Traffic Analysis and Forecasting GUIDELINES

Release Date: January 2023

Updated from JULY 2018 – Version 1

COLORADO
Department of Transportation

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Document Development and Version Tracking

The Colorado Department of Transportation (CDOT) identified a need to improve statewide uniformity, consistency, and reliability of our state's forecasting and traffic analysis efforts. The initial stakeholder group determined that a guidance document should be the first step in addressing this need. These guidelines address Colorado's lessons learned with best practices, provide technical guidance, and serve as a foundational document to build upon.

A core team was identified to steer the development of CDOT's *Traffic Analysis and Forecasting Guidelines*. This core team consisted of representatives from each Region, the Division of Transportation Development (DTD), the Division of Project Support, and the Federal Highway Administration (FHWA).

Version 1 - July 2018

Outreach was conducted in each Region to establish common terminology and compile existing workflows, lessons learned and known guidance needs. Ultimately, each Region's feedback provided the key topics to address in the document including, but not limited to: data collection, tool selection, and microsimulation calibration targets. Three formal review periods were provided for draft versions of the document. The review periods included input from: the core team, Region's stakeholders (including local agencies and MPO partners), and consultant industry. In addition, many specialties within CDOT had opportunity to review and comment on the document including access managers and planning staff.

The final version of the guidelines was presented and approved by the Traffic Engineers on June 12th, 2018, the Chief Engineer on July 3rd, 2018, and the PE IIIs on July 12th, 2018 for adoption.

Version 2 – January 2023

Phase II commenced spring 2020 to provide document updates and develop a Training Program tailored to CDOT operations for technical support. The core team, as noted above, reconvened to provide feedback on the implementation and use of the guidelines. Additional details were incorporated including Safety Analysis, Data Collection / Validation Plan, and Traffic Analysis. Two document review periods were provided for comment and input. The final version was approved on January 2023.

Version Tracking

01.012018	July 2018	First Issued Version
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The Colorado Department of Transportation thanks its staff and partner agencies for their continued dedication to shaping traffic analysis and forecasting guidelines across the state. These guidelines included the support of CDOT and agency stakeholders in each region across the state as well as a core team of the following members. The majority of core team members stay involved in Phase II, however, additional team members below contributed to the development of version 2.

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List of Abbreviations

AADT	Annual Average Daily Traffic	**NHTS**	National Household Travel Survey
AASHTO	American Association of State Highway and Transportation Officials	**O-D**	Origin-destination
ATMS	Advanced Transportation Management System	**OTIS**	Online Transportation Information Systems
AVO	Average Vehicle Occupancy	**PACOG**	Pueblo Area Council of Governments
CDOT	Colorado Department of Transportation	**PEL**	Planning and Environmental Linkage
COBRA	Corridor Operations & Bottleneck Reduction Assistance	**PHT**	Person-Hours of Travel
DRCOG	Denver Regional Council of Governments	**PMT**	Person-Miles of Travel
DTA	Dynamic Traffic Assignment	**PPACG**	Pikes Peak Area Council of Governments
FDOT	Florida Department of Transportation	**RITIS**	Regional Integrated Transportation Information System
FHWA	Federal Highway Administration	**RM**	Ramp Meters
GHG	Greenhouse Gas	**RTMS**	Remote Traffic Microwave Sensors
GPS	Global Positioning System	**PTSF**	Percent Time Spent Following
HCM	*Highway Capacity Manual*	**RTPO**	Regional Transportation Planning Organization
HCS	Highway Capacity Software	**RTDM**	Regional Travel Demand Model
HOT	High-Occupancy Tolling	**SPF**	Safety Performance Function
HOV	High-Occupancy Vehicle	**SOV**	Single-Occupant Vehicle
ICU	Intersection Capacity Utilization	**TAT**	Traffic Analysis Toolbox
ITE	Institute of Transportation Engineers	**TAZ**	Traffic Analysis Zone
ITS	Intelligent Transportation Systems	**TDM**	Travel Demand Model
LIDAR	Light Detection and Ranging	**TIS**	Traffic Impact Study
LOS	Level of Service	**TLFD**	Trip Length Frequency Distribution
LOSS	Level of Service of Safety	**TSM&O**	Transportation Systems Management & Operations
LUAM	Land Use Allocation Model	**USDOT**	United States Department of Transportation
MOE	Measure of Effectiveness	**VHT**	Vehicle-Hours of Travel
MOT	Maintenance of Traffic	**VMT**	Vehicle-Miles of Travel
MPH	Miles per Hour		
MPO	Metropolitan Planning Organization		
NCHRP	National Cooperative Highway Research Program		
NEPA	National Environmental Policy Act		
NFRMPO	North Front Range Metropolitan Planning Organization		

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1 Introduction

1.1 Purpose

The Colorado Department of Transportation (CDOT) published the Traffic Analysis and Forecasting Guidelines in 2018 to assist both CDOT and its stakeholders (MPOs, local agencies and consultants) in the completion of traffic analysis and forecasting procedures on the State Highway System. These guidelines aim to ensure consistent, state-of-the-practice traffic analysis and forecasting methods are used by those performing these functions. The guidelines build upon numerous Federal Highway Administration (FHWA) and other state agencies resources that guide transportation professionals with traffic analysis and forecasting processes and are tailored to the needs of CDOT and its stakeholders.

In 2020, CDOT initiated Phase II to provide needed document updates as part of version two (2) that reflect changes in resources referenced, new statewide guidance, the Operations Evaluation Web Tool, legislative/legal context, and stakeholder feedback. With a number of traffic analysis tools designed to fit projects of different sizes, scopes, and objectives, the guidance provided in this manual was updated and reorganized to assist CDOT and its stakeholders in selecting the most appropriate traffic analysis tool(s) during the initial project scoping, understanding the data requirements and standard assumptions related to each analysis tool, and producing documentation. The guidance provided herein shall be used by both CDOT and its stakeholders working on projects that will require CDOT review and approval. Deviation from the Traffic Forecasting and Analysis Guidelines may be considered on a project-by-project basis; revised methodology shall require prior approval from CDOT. This manual is a living document and does not address every aspect of traffic analysis but rather provides guidance when conducting traffic analyses, forecasting, and performing Operations Evaluations.

This manual supersedes the Traffic Analysis and Forecasting Guidelines released in July 2018.

Currently, the Department completes several types of projects for which traffic analysis and forecasting are necessary. These include, but are not limited to:

- National Environmental Policy Act (NEPA) studies, such as Environmental Assessments (EAs) and Environmental Impact Statements (EISs)
- Planning and Environmental Linkages (PEL) studies
- Corridor Operations & Bottleneck Reduction Assistance (COBRA) studies

- Traffic Impact Studies (TISs)
- Turn Lane Analyses
- Interstate Access Requests

In addition to the above, the Colorado Legislature has identified “Wildly Important Goals” (WIGs) to help reduce the vehicle crash rate as well as greenhouse gas (GHG) emissions throughout the state. Efforts include the passage of HB19-1261, which established GHG emissions reduction targets by reducing vehicle miles travelled (VMT). Significant regulatory and other efforts are on-going to meet these targets, which will in turn have effects on the studies supported by this guidance. Effects on the prioritization of traffic study Measures of Effectiveness (MOEs) are one likely outcome of these efforts (for example, elevating the importance of VMT impacts).

Safety performance is also an important factor as operational performance on existing and future transportation facilities often correlate with the traffic demand and operations. Although the guidance in this manual focused on the traffic analysis and forecasting, safety consideration should be integrated as appropriate in all traffic analysis to address safety for all users.

1.2 Typical Traffic Analysis, Safety Analysis, and Forecasting Processes

Traffic analysis tools are often used by transportation professionals to evaluate, simulate, optimize, and predict operational performance on existing and future transportation facilities. These tools consist of procedures, methodologies and computer models used to carry out the analyses. Understanding the differences between the tools is essential in selecting the appropriate tool(s) to develop solutions and recommendations that meet the goals and objectives of the project. Traffic analysis may be completed for multiple scenarios reflecting existing conditions, existing plus project conditions, future (no project) conditions, or future plus project conditions. In addition, project conditions can include multiple project alternatives. Traffic forecasting is necessary when evaluating future conditions.

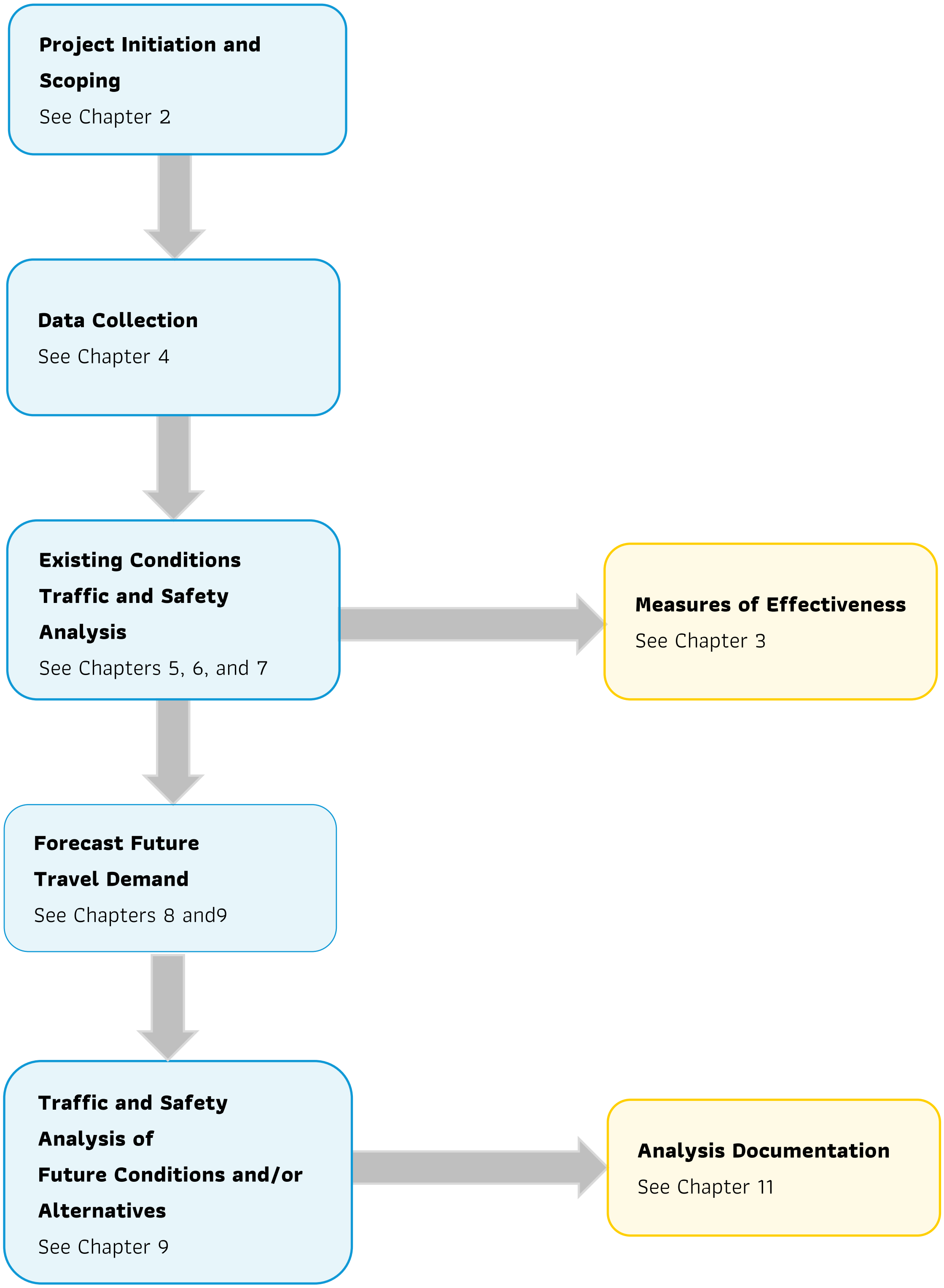
As used in these guidelines, the following definitions apply:

- ***Traffic Analysis:*** *The quantifiable evaluation, simulation, or optimization of the operations of multi-model transportation facilities and systems. Traffic analysis often includes modeling existing operations and predicting probable outcomes for proposed design alternatives.*
- ***Forecasting:*** *The prediction of future travel demand. The focus of forecasting may be predicting traffic flow along the highway network, or a more detailed focus may be the goal, such as destination choice, mode choice, time-of-day travel choice, or route choice.*
- ***Safety Analysis:*** *The quantifiable evaluation, simulation, or optimization of the safety of multi-modal transportation facilities and systems. Safety analysis often includes quantifying the safety performance*

of existing conditions or estimating the safety performance of future conditions or proposed design alternatives. Safety performance is defined by the observed, predicted, or expected crashes in terms of frequency and severity.

These guidelines address the various steps included in a typical traffic analysis, safety analysis, and forecasting process. **Figure 1** shows this typical process for a project on the State Highway System.

Figure 1: Typical Traffic Analysis, Safety Analysis, and Forecasting Process Flowchart



This report is organized into the following eleven (11) chapters. Additional details incorporated in Version 2 include the following: Safety Analysis, and the Data Collection / Validation Plan.

- **Chapter 1 - Introduction** provides an overview of the Guidelines purpose, Traffic/Safety Analysis and Forecasting Process, and Typical Analysis Scenarios.
- **Chapter 2 – Project Initiation and Scoping** presents Traffic Analysis Objective, Spatial and Temporal limits, Data Requirements and Data Collection Plan, Identification of Alternatives, Selected MOEs, Traffic Analysis Tool Selection, Project Traffic Demand Forecasting, and Analysis Report and Technical Documentation.
- **Chapter 3 – Measures of Effectiveness (MOE)** presents a review of the applicable tools for MOEs and defines the stages of a transportation planning/design project.
- **Chapter 4 – Data Collection** provides a Data Collection Plan, data verification/validation considerations, an overview of the spatial/temporal limits, CDOT data sources, and big data integration.
- **Chapter 5 – Traffic Modeling and Analysis Tools** provides an overview of the common traffic modeling and analysis tools and the selection of the appropriate tools for the analysis.
- **Chapter 6 – Deterministic Analysis Tools** provides guidance on the most commonly used deterministic analysis tools.
- **Chapter 7 – Microsimulation Analysis Tools** provides guidance the most commonly used microsimulation analysis tools.
- **Chapter 8 – Travel Demand Modeling** provides guidance on travel demand modeling methodology and lists travel demand models available for use within Colorado.
- **Chapter 9 – Traffic Forecasting and Alternative Analysis** provides guidance on the development project alternatives, forecasting future project traffic, and analyzing future project alternatives
- **Chapter 10 – Application of Guidelines** provides guidance on how to apply guidelines for Traffic Impact, Traffic Safety Studies, Dynamic Traffic Assignment
- **Chapter 11 – Analysis Documentation**

Quick Start Guide is designed to provide the analyst with a quick summary of the required steps for a typical traffic analysis and forecasting process for a project on the State Highway System that includes: Data collection, existing conditions traffic analysis, forecasting of future travel demand, and traffic analysis of future conditions and/or alternatives.

1.3 Typical Analysis Scenarios

There are many analysis scenarios that may be evaluated on any given project. It is important to understand the differences between the scenarios so that the appropriate analysis tool(s) may be selected. This section focuses on study area classifications and prevailing traffic and safety conditions to consider when defining an analysis scenario. Guidance on selecting analysis tools for specific traffic and safety scenarios is described in Chapter 5.

1.3.1 Study Area Classification

Identifying the study area classification is one of the most important steps in defining an analysis scenario to analyze. The Highway Capacity Manual (HCM) and Highway Safety Manual (HSM) reference the following six roadway system components to define the scope of a project.

- **Point:** A point is the smallest roadway system component. The HCM defines a point as a "place along a facility where (a) conflicting traffic streams cross, merge, or diverge; (b) a single traffic stream is regulated by a traffic control device; or (c) there is a significant change in the segment capacity (e.g., lane drop, lane addition, narrow bridge, significant upgrade, start or end of a ramp influence area)." Intersections, whether they are unsignalized, signalized, or roundabouts, are considered points. An intersection is defined by the HSM as a "general area where two or more roadways or highways meet, including the roadway, and roadside facilities for pedestrian and bicycle movements within the area."
- **Segment:** A segment consists of two points. The HCM defines a segment as, "the length of roadway between two points. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway). Segments may or may not be directional." The HSM defines as segment as "A portion of a facility on which a crash analysis is performed. A segment is defined by two endpoints." Example segments include urban street segments, weaving segments, freeway diverge/merge segments, and basic freeway segments.
- **Facility:** Facilities are made up of more than two points and segments. The HCM defines a facility as, "lengths of roadways, bicycle paths, and pedestrian walkways composed of a connected series of points and segments. Facilities may or may not be directional and are defined by two endpoints."
- **Corridor:** A corridor is comprised of multiple facilities. The HCM defines a corridor as "a set of parallel transportation facilities designed to move people between two locations." The facilities must be parallel and may be an assortment of freeway, urban street, transit, or pedestrian/bicycle facilities.
- **Area:** An area consists of numerous facilities. The HCM defines an area as a "interconnected set of transportation facilities serving movements within a specified geographic space, as well as movements to and from adjoining areas. The primary factor distinguishing areas from corridors is that the facilities within an area need not be parallel to each other. Area boundaries may be set by significant

transportation facilities, political boundaries, or topographical features such as ridgelines or major bodies of water."

- **System:** A system is a larger version of an area. The HCM defines a system as "all the transportation facilities and modes within a particular region. A large metropolitan area typically has multiple corridors passing through it, which divide the system into several smaller areas. Each area contains multiple facilities, which, in turn, are composed of a series of points and segments. Systems may also be divided into modal subsystems (e.g., the roadway subsystem, the transit subsystem) as well as subsystems composed of specific roadway components (e.g., the freeway subsystem, the urban street subsystem)."

Specific combinations of the six roadway system components create different analysis scenarios, including intersection, interchange, corridor, and network.

1.3.2 Prevailing Traffic Conditions

Once the study area classification has been defined, it is important to understand the prevailing traffic conditions with regards to the type of traffic flow and the operational conditions on the roadway system.

Uninterrupted and Interrupted Traffic Flow

Traffic flow can be divided into two primary types: uninterrupted and interrupted flow.

Uninterrupted Traffic Flow: The HCM defines uninterrupted traffic flow as "traffic flow that has no fixed cause of delay or interruption external to the traffic stream." Segments are considered to operate with uninterrupted flow when traffic is not influenced by traffic control devices and platoons are not formed at upstream traffic signals. In general, two-lane highway segments that are located two to three miles from traffic signals operate under uninterrupted-flow conditions. Within the uninterrupted-flow operations analyses category, multiple analysis types are considered in this manual, such as:

- **Freeway Segment:** For this type of analysis, freeway segments not influenced by merging, diverging, or weaving maneuvers are analyzed in terms of speed and density. Lane changing impacts within a basic freeway segment should only be attributed to passing operations.
- **Freeway Merge/Diverge Segment:** Freeway merging and diverging segments occur primarily at or near interchanges in the presence of an on- and off-ramp. A merging analysis is considered when two or more streams of traffic combine to form a single stream of traffic, while a diverging analysis is considered when a single stream of traffic divides into two or more streams of traffic. This type of analysis is used to evaluate the functionality of a merge or diverge area in terms of speed and density.
- **Freeway Weaving Segment:** Freeway weaving segments are formed when streams of traffic traveling in the same direction are forced to change lanes and cross paths over a significant length of

freeway. This type of analysis is used to evaluate the functionality of the weaving segment in terms of speed and density.

- **Freeway Facility:** an extended length of freeway composed of continuously connected basic freeway, waving, merge, and diverge segments.
- **Managed Lane or Ramp Metering:** Managed lanes and ramp metering control transportation demand by imposing travel restrictions. A managed lane provides operational flexibility by separating one or more lanes from the general-purpose lanes on a freeway. The managed lanes control demand through pricing and vehicle eligibility strategies. A ramp metering system restricts access to freeways by regulating traffic entering the network based on operational conditions on the freeway. This type of analysis is used to evaluate the functionality of managed lanes or the impacts of ramp metering on a freeway facility in terms of speed and density.
- **Two-Lane Highway:** This type of analysis is used to evaluate the functionality of a highway with one travel lane in each direction, although it may also include a truck climbing lane in one direction. This type of analysis does not account for interruptions in flow due to signalized intersections. This type of analysis is used to evaluate the functionality of the multilane highway in terms of average travel speed (ATS), percent time spent following (PTSF), and percent of free-flow speed (PFFS).
- **Multilane Highway:** This type of analysis is used to evaluate the functionality of a highway with at least two travel lanes in each direction, with traffic signals spaced greater than one mile apart, and with speeds greater than 45 mph. These types are facilities are not arterials nor are they freeways. Unlike freeways, multilane highway are not limited-access facilities; however, this type of analysis does not account for interruptions in flow due to signalized intersections. This type of analysis is used to evaluate the functionality of the multilane highway in terms of speed and density.

Interrupted Traffic Flow: The HCM defines interrupted traffic flow as “traffic flow characterized by traffic signals, STOP signs, YIELD signs, or other fixed causes of periodic delay or interruption to the traffic stream.” In general, segments are considered to operate under interrupted flow conditions when the segment is located within two miles of a traffic signal. Multiple types of interrupted traffic flow operations are considered in this manual, such as:

- **Conventional Signalized Intersection:** This type of analysis is used to evaluate the functionality of an intersection controlled by a traffic signal in terms of specific MOEs, such as delay and queue.
- **Conventional Signalized Intersection Preemption and/or Transit Priority:** This type of analysis is used to evaluate the impacts of a preemption or priority event at a signalized intersection, with or without transit operations with specific MOEs, such as delay and queue.
- **Conventional Unsignalized Intersection:** This type of analysis is used to evaluate the functionality of an intersection not controlled by a traffic signal in terms of specific MOEs, such as delay and queue. All-way stop-controlled and two-way stop-controlled intersections are included in this scenario.
- **Roundabout:** This type of analysis is used to evaluate the functionality of a roundabout in terms of specific MOEs including speed, delay, and queue.

- **Arterial:** This type of analysis is used to evaluate the functionality of a roadway featuring interruptions in flow due to signalized and unsignalized intersections and is used to determine the functionality of the facility in terms of speed and queue.
- **Innovative Intersection/Interchange:** This type of analysis is used to evaluate the functionality of unconventional intersections in terms of specific MOEs including speed, delay, and queue. Examples of this scenario include, but are not limited to, 5-legged intersections, Diverging Diamond Interchanges (DDI), Single Point Urban Interchanges (SPUI), Restrict Crossing U-Turn (RCUT) Intersections, Continuous Green-T Intersections (CGT), and Continuous-Flow Intersections (CFI). These analyses only pertain to the intersection operations for interchanges such as DDIs and SPUIs as opposed to the ramp and ramp-freeway junction operations.
- **Adaptive Signal Control Technologies (ASCT):** This type of analysis is used to evaluate ASCT at single intersections or on an arterial facility. ASCTs contain algorithms that adjust traffic signal timings every few minutes based on real-time traffic information.
- **Multimodal Facility:** This type of analysis is used to evaluate the functionality of roadway facilities that service a variety of transportation modes including automobiles, transit, bicycles, and pedestrians. These facilities may include areas such as transit centers and airport terminals.

Under-saturated and Over-saturated Conditions

It is important to recognize the difference between undersaturated and oversaturated traffic conditions when choosing the most appropriate traffic analysis tool. The HCM defines them as follows:

- **Under-saturated Flow:** “Traffic flow where (a) the arrival flow rate is lower than the capacity of a point or segment, (b) no residual queue remains from a prior breakdown of the facility, and (c) traffic flow is unaffected by downstream conditions.”
- **Over-saturated Flow:** “Traffic flow where (a) the arrival flow rate exceeds the capacity of a point or segment, (b) a queue created from a prior breakdown of a facility has not yet dissipated, or (c) traffic flow is affected by downstream conditions.”

For uninterrupted-flow facilities, speed may be used as an indicator of whether a facility is under-saturated or over-saturated. As uninterrupted-flow facilities approach capacity, travel speeds decline; therefore, a facility may be identified as operating in under-saturated conditions when speeds remain at or near the posted speed limit. When speeds drop below the posted speed limit this should indicate the approximate start of oversaturated conditions or period of congestion. This period would be considered recovered when speeds resume to those of the posted speed limit. This period of congestion would define a minimum analysis period of congestion to be evaluated by traffic analysis tools. The determination of when a study area should be considered over-saturated should be based on current traffic count data and traffic analysis results, results from studies completed within the last five (5) years in the study area, and congestion mapping.

In many instances, a study area may be considered under-saturated under existing conditions but may be oversaturated under future conditions. Special consideration should be given to the saturation conditions in the future year(s) when selecting the most appropriate traffic analysis tool(s). If facilities within a study area are approaching capacity under the base year condition, then depending on the assumed traffic growth rate, over-saturated conditions should be assumed in the future year. Because of this issue, estimated future traffic volumes should be discussed at the scoping meeting.

One common phenomenon resulting from over-saturated conditions is peak hour spreading. Peak hour spreading is most prevalent in urban and suburban transportation networks where peak hour traffic demand exceeds available traffic capacity throughout the entire peak hour. This excess traffic then “spreads” to either side of the computed peak hour, which creates a peak period of two or more hours as opposed to just one peak hour. There are various degrees of peak hour spreading that may occur depending on the extent of peak hour traffic demand and hourly peak period travel distributions; however, the occurrence of peak hour spreading should be accounted for in operational analyses by using a peak period consisting of more time than just the peak hour. The analysis of peak hour spreading may require the use of microsimulation tools, such as VISSIM, and requires traffic data to be entered in 15-minute intervals until all peak hour traffic demand is successfully spread across the adjacent 15-minute periods. The HCM is also capable of analyzing oversaturated conditions, especially on freeway facilities. The peak period analysis period should be long enough to allow the network to recover from peak hour spreading, which occurs when the demand no longer exceeds capacity.

