015 (Alternative A)		2015 (Alternative B)		2025	
	Speed (mi/h)	Density (vehicles/ lane/mi)	Speed (mi/h)	Density (vehicles/ lane/mi)	Speed (mi/h)	Density (vehicles/ lane/mi)	Speed (mi/h)	Density (vehicles/ lane/mi)
I-94 merge to High Ridge exit	64 (64)	11 (6)	32 (64)	34 (9)	64 (64)	15 (9)	64 (64)	16 (11)
High Ridge exit to High Ridge entrance	64 (64)	10 (4)	**7 (64)**	111 (9)	63 (64)	14 (6)	63 (64)	13 (7)
High Ridge entrance to I-94 diverge	58 (63)	12 (4)	**8 (62)**	108 (7)	61 (64)	15 (6)	61 (63)	17 (7)

Note: Table values are listed as XX (YY), where XX represents the morning peak average, and YY represents the afternoon average. Bolded cells represent where the average speed dropped below 30 mi/h for any peak period for that alternative.

Table 20. Delay comparison between two scenarios in vehicle-hours—I-210 VISSIM simulation.

Direction	Scenario 13	Scenario 14	Difference	Percent Difference
Westbound	14,109	10,757	-3,351	-23.8 percent
Eastbound	971	920	-51	-5.3 percent
Total	15,080	11,677	-3,403	-22.6 percent

	FAIR OAKS 1	MARENG O	LAKE 2	HILL 1	ALLEN	SAN GABRIEL	MICHILLI NDA	BALDWI N	SANTA ANITA 2	HUNTING TON 1	HUNTING TON 2	MYRTLE AV	MOUNTA IN	Buena Vista	IRWINDA LE	VERNON	AZUSA 2	CITRUS 2	SUNFLO WER AV	LONE HILL AV	FOOTHIL L BL
	R25.14	R25.74	R26.49	R27.16	R27.65	R28.7	R30.01	R30.95	R32.06	R32.86	R33.09	R34.15	R35.12	R35.36	R38.009	R39.05	R39.64	R40.7	R43.3	R44.2	R47
Time (PM)	717631	717633	717635	717638	717640	717646	717659	717667	717672	761128	761141	761152	761165	761177	761206	761220	717684	718469	716142	716143	767883
15:00	66	63	66	62	65	39	65	65	60	57	61	63	63	57	65	64	59	61	65	65	67
15:05	65	63	66	60	64	32	65	64	60	58	62	64	63	38	65	64	51	59	65	65	67
15:10	66	63	62	61	64	23	65	62	60	58	63	64	63	26	66	64	46	59	65	65	67
15:15	66	63	63	61	64	22	65	33	60	58	61	64	62	21	65	64	38	55	65	65	67
15:20	66	63	66	61	64	20	65	25	60	57	62	64	61	19	65	62	33	57	65	65	67
15:25	65	62	66	61	64	19	65	25	60	57	59	63	60	19	65	60	31	55	66	65	67
15:30	65	62	62	60	64	19	65	24	61	58	61	62	57	19	65	60	29	56	66	65	67
15:35	65	63	59	60	62	19	65	24	60	56	61	59	56	19	65	57	21	58	65	65	67
15:40	65	63	56	61	60	19	65	24	60	57	61	60	41	19	65	52	20	58	66	65	67
15:45	65	63	62	60	52	19	64	25	60	58	61	55	30	19	65	40	20	58	65	65	67
15:50	65	63	63	59	43	19	62	25	60	57	60	42	26	19	65	33	19	57	65	65	67
15:55	65	63	60	57	34	19	52	24	60	57	62	29	25	20	65	32	20	57	66	65	67
16:00	66	63	58	52	32	19	40	24	60	57	61	25	25	19	65	29	21	53	66	65	67
16:05	66	64	57	53	37	19	38	25	60	56	60	25	27	19	65	38	21	48	65	65	67
16:10	66	59	49	59	45	19	33	25	60	55	60	26	27	19	65	37	21	46	65	65	67
16:15	66	54	46	61	51	19	37	25	61	54	59	26	28	19	65	37	22	43	65	65	67
16:20	66	53	44	64	59	19	42	26	60	53	53	26	29	19	65	42	21	41	65	65	67
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16:50	66	53	48	64	65	39	64	26	60	45	40	24	25	19	65	55	21	35	65	65	67
16:55	66	53	48	62	65	49	65	26	60	46	37	24	25	19	65	56	23	34	65	65	67
17:00	66	54	48	63	65	54	65	26	58	45	37	25	26	19	65	55	20	35	64	65	67
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17:10	66	54	50	62	64	62	65	25	60	45	39	25	25	19	65	43	20	35	65	66	68
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17:50	66	54	57	63	63	66	66	63	60	61	64	25	26	19	65	34	21	35	66	65	68
17:55	66	54	56	62	61	66	65	63	59	61	65	25	26	19	65	34	21	36	66	66	68
18:00	66	55	57	62	61	66	65	65	60	60	65	28	25	19	65	35	21	36	66	65	68
18:05	66	55	57	65	66	66	65	65	60	61	66	36	26	19	65	41	21	36	66	65	67
18:10	67	55	57	64	65	66	65	65	60	60	65	41	29	19	65	41	21	35	65	65	67
18:15	67	55	57	64	65	66	65	66	59	60	65	50	33	19	65	43	21	37	65	65	67
18:20	67	55	57	64	66	66	66	66	63	62	66	53	32	19	65	48	21	39	65	65	67
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18:40	67	58	61	64	65	66	66	66	64	63	66	65	65	27	66	66	54	47	66	65	67
18:45	67	60	62	65	66	66	65	66	64	63	66	65	66	33	66	66	64	56	66	65	67
18:50	67	58	63	64	65	66	66	66	65	64	67	65	66	49	66	66	66	62	66	65	67
18:55	67	60	63	64	65	67	66	66	65	64	67	66	66	63	66	66	66	64	67	65	67