Miscellaneous Operations

At times, miscellaneous operations and methods such as parking area, public transit facility, toll plaza, gated/draw bridges, work zone, active traffic management (ATM), as well as more advanced operational analysis tools, such as dynamic traffic assignment (DTA), may need to be considered on large and complex project. These operations and methods are not addressed in detail in this guideline. Additional guidance on these topics may be found in the FHWA Traffic Analysis Toolbox.

Reinforcing with Project Examples:

Two project examples are provided throughout these guidelines to reinforce their principles.

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

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Project Initiation and Scoping

The project initiation and scoping process is an important first step for any project to ensure a successful cost-effective traffic analysis supported with a comprehensive traffic analysis plan. A properly developed scope and comprehensive traffic analysis plan identifies the project purpose and need, impacted stakeholders, assumptions/methodologies, data requirements, performance measure(s), schedule, and analysis deliverables. Effective January 20th, 2021, all CDOT projects are required to conduct an Operations Evaluation (formerly known as the TSM&O Evaluation) using the new Web Tool that allows the traffic specialty units covering safety, traffic operations, and ITS to develop recommendations for CDOT projects. The level of effort and scoping considerations vary based the project size and funding; therefore, the content of the analysis methodology should be tailored to the context and complexity of the project. The Operations Evaluation process provides CDOT Project Managers and its stakeholders (MPOs, localities and consultants), the opportunity to raise critical issues and concerns, and develop recommendations so they can be resolved and incorporated in the analysis early in the scoping process. A successful cost-effective traffic analysis should include the following scoping elements:

- Traffic analysis objective
- Spatial and temporal limits
- Data requirements and data collection plan
- Performance measures of effectiveness (MOEs)
- Traffic analysis tool selection
- Existing conditions analysis
- Project traffic demand forecasting
- Future no-build analysis
- Opportunities and constraints
- Identification of alternatives
- Alternatives screening and analysis
- Identification and justification of preferred alternative(s)
- Analysis report and technical documentation

Each scoping element is discussed in further detail in sections 2.1 through 2.8. Additional information and guidance can also be found in the FHWA Scoping and Conducting Data-Driven 21st Century Transportation System Analyses. The scope of work for modeling and traffic analysis tasks shall be commensurate with the scope of work of the project.

2.1 Traffic Analysis Objective

Upon identifying and understanding the study area classification and the prevailing traffic conditions on the project roadway system, it is critical to establish a clear objective of the analysis among CDOT Project Managers and stakeholders. The project team should meet early and often throughout the project to develop a clear purpose and need that drives the assumptions and information needed to address the system performance problem or the goal which the traffic analysis seeks to answer. Considerations to help define the goal and objective of the analysis include:

- What agencies and non-agency stakeholders are involved in the project and what are their roles?
- What decision(s) are being made and what questions need to be addressed?
- What type of process will this analysis be used for (system planning, improvement project, PEL, COBRA, NEPA, TIS, etc.)?
- What type of study is being considered (intersection, interchange, corridor, and/or network)?
- What key issues are known about the study area from prior studies or observations of existing conditions and what analysis tools were previously used?
- What types, timeliness, quality, and quantity of data are currently available?
- What type of transportation alternative(s) will be evaluated and what evaluation criteria will be used?
- What type of outputs and performance measures of effectiveness (MOEs) are important for the decision-making process? Who will review and make the decision on the analysis findings?
- What are the schedule and budget constraints, including agency review needs, for this traffic analysis effort?

After identifying project objectives, project managers should document the methodology and assumptions of each aspect of the project analysis to define the scope of work that analysts are expected to perform. Each of the headings in Chapter 2 represent an aspect of the project that may have documented methods and assumptions. Some examples of methodology and assumptions to be documented include:

- Traffic forecasting methodology (See Chapter 9)
- Use of travel demand models including model originator/owner, model base year, model horizon year, etc. (See Chapter 8)
- Assumed land uses or ROW constraints
- Data collection plan (See Chapter 4)
- Project open and design years
- Analysis tool to be used (See Chapters 5, 6, and 7)
- The number of alternatives that will be analyzed (See Chapter 9)
- Intermediate deliverables (such as calibration report, model development, other as needed)

2.2 Spatial and Temporal Limits

After the project team has reviewed and understood the study area classification and the prevailing traffic conditions on the project roadway system and developed the purpose and need, the next step is to clearly define the spatial (physical roadway) and temporal (duration of peak periods) study limits. The physical study area roadway limit should encompass all of the traffic congestion present in the primary influence area of the project during both the existing and future analysis periods. The study area should include areas that might be impacted by the proposed improvement strategies. For example, if an analysis is to be conducted for incident management strategies, the study area should include the area impacted by the diverted traffic. All potentially impacted areas should be included in the model network. For example, if queues are identified in the network boundary areas, the analyst might need to extend the network further upstream. However, given the extent of congestion in many urban areas and resource limitations, it may not always be possible to achieve this goal. If this goal cannot be achieved, then the analyst should attempt to encompass as much of the congestion as is feasible within the resource constraints.

The temporal limits or the duration of the peak periods is as important as the physical study area limit. Generally, a minimum study peak period is recommended from 7:00 AM to 9:00 AM for the morning peak and 4:00 PM to 6:00 PM for the evening peak during the typical weekday. Depending on the context and complexity of the project being evaluated, the analysis period may include the weekday mid-day, weekend, seasonal, and/or special event peak periods. For over-saturated traffic conditions, the actual duration of the peak period may extend beyond the two-hour peak periods in order to provide a complete picture of the impacts on system performance. Field observation and/or analysis of queue and count data should be used to help determine the appropriate time periods that should be evaluated.

Consideration of the degree of precision in system performance should also be determined to establish the existing baseline conditions and to differentiate alternatives. Are hourly average traffic volumes and system performance satisfactory? This is often required for most deterministic analysis/software such as HCS or Synchro. Or should the analysis require more disaggregation of the data is often required for microsimulation analysis/software such as VISSIM or TransModeler. Identifying the temporal limits helps support decision-making related to data collection and the selection of an appropriate analysis tool or combination of multiple tools.

2.3 Data Requirements and Data Collection Plan

Just as the project size, context, complexity, and objective dictate the selection of MOEs and analysis tool(s), the selected tool and the alternative analysis requirements dictates which data is needed for the analysis. The project team should review readily available traffic data to gain a preliminary understanding of existing and future traffic conditions in order to develop the appropriate and cost-effective data collection plan for the traffic analysis. Variables affecting operation of the study area roadway system (all roadway users and the environment) should be assessed and collected as appropriate to meet the analysis objectives. At a minimum, assumptions, input and calibration data must be identified when a microsimulation tool is proposed.

Required data should be clearly defined as available from existing sources or be field-measured with the appropriate data collection plan. The quality of the existing data should be verified to determine its fitness to the analysis method. Such verification can involve checking a combination of recent GIS files, maps, and drawings. Additionally, sample data may be collected during the field reviews to verify the accuracy of the existing data.

Additional guidance on data requirements and data collection plans are provided in Chapter 4.

2.4 Performance Measures of Effectiveness (MOEs)

After compiling and reviewing readily-available data, including spot observations of existing conditions, to understand current operations and/or safety challenges the project team should have an idea of which MOE(s) will be recorded for the traffic and/or safety analysis project. MOEs can be numerical outputs from the traffic analysis or field-measured metrics used to assess the performance of an isolated location or system. MOEs are also used to compare the performance under various design or improvement alternatives.

Level-of-Service (LOS) and its associated measures (delay, density, speed, etc.) are a readily recognizable indicator of traffic operations and is widely used by different agencies when evaluating the traffic operations performance of facilities. However, LOS alone does not necessarily give insight about the overall performance of the facility. Thus, additional quantifiable measures should be included in the analysis to better assess the performance of the location or network being analyzed. The project team should consider how many MOEs are necessary to address the project objective and take into consideration the audience whom the MOEs need to be communicated when making the final determination on the number of MOEs required. At a minimum, the LOS, delay or density, and queue length should be reported for all analyses. The Level of Service of Safety (LOSS) has been developed by CDOT to provide an estimate of the normal or expected crash frequency and severity for a range of ADT among similar facilities. Similar to the LOSS, the Operational Level of Service (OLOS) is currently being developed by CDOT to reflect how the roadway segment is performing in regard to its expected operation for travel times using a planning time index (PTI) that provides for a holistic performance measure for travel reliability.

When the proposed analysis requires calibration, the methodology should outline how the calibration process will be conducted and what calibration performance measures will be used.

Additional guidance on the MOEs are provided in Chapter 3.

2.5 Traffic Analysis Tool Selection

There are many traffic analysis tools used to evaluate, simulate, optimize, and/or predict operational and safety performance on existing and future transportation facilities. Understanding the differences between the tools is essential in selecting the appropriate tool(s) on a given project. Traffic analysis may be completed for multiple scenarios reflecting existing conditions, existing plus project conditions, future (no project) conditions, or future plus project conditions. In addition, project conditions can include multiple project alternatives. If the analyst's scenarios require traffic or safety analysis of a future condition, forecasting is necessary.

In many cases, the deterministic, or analytical, tools based on the Highway Capacity Manual (HCM) methodologies can provide MOEs necessary to assess the system performance and project objective. In some cases, microsimulation tools may be required to effectively model heavily congested conditions, complex geometric configuration, and system-level impacts of transportation improvements that are beyond the limitations of deterministic tools. The project team should consider the following questions to guide the selection of the appropriate and cost-effective traffic analysis tool(s):

- Can the saturation level be determined based on traffic volumes alone?
- Do typical traffic conditions (reference probe data sources) indicate oversaturation? If so, microsimulation may be considered.
- Are there any project needs, such as a need for visualization that could drive the use of a more robust tool (e.g., are there expected alternatives that could need microsimulation)?
- Is there a need for origin-destination data given travel patterns within the study area? If so, certain traffic analysis tools cannot be used given the limitations of data input.
- What is the expected future demand? A currently undersaturated network could be oversaturated with future demand and may require a different approach to analysis.
- Consider the end goal of the project. What is trying to be conveyed?

Additional guidance on the traffic analysis tool selection are provided in Chapter 5 and in FHWA Traffic Analysis Toolbox Volumes II: Decision Support Methodology for Selection Traffic Analysis.

2.6 Existing Conditions Analysis

Analysis of existing conditions is a critical first step to identifying and quantifying the needs within the study area. Analysts should perform the existing conditions analysis using the same software that will be used for the future no-build and build conditions analysis unless a different software is needed for alternative intersection types (see discussion in Chapter 5 regarding the use of multiple analysis tools). The existing analysis should produce all measures of effectiveness identified for the project for comparison with future no-build results. The existing analysis should be performed for all conditions which will be modeled in the alternatives analysis which may include AM and PM weekday peak periods, weekend peak periods, and other periods experiencing congestion as needed. The results of existing conditions analysis should be verified with field measurements where possible to validate the analysis methodology for future conditions.

Existing conditions models are particularly important for microsimulation studies, which need to be calibrated to existing conditions before proceeding to future no-build and alternatives analysis. Microsimulation model calibration guidance is provided in Chapter 7.

2.7 Project Traffic Demand Forecasting

The project analysis methodology should include the traffic demand forecasting procedure for the future year analysis that corresponds with the appropriate timeframe associated with the type of improvement alternatives being analyzed. Travel demand models have been developed to forecast travel demand in some areas of the state by various Metropolitan Planning Organizations (MPOs) and local governments. The MPOs develop the models based on long-range socioeconomic data and aggregated local land use plans. In addition to the regional travel demand models, CDOT now has a Statewide Travel Model available for use. The Statewide Travel Demand Model uses data from the established regional models and U.S. Census and other data for all other areas of the state.

The project team should consider the CDOT Statewide Travel Demand Model among other regional models. Most rural areas in the state do not have an approved, calibrated model; therefore, a Sketch Planning method, the Statewide Travel Model, or a combination of both must be used.

Additional guidance on regional models and traffic demand forecasting are provided in Chapters 8 and 9, respectively.

2.8 Future No-Build Analysis

Future no-build analysis uses forecasted traffic volumes to assess the future operations within the project area without improvements for all time periods included in the project scope. No-Build conditions include not only maintenance, but also committed improvements with programmed funding to the analysis location. The results of this analysis can be used to quantify the severity of congestion, or other MOE of interest, and to identify potential alternatives for analysis. Future no-build analysis should be performed using the same software that was be used for the existing conditions and the alternatives analysis unless a different software is needed for alternative intersection types (see discussion in Chapter 5 regarding the use of multiple analysis tools). The future no-build analysis should produce all measures of effectiveness identified in the project scope or methodology and assumption documentation for comparison with existing conditions and future alternatives.

2.9 Opportunities and Constraints

The project team should compile a list of opportunities and constraints within the project area. This deliberate process will facilitate the process of identifying alternatives in the following steps by providing additional context through highlighting potential areas for improvement as well as barriers to development. The list below includes some examples of the topics the project team should consider when developing an opportunities and constraints list.

- Connectivity of the roadway network, consider all users such as vehicles, transit, bike/ped, etc.
- Safety, including on- and off-road considerations
- Planned or proposed projects from previous studies
- Surrounding land use, future land use, available right-of-way
- Physical barriers, such as terrain, utility lines, railroads, etc.
- Visual, recreational, and cultural resources
- Environmental considerations, including permitting requirements
- Social considerations
- Economic and financial considerations
- Political environment

2.10 Identification of Alternatives

Establishing expectations allows the project team to define the expected outcomes and consider reasonable alternatives based on the project size and context. For example, an individual intersection analysis (safety or operations) should consider localized alternatives to address existing conditions commensurate with the opportunity to implement improvements. Questions to consider include:

- Will access restrictions be permitted to improve safety or operations?
- Is grade separation feasible at this location or included in an existing comprehensive plan?
- Is it feasible to implement additional capacity improvements without significantly impacting the surrounding area, thereby precluding the project?

The project team should consider what a reasonable alternative could be to satisfy the purpose and need of the project at a scope consistent with the project context and project location. In some cases, the alternative improvements may have already been developed for the project and this traffic analysis may be required and/or requested to evaluate and be in support of the decision-making. The "No-Build" alternative must be considered as one of the project alternatives. No-Build alternatives include not only maintenance, but also committed improvements with programmed funding to the analysis location. A description of how the alternative will be evaluated should be included in the scope.

The project team should also consider the timeframe as to when the improvement alternatives could be implemented. The timeframe is generally dictated by the regulatory agency responsible for the project and the various type of projects. Typical signal retiming and other low hanging fruit operational and safety improvement projects can generally be completed in 0-2 years. Traffic impact studies and other minor intersection improvement projects can generally be completed in 2-10 years while the PELs, NEPA, and/or other widening/new roadway/intersection/interchange projects would require a 20-30 year horizon timeframe.

Additional guidance on the potential project alternatives are provided in Chapter 9.

2.11 Alternatives Screening and Analysis

The alternatives screening process may take place simultaneously with the identification of alternatives process or as a separate exercise after all viable alternatives have been identified to parse the list down to a manageable number of alternatives for analysis. The number of alternatives that will be analyzed should be defined in the project scope. The project team should consult the opportunities and constraints list when reviewing alternatives and choose the alternatives most likely to successfully meet project goals and objectives to advance.

Once the most promising alternatives have been identified analysis of each alternative should be performed to generate MOEs for project performance indicators identified in the project scope. The analysis should be performed for the open and design years identified in the scope using the same software that was used for the existing conditions and the future no-build analysis unless a different software is needed for alternative intersection types (see discussion in Chapter 5 regarding the use of multiple analysis tools).

For intersection specific alternatives, CDOT has developed the Intersection Control Assessment Tool (ICAT)[1] to document the considerations and ultimate selection of a final intersection design concept. The ICAT objectively screens multiple alternatives to identify optimal intersection control ensuring intersection investments across the state are prioritized. The spreadsheet-based tool supports Colorado's safety policies and procedures by focusing on areas with the greatest potential to improve safety. CDOT's ICAT is applicable to intersections along Colorado State Highways that will utilize Federal or State funds. Use of the ICAT is required for new intersections or projects that will include substantive changes to the traffic control or geometry of existing intersection along state highways. Use of the ICAT is recommended, but not required, for intersection projects off the state system and involving funds other than Federal or State. A separate ICAT document is required for each intersection within the project area. While each ICAT may recommend a different intersection type, the analyst should

[1] https://www.codot.gov/programs/operations/tsmo-evaluation

consider the entire corridor together as one system when making final recommendations for intersection treatments along a corridor.

2.12 Identification and Justification of Preferred Alternative

The analysis of alternatives should result in one or more alternatives that meet the project goals and objectives as defined during project scoping. The final selection of a preferred alternative should be justified from various standpoints including:

- **Project Cost** - A benefit-cost analysis may be helpful in ranking alternatives to decide on a final preferred alternative. In addition to design and construction costs, many indirect costs may be taken into consideration when performing a benefit-cost analysis including environmental impacts, political and public support, and safety impacts.
- **Systematic** - How well does the proposed improvement fit into the transportation system surrounding the project area? Does the project fit in with the vision identified by previous transportation plans that encompass the project area?
- **Resiliency** - How well does the proposed improvement allow for future modifications or improvements in response to changes in travel patterns and demand?

In some cases, it may be appropriate to recommend multiple alternatives with different project costs and time horizons to allow a phased approach to design and construction. For example, a low-cost, short-term project to add turn lanes may solve expected congestion issues at an interchange while the long-term demand necessitates a bridge replacement and roadway widening.

2.13 Traffic Analysis Report and Technical Documentation

The traffic analysis report documents the project objective, analysis results, and conclusions. The report and technical documentation should be submitted in electronic format and contain the complete report, including the analysis files from all analysis tools used so the CDOT project manager and/or their designee can review the results using the appropriate traffic operations analysis tools. Report formats and level of detail will vary depending on the type and complexity of the project, and the intended audience. Project-specific reporting guidelines, including any requirements for hard copies should be determined on a case-by-case basis and agreed upon by the CDOT project manager during the project scoping process.

The following list of basic report sections should be considered (additional sections not listed below may also be considered depending on the nature of the project):

- **Introduction** – document the project background, purpose and need, project location map, and analysis objective(s).
- **Analysis Methodology** – document assumptions and deviations, if any from the guidance, identification of analysis years/scenarios, analysis tools and outputs, and measures of effectiveness.
- **Existing Conditions Analysis** - document data collection, field review, analysis tool calibration and validation, analysis approach and results, and crash analysis.
- **Future Alternatives Analysis** – document traffic forecasting, no-build operational and/or safety analysis results, development of alternatives, build alternatives operational and/or safety analysis results, predictive crash analysis (if applicable), summary of results, and public involvement or stakeholder engagement (if applicable).
- **Conclusions and Recommendations** – document final results and project recommendations.

Every CDOT project is also required to conduct an Operations Evaluation for the project. The purpose of the operations evaluation is to ensure a consistent and interdisciplinary approach between CDOT teams, including Maintenance, Access, Regions, Operations, Safety, Intelligent Transportation Systems, and FHWA. The level one operations analysis should be initiated at the onset of a project to document project assumptions including existing geometry, operational characteristics, and potential for improvement. A level two operations analysis may be required to document that the required analysis has been properly performed for the project. The traffic analysis report should document the assumptions, analysis methodology, and conclusions reached as part of the level two operations analysis.

3 Measures of Effectiveness

3.1 Overview

The purpose of analyzing one or more Measures of Effectiveness (MOEs) for traffic studies is to assess the achievement of a project's defined traffic operations and safety objectives and goals. The analyst must identify the MOEs for their project to determine the need for forecasting, traffic analysis, safety analysis or a combination. Traffic and safety analyses generally are used to report MOEs related to existing and/or future capacity or performance (operational and/or safety) of a transportation system. Selection of MOEs must be guided by the various applicable regulatory structures (e.g., the National Environmental Policy Act, Colorado's HB19-1261 and associated regulations, etc.)

Level-of-Service (LOS) along with its associated measures (delay, density, speed, etc.), is a readily recognizable indicator of traffic operations that is widely used by different agencies when evaluating the traffic operations performance of facilities. However, LOS alone does not necessarily give insight about the overall performance of the facility. Thus, additional quantifiable measures should be included in the analysis to better assess the performance of the location or network being analyzed. The project team should consider how many MOEs are necessary to address the project objective and take into consideration the audience whom the MOEs need to be communicated when making the final determination on the number of MOEs required. At a minimum, the LOS, delay or density, and queue length should be reported for all analyses. Recent Colorado legislative actions are likely to elevate consideration of VMT as an MOE.

The Level of Service of Safety (LOSS) has been developed by CDOT to provide an estimate of the normal or expected accident frequency and severity for a range of ADT among similar facilities. MOEs for safety analysis typically include the expected frequency and severity of crashes for current and future conditions. Traffic volumes are critical inputs to estimating these MOEs. Specifically, safety performance functions (SPFs) are used to predict the number of crashes for a given facility based on traffic volume and other geometric and operational characteristics. Forecasting would be needed to estimate future traffic volumes for use in these predictive methods to evaluate future conditions.

Similar to the LOSS, the Operational Level of Service (OLOS) was developed by CDOT to evaluate the performance of a facility, relative to the performance of similar facilities across the state. The OLOS is based on planning time index (PTI) and provides a holistic performance measure for travel time reliability. CDOT has developed an OLOS dashboard that reports the OLOS of roadways and facilitates the use of OLOS to make operational and investment decisions related to bottleneck identification, corridor improvement potential, operations evaluation, incident, weather, event, and construction management, analysis for funding pool approvals, and project prioritization for long term planning.

3.1.1 Applicable Tools for MOEs

Table 1 below lists and describes potential MOEs applicable to typical traffic engineering projects and states whether they are produced using traffic analysis tools, safety analysis tools, or forecasting tools. This table lists many common MOEs; however, it is not a complete list nor does it establish CDOT policy regarding what MOEs apply to different project types.

Table 1: Traffic Analysis, Safety Analysis, and Forecasting MOEs

Measure of Effectiveness	Description	Traffic Analysis	Safety Analysis	Forecasting	Notes
Average Vehicle Occupancy (AVO)	The average number of persons per vehicle, including transit, on the transportation facility or system.	○	○	◉	
Buffer Time Index (BTI)	Expresses the amount of extra 'buffer' time needed to be on-time 95 percent of the time (late one day per month). Indexing the measure provides a time and distance neutral measure, but the actual minute values could be used by an individual traveler for a particular trip length. The index is calculated for each road segment and a weighted average is calculated using vehicle-miles of travel as the weighting factor.	●	○	○	
Crash Frequency	Quantitative measure of safety performance representing the number of crashes estimated to occur at a particular site, facility, or network based on crash history, traffic volume, and other site characteristics. There are three specific terms used to define crash frequency: 1) observed crashes, 2) predicted crashes, and 3) expected crashes. Observed crashes are the number of reported crashes at a specific location during a defined time period. Predicted crashes are the estimated number of crashes from a safety performance function. Expected crashes are an estimate of the long-term average safety performance based on the weighted average of observed and predicted crashes using the Empirical Bayes method.	○	●	○	Traffic volumes are a critical input to safety analysis tools, including the use of forecasting to estimate future volumes to input into safety performance functions (SPFs).
Crash Severity	The level of most serious injury or property damage due to a crash, commonly divided into categories based on the KABCO scale.	○	●	○	Traffic volumes are a critical input to safety analysis tools, including the use of forecasting to estimate future volumes to input into safety performance functions (SPFs).
Delay	The additional travel time experienced by travelers at speeds less than the free-flow (posted) speed, expressed in seconds or minutes.	●	◉	○	Safety analysis tools produce the expected crash frequency and severity, which serve as inputs to other tools to estimate the change in delay as a result of a change in crashes.
Demand Volume	The measurement of how many people or vehicles need to get through a transportation network over a studied period.	○	○	●	
Density	The number of vehicles on a roadway segment averaged over space, usually expressed as vehicles per mile or vehicles per mile per lane.	●	○	○	
Flow Rate	The volume of vehicles over a specific period.	●	○	○	
Fuel Consumption	The fuel consumption rate associated with the use of a transportation facility or network.	●	◉	○	Forecasting provides demand volumes, which are inputs for fuel consumption measurement; however, additional tools are required. Some traffic analysis tools produce this directly. Safety analysis tools produce the expected crash frequency and severity, which serve as inputs to other tools to estimate the change in fuel consumption as a result of a change in crashes.
LOS	Qualitative measure describing operational conditions within a traffic stream, based on related measures, such as speed and travel time, freedom to maneuver, traffic interruptions, control delay, comfort/convenience; ranges from LOS A (best) to LOS F (worst).	●	○	◉	Travel demand models produce volume-to-capacity estimates; however, these are only coarse estimates of LOS. Traffic analysis tools are better for deriving LOS and its related measures. In over-saturated conditions, measures such as speed or control delay may be more suitable MOEs than LOS.
LOSS	Quantitative measure of the safety performance (level of service of safety) of a roadway or intersection in regard to its expected crash frequency based on traffic volume, segment length (for segments), and other site characteristics. It does not provide any indication of the nature of the safety problem itself. If a safety problem is present, there is a need for diagnostic analysis to understand the nature of the problem. Refer to CDOT's Highway Safety Improvement Program (HSIP) Manual for further details on LOSS and diagnostic methods. If a Safety Assessment is required, please contact the Safety Engineering and Analysis Group for assistance.	○	●	○	Traffic volumes are a critical input to safety analysis tools, including the use of forecasting to estimate future volumes to predict future LOSS.
Mode Split	Percent of travelers using each travel mode (Single-Occupant Vehicle (SOV), High-Occupancy Vehicle (HOV), transit, bicycle, pedestrian, etc.).	○	○	●	
Number of Stops	Number of stops experienced by section and/or corridor, based on some minimum travel speed.	●	○	○	

● This MOE is derived entirely by a tool/method.

◉ This MOE is derived from a tool/method using unrefined methodology, or needed inputs for this MOE are produced with a tool/method but the MOE itself is not produced.

○ This MOE is not produced by a tool/method

Table 1: Traffic Analysis, Safety Analysis, and Forecasting MOEs (Cont.)

Measure of Effectiveness	Description	Traffic Analysis	Safety Analysis	Forecasting	Notes
OLOS	Evaluates the performance of a facility, relative to the performance of similar facilities across the state. Based on the planning time index (PTI) and provides a holistic performance measure for travel time reliability.	●	○	○	
Percent Time Spent Following (PTSF)	The ratio between the time spent in platoons due to inability to pass and the total travel time on two-lane highways.	●	○	○	
Planning Time Index (PTI)	The 95th percentile travel time index. It is used as a supplemental measure for reliability. Because reliability is related to the distribution of travel rates, the 95th percentile indicates an excessively high travel rate, one that only five percent of all travel rates exceed for the time period under consideration.	●	○	○	
Queue Length	Length of queued vehicles waiting to be served by the system, expressed as a distance unit or number of vehicles.	●	○	○	
Ridership	The number of passengers on the evaluated transit system.	○	○	●	
Speed	A rate of motion expressed as distance per unit of time.	●	○	◐	Some forecasting tools provide speed at the regional/inter-city scale, and along major links. Traffic analysis tools provide speed at a roadway segment/intersection level, accounting for interrupted flow.
Travel Distance	The extent of space between the trip origin and destination, measured along a vehicular route.	○	○	●	Note that traffic analysis tools provide travel distance between model gateways and usually not between the trip origin and destination.
Travel Time	Average time spent by vehicles traversing a facility, including control delay and crash-related, in seconds or minutes per vehicle.	●	◐	●	Some forecasting tools provide travel time at a scale of regional, inter-city, and along major links. Traffic analysis tools provide travel time at a roadway segment or intersection level, accounting for interrupted flow. Safety analysis tools produce the expected crash frequency and severity, which serve as inputs to other tools to estimate the change in travel time as a result of a change in crashes.
Travel Time Index (TTI)	A comparison between the travel conditions in the peak period to free-flow conditions. It uses the units of travel rate due to the ease of mathematical calculation and due to the data elements included in the MMP database. The TTI could also use direct travel time comparisons for trips of the same length.	●	○	○	
Vehicle Hours of Travel (VHT)	This is the total travel time spent by all vehicles on a transportation facility or network during a specified period, expressed in hours. When accounting for vehicle occupancy, this becomes Person-Hours of Travel (PHT).	◐	○	●	Some forecasting tools estimate VHT across an entire transportation network from origin to destination. Traffic analysis tools only estimate VHT within their limited study network.
Vehicle Miles of Travel (VMT)	This is the total distance traveled by all vehicles on a transportation facility or network during a specified period, expressed in miles. When accounting for vehicle occupancy, this becomes Person-Miles of Travel (PMT).	◐	○	●	Some forecasting tools estimate VMT across an entire transportation network from origin to destination. Traffic analysis tools only estimate VMT within their limited study network.
Volume-to-Capacity (v/c) Ratio	The ratio of flow rate to capacity for a transportation facility.	●	○	◐	Some forecasting tools provide v/c based on roadway class and per lane capacities. Traffic analysis tools provide a more detailed accounting of v/c on roadway segments, resulting in more detailed data inputs (such as truck percentage, grade, etc.) and accounting for interrupted flow.

Source: Adapted from the FHWA TAT, Volume II

● This MOE is derived entirely by a tool/method.

◐ This MOE is derived from a tool/method using unrefined methodology or needed inputs for this MOE are produced with a tool/method but the MOE itself is not produced.

○ This MOE is not produced by a tool/method

3.1.2 System-Wide vs. Location-Specific MOEs

Traffic and safety analysis tools produce a set of MOEs that indicate how well a location-specific transportation facility is performing. Other tools, such as travel demand models, are more commonly used for system-wide MOEs. **Table 2** defines, at a high level, the different stages of a transportation planning and design project. **Table 2** identifies whether system-wide or location-specific MOEs, or a combination of the two, are appropriate for each stage.

Table 2: Project Scale & Candidate MOEs

Project Scale	Candidate MOEs
System-wide/area-wide studies	Nearly all MOEs will be system-wide (e.g., v/c ratio on major facilities, total (network) delay, total (network) crash frequency, VMT, VHT).
System-wide prioritization studies	May use some system-wide MOEs (e.g., v/c on major facilities, total (network) delay, total (network) crash frequency, VMT, VHT), but also use location-specific MOEs (e.g., LOS, LOSS, v/c, flow rate, density, control delay, travel time, operating speed, queue length).
Location-specific studies (e.g., corridors/ intersections/interchanges; future capacity needs; alternatives analysis, including NEPA)	Most MOEs will be location-specific (e.g., LOS, LOSS, v/c, flow rate, density, control delay, travel time, operating speed, queue length); system-wide MOEs such as total (network) delay and VMT still may be appropriate.
Preliminary engineering through construction bid documents, including operations during construction	Nearly all MOEs will be location-specific (e.g., LOS, LOSS, v/c, flow rate, density, control delay, travel time, speed, queue length).

Location-specific MOEs relevant to different transportation facility types and common project needs are presented in **Table 3**. If the analyst's desired MOE is not listed in **Table 3**, the traffic and safety analysis tools described in this chapter may not be relevant to the analysis. LOS and LOSS are MOEs for each transportation facility; however, in each case, LOS and LOSS are derived from other quantitative MOEs already listed. In many cases, the quantitative MOEs may be more appropriate than LOS for over-saturated conditions. It is important to note that transportation facilities, such as freeway interchanges, may combine multiple facility types.

Table 3: Facility Type, Project Need & MOEs

Facility Type	Considerations	Candidate MOEs
Uninterrupted Flow		
Basic Freeway Segments	Determining how well the facility operates or will operate	LOS, density, speed, travel time, person-throughput (by mode), LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining number of lanes	
	Determining a need for multi-modal facilities	
Freeway Merge and Diverge Segments	Determining how well the facility operates or will operate	LOS, density, speed, travel time, LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining number of lanes, merge/diverge lengths, etc.	
Freeway Weaving Segments	Determining how well the facility operates or will operate	LOS, density, flow rate, speed, travel time, queue length, LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining number of lane changes, weave length, etc.	
	Analyzing ramp terminal managed lane, and intersection/weaving segment interactions	
Multi-Lane and Two-Lane Highways	Determining how well the facility operates or will operate	LOS, density, PTSF, person-throughput (by mode), LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining number of lanes	
	Determining a need for multi-modal facilities	

Table continues on next page.

Table 3: Facility Type, Project Need & MOEs Cont.

Facility Type	Considerations	Candidate MOEs
Interrupted Flow		
Urban Arterials	Determining how well the facility operates or will operate	LOS, v/c ratio, control delay, travel time, operating speed, queue length, person-throughput (by mode), LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining number of lanes	
	Evaluating existing signal timing plans	
	Optimizing or coordinating signals	
	Evaluating the effect of technology application or traffic demand management strategies	
	Determining a need for multi-modal facilities	
Intersections (Signal, Stop-Controlled and Roundabout)	Determining how well the facility operates or will operate	LOS, v/c ratio, control delay (by mode), travel time, operating speed, queue length, person-throughput (by mode), LOSS, crash frequency, crash severity
	Determining a need for additional capacity	
	Determining intersection control or number of lanes	
	Designing new intersections	
	Analyzing new intersection types (control, innovative designs, etc.)	
	Determining a need for multi-modal facilities	

Source: Adapted from Florida Department of Transportation *Traffic Analysis Handbook.*

Reinforcing with Project Examples:

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

Core MOEs include:

- MOEs for intersections, including LOS (derived from control delay), LOSS and queue length
- MOEs for freeway facilities, including LOS (derived from density, speed, or flow rate), LOSS and travel time
- Microsimulation calibration MOEs, including travel speed, travel time, and queue length

Other MOEs, such as crash frequency and severity, travel distance, VHT/PHT, and VMT/PMT, also should be considered. Most recent state legislature actions and associated regulations (e.g., Air Quality Control Commission) should always be consulted to ensure that study MOE priority is consistent with up-to-date legal/regulatory context.

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

Core MOEs include:

- MOEs for intersections, including LOS (derived from control delay), LOSS and queue length
- MOEs for urban arterials, including LOSS, travel time, and operating speed

Other MOEs, such as crash frequency and severity, travel distance, VHT/PHT, and VMT/PMT, also should be considered.

4
Data Collection

4.1 Overview

Traffic analysis, safety analysis, and forecasting rely on accurate data. Data collection is expensive and needs to be planned carefully. Without quality data, neither traffic analysis, safety analysis, nor forecasting is likely to produce meaningful results. It is important to understand the issues that need to be investigated and what types of data is needed to evaluate and mitigate the issues. The precise data requirements for developing and calibrating a traffic analysis model vary depending on the operation conditions and the software tool selected; however, they all require five basic types of input:

- Roadway geometrics (segment lengths, lanes, curves, etc.)
- Traffic controls (control type, signal timing, signs, etc.)
- Vehicle characteristics (vehicle classification, such as passenger vehicles versus heavy vehicles or FHWA's vehicle classification scheme)
- Demand (entry volumes, per lane volumes, turning volumes, origin-destination (O-D) data)
- Performance (travel speeds, crash frequency, lane utilization, travel times, delay, queues)

Collection of roadway geometric data and traffic control data usually is straightforward. Vehicle characteristics, demand, and performance data is more subject to error or inconsistency; therefore, these guidelines address ways of minimizing this error or inconsistency. The FHWA publication *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* is an additional resource that provides in-depth guidance for developing a data collection plan and utilizing emerging technologies and data sources for traffic analysis and forecasting.

FHWA also updated the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* in 2019 to allow for the analysis of the projects under different operational conditions with a better-expected statistical fit than a "typical day" trying to present a reliability space including operation conditions affected by incidents, work zones, weather events, special events, etc. The data-driven cluster analysis can be time-consuming and resource-intensive therefore adequate time and budget should be allotted to collect sufficient data and conduct a successful analysis.

4.1.1 Data Collection Plan

A Data Collection Plan is prepared to document data needs and the procedures for collecting the data. The plan includes data reduction procedures and quality assurance protocols that the analyst will follow to ensure both correctness and completeness of the data collected. FHWA's Integrated Corridor Management Analysis Modeling and Simulation Guide postulates that 10 to 20 percent of the overall study budget should be allocated to developing the data collection plan and to assembling/collecting data. The following outline provides an overview of the approach and steps in collecting data.

1. **Research and Identify Available Data for the Study Area** - Existing data sources and data requirements should be researched to identify the quantity and quality of available data for the analysis area. The Data Collection Plan should identify those individuals responsible for compiling the data. The analysis manager should work closely with stakeholders in compiling the data. If possible, the analysis manager should obtain samples of datasets prior to full collection to view the content and format of the data and adjust collection plans as necessary.
2. **Identify Gaps and Recommend an Approach to Filling Them** – Once available data sources have been investigated and dataset samples reviewed, the analyst should assess the appropriateness of the available data for use in the analysis and identify any critical gaps in data availability. This process should be undertaken during the project scoping phase to inform the project budget and timeline. Note that the analysis method chosen for the project will impact the depth and breadth of data needed to conduct the analysis. Data collected should be sufficient to estimate variations in travel demand. 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** - In this step, procedures for conducting data quality control and project data archiving should be identified. Any required thresholds for minimum data quality should be identified, as should high-level descriptions of processes for addressing data shortcomings. Plans for archiving the data also should be identified. Responsibilities for data quality testing and data archiving should be clearly defined.
4. **Develop Data Collection Plan** - The Data Collection Plan outlines data needs, sources of available data, and the methods for collecting any additional data. This plan, typically prepared for agency stakeholders to approve, should contain budget and schedule estimates.

Once the Data Collection Plan is developed, the required data should be collected in accordance with the plan. Generally, implementing the plan will involve the following activities:

1. **Assemble/Collect Data on Physical Infrastructure and Geometrics** - Much of these data sets are likely to be available in existing models and regional geographic information systems (GIS). Analysts should verify all data with field observations.

2. **Assemble/Collect Existing Traffic Performance Data within the Study Area** - Current and historical CDOT traffic data is available on OTIS.
3. **Gather Available Information from Existing Studies** - These studies include those currently underway as well as those that have been recently completed. Example studies include existing conditions analyses, environmental impact studies, and lists of projects and strategies that have been planned or programmed.
4. **Conduct Field Reviews within the Study Area** - Observation of traffic and road, bicycle, and pedestrian user behavior is a critical part of the data collection effort. Items to note are vehicle speeds, pedestrian walking speeds, queue lengths, weaving behavior, crossing behavior, and if possible, origin-destination patterns. Travel time runs should also be performed to refine/confirm third party travel time data. Noted observations of traffic should be quantified and integrated into the collected field data in order to strengthen the understanding of traffic and road user behavior, such as identifying saturated traffic flows to ensure demand volumes are captured instead of service demand.
5. **Collect 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.

4.1.2 Spatial & Temporal Limits

Spatial limits are the geographic extents that the analyst includes in the study area or model. Temporal limits are the time periods during which the analyst studies a transportation facility. Spatial and temporal limits are determined based on data collected, field observations, and engineering judgment. Determining the spatial and temporal limits is dependent on the study facility's saturation level. A facility is under-saturated if it is operating below its capacity and over-saturated if the facility is over capacity.

Under-Saturated Conditions

For under-saturated conditions, the spatial limits can include only the transportation facilities directly within the study area. The temporal limits generally should correspond to the design hour. The American Association of State Highway and Transportation Officials' (AASHTO's) *A Policy on Geometric Design of Highways and Streets* (the "AASHTO Green Book") generally recommends the 30th highest hourly volume as an appropriate design hour. The data required to determine the 30th highest hourly volume usually are unavailable unless permanent count station data is available. In urban areas, typical weekday (Tuesday through Thursday) peak hour conditions are a reasonable representation of the 30th highest hourly volume provided that school is in session, the day is not near a holiday, and no special seasonal variations or construction activity are occurring. Incidents may cause data to become unusable. Selection of the appropriate design hour is a project-specific decision. Commuter travel patterns usually dictate that both AM and PM peak periods be collected. Midday and weekend peak periods also may be needed based on local traffic patterns.

Over-Saturated Conditions

For over-saturated conditions, the spatial limits of the study area should include upstream queueing, which will be based on field observation. On urban freeways, for example, the spatial limits of a study area may need to be extended several miles to capture upstream queuing. Generally, it is only necessary to capture queuing that affects the analyst's study area to avoid modeling an entire region's worth of arterials or freeways. There are no clear standards for this decision, and engineering judgment must be applied to determine when extending spatial limits achieves only marginal or no benefits. Spatial limits should be expanded to include potential for additional congestion in future analysis years as well as possible downstream locations that could become bottlenecks if demand volume is "released" by the project. Over-saturated conditions may indicate a certain level of latent demand. Although this can only be estimated, it may be prudent to perform a sensitivity analysis to measure how effective each alternative performs. This may expose weaknesses that can be addressed.

Temporal limits should capture the beginning and ending of congestion. This confirms that the model and traffic volume data capture the true demand volume and not just the volume served. It is important to understand that traffic typically will be under-counted during congestion (over-saturated) conditions because the facility is only serving the traffic that can be serviced by that facility. The temporal limits should be sufficient to include all congestion related to the base case and each alternative. Otherwise, the model will not measure all the congestion associated with an alternative, resulting in under-reporting the benefits because the demand volume has not been captured. The temporal limits need to capture traffic volumes starting from and ending in uncongested conditions.

4.1.3 Data Age

Generally, vehicle characteristic, demand, and performance data should be no more than two years old at the onset of a study. Roadway geometric and traffic control data should reflect existing conditions at the onset of a study. The analyst will document reasonable exceptions to this general rule. Examples include projects in parts of the state that grow at a slow pace or projects in parts of the state where recent growth causes even two-year-old counts to be outdated. For crash data, it is generally desirable to use three to five years of historical data.

4.1.4 Data Verification/Validation

Verifying that data is correct and replicate expected field conditions is necessary to ensure quality. Key considerations in data verification/validation include:

- **Volume balancing**—imbalances in traffic volumes between two locations can occur during data collection and can often be attributed to different peak hours, congestion restricting flow along the corridor, and interruptions by driveways, parking lots/garages and/or major traffic generators.

Generally, the network should be balanced within +/- 10 percent of the approach and departure volumes between locations. However, volume imbalances between locations are considered acceptable if they are within the following thresholds:

- < 100 vph, within +/- 20 percent of observed traffic volumes
- 100 to 1,000 vph, within +/- 15 percent of observed traffic volumes
- 1,000 to 5,000 vph, within +/- 10 percent of observed traffic volumes
- > 5,000 vph, within +/- 5 percent of observed traffic volumes

In most cases, deterministic tools with minor fluctuations in volumes (less than 25 vehicles or 10 percent of the total approach traffic volumes) can still yield accurate results; however, minor fluctuations in volumes can have significant impacts on results from microsimulation tools. A balanced volume network should be used for microsimulation tools.

- **Field observations**—visual inspection is necessary for certain types of data, especially performance data, such as queue lengths, and qualitative driver characteristic information, such as gap acceptance (the process by which a minor stream vehicle accepts an available gap to maneuver) and lane utilization. Some forms of data, such as the floating car method of measuring travel speed on the road network (empirical runs in the direction of the traffic flow of interest), can only be collected in the field. Additionally, field observations can identify behavior not apparent in counts or travel time runs, as well as potential errors in data collection. Video may be useful but does not always capture upstream conditions. Gathering input from a variety of viewpoints (system managers, agency staff, public safety officers, travelers, etc.) may reveal insights otherwise not noticed.
- **Alternative data observations**—speed data from probe data sources such as INRIX and Web-based traffic maps, such as those from Google, are readily available for most freeway segment and other facility types. The data can be used as a basic for comparison and validation purposes but it should not be used as a replacement for field-measured speed and travel time. Limitations with INRIX at high signal density corridors should be noted. Be sure to review the impacts of signal density on average running speed.
- **Count simultaneity**—as much as possible, counts and other performance data (such as speed) should be collected simultaneously so that all count information is consistent within a single study period. Where study areas are too large for this to be effective, applying control stations where a continuous count is maintained can help resolve inconsistencies between counts.
- **Drones**—using drones to collect video can help identify behavior not apparent in counts or travel time runs without having to be at a location physically for field observations.

4.2 CDOT Data Sources

CDOT currently maintains two common sources of traffic data: the Online Transportation Information System (OTIS) and the COGNOS Data Reporting System. OTIS provides traffic counts from continuous-count sites, short-duration traffic counts from locations throughout the state, and 20-year growth factors. COGNOS primarily stores speed and volumes data from side-fire radar, ramp meters, and toll tag indicators. CDOT is currently working on changing over from COGNOS to OpenTMS (CDOT's ATMS system) to allow users access a variety of data types to support transportation plan and project development including field collected and passive data (probe data), geometry, weather, incident, safety, and work zone data. CDOT also utilizes a transportation data management system[2] where raw traffic data and the most up to date counts from continuous monitoring stations can be accessed.

4.2.1 OTIS

CDOT Online Transportation Information System (OTIS) is the public access point to information frequently used for transportation planning and project development. OTIS provides a variety of data, including volumes from over 100 continuous-count sites throughout the state. Approximately half of the continuous-count sites provide vehicle classification. OTIS also includes short-duration counts for approximately 9,000 locations throughout the state (approximately 3,000 locations are collected each year), with approximately one-third of these counts providing vehicle classification. Short-duration counts are collected from May through October.

Counts from both the continuous-count sites and the short-duration counts are reviewed by CDOT staff and generally are considered sufficiently accurate for use in forecasting and traffic analysis projects. It may still be valuable to collect some project-specific counts to verify the OTIS count data.

OTIS also provides 20-year growth factors for Annual Average Daily Traffic (AADT) using a simple trend analysis based on growth that occurred over the last 20-years. For intermediate years, linear interpolation/extrapolation is applied. Twenty-year growth factors may be suitable in some instances where Sketch Planning is an appropriate forecasting method; however, the analyst should use their own judgment when identifying growth factors on state highways.

Web address: https://dtdapps.coloradodot.info/otis

4.2.2 COGNOS

The primarily data stores in the system are speed and volume data collected by the following ATMS devices:

[2] https://cdot.public.ms2soft.com/tcds/tsearch.asp?loc=Cdot&mod=TCDS

- Automated Traffic Recorders (ATRs)
- Ramp Meter (RM)
- Remote Traffic Microwave Sensor (RTMS)

All data available through COGNOS are raw; CDOT staff do not review COGNOS data prior to publication on COGNOS. Data should be carefully validated before using for traffic analysis for inconsistencies such as a lack of data when there should be or unusual patterns such as a device reporting the same volume or speed for multiple consecutive intervals. Given the depth of data available through COGNOS, it can be helpful for providing granular data within a study area; however, project-specific counts and speed surveys should be collected to establish control stations within a study area.

Surface and atmospheric weather data are being collected by Weather Stations on all state roads and is available in COGNOS. COGNOS may also be used to supplement data not current in CDOT's crash database.

Automatic Traffic Recorders

CDOT's automatic traffic recorders provide the best source for continuous link volume data for analysis. The Traffic Analysis Unit within the Department of Transportation Development (DTD) maintains the traffic count data within CDOT. There are currently 118 continuous count stations on Colorado state highways that record traffic volumes in one-hour intervals. **Figures 2 and 3** show the locations of these continuous count stations statewide as well as in the Denver Metropolitan Area.

Figure 2: Continuous Count Stations - Statewide

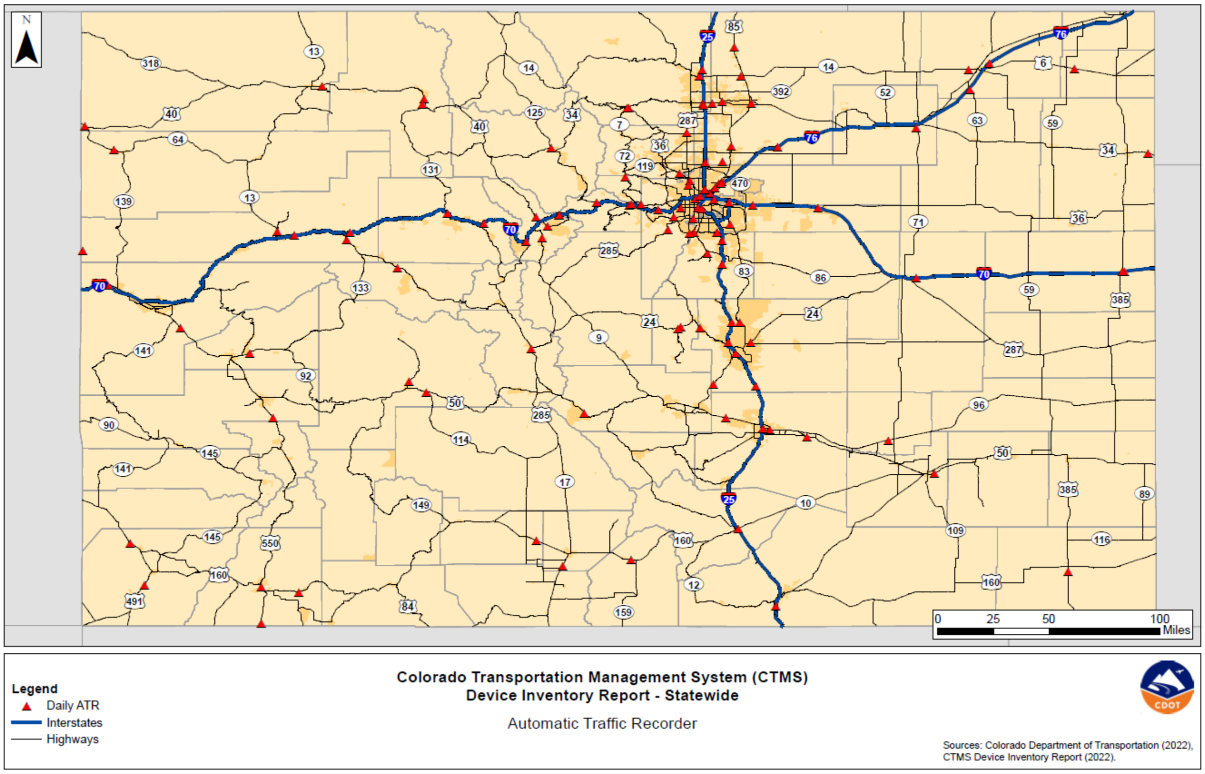
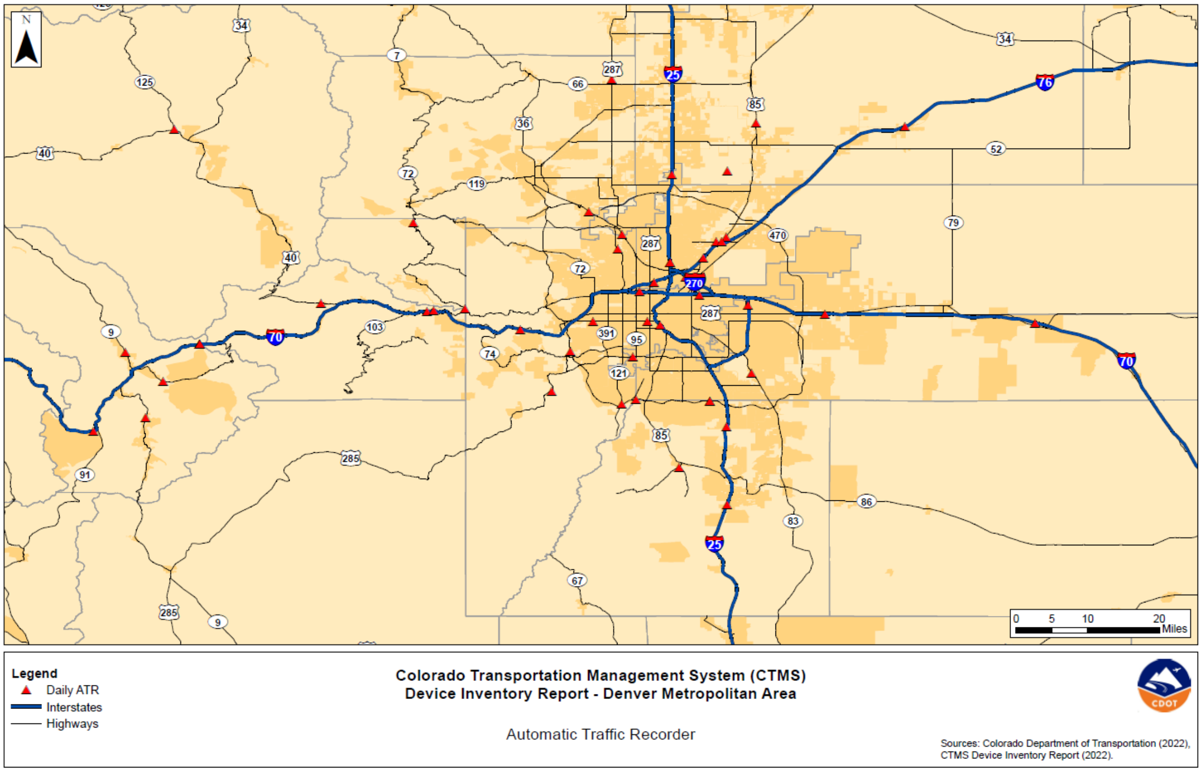


Figure 3: Continuous Count Stations – Denver Metropolitan Area



The data can be a useful point of reference to estimate the historical traffic demand pattern/trend for state highway facilities. Although the data provides historical counts and traffic patterns/trends, it is limited to Interstate and CDOT roadway network and also not yet reported in 15 minutes interval as recommended for inputs for microsimulation analysis. CDOT would need to reconfigure the collecting and reporting mechanisms for the 15 minutes intervals. As shown in **Figures 2 and 3**, most of the count stations are located in the urban area where more days of data are archived and readily available. In a more rural areas where there is no count station, the amount of data to be collected is more resource-intensive to provide sufficient data for the updated cluster analysis.