Figure 27. Graph. Speed diagram for I-210 VISSIM simulation.

Graphical Techniques

Graphical techniques are another way of representing the simulation analysis results in an effective manner. When developing a graphical representation of data, it is important to clearly explain the criteria for any shading or coloring used to highlight where there may be issues with the depicted operations. Furthermore, it is always good practice to accompany graphics with a corresponding narrative explaining the context, findings, and recommendations. Figure 28 through figure 30 include examples of graphics that can be used.

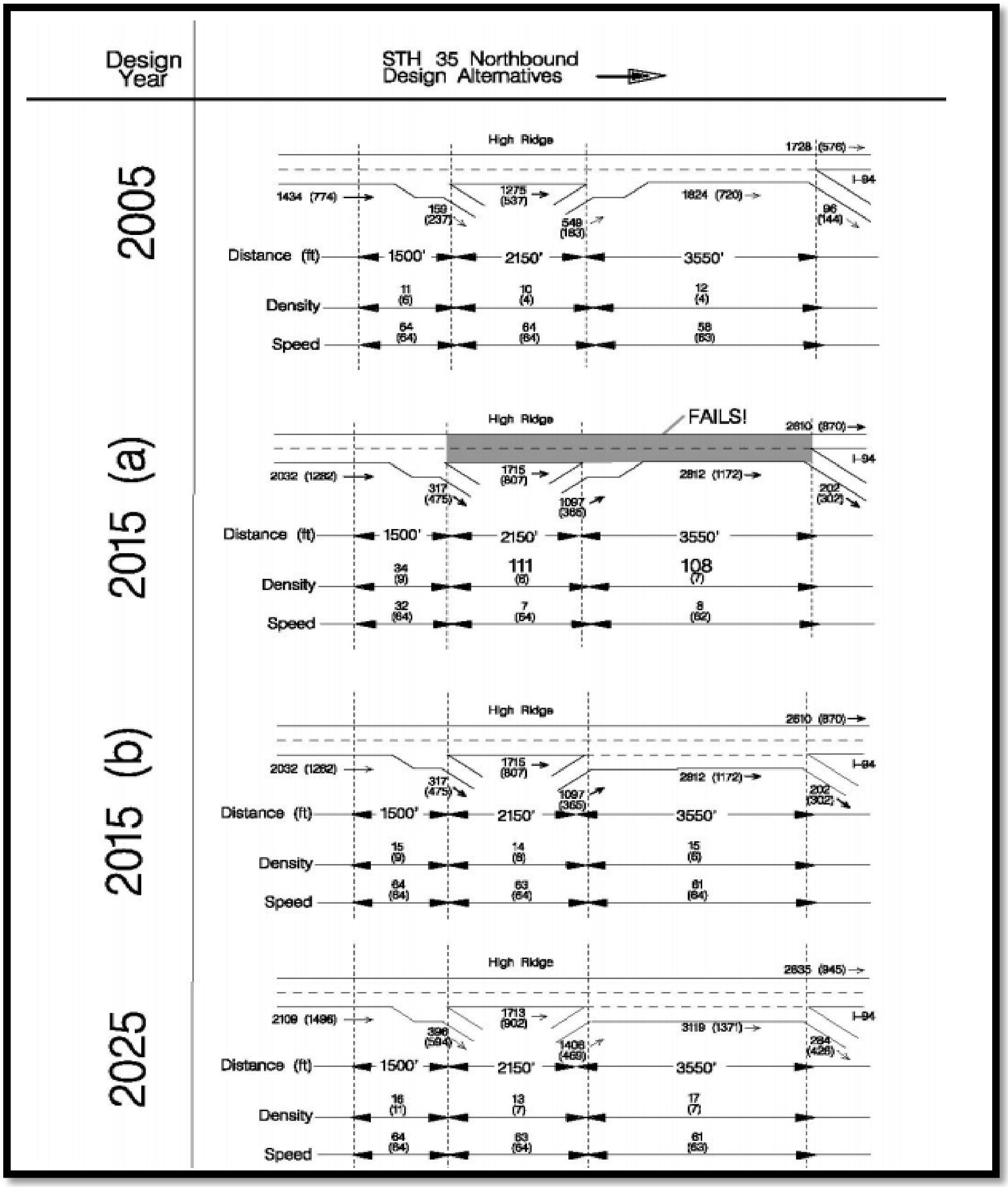

Figure 28. Illustration. Sample comparison of project alternatives using schematic drawing.(7)

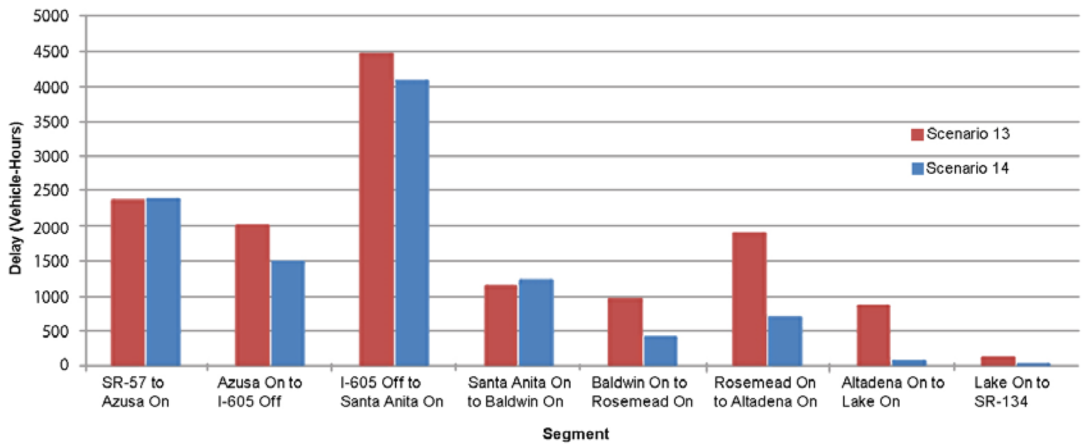

Figure 29. Graph. Delay by segment for two scenarios in vehicle-hours—I-210 VISSIM simulation.

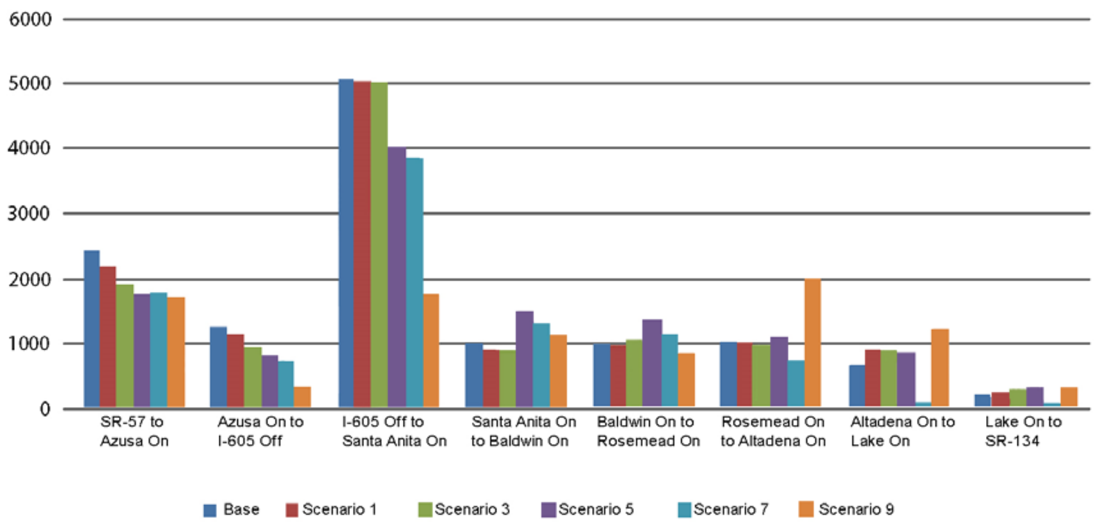

Figure 30. Graph. Delay by segment for all scenarios in vehicle-hours—I-210 VISSIM simulation.

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