Remote Traffic Microwave Sensors (RTMS) and Ramp Meters (RM)

CDOT collects and maintains travel time and speed data on limited roadway segments from Remote Traffic Microwave Sensors (RTMS) and Ramp Meters (RM). There are currently 382 Remote Traffic Microwave Sensors on Colorado state highways that record traffic volumes, speed, and occupancy for each travel lane in granularity as small as 30-second intervals. Data from these devices can be useful to detect and assess impacts of incidents. CDOT also maintains 131 Ramp Meters that collect traffic volumes, speed, and occupancy on the mainline adjacent to the ramp meter currently available in 1 minutes and 60 minutes intervals. CDOT in currently evaluating the 5-minutes and 15-minutes granularity for future use and perhaps for the updated cluster analysis. **Figures 4 and 5** (next page) show the RTMS and RM locations statewide as well as in the Denver Metropolitan Area.

As shown in **Figures 4 and 5**, although both the RTMS and RM devices provide valuable insight on the traffic demand and operations, the availability of the data is limited to only the Denver metro area and along I-70 west of Denver.

CDOT also has access to INRIX data. Typically field collected data should be obtained and probe data like INRIX can be used to supplement field-collected data. Although CDOT can query INRIX travel time and speed data for roadway segments, it should not be used as a replacement for field collected travel time and speed information used for calibration of microsimulation models. Similar to INRIX, the Regional Integrated Transportation Information System (RITIS) is a leading platform that provides data including traffic volumes, speed, class, and occupancy from sensors; event, work zone, and incident information; weather data; and several other types. Traffic data can be extracted for as granular as 1-minute intervals for the freeways, highways, and some local roads.

Weather Stations

CDOT collects and maintains surface and atmospheric weather data limited to all state roads. As shown in **Figures 6 and 7,** there are currently 178 weather stations on Colorado state highways.

Figure 4: Remote Traffic Microwave Sensors and Ramp Meters - Statewide

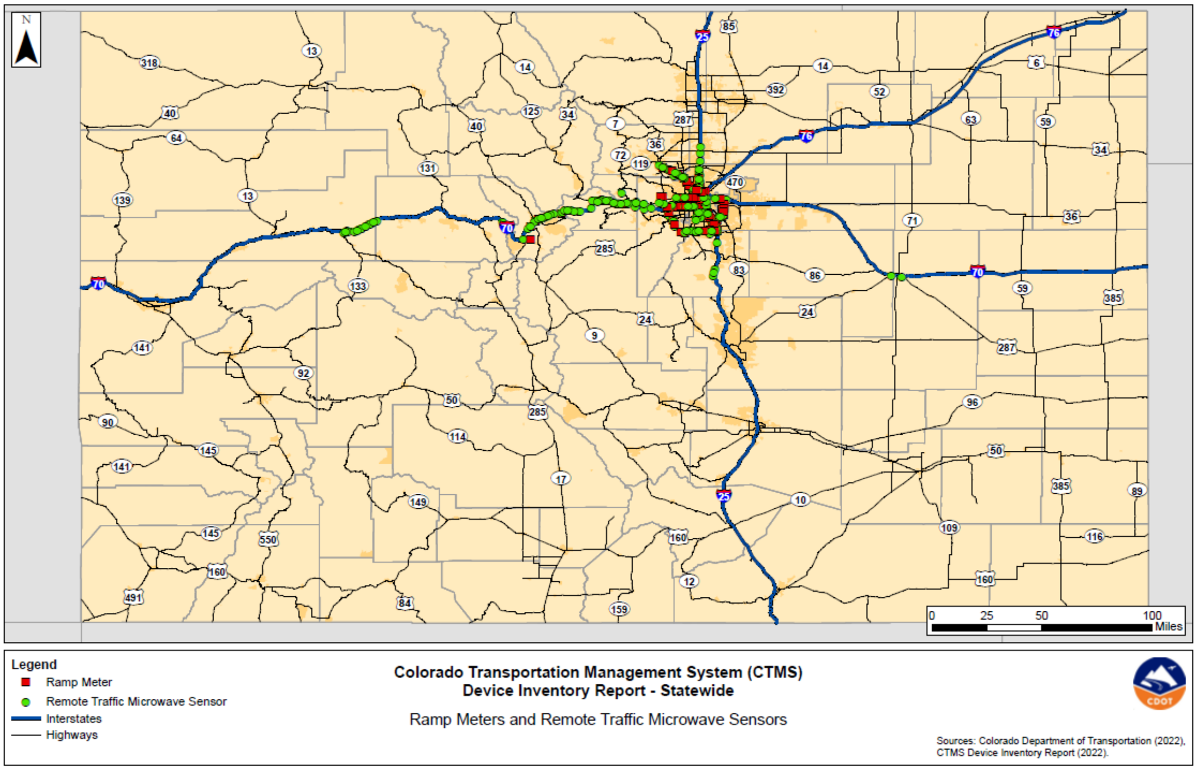


Figure 5: Remote Traffic Microwave Sensors and Ramp Meters – Denver Metropolitan Area

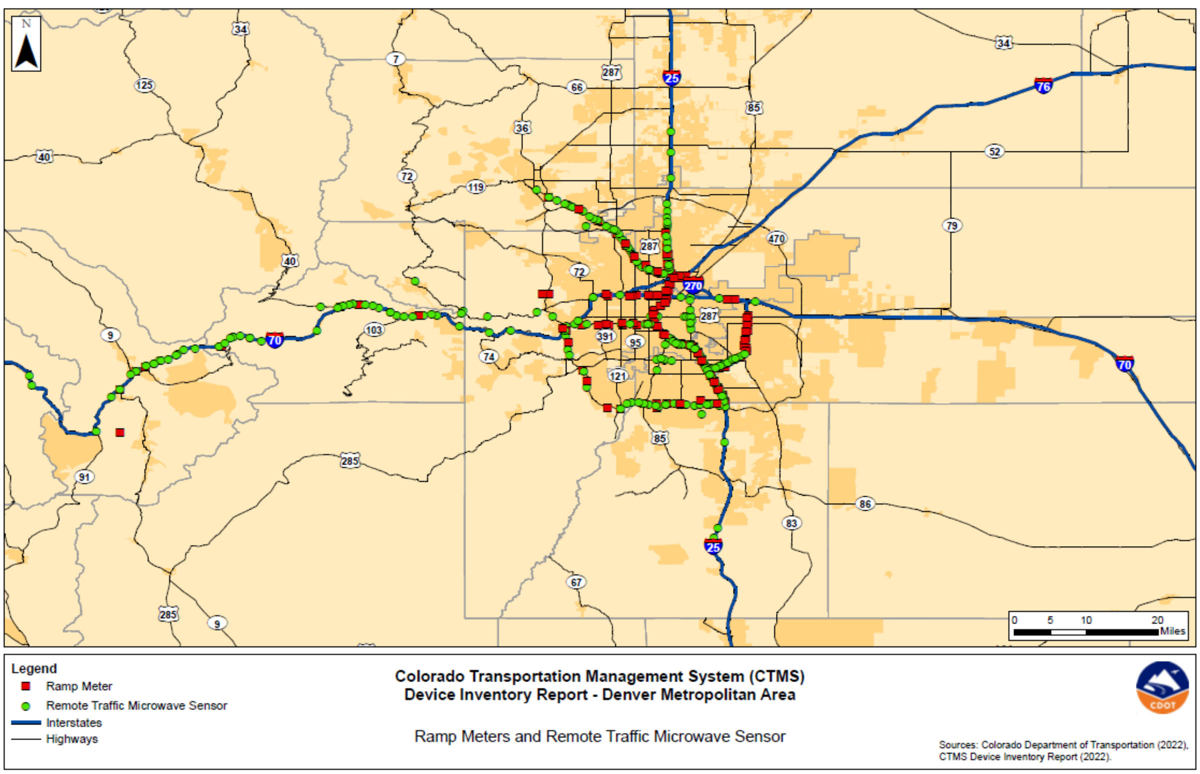


Figure 6: Weather Stations - Statewide

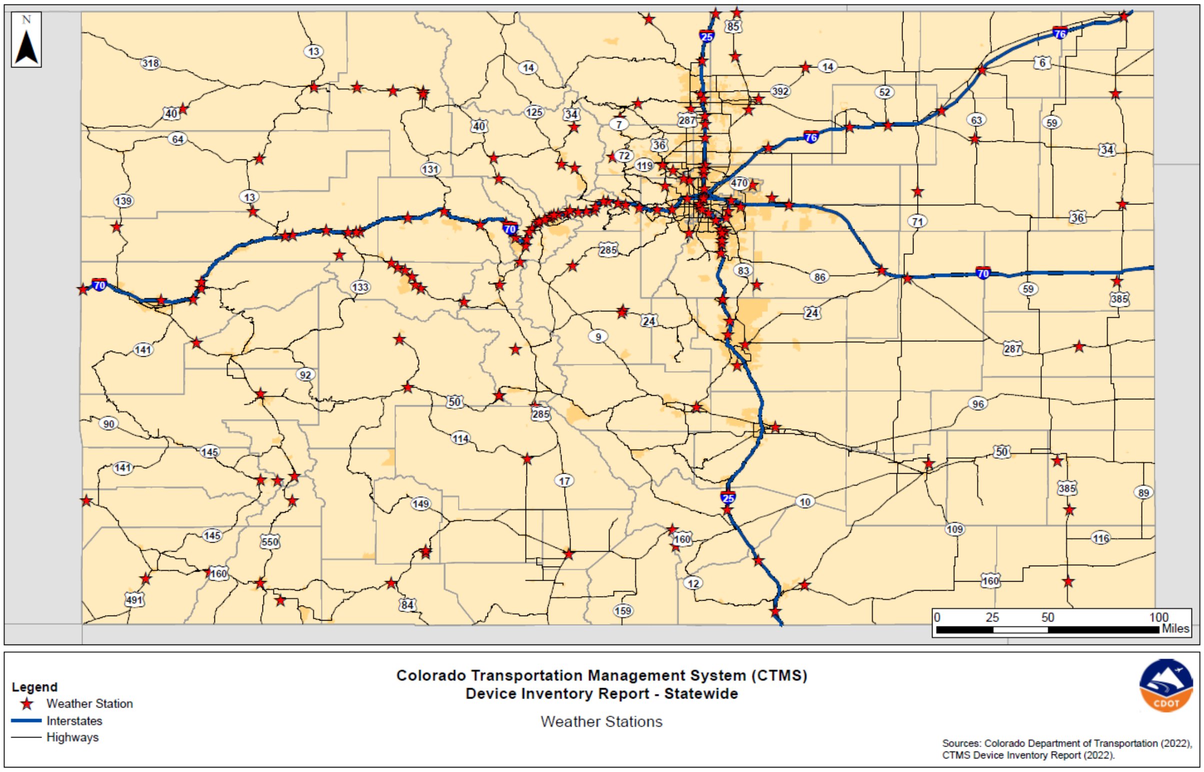
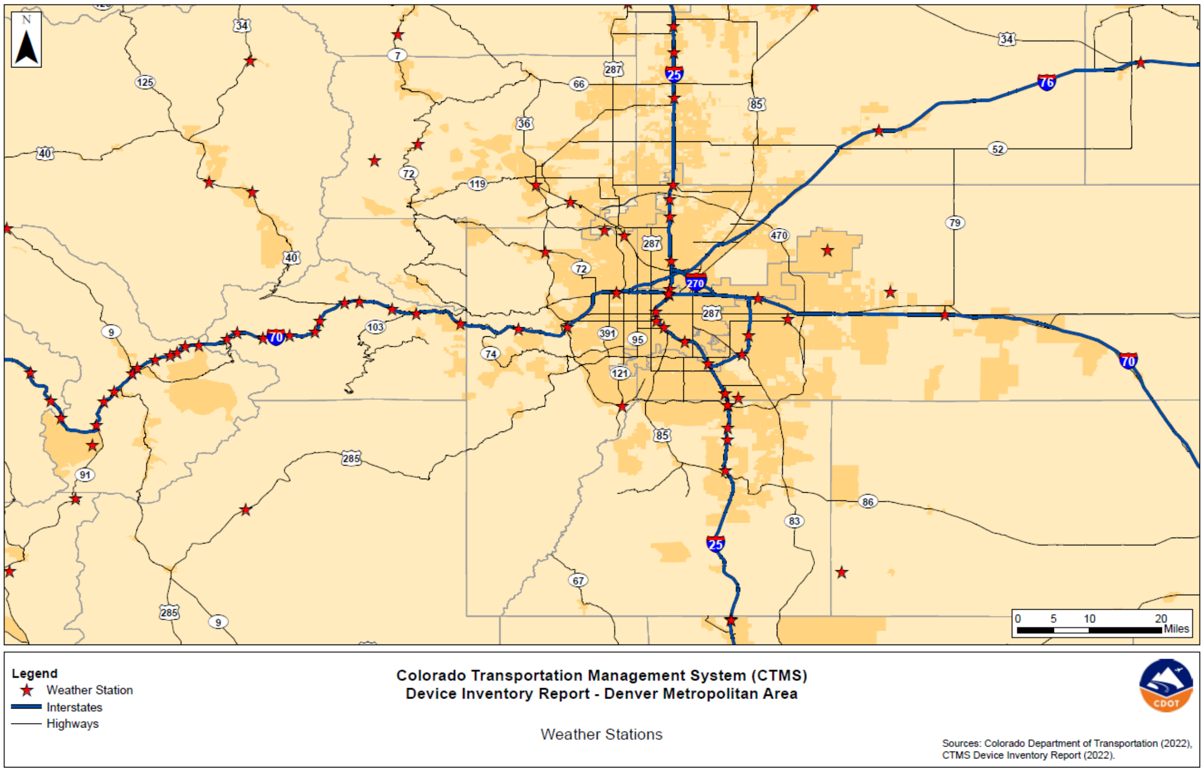


Figure 7: Weather Stations – Denver Metropolitan Area



4.2.3 Crash Data

CDOT maintains a crash database for purposes of improving traffic and highway safety. Crash data is typically compiled and released in six month increments with approximately a three-month delay when data becomes available. CDOT provides summary crash data upon request. Summary data is in tabular format and is provided for a specific location or geographic area, filtered for a specific type of crash, weather condition, and/or date range. Data provided by CDOT does not release personal identifying information. Visit CDOT's Crash Data webpage[3] for the most up to date instructions to make a crash data request.

4.3 Integrating Big Data

The term "Big Data" describes vast data sets that are so voluminous and complex that traditional data-processing application software is inadequate to deal with them. In transportation, Big Data is generated through numerous devices, including probe data, smartphones, and traffic sensors, and it is available for purchase from third-party vendors. Big Data is valuable for providing large amounts of information over broad periods of time and for verifying data received from detection-based systems. Additionally, a variety of new, useful MOEs can be established using Big Data. A variety of Big Data sources are available to apply to transportation planning and engineering projects.

Table 4 describes available Big Data sources along with their advantages, disadvantages, and sample vendors.

[3] https://www.codot.gov/safety/traffic-safety/safety-programs-data/crash-data

Table 4: Available Sources of Big Data

Method & Sample Vendors (if available)	Advantages	Disadvantages
Aerial LIDAR Colorado Hazard Mapping & Risk MAP Portal, Ecopia, Mapillary, Sanborn, Orbital Insight	• Determines elevation and geospatial location of features on the Earth's surface. • Can differentiate between terrain elements and man-made structures.	• Relationship between changes in features and corresponding socio-economic/demographic information not empirical.
Mobile Device Matching (Bluetooth or WiFi) Usually available from traffic and transportation data consultants or Hardware vendors, such as Acyclica or BlueTOAD by TrafficCast.	• Provides information on vehicles that travel through an area, such as their entry and exit points, their travel time between points, and percent makeup of total traffic. • Easier to capture and analyze and less expensive than license plate matching.	• No trip purpose, frequency, starting or ending point, characteristics of travel, or demographics information. • Does not provide data for subsequent mail surveys. • Data only available for locations with detectors.
Cellular-Based Data Airsage or other vendors with similar products	• Usually provides sufficient sample size due to reliance on cellular towers. • O-D data in a format suitable for integration with Regional Travel Demand Models (RTDMs) for city-to-city, city-to-county, or county-to-county flows. • O-D data includes residents and visitors plus trip purpose for all 365 days of the year, allowing for segmentation (i.e., by month, season, etc.). • Data can be queried, aggregated, and disaggregated. • Data collection method does not require set up time or human transcribing of observed field data, which can potentially introduce error.	• 1.2-mile spatial resolution exacerbated by topography makes these data more suitable for city-to-city or county-to-county flows. • Spatial resolution makes capture of intercity trips on specific roadways difficult. • Unable to directly measure information regarding trip characteristics or demographics; however, much of this information can be supplemented with information from other sources. • No data from cell phones registered to minors, unidentified telco providers (but acknowledgement that regional biases may exist based on exclusion of smaller providers). • Fixed definition of a stop (device must move at least 300 meters in five minutes) results in the creation of artificial stops in highly congested areas. • Data measures "device trips," not vehicle trips. Expansion factor applied based on ratio of devices to total population, which has no known relationship to the device/vehicle trip ratio. • Data product only includes index values based on expansion factor. Obtaining raw data requires additional cost.
GPS-Based Data StreetLight Data, although the data is processed from INRIX data.	• Similar advantages to Airsage data, but with three- to five-meter spatial resolution. • Includes separate trip tables for passenger vehicles and commercial vehicles. • Includes routing and ability to perform select link analysis and evaluate trip circuity (extra distance traveled).	• Smaller sample size with bias toward higher-income people due to requirement of having GPS-enabled device. • Generally limited to vehicular sources of travel.
Location-Based Services Data StreetLight Data	• Similar advantages to Airsage cellular-based data, but with an average 25-meter spatial resolution. • Generally, represents person rather than vehicular trip (data represents all modes, but is processed into vehicular trip tables). • Similar sample size to Airsage data. • Includes routing and ability to perform select link analysis and evaluate trip circuity (extra distance traveled). • Can be used to accurately capture directly observed trip lengths and VMT.	• Reduced bias toward higher-income people due to requirement of having smartphone rather than GPS-enabled device, although some bias still exists.
Travel Speed Data INRIX, HERE, TomTom	• Aggregates data from multiple sources (in-vehicle navigation systems, after-market navigation systems, cell phone apps, roadway sensors). • Can be separated for passenger and commercial vehicles. • Can view and summarize speeds and bottlenecks. • Speeds are a direct proxy for LOS and can be used to quickly assess large area network performance for low cost. • Non-recurring congestion locations can be separated from recurring congestion locations. • On the National Highway System, National Performance Management Research Data Set is available for free to state DOTs.	• Level of aggregation most appropriate at larger segment or corridor scales.

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Big Data can apply to several transportation planning and engineering project types and procedures, as outlined below.

4.3.1 Traffic Analysis Procedures

Big Data generally can be used for microsimulation model input estimation, microsimulation model calibration, and bottleneck/queue identification. Specific Big Data applications to traffic analysis procedures are:

- Using mobile device matching data
  - O-D estimation for microsimulation of smaller segments or corridors
  - Travel speed calibration for microsimulation of smaller segments or corridors
- Using cellular, GPS, or location-based services data
  - O-D calibration for microsimulation of larger segments or corridors
- Using travel speed data
  - Travel speed calibration for microsimulation of larger corridors
  - Bottleneck/queue identification, measurement (length, duration), sourcing, and reliability analysis (seasonality fluctuations)

4.3.2 Forecasting Procedures

When used for forecasting, Big Data is most applicable to travel demand model calibration/ validation, including:

- Using aerial Light Detection and Ranging (LIDAR) data
  - Roadway network and socioeconomic/demographic file building to identify changes to roadway networks or land use over time
- Using mobile device matching data
  - Assigned travel speed calibration to the segment/corridor level for all vehicles
  - Trip routing assignment/estimation and calibration at the segment/corridor level for all vehicles
- Using license plate matching
  - Trip routing assignment/estimation and calibration for subareas, individual Traffic Analysis Zones (TAZs), or at the segment/corridor level
  - Trip distribution estimation and calibration for subareas or individual TAZs
  - Internal-external (I-E) trip estimation
  - Through trip estimation

- Using cellular, GPS, or location-based services data
  - O-D matrix estimation and calibration (many possible breakdowns, including passenger vehicles vs. commercial vehicles, residents vs. visitors, trip purpose)
  - Trip distribution estimation and calibration for subareas or individual TAZs
  - Trip routing/assignment estimation and calibration for subareas, individual TAZs, or roadway segments
  - Link volume estimation
  - I-E trip estimation
  - Through trip estimation
  - Vehicle Miles Traveled (VMT) calibration
- Using travel speed data
  - Assigned travel speed calibration to the segment/corridor level for passenger vehicles and commercial vehicles

Reinforcing with Project Examples:

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

- Roadway geometric data will be available from aerial imagery but should be verified in the field.
- Traffic control data, such as control type or signs, will be available from online imagery, but should be verified in the field. As no traffic signals yet exist (as the interchange is planned but not existing), no signal timing data is necessary.
- Vehicle characteristic data may be available in OTIS. If not, vehicle classification data should be collected, along with demand volume data (i.e., traffic counts).
- Demand volume will be collected at study intersections. Since the highway currently is congested, peak hour volumes may not accurately reflect the demand volume. Count durations should be extended to capture the beginning and end of congestion in the study area. Count data should be supplemented with data from vendors to create a daily profile of traffic for up to one year to identify clusters for analysis.
- Since a microsimulation will be performed (per Chapter 7: Microsimulation Analysis Tools), O-D data and performance data, such as travel speeds/times and queue lengths, are necessary. O-D data can be collected with license plate matching, mobile device matching, cellular-based data, GPS-based data, or location-based services data. Travel speeds/times can be estimated using the floating car method or with travel speed data from Big Data vendors. COGNOS may be able to provide some of these data; however, COGNOS data is not reviewed prior to publishing. Project-specific speed data should be collected to establish control stations within the study area. Queue lengths should be observed in the field and the study area should be extended to capture the end of the queue.
- Field observations should be completed to verify roadway geometric data, traffic control data, and performance data (e.g., queue lengths, travel speeds/times).

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

- Roadway geometric data will be available from aerial imagery but should be verified in the field.
- Traffic control data, such as control type or signs, will be available from aerial imagery, but should be verified in the field. Signal timings must be requested from the agency that operates the traffic signals.
- Vehicle characteristic data may be available in OTIS. If not, vehicle classification data should be collected, along with demand volume data (i.e., traffic counts).
- Demand volume (i.e., traffic counts) will be collected at study intersections. As the highway is not congested currently, peak hour volumes should accurately reflect the demand volume.
- As no microsimulation will be performed (per Chapter 7: Microsimulation Analysis Tools),), O-D data and performance data, such as travel speeds/times, are not necessary. Queue lengths still may be valuable.
- Field observations should be completed to verify roadway geometric data, traffic control data, and performance data (e.g., queue lengths, travel speeds/times).

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5
Traffic Modeling and Analysis Tools

5.1 Traffic Modeling and Analysis Tools Overview

There are many traffic modeling and analysis tools used to evaluate, simulate, optimize, and/or predict operational and safety performance on existing and future transportation facilities. Understanding the differences between the modeling and analysis tools is essential in selecting the appropriate tool(s) on a given project. Traffic modeling and analysis may be completed for multiple scenarios reflecting existing conditions, existing plus project conditions, future (no project) conditions, or future plus project conditions. In addition, project conditions can include multiple project alternatives.

This section provides an overview of available traffic modeling and analysis tools and guidance on the most commonly used deterministic/analytical and microscopic/stochastic traffic analysis tools.

FHWA's *Traffic Analysis Toolbox* (TAT) Volume II provided general definitions and grouped the traffic modeling and analysis tools into the following categories:

- **Macroscopic Simulation Models:** Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as the microscopic models.
- **Mesoscopic Simulation Models:** Mesoscopic simulation models combine the properties of both microscopic (discussed below) and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link.

Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques.

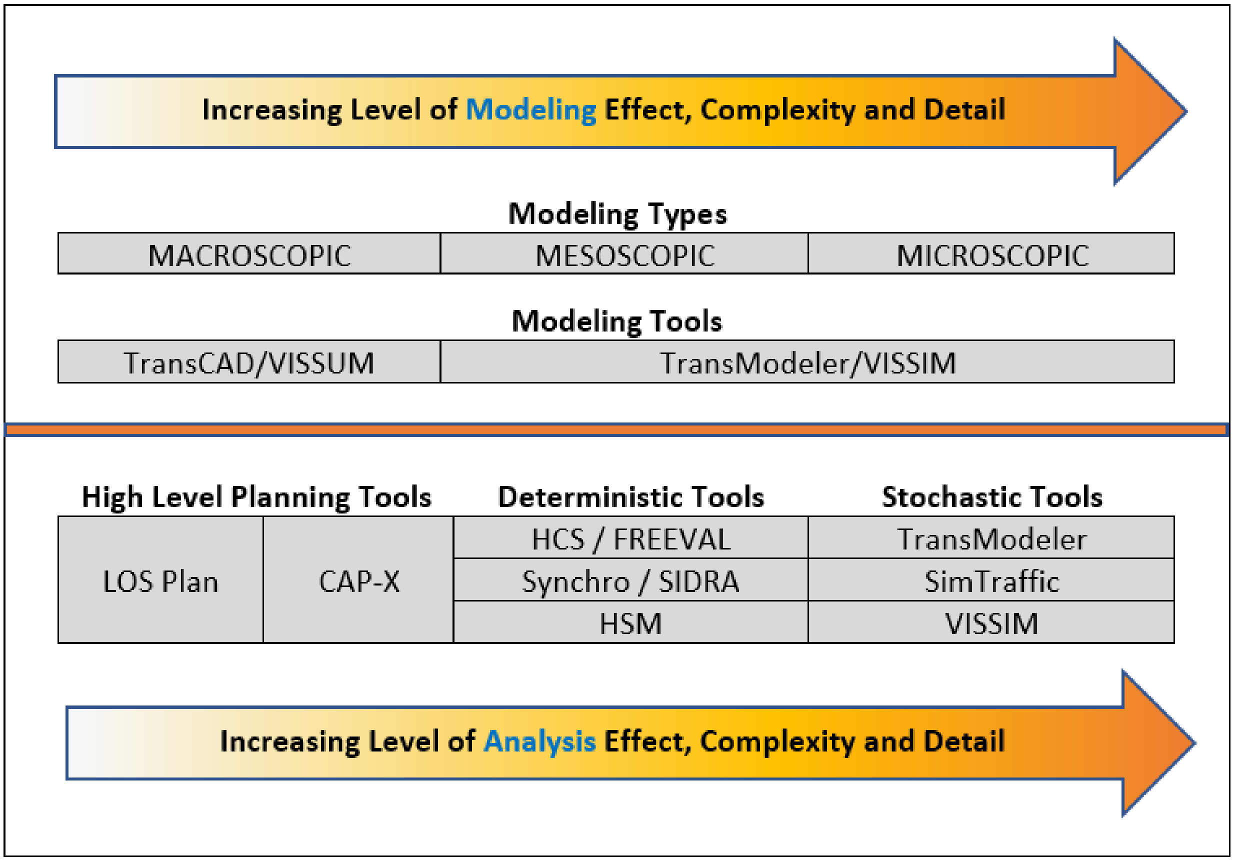
- **Microscopic Simulation Models:** Microscopic simulation models simulate the movement of individual vehicles based on car-following and lane-changing theories. Vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over brief time intervals (e.g., one second or a fraction of a second). Typically upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, the traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation, based on relationships developed in prior research. The primary means of calibrating and validating microscopic simulation models are through the adjustment of driver behavior factors. Computer time and storage requirements for microscopic models are significant, usually limiting the network size and the number of simulation runs that can be completed.
- **Sketch Planning Tools:** Sketch Planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. They allow for the evaluation of specific projects or alternatives without conducting an in-depth engineering analysis. Sketch Planning tools perform some or all the functions of other analytical tools using simplified analytical techniques and highly aggregated data. For example, a highway engineer can estimate how much it will cost to add a lane to an existing roadway simply by using Sketch Planning techniques and without doing a complete site evaluation. Similarly, traffic volume-to-capacity ratios are often used in congestion analyses. Such techniques are primarily used to prepare preliminary budgets and proposals and are not considered a substitute for the detailed engineering analysis often needed later in the implementation process. Therefore, Sketch Planning approaches are typically the simplest and least costly of the traffic analysis techniques. However, Sketch Planning techniques are usually limited in scope, analytical robustness, and presentation capabilities.
- **Travel Demand Models:** Travel demand models have specific analytical capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, route choice, and the representation of traffic flow in the highway network. These are mathematical models that forecast future travel demand based on current conditions and future projections of household and employment characteristics. Travel demand models were developed originally to determine the benefits and impact of major highway improvements in metropolitan areas. However, they were not designed to evaluate travel management strategies, such as intelligent transportation systems (ITS)/operational strategies. Travel demand models have limited capabilities to accurately estimate changes in operational characteristics (i.e., speed, delay, and queuing) resulting from implementation of ITS/operational strategies. These inadequacies generally occur because of the poor representation of the dynamic nature of traffic in travel demand models.
- **Traffic Signal Optimization Tools:** Traffic signal optimization tools are primarily designed to develop optimal signal-phasing and timing plans for isolated signal intersections, arterial streets, or

signal network. This may include capacity calculations' cycle length; split optimization, including left turns; and coordination/offset plans. Some optimization tools can also be used for optimizing ramp metering rates for freeway ramp control. Refer to the Objective, Strategy, and Tactic tables presented by FHWA in Appendix B of this document for recommended approaches to a variety of signal timing issues which may inform your traffic analysis tool decision.

- **Analytical / Deterministic Tools (HCM-based):** Most analytical/deterministic tools implement the procedures of the Highway Capacity Manual (HCM). These tools quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities and are validated with field data, laboratory test beds, or small-scale experiments. Analytical/deterministic tools are good for analyzing the performance of isolated or small-scale transportation facilities; however, they are limited in their ability to analyze network or system effects.
- **Deterministic Safety Analysis Tools:** Most deterministic safety tools implement the procedures of the Highway Safety Manual (HSM) to estimate the frequency and severity of crashes for a given facility under current or future conditions. The HSM procedures are akin to the HCM: closed-form (not iterative), macroscopic (input and output deal with average annual performance), deterministic (any given set of inputs will always yield the same answer), and static (they predict average safety performance over a fixed time period and do not deal with transitions in safety from one system state to another). There are two levels of safety predictions: planning-level and design-level. Both levels predict the frequency of crashes by type and severity based on as SPF for a given facility type. SPFs are available for a variety of transportation facilities. Planning-level SPFs provide an estimate of the average safety performance of a given facility based on minimal inputs, typically traffic volume and segment length (if applicable). Design-level SPFs provide an estimate of the expected safety performance of the location of interest based on traffic volume, segment length, and specific roadway and traffic characteristics at the site. Both levels of models should be calibrated to local conditions based on a sample of data representative of the site of interest. Further, both levels of models can be used to analyze existing conditions, future conditions, or proposed design alternatives under existing or future traffic volumes. To use these models to assess future conditions, there is a need to use forecasting methods to obtain estimates of future traffic volumes.

Figure 8 illustrates the relation between the levels of analysis, effort, and the degree of complexity among different traffic analysis tools used by CDOT.

Figure 8: Traffic Analysis Tool Degree of Complexity



5.2 Common Traffic and Safety Analysis Tools/Software

A variety of common traffic and safety analysis tools, software, and a summary of the strengths and weaknesses are highlighted in **Table 5, Table 6, and Table 7**. They are generally categorized as deterministic/analytical or stochastic/microsimulation. While this is not an exhaustive or historical list of all the tools or software, it encompasses many software tools commonly used today. This section also provides a list of safety analysis tools based on FHWA's Data-Driven Safety Analysis Toolbox[4].

[4] Data-Driven Safety Analysis Resources: https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/ddsa_resources/

Table 5: Deterministic Traffic Software Strengths & Weaknesses

Deterministic Software	Strengths	Weaknesses
ARCADY	• Implements British (Kimber) methodology for roundabout analysis. • Methodology accounts better for roundabout geometric features than HCS or SIDRA.	• If analyzing roundabouts based on geometrics rather than lanes (entry width, circulating width, etc.), can overstate capacity if the analyst is not a skilled user.
Cap-X	• Useful for comparing multiple innovative intersection designs.	• Limited in scope to evaluating innovative intersection designs; more-detailed traffic analysis using other tools still is necessary.
FREEVAL	• Implements HCM freeway facilities methodology. • Has feature to directly connect to INRIX data. • Diverse MOE options compared to HCS.	• Limited in scope to freeway facilities. • HCS now implements HCM freeway facilities methodology.
HCS	• Implements HCM methodologies for uninterrupted flow and interrupted flow facilities. • Commonly used nationwide. • Simple output reports.	• User interface not as visually intuitive as other software packages. • Single facility analysis only (no network modeling analyses). • Some lane configurations cannot be modeled.
Rodel	• Implements British (Kimber) methodology for roundabout analysis. • Methodology accounts better for roundabout geometric features than HCS or SIDRA.	• If analyzing roundabouts based on geometrics rather than lanes (entry width, circulating width, etc.), can overstate capacity if the analyst is not a skilled user.
SIDRA	• Implements SIDRA methodology for roundabout analysis based on long history of roundabouts in Australia. • Implements HCM methodologies for roundabouts and other intersection types.	• Movement summary report does not show adjusted inputs (requires the reviewer to either look at other output reports or the actual SIDRA file). • Users are generally less familiar with SIDRA as an intersection analysis tool.
Synchro	• Implements HCM methodologies for signalized intersections, stop-controlled intersections and roundabouts. • Commonly used nationwide. • Simple output reports. • User interface visually intuitive. • Can create networks for multiple intersection analysis. • Can be used for signal timing/coordination.	• Will apply past versions of HCM if most-recent version cannot be applied. • Does not apply HCM methodologies for ramp and freeway • Limited capabilities to analyze alternative intersection designs • Does not model ramp terminals and some alternative intersection types

Table 5: Deterministic Traffic Software Strengths & Weaknesses Cont.

Deterministic Software	Strengths	Weaknesses
VISTRO	• Implements HCM methodologies for signalized intersections, stop-controlled intersections, and roundabouts. • Strongest when generating and distributing trips through a network. • Can analyze multiple scenarios within one file, allowing for global changes in the base file to change all scenarios. • Can be used for signal timing/coordination.	• User interface not as visually intuitive as other software packages. • Does not model ramp terminals and some alternative intersection types

Table 6: Deterministic Safety Software Strengths & Weaknesses

Deterministic Software	Strengths	Weaknesses
AASHTO Highway Safety Manual Part C Spreadsheets	• Free of charge. • Implements the HSM Part C Predictive Method for all facility types. • Supports design-level analysis.	• Not intended for network level analysis.
AASHTOWare Safety Analyst	• Facilitates planning-level safety management process. • Provides data visualization and reporting capabilities.	• Data intensive and is publicly developed so it may require additional contracts with 3rd party if assistance is needed. • Does not implement the HSM Part C Predictive Method. • Does not support design-level analysis.
Agile Assets Safety Analyst	• Facilitates planning-level safety management process. • Provides data visualization and reporting capabilities. • Built on algorithms from initial versions of AASHTOWare Safety Analyst with some development and a new interface.	• Data intensive. • Does not implement the HSM Part C Predictive Method. • Does not support design-level analysis.
CDOT LOSS	• Colorado-specific safety performance measure	• List provided by CDOT (no analysis capabilities)
ISATe	• Free of charge. • Implements the HSM Part C Predictive Method for freeways and interchanges. • Supports design-level analysis.	• Does not support evaluation of crossroad segments at an interchange. • Not intended for network level analysis.
IHSDM	• Free of charge. • Implements the HSM Part C Predictive Method for all facility types. • Supports design-level analysis.	• Design Consistency, Intersection Review, Policy Review, Traffic Analysis, and Driver/Vehicle modules only apply to two-lane rural highways. • Not intended for network level analysis.
Numetric	• Facilitates planning-level safety management process. • Provides data visualization and reporting capabilities.	• Does not implement the HSM Part C Predictive Method. • Does not support design-level analysis. • Does not support safety effectiveness evaluation.
SPF Tool	• Facilitates planning-level safety management process. • Provides data visualization and reporting capabilities.	• Does not implement the HSM Part C Predictive Method. • Does not support design-level analysis.

Table 6: Deterministic Safety Software Strengths & Weaknesses Cont.

Deterministic Software	Strengths	Weaknesses
VZS	• Facilitates planning-level safety management process.	• Does not implement the HSM Part C Predictive Method. • Does not support design-level analysis. • Does not support safety effectiveness evaluation.

Table 7: Microsimulation Software Strengths and Weaknesses

Microsimulation Software	Strengths	Weaknesses
SimTraffic	• Inputs entered via Synchro's user interface, so generally easy to use. • Easily reports various network-wide and location-specific MOEs. • Easy to apply on interrupted flow facilities where multi-modal MOEs are not desired.	• Only applicable to interrupted flow facilities, such as urban streets or arterials. Does not apply to uninterrupted flow facilities. • Limited multi-modal capabilities. Pedestrians and bicyclists can be modeled to understand their effect on traffic; however, no pedestrian- or bicycle-specific MOEs can be extracted. No ability to model transit or preemption.
TransModeler	• Can model both interrupted flow and uninterrupted flow facilities. • Capable of multi-modal analysis, including pedestrians, bicyclists, and transit. • Can integrate with TransCAD.	• Model development and calibration is time-intensive and likely requires specialized training. • Outputs and MOEs almost always require post-processing and formatting to be useful.
VISSIM	• Can model both interrupted flow and uninterrupted flow facilities. • Capable of multi-modal analysis, including pedestrians, bicyclists, and transit. • Can integrate with VISTRO and VISUM.	• Model development and calibration is time-intensive and likely requires specialized training. • Outputs and MOEs almost always require post-processing and formatting to be useful.

5.3 Selecting the Appropriate Traffic and Safety Analysis Tools

Understanding the strengths, weaknesses, and capabilities/limitations between the tools are essential in selecting the appropriate tool(s) on a given project. Traffic analysis may be completed for multiple scenarios reflecting existing conditions, existing plus project conditions, future (no project) conditions, or future plus project conditions.

In many cases, the deterministic tools based on Highway Capacity Manual (HCM) methodologies can provide MOEs necessary to assess the system performance and project objective. In some cases, microsimulation tools may be required to effectively model heavily congested conditions, complex geometric configuration, and system-level impacts of transportation improvements that are beyond the limitations of deterministic tools. A traffic analysis tool selection matrix shown in **Table 8** has been developed to help the project team select the appropriate and cost-effective traffic analysis tool(s) based on the understanding of the traffic flow type on the study facilities and the existing or anticipated saturation level. Additional guidance in available in FHWA's *Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools.*

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Table 8: Traffic Analysis Tool Selection Matrix

Saturation Level		Under Saturated Conditions			Over Saturated Conditions			Notes
Facility Description		Intersection	Segment	Facility, Corridor, or System	Intersection	Segment	Facility, Corridor, or System	
Uninterrupted Flow	Freeway Facilities	N/A	N/A	Freeval HCS TransModeler VISSIM	N/A	HCS	Freeval HCS TransModeler VISSIM	Freeval and HCS are the preferred tool for under-saturated freeway facility analysis. Where complex geometry affects downstream flow rates in ways not accounted for by Freeval or HCS, TransModeler and VISSIM are the preferred tool for over-saturated freeway facility analysis.
	Freeway Segment Operations	N/A	HCS	TransModeler VISSIM	N/A	TransModeler VISSIM	TransModeler VISSIM	HCS is the preferred tool unless complex geometry is involved, in which case TransModeler and VISSIM may be preferred.
	Merge/Diverge Operations	N/A	HCS	TransModeler VISSIM	N/A	TransModeler VISSIM	N/A	HCS is the preferred tool unless complex geometry is involved, in which case TransModeler and VISSIM may be preferred.
	Weaving Segment Operations	N/A	HCS	TransModeler VISSIM	N/A	TransModeler VISSIM	N/A	HCS is the preferred tool unless complex geometry is involved, in which case TransModeler and VISSIM may be preferred.
	Freeway HOV/Ramp Metering Operating/Managed Lanes	N/A	TransModeler VISSIM	TransModeler VISSIM	N/A	TransModeler VISSIM	TransModeler VISSIM	
	Two-Lane Highway Operations	N/A	HCS	TransModeler VISSIM	N/A	TransModeler VISSIM	TransModeler VISSIM	HCS is the preferred tool for under-saturated two-lane highway analysis.
	Multi-Lane Highway Operations	N/A	HCS	TransModeler VISSIM	N/A	TransModeler VISSIM	TransModeler VISSIM	HCS is the preferred tool for under-saturated multi-lane highway analysis.
Interrupted Flow	Signalized Intersection Operations	HCS Synchro Vistro	HCS Synchro Vistro	HCS Synchro Vistro	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	Synchro is the preferred tool for under-saturated signalized intersection analysis.
	Signalized Intersection Preemption/Transit Priority	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	
	Unsignalized Intersection Operations (AWS and TWS)	HCS Synchro Vistro	HCS Synchro Vistro	HCS Synchro Vistro	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	Synchro is the preferred tool for under-saturated unsignalized intersection analysis.
	Roundabout Operations	ARCADY HCS SIDRA Rodel	ARCADY HCS SIDRA Rodel	ARCADY HCS SIDRA Rodel	ARCADY HCS SIDRA Rodel TransModeler VISSIM	ARCADY HCS SIDRA Rodel TransModeler VISSIM	ARCADY HCS SIDRA Rodel TransModeler VISSIM	For under-saturated conditions, use and compare results from ARCADY/Rodel, HCS, and SIDRA. ARCADY/Rodel, HCS, and SIDRA analysis are required to accompany any roundabout analysis completed using TransModeler or VISSIM.TransModeler or VISSIM is necessary to analyze channelized roundabouts (Turbo Roundabouts).
	Arterial Operations	N/A	HCS Synchro Vistro	HCS Synchro Vistro	N/A	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	HCS can apply Highway Capacity Manual 6th edition (HCM6) methodology for Urban Streets. Synchro applies its own methodology for arterials.

Table 8: Traffic Analysis Tool Selection Matrix Cont.

Saturation Level		Under Saturated Conditions			Over Saturated Conditions			Notes
Facility Description		Intersection	Segment	Facility, Corridor, or System	Intersection	Segment	Facility, Corridor, or System	
	Alternative/Innovative Intersection/interchange Operations (DLT, DDI, , RCUT, MUT, SPUI, and PARCLO)	HCS Cap-X	HCS Cap-X	HCS Cap-X	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	SimTraffic TransModeler VISSIM	HCS can model CFI, DDI, SPUI, and 5-legged intersections using HCM6 methodology. SimTraffic has the capability to model CFI, DDI, SPUI, and 5-legged intersections for under-saturated conditions but requires post-processing.
	Adaptive Signal Control Technologies (ASCT) Operations	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	If using a fixed set of demand volumes, it may be acceptable to use HCS, Synchro, or Vistro by applying signal timings from the ASCT system.
	Multi-Modal Facilities (including bike, pedestrian, and transit)	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	
Miscellaneous Operations	Toll Plaza Operations	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	
	Gated Operations	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	
	Active Traffic Management (ATM)	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	TransModeler VISSIM	

Source: Adapted from Virginia Department of Transportation Traffic Operations and Safety Analysis Manual

5.3.1 Use of Multiple Analysis Tools

In many cases, only one analysis tool may be required to analyze the geometric and traffic conditions of a project; however, there may also be cases when multiple analysis tools are needed. It is important that the strengths, functionality, and limitations of each analysis tool are accounted for during the traffic and safety analysis scoping process to verify when multiple tools are required. When multiple tools are required, it is best to report the MOEs produced by the more appropriate tool and discard the results produced by the less appropriate tool. Each tool has different methodologies for approximating real-world conditions; therefore, two tools may not present the same results. Results from both tools should be evaluated and presented. Both analysis tools should produce the same general conclusions if a thorough analysis has been conducted. Within the same evaluation round, the same tool must be applied to each of the different alternatives being evaluated, as MOE's may not be equivalate, despite being called the same MOE. If the no build is analyzed in microsimulation, the preferred alternative or all modeled alternatives still competing at the modeling round would need to be evaluated in microsimulation. Other tools may be utilized to inform the tool being utilized. e.g. Deterministic based tools may be utilized to minimize microsimulation runs, to determine proposed changes like the number of lanes needed on a facility or a ramp in the build scenario.

Examples of common situations where multiple tools may be selected are described below in more detail.

- **Synchro and HCS**: This combination may occur when a project encompasses an arterial, an interchange, and multiple freeway segments when microsimulation is not required. Synchro may be used to analyze the signalized intersections along the arterial as well as the operations on the arterial facility. HCS may be used to analyze interchange merging, diverging, and weaving segments, if applicable, for undersaturated freeway conditions. The CDOT project manager should verify that arterial operations do not influence freeway and ramp operations to confirm that microsimulation is not required. Users should verify that queues at ramp terminals do not spill back onto the freeway and that the queues from arterial intersections do not spill back to adjacent interchanges. Additionally, users should have enough information to determine whether arterial operations will influence freeway and ramp operations for future conditions.
- **Synchro and VISSIM:** This combination may occur for a project that encompasses an arterial, an interchange, and multiple freeway segments when microsimulation is required to model freeway and over-saturated conditions. Synchro may be used to analyze the signalized intersections along the arterial as well as the operations on the arterial facility. Alternatively, Synchro may simply be used to develop optimized traffic signal timings for input into VISSIM. VISSIM may be used to analyze the intersections, arterials, especially for oversaturated conditions, and/or interchange ramps, and freeway operations in one model. Networks should overlap when splitting them between multiple tools to model the interaction between arterials and freeways. In this case, the VISSIM model should include arterial intersections adjacent to the interchange to account for the interaction between the arterial facility and the freeway facility. The practice of modeling arterial intersections adjacent to

interchanges assists in the calibration process of the freeway. In many cases, arterial intersections impact how traffic flows enter the freeway by creating platoons and metering traffic. It is best practice to model the arterial intersections directly adjacent to the interchange ramp terminals.

- **Synchro or HCS and SIDRA Intersection:** This combination may occur when a project involves the analysis of an arterial that includes a roundabout and one or more signalized or unsignalized intersections when microsimulation is not required. Synchro or HCS may be used to analyze the signalized or unsignalized intersections along an arterial as well as the operations of the arterial facility for undersaturated conditions. Although HCS, SIDRA, ARCADY, and Rodel can all analyze roundabouts, it is best practice to use SIDRA which incorporated both the HCM6 roundabout capacity model as well as its own Standard SIDRA roundabout capacity model. It is recommended that both the HCM6 and Standard SIDRA roundabout capacity model be evaluated and presented.
- **Cap-X and Synchro/SimTraffic:** This combination may occur when a project involves the screening of alternative/innovative intersection/interchange designs (DDI, DLT, RCUT, MUT, SPUI, etc). Cap-X is often used to screen and identify potential lane configurations of the alternative/innovative intersection/interchange designs while Synchro and SimTraffic may be used to provide a more-detailed traffic analysis on the preferred alternative(s).

5.3.2 Traffic and Safety Analysis Tool Inputs & Outputs

Typical data inputs and MOE outputs vary based on the type of tool used and flow type of a study facility. **Table 9** provides an overview of the typical data inputs and MOE outputs required for each method.

Table 9: Typical Inputs and Outputs for Deterministic and Microsimulation

Method	Typical Inputs	Typical Outputs
Deterministic Traffic Analysis (Uninterrupted Flow)	Link speed, lane width, lane configurations, vehicular volumes, peak hour factor, heavy vehicle percentages	LOS, density, speed, travel time, flow rate, queue length, PTSF
Deterministic Traffic Analysis (Interrupted Flow)	Link speed, lane width, lane configurations, right turn on red, vehicular volumes, bicycle and pedestrian conflict volumes, peak hour factor, heavy vehicle percentages, signal timings, controller type, cycle length, turn types (permitted, protected, protected-permitted)	LOS, v/c ratio, control delay, travel time, operating speed, queue length
Deterministic Safety Analysis (Planning-Level)	Traffic volume (existing or forecasted), segment length, crash history	LOSS, predicted crashes, expected crashes
Deterministic Safety Analysis (Design-Level)	Traffic volume (existing or forecasted), bicycle and pedestrian volumes, segment length, number of lanes, lane configuration, traffic control, turn types (permitted, protected, protected-permitted), right turn on red, lane width, shoulder width, median type/width	Predicted crashes, expected crashes
Microsimulation Traffic Analysis (Uninterrupted Flow)	Link speed, lane width, lane configurations, vehicular volumes, peak hour factor, heavy vehicle percentages, driver parameters (gap acceptance, positioning, perception-reaction, etc.), vehicle parameters (length, occurrence, acceleration, etc.)	LOS, density, speed, travel time, flow rate, queue length, person-throughput (by mode)
Microsimulation Traffic Analysis (Interrupted Flow)	Link speed, lane width, lane configurations, right-turn on red, vehicular volumes, bicycle and pedestrian conflict volumes, peak hour factor, heavy vehicle percentages, signal timings, controller type, cycle length, turn types (permitted, protected, protected-permitted), turning speed, driver parameters (gap acceptance, positioning, perception-reaction, etc.), vehicle parameters (length, occurrence, acceleration, etc.)	LOS, control delay, travel time, operating speed, queue length, person-throughput (by mode)

Reinforcing with Project Examples:

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

- The study will include both uninterrupted flow facilities (freeway segments and merge/diverge segments) and interrupted flow facilities (interchange ramp terminal intersections).
- Light congestion indicates that the study area is nearing a point of over-saturation. Given that congestion is anticipated to increase, the analyst should assume over-saturated conditions.
- TransModeler and VISSIM are both appropriate traffic analysis tools for this study since one model can analyze both the freeway facilities and the ramp terminal intersections.
- If roundabouts are being considered for the ramp terminal intersections, additional tools are necessary (ARCADY, HCS, Rodel, and/or SIDRA).

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

- The study will only include interrupted flow facilities (unsignalized and signalized intersections)
- Although some turning movements experience high delay during peak hours, the highway is not congested currently nor is it anticipated to be in the future; therefore, the analyst should assume under-saturated conditions.
- HCS, Synchro, and VISTRO are appropriate traffic analysis tools for this study.
- If roundabouts are being considered for intersections, additional tools are necessary (ARCADY, HCS, Rodel, and/or SIDRA).

6
Deterministic Analysis Tools

The use of deterministic tools is often used for high-level operational evaluations where the operational performances are still considered under-saturated conditions. Most deterministic tools implement the procedures of the Highway Capacity Manual (HCM). These tools quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities and are validated with field data, laboratory test beds, or small-scale experiments. Deterministic tools are good for analyzing the performance of isolated or small-scale transportation facilities; however, they are limited in their ability to analyze network or system effects especially in over-saturated conditions and time-varying demand. The HCM methodologies contain default values which represent nationally accepted values. Analysts should be required to adjust some of the default values/parameters to reflect conditions in Colorado.

Deterministic Model Parameters

Deterministic tools/software programs come with a set of user-adjustable parameters for the purpose of calibrating the model to local conditions. Analysts should refer to the software user manual for more details on the specific parameters. This section provides guidance on what to consider when planning and conducting a cost-effective deterministic analysis.

Deterministic tools apply formulas to input data to produce outputs and results, so errors in inputs will result in output errors. The following inputs can be double-checked to confirm correct results. These inputs are used for deterministic intersection analysis tools; however, several of these inputs also apply to uninterrupted flow facilities.

- Roadway network
  - Network is to-scale
  - Link speeds
- Lane settings
  - Lane configurations
  - Lane widths
  - Turn pocket lengths
  - Channelized right-turn treatments (none, yield, free, overlap, etc.)

- Adjust lane utilization factors based on field observations
- Right turn on red

- Demand/Volume
  - Balance vehicle volumes where appropriate
  - Pedestrian conflict volumes
  - Bicyclist conflict volumes
  - Peak hour factor based on counts
  - Truck percentage based on counts
- Timing/phasing settings
  - Signal timings
  - Controller type
  - Cycle length
  - Turn type (permitted, protected, protected-permitted)
  - Phasing
  - Minimum green, minimum split, total split, yellow time and all-red time
  - Pedestrian phase, walk time, and flash-don't-walk time

In general, the analyst collects data prior to modeling. Every effort should be made to collect and forecast demand traffic volumes to ensure that the analysis reflects real traffic in the project area. After collecting data, the analyst develops a base model and, upon checking the base model for errors, has an existing conditions model. The output MOEs of the existing conditions model should be compared to results from field observations. If the output MOEs generally match field observations, the model is ready to use for future conditions or alternatives analysis. If the output MOEs do not match field observations—often because the output MOE shows a better LOS than is observed in the field—the analyst should consider microsimulation rather than a deterministic tool.

Analyst may refer to the following guidelines for additional guidance when preparing these three commonly used deterministic traffic models (HCS, Synchro, and SIDRA).

Highway Capacity Software (HCS)

Highway capacity software (HCS) is a deterministic tool based on methodologies outlined in the Highway Capacity Manual. Special considerations should be given to the following parameters when preparing HCS traffic models:

Peak Hour Factor (PHF) - HCM methodologies use demand flow rates for the 15-minute peak period. If flow rates have been measured from the field the flow rates for the worst 15 minutes should be used in operational analyses. PHF is used to calculate the equivalent hourly flow rate. In absence of field measurements of the PHF, design analyses may use a default PHF of 0.95 on freeway facilities and urban arterials. A PHF value of 0.92 may be used on other facilities; however, data shows that PHF increases as demand volume increases. Lower PHF signifies greater variability of flow while higher PHF signifies less flow variation within the analysis hour. Rural areas tend to have slightly lower PHF values than urban areas. Thus, PHF higher than 0.95 may be used on urban areas if justified by traffic conditions. PHF may also be lower in areas around time specific generators like a school or factory as there may be pronounced demand spikes around a start time or end time. When the 15-minute forecast demands are not available, conceptual planning and preliminary engineering levels of analyses may use a PHF of 1.0. However, as previously discussed it is advantageous to use lower PHF values consistent with field observations at locations that may experience capacity problems. It is recommended that the analyst seek concurrence with the reviewing and approving entity (of the analysis results) prior to using default PHF values in the analysis. PHF is not needed in multiple analysis periods where 15-minute traffic demand measurements are directly used. This approach tends to account for residual queues from one 15-minute period to another.

Free-Flow Speed (FFS) - Free-flow speed is field-measured under low volume conditions, when drivers are not constrained by other vehicles, roadway geometry or traffic control. In absence of field data, FFS can be estimated at five (5) mph above the posted speed limit.

Saturation Flow Rates and Capacities – The default saturation flow rates values were developed based on national research. Coordination with the reviewing entity or lead agency is required before overriding these values.

Signalized Intersection Parameters - It is recommended to obtain input values for intersection signal parameters (such as signal control type, sequence of operation, controller settings, signal phase and timings, and offsets between signals) from the agencies that maintain the signals. However, planning analyses may use the HCM methodology to estimate a reasonable signal timing plan. For arterial street analysis, each intersection is individually analyzed before their inputs are imported into the module that analyzes streets.

Level of Service (LOS) - LOS is an input for high-level planning analyses to determine number of lanes for a new road facility.

Synchro

Synchro is another deterministic tool that implements HCM methodology in addition to some less frequently used methodologies (e.g., Intersection Capacity Utilization (ICU)) and tool-specific methodologies. This tool has a map-based user interface and broader traffic operations applications, including signal retiming and coordination. Synchro does not have capability to analyze freeway, multilane highways, and two-lane rural roads. Special considerations should be given to the following parameters when preparing Synchro traffic models:

Nodes - Numbering of nodes in logical order along the main street is recommended to enhance the review of the results.

Traffic Demand – Hourly volumes should be used. Volumes and heavy vehicle percentages should be calculated based on the existing turning movement counts data.

Lane Utilization Factor - This parameter only affects Synchro's saturation flow rate, it is not used by SimTraffic. Default lane utilization factors should be overridden with field measurements when more vehicles use one lane group than the other. Additionally, as demand approaches capacity, lane utilization factors that are closer to 1.0 may be used to override default values.

Peak Hour Factor (PHF) - The Synchro default PHF is 0.92. See more detailed PHF guidance in the HCS parameters section.

SIDRA

SIDRA is another deterministic tool often used to model roundabouts and implements all three HCM methodologies (HCM 2000, 2010, and HCM6) in addition to SIDRA standard roundabout capacity models (Australian model). Special considerations should be given to the following parameters when preparing SIDRA traffic models:

Roundabout Capacity Model – Under the Roundabout Dialog/Options Tab, analysts have the option to select which roundabout capacity model to use. In general, the SIDRA Standard model provides optimistic results when compared to the HCM capacity models. For an existing roundabout location, it is a good practice to initially start with the HCM6 roundabout capacity model. Under future conditions, a supplemental analysis using SIDRA Standard model may be necessary if the delays and queues from the HCM6 indicates poor operations and/or require additional lanes to ensure that the roundabout is not over designed.

Lane Geometry – Under the Lane Configuration Tab, unless the roundabout being analyzed already exists or there is a detailed plan available, consider using the lane width of 15 ft for single lane approach and 14 ft (each lane) for multi-lane approach.

Roundabout Geometry – under the Roundabout Data Tab, consider using the circulating width of 18-20 feet for single lane roundabout and 15 feet (each lane) for multi-lane roundabout. The entry radius should be between 90-110 feet unless a site specific design is available. Use the Environment Factor of 1.1 for existing/opening year and 1.05 for design year when using the SIDRA Standard roundabout capacity.

7 Microsimulation Analysis Tools

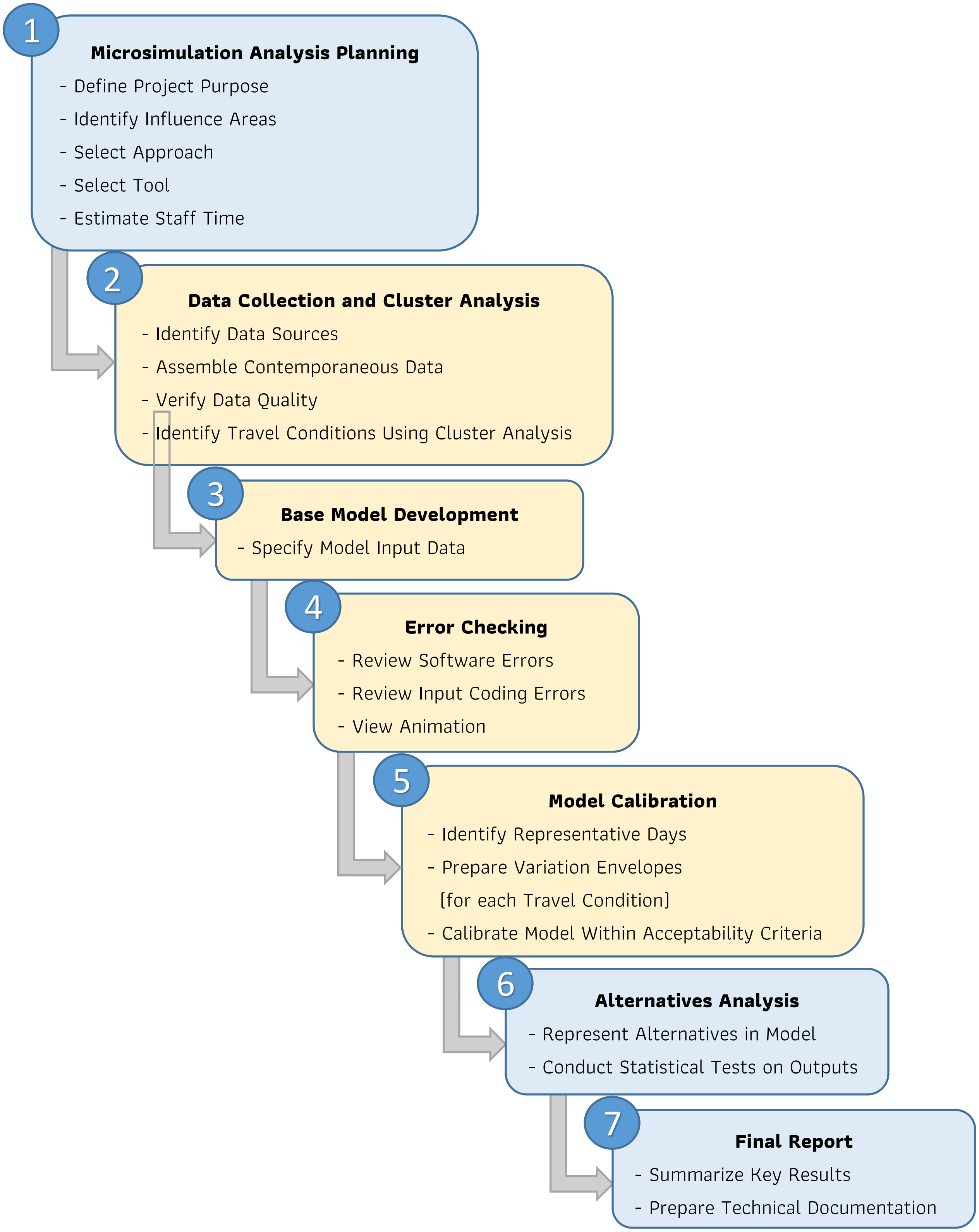
The use of microsimulation tools and analyses are increasingly demanding and necessary to evaluate and test the design of complex multimodal transportation facilities. Microsimulation provides detailed modeling of individual vehicles movements through car-following and lane-changing behaviors and offers the most detailed understanding of congestion formation, propagation, and dissipation on complex transportation facilities. MOEs are measured over time in series of intervals (1 min, 5 min, 15 min, 60 min, etc.) compared to deterministic analysis that predicts the average peak hour and daily performances. However, microsimulation can also be a time-consuming process and requires the greatest amount of input data for each of the model development, calibration/validation, and predicting stages. This section provides guidance on what to consider when planning and conducting a cost-effective microsimulation analysis.

In April 2019, FHWA released an update to the 2004 version of the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* (TAT Vol. III). The goal of the revised methodology is to capture the variation the system experiences across the year including incidents, inclement weather, and unusually high or low travel demand and create models of multiple real, representative days instead of averaging unlike days into one "average" day that is difficult to model and calibrate. Utilizing a series of models representing real traffic conditions can help to make transportation investment decisions that lead to a cost-effective alternative. With this goal, the revised 2019 methodology requires significantly more data in terms of both magnitude and variety to conduct microsimulation analysis. This updated FHWA methodology is recommended for all microsimulation projects and encourages analysts to explore alternative solutions to microsimulation if the data cannot be obtained within a project's budget and schedule.

CDOT recognizes the benefits of the updated FHWA microsimulation methodology, however, has reservations about recommending it for all microsimulation projects due to the general limitations of data availability to determine clusters/groups of travel conditions, particularly in rural settings. At the same time, CDOT also recognizes that the use of the 2004 microsimulation methodology has proven beneficial and provided satisfactory results on projects with complex geometry and minimal variation in travel conditions over the deterministic analysis tools. CDOT will evaluate the use of the cluster analysis on a case-by-case basis depending on the complexity of the project, its geographic and temporal limits, and the ability to obtain quality data. The HCM Facilities methodology should be reviewed as an alternative to microsimulation when the cluster analysis and the 2004 methodology cannot be followed. A project that requires microsimulation should be reviewed and discussed during the project scoping stage to assess the most appropriate methodology to accomplish project goals.

Figure 9 illustrates the overview of the seven (7) key steps in microsimulation analysis process. The microsimulation analysis planning in Step 1 is covered in Chapter 2 of this guideline, respectively. The data collection, base model development, error checking, and model calibration in Steps 2, 3, 4, and 5 are covered in this chapter. The alternative analysis and final report in Steps 6 and 7 are covered in Chapter 9 and 10, respectively. A microsimulation model review checklist can be found in Appendix C.

Figure 9: Microsimulation Analysis Process



7.1.1 Data Collection

Microsimulation studies require data collection for three main purposes: base model development, determining travel conditions, and calibration. **Table 10** illustrates the types of data that are applicable to each purpose.

Table 10: Microsimulation Data Collection

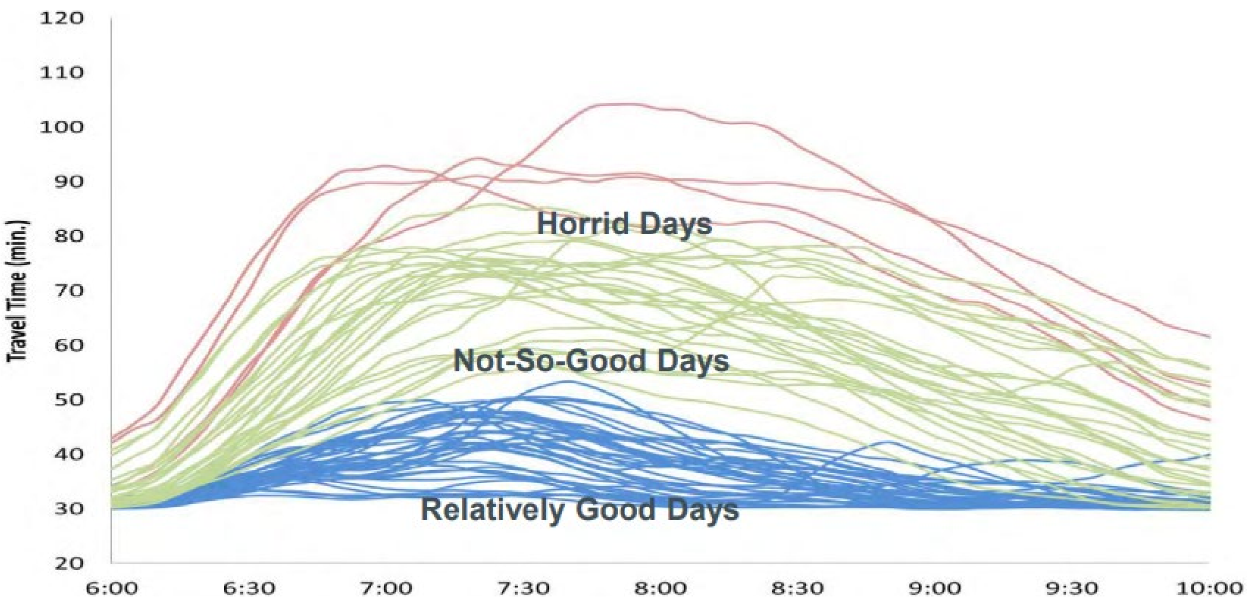
Data Type	Microsimulation Application			Notes
	Base Model Development	Determining Travel Conditions	Calibration	
Road Geometry	●			
Traffic Controls	●			
Demand Volumes	●	●	●	
Vehicle Characteristics	●			
Driver Characteristics	●			
Traffic Operations and Management Strategies	●			
Transit Data	●	●		
Weather Conditions		●		
Incident Reports		●		
Freight Data		●		
Bottleneck Throughput		●	●	May include bottleneck duration, density, and/or queueing
Travel Times		●	●	May also include speed profiles

The project's data collection plan will vary depending on the microsimulation methodology selected for the project. Traditional data collection plans for microsimulation typically collects travel demand and operational data over relatively short periods of time or average historical data in an effort to create a model representative of a single typical day within the study area. On a large complex project with time-dynamic traffic conditions, this methodology often results in models that are challenging to calibrate as they do not adequately capture the variable traffic patterns and operational conditions that characterize many roadways, particularly in highly congested areas.

FHWA's updated methodology recommends collecting time-dynamic data over an extended period of time (a minimum of one year of contemporaneous travel demand and operational data) to capture the variations in travel conditions caused by weather, incidents, fluctuation in demand, and planned events. The demand and system performance data required by the methodology would be near bottlenecks or other locations of concern or interest. It is intended that this data be captured by existing ATR or similar devices and augmented by third party data. Travel conditions are defined as a combination of operational conditions and resulting system performance. Operational conditions are identified by a combination of demand levels and patterns (e.g., low, medium or high demand), weather (e.g., clear, rain, snow, ice, fog, poor visibility), incident (e.g., no impact, medium impact, high impact), and other planned disruptions (e.g., work zones, special events) that impact system performance (e.g., travel times, bottleneck throughput)

The operational conditions are then statistically analyzed to identify different clusters/groups of travel conditions allowing the analyst to create a representative model for each cluster. Cluster analysis helps to partition data into groups or clusters to minimize the variance within each cluster (so that days within each cluster are similar) and maximize the variance between clusters (so that days in different clusters are dissimilar)[5]. **Figure 10** shows an example of how a range of travel times along a corridor may be separated into three different clusters based on travel time performance. In this example three base models would be developed for the project, one for each cluster.

Figure 10: Clustering of Travel Time Data



Source: FHWA & Noblis "TAT Volume III Guidelines for Microsimulation" presentation

While the updated methodology is statically superior to the traditional methodology, CDOT anticipates that gathering one year of historical demand (especially turning movement data) and operational data required will present a challenge to fully implementing the updated methodology on all microsimulation projects. The updated TAT Vol. III contains some guidance related to the large-scale data collection required by the updated

[5] TAT Vol. III 2019 update, page 17

methodology. Regarding travel demand data, the guidance recognizes that simultaneous data collection may not be feasible with existing resources and recommends using control and coverage count locations to generate the appropriate data set, preferably for one year of data. It may be possible to utilize demand/speed capture locations as reference points to determine demand adjustments within the O-D matrix for the project which would negate the need to obtain historical turning movement counts. In situations where there is not enough historical data and project budget and schedules do not permit the appropriate data collection to perform a cluster analysis, the guidelines recommend that alternative solutions to microsimulation should be explored for the project.

7.1.2 Base Model Development

The development of an existing base year model is an essential step to accurately simulate existing transportation conditions and to establish a base model to evaluate/simulate alternatives and future year conditions. Analysts should refer to the microsimulation tool/software user manual and Guidelines for Applying Traffic Microsimulation Modeling Software from FHWA for more details on model development. Note that a base model will need to be developed for each travel condition group determined in the cluster analysis. If your project is following the traditional methodology, a base model will be developed for each peak period being analyzed. Here are some key highlights on developing an existing base year model.

Transportation Network Geometry – After the initial scoping phase, during which the temporal and spatial limits of the simulation are established and MOEs and data sources are confirmed, the first step of developing an existing base year model is to code/enter the geometric configuration of the study area to be simulated (roadway segments, intersections, ramps, number of lanes, etc.). The next step is to code/enter the traffic control (traffic signals, stop/yield signs, stop bars, turn restrictions, etc.). Traffic operations and management data should also be coded (posted/free flow speed limits, variable speed limits, etc.). The geometry and traffic control should be confirmed and/or verified in the field.

Traffic Demand – once the geometry and traffic control has been coded and confirmed and/or verified in the field, start loading the traffic demand by coding/entering the traffic volumes (vehicular, bus, truck, bike, pedestrian, etc.) explicitly for time interval/analysis period agreed upon during the scoping. Turning movement volumes should always be balanced. Use Origin-Destination (O-D) information to accurately code/model lane-changing and weaving behaviors as traffic are being routed through the network.

A detailed overview of the model input data and parameters are included in the model calibration section.

7.1.3 Error Checking

After the initial base year model has been developed, it is important run the model and visually inspect the animation to ensure that there are no unrealistic movements or lane changing behaviors. Double check all the network and demand inputs and address all the software errors before proceeding to the model calibration process. Consider running the model with significantly lower demand volumes than existing conditions to simulate presumably uncongested conditions to look for queues or other congestion that may indicate a coding error. This error checking step is essential in developing a working model (not yet calibrated) so that the calibration process does results in parameters that are distorted to compensate for overlooked coding errors.

7.1.4 Model Calibration

Calibration Process

Model calibration is an iterative process of making adjustments to the existing base year model parameters until the simulated measures reasonably match the field measured performances. Model validation is the process of testing the calibrated model using an independent data set (not previously used in the calibration) to confirm that calibrated model reasonably simulates the local driving behavior and operational performances. The existing base year model is considered validated when field data (volumes, speed, travel time, queue length, etc.) closely resemble the simulation output within the model calibration thresholds agreed upon during the project scoping process, thus establishing that the model reflects actual traffic conditions in the study area and therefore should appropriately be ready to simulate alternatives and future year conditions. The calibration process will vary depending on if the project is following the traditional microsimulation methodology or the updated 2019 TAT Vol. III cluster analysis process. Calibration procedures for each approach are outlined below.

Traditional Calibration Methodology

This calibration methodology should not be used to calibrate microsimulation projects that are following the updated 2019 TAT Vol. III methodology. For a smaller project with complex geometry and minimal variation in travel conditions where deterministic analysis cannot provide satisfactory results, the use of the 2004 microsimulation methodology and the calibration targets show in **Table 11** may still be applicable however analysts may choose to follow the calibration methodology in the updated 2019 TAT Vol. III.

CDOT project managers may develop calibration targets exceeding the targets shown in **Table 11** based on field conditions and the specific project propose and need. Although multiple calibration measures should be selected, the peak hour volumes target must be met first in order for the model to provides any meaningful results on the simulated travel time and queue length. Simulated average speed and bottlenecks can be considered as a project-specific validation measure in cases where significant speed differentials exist in the network.

Table 11: Microsimulation Model Calibration Targets

Simulated Measure	Calibration Target
Simulated Traffic Volume Served (vehicle per hour) 85% of network links, or additional critical links or movements as determined by CDOT, must meet the calibration target.	• For < 100 vph, within ± 20% of observed traffic volumes • For 100 to 1,000 vph, within ± 15% of observed traffic volumes • For 1,000 to 5,000 vph, within ± 10% of observed traffic volumes • For > 5,000 vph, within 5% of observed traffic volumes
Simulated Travel Time (seconds) 85% of travel time routes, or additional critical links or movements as determined by CDOT, must meet the calibration target.	• Within ± 1 minute for routes with observed travel times less than seven (7) minutes • Within ± 15% for routes with observed travel times greater than seven (7) minutes
Simulated Travel Speed (miles per hour) 85% of network links where speed data is available, or additional critical links or movements as determined by CDOT, must meet the calibration target.	• Within ±10% of average observed speeds. (Note - speed should be calibrated in 15-minute intervals.)
Simulated Queue Length (feet) A selected number of critical locations or movements as determined by CDOT, must meet the calibration target.	• Visually acceptable maximum queue lengths are represented at critical locations

Source: Adapted from Virginia Department of Transportation *Traffic Operations and Safety Analysis Manual* and Florida Department of Transportation Traffic Analysis Handbook

Cluster Analysis Calibration Methodology

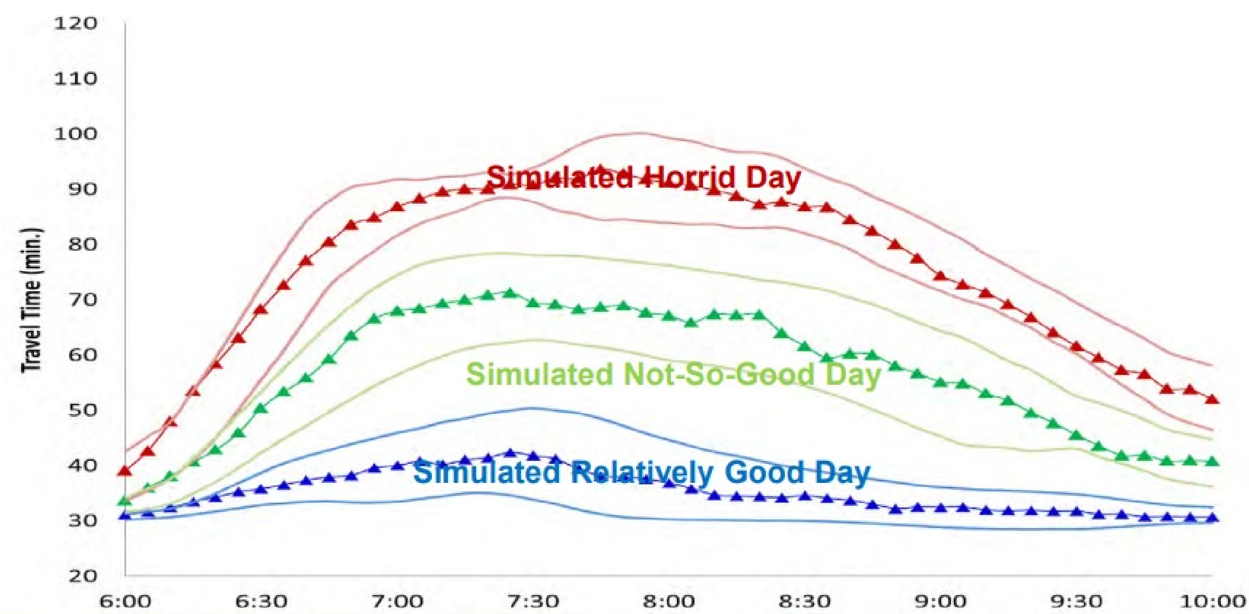
CDOT recognizes the continuous advancements by FHWA to improve the calibration and validation methodology. Microsimulation tool/software vendors are also improving their software functionalities/features and provide hands-on training to help ease the time-consuming and data-intensive process of model calibration. This section provides an overview of the calibration process, calibration targets, and software parameters to adjust as a part of the calibration process. The 2019 FHWA Traffic Analysis Toolbox Volume III lists the following three steps for the calibration process:

1. Identify representative days for each cluster. Travel conditions data is collected and prepared for calibration support. The process to identify a representative day is outlined in the 2019 Traffic Analysis Toolbox Volume III and involves comparing key performance measures collected on each day within a cluster to identify the individual day that minimizes differences between the individual day and the average values of all days.
2. Prepare variation envelopes. Once clusters of similar days have been identified, a base model is created for each cluster and one representative day from each respective cluster is used to calibrate the corresponding model. The representative day is an actual day of contemporaneous observed data with

clear causes and effect relationships between factors related to congestion and delay as opposed to a conglomeration of averages, making the representative day easier to calibrate. Observations from all days within the cluster are used to create variation envelopes around the representative day values to serve as the upper and lower bounds for simulation data to be deemed calibrated. **Figure 11** illustrates a time-dynamic envelope consistent with variation in observed field data for all days in the cluster is created for each representative day. This envelope creates a data-driven calibration target for the calibration of an individual model variant consistent with each travel condition.

3. Calibrate model variants within acceptability criteria. Specific software parameters within a model variant are adjusted until key performance measures derived from simulation outputs are acceptably close to the target variation envelope. Calibration of each model variant is complete when the simulation outputs meet three acceptability criteria described in the following section.

Figure 11: Calibration of Travel Time Data within Clusters



Source: FHWA & Noblis "TAT Volume III Guidelines for Microsimulation" presentation

At a minimum, the analyst should calibrate to at least one localized performance measure which should capture bottleneck dynamics, and one system performance measure which may include travel time or speed profiles along one or more key routes on the roadway network. Other calibration measures can also be included that are critical to the purpose and needs of the project or in differentiating alternatives evaluated in the analysis.

Microsimulation Model Parameters

Microsimulation tools/software programs such as SimTraffic, TransModeler, and VISSIM come with a set of user-adjustable parameters for the purpose of calibrating the model to local conditions. Analysts should refer to the software user manual for more details on the specific parameters.

The following settings and parameters are allowable adjustments as a part of the model calibration process. These guidelines provide recommendations for calibrating particular settings or adjustments. Furthermore, these guidelines provide overall ranges in acceptable values for calibration, usually in comparison to the default value.

SimTraffic

SimTraffic is a microsimulation software application that is part of a macroscopic analysis and optimization software Synchro. A SimTraffic model is created by importing a Synchro model. Therefore, any Synchro coding error or warning should be reviewed and corrected before initiating SimTraffic. **Table 12** shows parameters that are options for adjustment when calibrating SimTraffic microsimulation models. Note that some parameters must be reviewed and modified in Synchro. Multiple simulation runs should be performed with different random seeding and appropriate warm up timings as approved by CDOT.

Table 12: SimTraffic Model Parameters

Parameter	Description	Guidance
Adjusted in Synchro		
Turning speed (mph)	The turning speed for vehicles while inside the intersection.	Turning speeds should be based on field observations and intersection geometry. Larger intersections should have higher turning speeds. Intersection skew can affect speed.
Mandatory distance 1 (ft)	The distance back from the stop bar where a lane change must commence	The mandatory distance should be lower than positioning distance. The calibrated value should be within ± 50% of the default value.
Positioning distance 1 (ft)	The distance back from the mandatory point where a vehicle first attempts to change lanes	The calibrated value should be within ± 50% of the default value.
Mandatory distance 2 (ft)	Mandatory distance 2 is added to mandatory distance 1 if a second lane change is required during the simulation	Mandatory distance 2 should be lower than positioning distance 1. The calibrated value should be within ± 50% of the default value.
Positioning distance 2 (ft)	Positioning distance 2 is added to both mandatory distance 2 and mandatory distance 1 to determine the beginning of the positioning zone for the first two lane changes	The calibrated value should be within ± 50% of the default value.

Parameter	Description	Guidance
Headway factor	The headway factor is based on the ideal saturation flow, lane width factor, the grade factor, the parking factor, the bus stops factor, and the area factor	The headway factor should only be adjusted if adjusting other factors to achieve a calibrated model. An acceptable range should be from 0.8 to 1.2 (in most cases). The overall limits should be between 0.5 to 1.5.

Table 12: SimTraffic Model Parameters Cont.

Parameter	Description	Guidance
Adjusted in SimTraffic		
Vehicle length	The average length of a vehicle when stopped, including distance to the next vehicle	Vehicle length and vehicle occurrence should be based on field observations (including aerial photos).
Vehicle occurrence	Describes the classification of vehicles, represented as a percentage of overall vehicle fleet	
Gap acceptance factor	The gap vehicles will accept at unsignalized intersections, for permitted left turns, and for right turns on red	Adjustments to gap acceptance factor, mandatory distance adjustment, positioning distance adjustment, yellow react, and green react should be applied systematically across driver types. In general, calibrated values should be within ± 50% of the default values.
Mandatory distance adjustment (%)	The factor by which the mandatory lane change distances are multiplied	
Positioning distance adjustment (%)	The factor by which the positioning lane change distances are multiplied	
Yellow react	The amount of time it takes the driver to respond to a signal changing to yellow	
Green react	The amount of time it takes the driver to respond to a signal changing to green	

TransModeler

TransModeler is another microsimulation software application that simulates a wide array of traffic planning and modeling tasks. **Table 13** shows parameters that are options for adjustment when calibrating TransModeler microsimulation models. Research regarding the adjustable parameters and the range of reasonable values for which parameters can be modified is evolving. For the purposes of these guidelines, constraining any variation between halving and doubling the value is a good rule-of-thumb for the limits of what is a reasonable modification to parameters.

Table 13: TransModeler Model Parameters

Parameter	Adjustment Guidance
Desired speed distribution curve	The default distribution (driver population and deviation from speed limit increment) generally should be maintained, but the actual values in the deviation from speed limit can be shifted up or down.
Maximum turning speed	Modifying the turning speeds at intersections can increase or decrease the saturation flow at the intersection.
Headway threshold and buffer	Modifying this parameter affects the spacing between vehicles and the threshold between emergency braking, following regime, and free-flow regime.
Discretionary lane changing behavior	These may be modified and include Path Influence Factor, Heavy Vehicle Ahead, On-Ramp Ahead, Off-Ramp Ahead, and Weaving Influence.
Mandatory lane changing behavior	This may be modified.
Stopped gaps	Controls the spacing of vehicles when queued. This parameter can increase saturation flow rate at intersections if increased slightly but tends to have an opposite effect on freeways discharging from queues during congestion.
Lane connector connectivity bias	This may be modified.

Source: Adapted from North Carolina Department of Transportation *Congestion Management Simulation Guidelines*.

VISSIM

VISSIM is a microsimulation software application that simulates complex and realistic interactions between all modes of transportation on a microscopic level. VISSIM provides default driver behavior (lane changing and car-following) parameters for both the freeway and arterial systems. Note that adjusting the headway time (CC1) in the Wiedemann 90 freeway car following model and the multiplicative part of safety distance in the Wiedemann 75 arterial car following model parameters have significant effect on the saturation flow.

Freeways

The following parameters are allowable for adjustment as a part of the model calibration process.

- Vehicle type and characteristics
- Speed distributions (for desired speed decisions and reduced speed areas)
- Connector lane change and emergency stop distances
- Location of static route decision points
- Car following parameters—Wiedemann 99 model, freeway traffic:
    - Standstill distance
    - Headway time
    - Necessary lane change parameters
    - Waiting time before diffusion
    - Safety distance reduction factor
    - Advanced merging
    - Cooperative lane change

Table 14 shows Wiedemann 99 model car following parameters that are options for adjustment when calibrating VISSIM microsimulation models.

Table 14: Freeway Car Following Model (Wiedemann 99)—Calibration Parameters

Parameter		Default Value	Unit	Suggested Range	
				Basic Segment	Weave/Merge/ Diverge Segment
CC0	Standstill distance *Desired distance between lead and following vehicle at 0 mph*	4.92	feet (ft)	4.5 to 5.5	>4.92
CC1	Headway time *Desired time in seconds between lead and following vehicle*	0.9	seconds (s)	0.85 to 1.05	0.90 to 1.50
CC2	"Following" variation *Additional distance over safety distance that a vehicle requires*	13.12	ft	6.56 to 22.97	13.12 to 39.37
CC3	Threshold for entering "following" *Time in seconds before a vehicle starts to decelerate to reach safety distance (negative)*	-8	–	Use default	
CC4	Negative "following" threshold *Specifies variation in speed between lead and following vehicle*	-0.35	–	Use default	
CC5	Positive "following" threshold *Specifies variation in speed between lead and following vehicle*	0.35	–	Use default	
CC6	Speed dependency of oscillation *Influence of distance on speed oscillation*	11.44	–	Use default	
CC7	Oscillation acceleration *Acceleration during the oscillation process*	0.82	ft/s^2	Use default	
CC8	Standstill acceleration *Desired acceleration starting from standstill*	11.48	ft/s^2	Use default	
CC9	Acceleration at 50 mph *Desired acceleration at 50 mph*	4.92	ft/s^2	Use default	

Source: Adapted from Virginia Department of Transportation Traffic Operations and Safety Analysis Manual

Arterials

The following parameters are allowable for adjustment as a part of the model calibration process.

- Vehicle type and characteristics
- Speed distributions (for desired speed decisions and reduced speed areas)
- Connector lane change and emergency stop distances
- Location of static route decision points
- Dwell time distribution at stop signs (if needed)
- Minimum headway—priority rules (if applicable)
- Conflict area parameters:
    - Front gap
    - Rear gap
    - Safety distance factor
- Car following parameters—Wiedemann 74 model, arterial/urban traffic:
    - Average standstill distance
    - Necessary lane change parameters
    - Waiting time before diffusion
    - Safety distance reduction factor
    - Advanced merging
    - Cooperative lane change

Table 15 shows Wiedemann 74 model car following parameters that are options for adjustment when calibrating VISSIM microsimulation models.

Table 15: Arterial Car Following Model (Wiedemann 74)—Calibration Parameters

Parameter	Default Value	Unit	Suggested Range
Average standstill distance *Desired distance between lead and following vehicle at 0 mph*	6.56	feet (ft)	3.28 to 6.56
Additive part of safety distance	2.00	--	2.0 to 2.2
Multiplicative part of safety distance	3.00	--	2.8 to 3.3

Source: Adapted from Virginia Department of Transportation Traffic Operations and Safety Analysis Manual

7.1.5 Microsimulation Model Post-Processing

A microsimulation model applies some random variation between runs, known as a random seed. To account for this random variation, microsimulation model outputs must be post-processed to produce MOEs. Analysts should follow guidance in FHWA's 2019 Traffic Analysis Toolbox Volume III to determine the required number of replications for a model. This process involves calculating the required number of model runs needed to achieve a 95% confidence level based on the observed average and standard deviation. For large models that take a lot of time and resources to run, it is recommended that the analysts run the model 4 times and use the average and standard deviation to calculate the required number of additional runs needed for arcuate reporting. For small models that run quickly, the analyst may follow the same methodology or they may choose to run the model many times (10-20 runs with random seeds) and then use the outputs to calculate the minimum number of runs to include in reporting. Theoretically, a well calibrated model will need only a handful of runs for reporting MOEs. However, if the minimum number of replications is found to be higher than 20 the analyst should investigate reasons why the model produces such large variations in output, which may be indicative of unrealistic gridlock conditions or model coding errors.

Microsimulation post-processing reports should generate similar MOEs as reports from deterministic tools. For example, for intersection control delay, the reports should provide (for each intersection, approach, and movement):

- Average control delay
- Standard deviation of control delay
- Minimum control delay
- Maximum control delay
- LOS

Intersection queue reports should provide (for each intersection, approach, and movement):

- Average queue lengths
- 95th percentile queue lengths
- Maximum queue lengths

7.1.6 Model Development and Calibration Report

Documentation of the existing base year model development and calibration is necessary to the reviewing entity for concurrence prior to moving on to the alternatives analysis. The memorandum summarizing the model development, data collection and site observations, assumptions and modeling methodology, calibration parameters and targets, and model calibration results will streamline the reviewing process for CDOT.

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8

Travel Demand Modeling

8.1 Available Travel Demand Models

Within Colorado, a major consideration for selecting a forecasting method is the type of resources available. Most rural areas in the state do not have an approved, calibrated model; therefore, a Sketch Planning method, the Statewide Travel Model, or a combination of both must be used. NCHRP Report 765: Analytical Travel Forecasting Approaches for Project Level Planning and Design is a good resource to reference, in addition to this guide, for choosing the appropriate forecasting methodology.

Travel demand models have been developed to forecast travel demand in some areas of the state by various Metropolitan Planning Organizations (MPOs) and local governments. The MPOs develop the models based on long-range socioeconomic data and aggregated local land use plans. In addition to the regional travel demand models, CDOT now has a Statewide Travel Model available for use. The Statewide Travel Model uses data from the established regional models and U.S. Census and other data for all other areas of the state.

Each travel demand model has a published base year and a horizon year (i.e., forecast year). The base year represents the year to which the model is calibrated (see Section 5.5.1). A base year model is considered calibrated when the output volumes accurately reflect transportation system use collected for that year (e.g., traffic counts, roadway speeds, transit ridership, etc.) A model's horizon year is the farthest year in the future for which input data (demographic data, land use, programmed/planned infrastructure) has been projected. Models typically are set up to provide a minimum 20-year horizon for planning purposes, so most current models have a 2040 or 2045 horizon year. Within Colorado, all MPOs are on a consistent four-year planning cycle. Travel demand models also incorporate interim years, which reflect more near-term demographic data and network improvements and comply with air quality conformity requirements. Each travel demand model also is defined as trip-based or activity-based. **Table 16** shows typical inputs and outputs of each type of travel demand model.

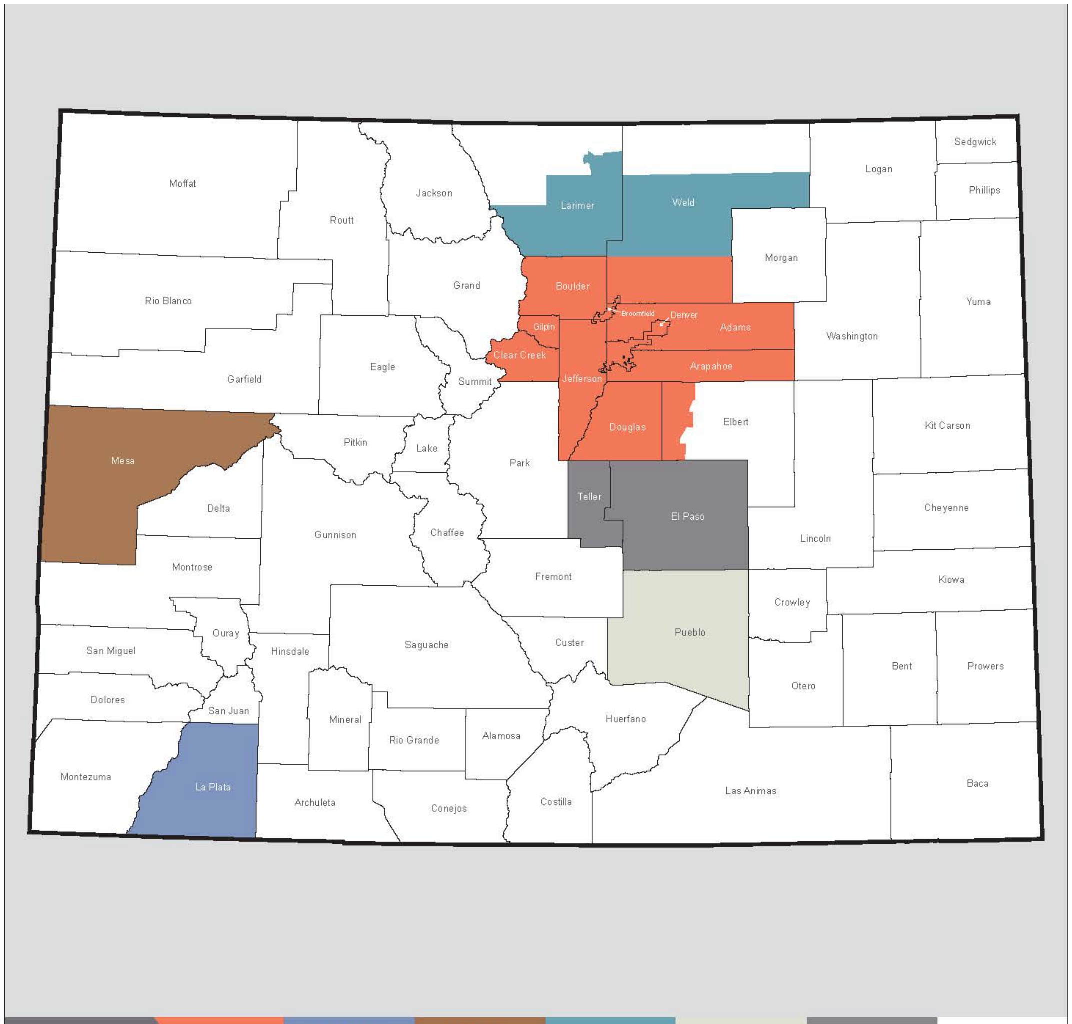
Table 16: Travel Demand Model Inputs & Outputs

Method		Typical Inputs	Typical Outputs
Travel Demand Model	Four-step (Trip-based)	• Roadway, transit, and non-motorized networks • Socioeconomic data (population, households, employment)—by TAZ • External data (internal external (I-E) and external-external [E-E] trips) • Special generators	• Trip information by each mode (origin/destination, time of day, mode, purpose, time and distance) • Demand volumes and congested speeds • Transit and non-motorized volumes • Limited sensitivity to induced/latent demand (e.g., VMT effects of capacity expansion).
	Activity-based	• Roadway, transit, and non-motorized networks • Socioeconomic data (population, households, employment)—by individual household • External data (I-E and E-E trips) • Special generators	• Trip information by each mode (origin/destination, time of day, mode, purpose, time and distance) • Demand volumes and congested speeds • Transit and non-motorized volumes • Trip characteristics by household • Superior sensitivity to induced/latent demand.

A map of the available travel demand models and corresponding coverage areas is illustrated in **Figure 12**. There are seven available travel demand models within the state (six regional and one statewide). The information provided within these guidelines is up-to-date as of January 2022.When using a travel demand model, the analyst should coordinate with the MPO regarding the latest available model.

It should be noted that all of the available travel demand models discussed below have been developed for average weekday travel only. Weekday models are focused on regular and routine trip patterns, focusing on peak period travel containing typical work commute and school trip patterns. Sometimes, a user will want to know information about weekend travel—which is more variable and commonly based on discretionary activities, special events, and seasonal/recreational activities. A good approach to quantifying weekend travel demand would include conducting travel surveys and/or using commercially available data from travel information companies, such as AirSage or StreetLight Data, in combination with traffic count data collection to create an overall picture of weekend travel patterns. While weekend traffic volumes may compare to weekday volumes over the course of the day, typically there is not a consistent peak period or peak direction as there is with weekdays; therefore, from a capacity planning perspective, it is sufficient to design for the weekday peak volumes.

Figure 12: Available Travel Demand Models



Adopted TDM	DRCOG	La Plata County	Mesa County	NFRMPO	PACOG	PPACG	CDOT Statewide
Type	Activity	Trip	Trip	Trip	Trip	Activity	Activity
Software	TransCad	TransCad	TransCad	TransCad	TransCad	Visum	TransCad
Base Year	2015	2015	2010	2015	2010	2015	2010
Horizon Year	2040	2040	2040	2045	2040	2045	2045

N

- DRCOG
- La Plata County
- Mesa County
- NFRMPO
- PACOG
- PPACG
- No Adopted Regional Model (Covered by Statewide model)

Available Travel Demand Models (TDM)

8.1.1 Denver Regional Council of Governments

The Denver Regional Council of Governments (DRCOG) Travel Demand Model, known as FOCUS, helps local officials, CDOT, and the Regional Transportation District (RTD) evaluate transportation improvements. FOCUS is an activity-based travel model for the Denver region developed by DRCOG in conjunction with Cambridge Systematics, Mark Bradley, and John Bowman. FOCUS creates trip tables (2,800 TAZs) with origins and destinations for transit, highway, bicycle, and pedestrian trips. The transit and highway trip tables then are run through "assignments" with TransCAD software. Outputs include traffic volumes (and growth rates), transit ridership, and other general operational data for all segments of the roadway network system. DRCOG's FOCUS model requires a spec-built machine (or virtual machine), down to the number and speed of the processors to be run. **Table 17** provides an overview of the DRCOG model.

Table 17: DRCOG Model

Model Type	Activity-based
Coverage Area	DRCOG boundaries, including: Adams, Arapahoe, Boulder, Clear Creek, Douglas, Gilpin, and Jefferson counties, the City and County of Denver, the City and County of Broomfield, western Elbert County, and southern Weld County
Developer	DRCOG, Cambridge Systematics, Mark Bradley, and John Bowman
Software	TransCAD
Base Year	2015
Interim Years	2020, 2030
Horizon Year	2040

More information is available here: https://drcog.org/services-and-resources/data-maps-and-modeling/travel-modeling

8.1.2 La Plata County

The La Plata County Travel Demand Model is designed to forecast future travel patterns on both roadway and transit routes throughout La Plata County. The major municipality included in the model is Durango. The model can be used to assess how changes in population, employment, demographics, and transportation infrastructure affect travel patterns within the county. The La Plata County Travel Demand Model is a trip-based travel demand model that uses the TransCAD platform. The model is calibrated to the 2015 base year and the future land use assumptions are based on the 2040 horizon year. All other interim years are derived based on specific development projects or an interpolation of growth between 2015 and 2040. **Table 18** provides an overview of the La Plata County Travel Demand Model.

Table 18: La Plata County Model

Model Type	Trip-based
Coverage Area	La Plata County
Developer	La Plata County, CDOT, City of Durango, Fehr & Peers
Software	TransCAD
Base Year	2015
Interim Years	2020, 2030
Horizon Year	2040

8.1.3 Mesa County/Grand Valley

The Mesa County Regional Travel Model is a tool used by the Mesa County Regional Transportation Planning Office (RTPO)/Grand Valley Metropolitan Planning Organization (GVMPO), and member jurisdictions to forecast traffic and travel in Mesa County. The model has been calibrated to reflect a base year of 2010 and contains forecasts for future year conditions at 2020, 2030, and 2040. The most recent model was prepared and customized using TransCAD 6 modeling software. **Table 19** provides an overview of the Mesa County Regional Travel Model.

Table 19: Mesa County Regional Model

Model Type	Trip-based
Coverage Area	Mesa County/GVMPO
Developer	Mesa County, Cambridge Systematics
Software	TransCAD
Base Year	2010
Interim Years	2020, 2030
Horizon Year	2040

8.1.4 North Front Range Metropolitan Planning Organization

The North Front Range Metropolitan Planning Organization (NFRMPO) Travel Demand Model supports the development of the Regional Transportation Plan and air quality conformity analysis. For future traffic and land use projections, the NFRMPO uses two separate but related models: the 2040 Regional Travel Demand Model (RTDM) and the 2040 Land Use Allocation Model (LUAM). The models were developed in 2014. The LUAM is an ArcGIS-based application, which uses information provided by local and state agencies to estimate how growth will occur through 2040. The output information then is incorporated into the 2040 RTDM to estimate how and where people will travel in future years. The 2040 RTDM uses the four-step model to allocate travel demand.

The NFRMPO conducts major updates to both the LUAM and RTDM every four years, with minor updates in between as necessary. The 2045 LUAM and RTDM are under development and expected to be completed in winter 2018/2019. **Table 20** provides an overview of the NFRMPO model.

Table 20: NFRMPO Model

Model Type	Trip-based
Coverage Area	NFRMPO boundaries, including: Larimer and Weld counties, and five major sub regions: Fort Collins, Greeley, Loveland, Central I-25, and all other areas.
Developer	NFRMPO, Cambridge Systematics
Software	TransCAD, ArcGIS
Base Year	2015
Interim Years	2020, 2025, 2030, 2035, 2040
Horizon Year	2045

More information is available here: https://nfrmpo.org/modeling/

8.1.5 Pikes Peak Area Council of Governments

The Pikes Peak Area Council of Governments (PPACG) uses an activity/tour-based travel demand model with 802 TAZs. The model covers the Colorado Springs Metropolitan Statistical Area, including El Paso and Teller counties. It operates in the PTV VISUM platform. Socioeconomic forecasts are obtained from the Colorado State Demographer, elaborated upon with InfoUSA data, then disaggregated to the TAZ level using the UrbanSim socioeconomic/land use model. **Table 21** provides an overview of the PPACG model.

More information is available at https://www.ppacg.org/transportation/small-area-forecast/

Table 21: PPACG Model

Model Type	Hybrid/Activity-based
Coverage Area	El Paso and Teller counties
Developer	PPACG, Wilson & Company / WSP, PTV plus POPGEN, Cambridge Systematics
Software	Visum
Base Year	2015
Interim Years	2020, 2025, 2030, 2035, 2040
Horizon Year	2045

8.1.6 Pueblo Area Council of Governments

The Pueblo Area Council of Governments (PACOG) Travel Demand Model has a long-standing history. It was developed and maintained by the then Colorado Department of Highways and eventually transitioned to the MPO in 1984. The current model (last updated in 2014) maintains the TransCAD software platform with a 2010 calibrated base year that captures more than 154,000 persons in 63,000 households and a 2040 future year. The PACOG model also includes a scenario builder that interpolates data to facilitate interim year assessments. The travel demand model extents cover Pueblo County and incorporate a trip-based model. **Table 22** provides an overview of the PACOG model.

Table 22: PACOG Model

Model Type	Trip-based
Coverage Area	Pueblo County
Developer	PACOG, HDR, Wilson & Company/WSP
Software	TransCAD
Base Year	2010
Interim Years	Flexible with Scenario Builder
Horizon Year	2040

More information is available at https://county.pueblo.org/pacog/transportation/urban-transportation-planning

8.1.7 CDOT Statewide Model

As of June 2020, CDOT finalized the statewide activity-based travel model based on DRCOG's FOCUS model (see above). The CDOT model was developed by a team led by Cambridge Systematics and is very similar in structure to DRCOG's model. The primary difference between the CDOT and DRCOG model is adaptations to the CDOT model to address the longer-distance trips that take place at the state level. The model consists of a series of discrete choice models that produce trip tables (6,400 zones) for transit, highway, bicycle, and pedestrian trips. The transit and highway trip tables then are run through "assignments" with TransCAD software. Outputs include traffic volumes (and growth rates), transit ridership, and other general operational data for all segments of the roadway network system of collector and higher roadway class. **Table 23** provides an overview of the CDOT Statewide model. CDOT's Release Agreement for the *StateFocus* Travel Model is available in Appendix D. Authorized representatives of contractors and agents must execute a copy of the Release Agreement.

Table 23: CDOT Statewide Model

Model Type	Activity-based
Coverage Area	The State of Colorado, including all counties/cities/towns
Developer	CDOT, Cambridge Systematics, CDM-Smith, Arizona State University, and the University of Texas
Software	TransCad
Base Year	2010
Interim Years	2015
Horizon Year	2045

8.2 Model Calibration and Validation

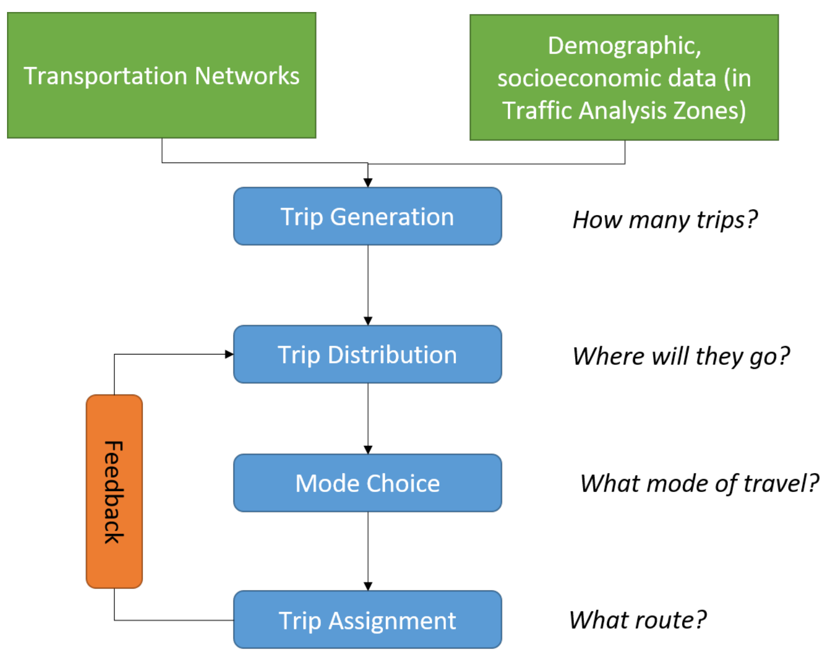
Typically, in an analyst's application, it can be safely assumed that the base year travel demand model has been properly calibrated and/or validated by the responsible/owner agency (e.g., MPO). If the model has been validated, then it can be reasonably assumed that future interim and horizon year models will reasonably predict future volumes. The analyst should work with the model owner agency to verify a properly calibrated and/or validated model is being used. The purpose of the guidance below will be to establish that CDOT is using properly calibrated and/or validated models for project application. The MPO should have a calibration/validation document available that will confirm a properly calibrated model.

Model calibration is the process of adjusting model parameters and variables until predicted travel matches observed travel in the base year, as defined by the selected model. The model base year is a fixed year available from the owner agency and will not change until the model undergoes an update process. Calibration is done as an iterative process where the model component is run and then compared to a known set of observed data (i.e., traffic counts, travel survey, trip length frequency distributions). At each iteration, small changes are made to the input parameters in the model until the output reasonably matches the observed data. It is essential that a travel demand model is properly calibrated to provide reasonable current and future predicted volume flows in a study region. The parameters that are adjusted and set during calibration, such as trip generation rates, friction factors, mode choice coefficients, and highway speed/capacities, will not change during travel demand forecasting efforts.

Model validation is the process of testing a model's ability to reasonably predict future travel behavior. A properly validated model demonstrates that the output has reasonable sensitivities to changes in inputs and will provide reasonable forecasts of travel based on tested alternative network and demographic conditions. Model validation differs from calibration in that the set of observed data used to compare is different than the set used during calibration. These data should be from a different year than the base year (i.e., the most current available traffic counts).

Generally, model calibration is performed after each of the major steps, or modules, in a typical four-step (trip-based) travel demand model, as shown in **Figure 13**.

Figure 13: Four-Step (Trip-Based) Travel Demand Model Process



These steps and the associated data used for calibration are described below.

8.2.1 Trip Generation

Calibrating the trip generation module establishes that reasonable estimates of trip productions and attractions are being calculated according to the expected land use and demographic data for each TAZ in the study area. Typically, a household travel survey can be used to calibrate trip rates. Household travel surveys can be conducted locally within each jurisdiction, regionally, statewide, or nationally. Results are available nationally through resources such as the National Household Travel Survey (NHTS). These surveys gather trip-related data for a cross section of the population to glean information about trip lengths, mode of transportation, and trip purpose. Then, this information can be linked to individual socioeconomic data and trip locations for use in travel demand analysis. Trip rates are defined as the number of person trips that move in or out of a particular TAZ based on the individual land uses and associated activities within that TAZ. As a reasonableness check for the analyst, average trip rates, derived from the NHTS or, if available, from local studies and surveys, can be used to verify reasonable trip generation results. The NHTS is conducted and information is maintained by the USDOT. More information is available at https://nhts.ornl.gov/2009/pub/stt.pdf.

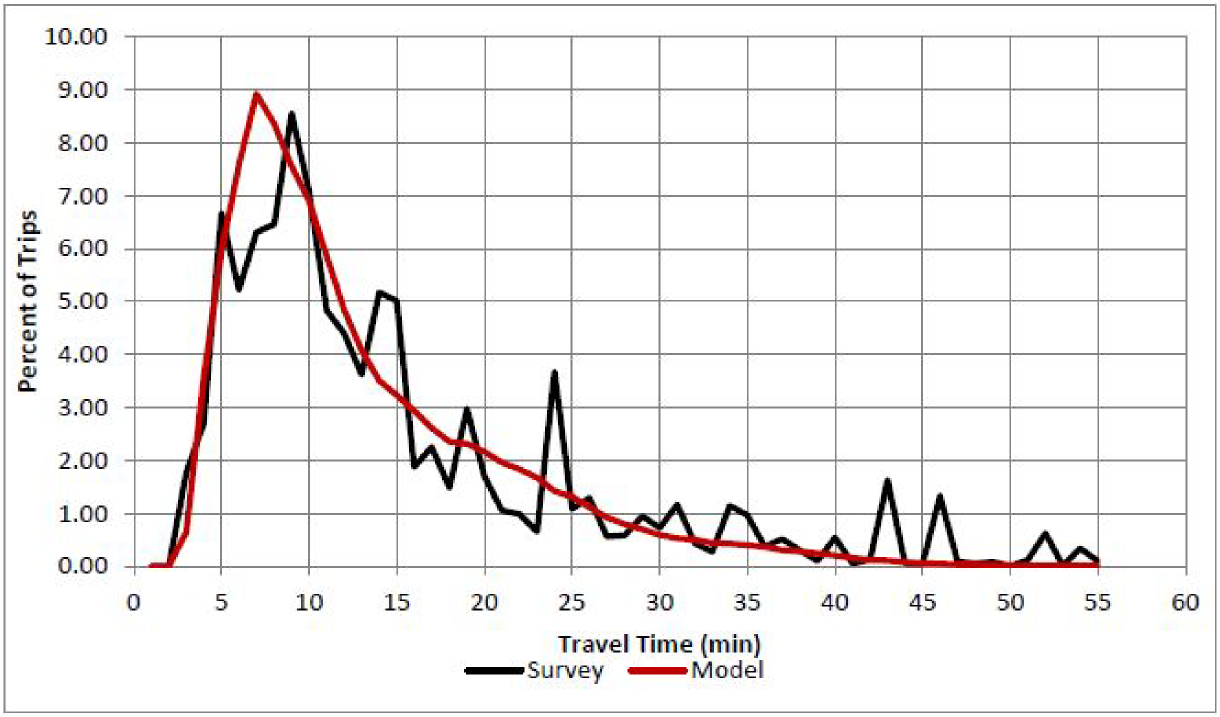
8.2.2 Trip Distribution

Trip distribution is calibrated using two methods:

1. Comparison of regional Trip Length Frequency Distribution (TLFD) and observed average trip lengths by purpose
2. Evaluation of estimated versus observed O-D flows across the region

TLFD and trip lengths usually are derived from local household travel survey data. TLFD represents the percent of trips that travel in each bin of travel time/distance. These data can be plotted against the output from the model trip distribution module to compare results. **Figure 14** shows a typical TLFD curve.

Figure 14: Illustration of Model Calibration



The trip distribution module (i.e., gravity model) is calibrated by adjusting friction factors until the two curves in the TLFD plot match closely. Friction factors are model parameters/ coefficients within the gravity model equations that affect the distribution of trips between origins and destinations.

Sample O-D data obtained from a household travel survey also can be used to verify that trips are traveling within the region as expected based on observed data. In addition, a wide variety of data sources is available to validate trip tables and O-D flows across the region using commercially available data sets. Examples of these data sets include information from AirSage and StreetLight Data. These services offer anonymous and processed information pertaining to trip patterns of a regional population based on the geo-location information from cell phone data.

8.2.3 Mode Choice

The mode choice or mode split module determines what type of mode each person will choose (SOV, HOV, transit, etc.). This module typically is calibrated using on-board travel surveys as well as household surveys conducted at the local level.

8.2.4 Trip Assignment

Calibration of the trip assignment establishes that the model is reasonably predicting volume flows on major roadways throughout the model's area. A properly calibrated volume assignment is based on the assumption that the previously discussed model components (trip generation/trip distribution/mode choice) have been adequately calibrated. Trip assignment calibration typically involves comparison of modeled volumes to available recent traffic counts (less than five years old), and is categorized at different levels within the model as follows:

3. Geographic areas of the model region (i.e., counties, cities, quadrants)
4. Functional classification of roadways
5. Screenlines/cordons: an abstract line dividing two geographic sections of the model; captures flow from one part of the model to another
6. Individual link/corridor comparisons

Volume comparisons usually are based on percent differences, and have variable allowable deviations based on the functional class/volumes of the roadways. FHWA provides recommended maximum allowable deviations as shown in **Table 24** below. The allowable percent error shown is calculated by summing the total assigned traffic volumes and dividing by the total counted volumes (i.e., ground counts) for all links that have counted volumes, categorized by the functional classification shown in **Table 24**.

Percent Error, by Functional Class = Σ Assigned Traffic Volumes / Σ Counted Volumes

Calibration to daily volumes is the standard acceptable method; however, some jurisdictions/ MPOs across the country have used peak hour assignment calibration. Peak hour calibration requires significantly more detailed data collected during the peak hours, and the model requires a higher level of accuracy compared to daily assignments.

Table 24: FHWA Maximum Deviations for Daily Volumes

Functional Classification	Allowable Percent Error (FHWA)
Freeways	± 7 percent
Principal arterials	± 10 percent
Minor arterials	± 15 percent
Collectors	± 25 percent
Frontage roads/local roads	± 25 percent

8.2.5 Activity-Based Model Calibration/Validation

Activity-based models are calibrated and/or validated using similar techniques and data sets as those described above for four-step models. Data for activity-based model calibration commonly are derived from regional household travel surveys as well as U.S. Census data. Highway assignment output is calibrated the same as described above for four-step models.

Running the Travel Demand Model: In many potential applications, the analyst does not need to run the entire travel demand model to generate projected link volumes for a study alternative. This is the case when a project is expected to have a less-than-regional impact on travel patterns along the corridor. In these "small impact" cases, the analyst can simply code the project into the highway network and run the highway assignment only using fixed trip tables from a previously run full model. Examples of small projects of this type would include roadway widenings in a relatively short corridor, new connector roadways, and small developments. Run times for highway assignments vary by model depending on the complexity and size of the region.

In other cases, a proposed project may be large enough in scale to affect regional travel patterns, including the overall distribution of trips between activity centers. In this instance, it would be necessary to run the travel demand model in its entirety so that trip distribution, mode choice, trip assignment, and the feedback loop of these elements can have their intended influence on regional travel patterns and resulting projected link volumes. Examples of regionally significant projects include major changes in demographics of the study area, toll projects, transit projects, major intra-regional highway widenings, and HOV/High-Occupancy Tolling (HOT) lanes. The analyst will exercise their professional judgment to determine the regional significance of each project application. Full travel demand model run times can exceed eight hours depending on the complexity and size of the region.

Guidance related to post-processing model results to develop future demand volume forecasts in discussed in section 9.2.3.

8.3 Subarea Modeling

A subarea model is a smaller network where greater detail is added within the full regional travel demand model network. While regional travel demand models are useful for major area-wide corridor projects that have systemwide impacts, subarea modeling is useful for localized project analysis where the impacts are only seen in the defined sub region. In this case, a finer level of detail is required in terms of roadway network and TAZ structure.

Determining the need for the development of a subarea model in a project analysis situation is dependent on a number of key considerations, including:

- Existing and future demographic/land use characteristics of the analysis area
- Existing and future transportation system characteristics of the analysis area
- Desired results and character of the analysis
- Data requirements and availability
- Technical skills and resource requirements
- Forecasting near travel demand boundaries

Each of these factors should be considered in making the decision on the application of a subarea model in a project analysis. However, these factors are not equally important in every situation, with certain factors having greater significance in specific applications than in other applications. Thus, each potential use of a subarea model needs to be evaluated as a special case. A description of each consideration is provided below.

Existing and Future Demographic/Land Use Characteristics of the Analysis Area

The existing and future demographic/land use characteristics of the analysis area are important aspects in the consideration for the application of the subarea model to be employed. It is assumed that the subarea to be analyzed would be a minimum of at least one-quarter square mile. If the subarea is smaller than this, consideration of alternate analysis techniques might be more cost effective. If the demographic/land use characteristics of the analysis area are to remain relatively stable over time with only minor changes to the transportation system characteristics, the use of a subarea model might not be warranted. If the demographic/land use characteristics of the analysis area are anticipated to significantly change over the analysis period, with or without significant transportation system changes, the application of a subarea model should be considered.

Existing and Future Transportation System Characteristics of the Analysis Area

As with the demographic/land use characteristics of the analysis area, the existing and future transportation system characteristics of the analysis area are a key consideration in the decision to employ subarea modeling procedures. If major changes in the transportation system (new roadways, major transit improvements, etc.) are envisioned beyond already planned and/or programmed projects, the need for a subarea model becomes evident, even if there are only minor changes in the demographic/land use characteristics of the analysis area. Major changes in the transportation system generally result in substantial changes in the traffic patterns in the analysis area. These travel pattern changes cannot be objectively evaluated without the use of a subarea model.

Desired Results and Character of the Analysis

It is important to clearly understand and describe the overall objectives of the subarea analysis that drive the character of the analysis requirements and desired analysis results. One of the primary utilities of a subarea model is to understand the changes in the overall operational characteristics of the transportation system, similar to a regional model, but within a more detailed and defined analysis area with changes in demographic/land use characteristics and/or transportation system characteristics, including:

- Changes in overall system delays
- Changes in travel times
- Changes in traffic volumes
- Changes in transit utilization
- Impacts on bicycle and pedestrian flows
- Estimates of specific movements (ramp-to-ramp weaving and arterial paths)

Data Requirements and Availability

Development of a subarea model generally requires substantial data beyond that available within the existing travel demand model. Generally, a significant number of traffic counts will be required, including 24-hour directional traffic counts, vehicle classification counts, peak period counts, and intersection turning movement counts.

In addition, roadway geometry and traffic control data could be required if additional roadways not in the travel demand model will be added to the subarea model network. The availability of these data and/or the time and resources required to obtain these data must be considered in determining the utility of subarea model development.

Technical Skills and Resource Requirements

Another key consideration in determining the utility of a subarea model is the availability of requisite technical resources necessary for the development of the subarea model. Generally, the development of a subarea model requires the modification, by the analyst, of the travel demand model trip table for the subarea. In certain instances, modeling tools, such as matrix estimation techniques using computer programs such as TransCAD may be required. It is also important that the analyst have the experience in the application of these procedures.

Depending on the complexity of the model, its development and calibration can require from three to eight weeks. If this timeframe is not available for subarea model development, then consideration of a subarea model may not be applicable for the analysis.

Forecasting Near Travel Demand Boundaries

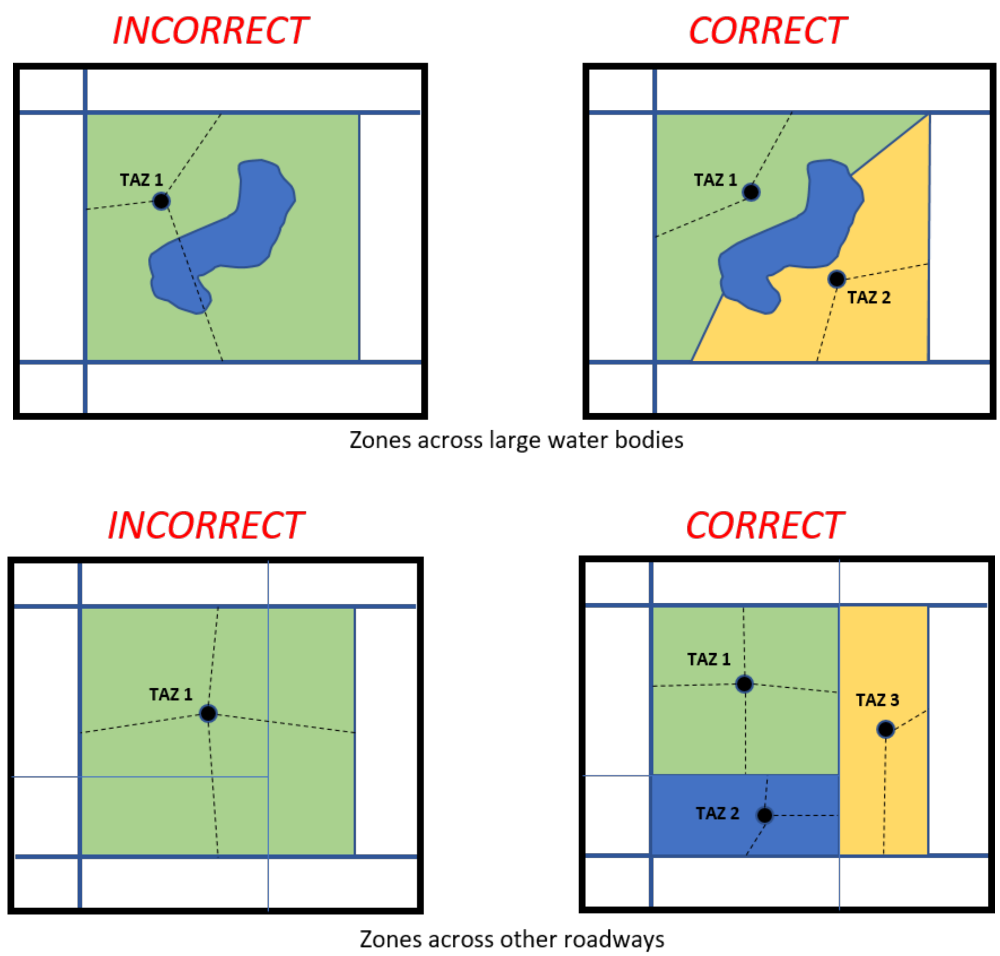
Developing subarea models, or refining regional models, near the boundary of the regional travel demand model requires addressing several unique issues:

- Size of TAZs
- Influence of I-E/E-I trips
- Influence of E-E trips

Model results tend to be susceptible to inaccuracies near the boundary regions. This is primarily due to the large, geographic scope of TAZs at the edges, which may be too coarse to account for varying land uses and the rapid growth that typically would be expected on the outer edges of urbanized areas. In general, the geographic size of the TAZs near the boundary of the regional travel demand model is much larger than those more centrally located within the travel demand model study area. Therefore, significant TAZ subdivision is required to address the needs of a boundary analysis. This issue also applies to the level of detail of the highway network. Therefore, the increase in the level of detail for TAZs also must have a complimentary increase in the level of detail for the highway network.

As with the development of any subarea model, an important consideration is the definition of the highway network for the model. **Figure 15** represents common errors in TAZ/network compatibility and how they should be correctly coded.

Figure 15: Example of TAZ/Network Compatibility Coding



Since the study area is close to the travel demand model study area boundary, the influence of the I-E/E-I trips needs to be examined closely. I-E/E-I trips are those that originate from an area within the boundary of the regional model and are bound to an area outside the boundary of the regional model (I-E), or vice versa (E-I). Since these trips generally are controlled (total trips) at the regional travel demand model external station, their overall travel patterns need to be reviewed to confirm that they are logical in terms of the travel patterns into, out of, and through the study area. It also may be necessary to add a new external station for the subarea if travel to and from a specific area adjacent to and outside the regional travel demand model study area has a significant influence on travel within the study area. General distribution of the trips to and from this new subarea external station can be extrapolated using adjacent regional travel demand model external station travel patterns.

Regional travel demand E-E trips can be incorporated directly into the study area model since they also will represent E-E trips in the subarea model. These can be extracted from the regional model using a subarea identification and extraction process.

Subarea Model Development

In the subarea model development process, certain factors need to be considered, including:

- TAZ geographic granularity
- Highway network
- TAZ and highway network compatibility

In general, the TAZs of the regional travel demand model are not at a sufficient detail to facilitate accurate analysis at the subarea model level.

An important consideration in the development of a subarea model is the definition of the highway network for the model. The network should include all facilities that provide connectivity and accessibility to major development features in the subarea—existing and future. A number of facilities will need to be added to the subarea highway network that are not included in the regional travel demand model network to adequately replicate the traffic flows in the subarea. While regional travel demand model TAZs are larger and often contain different land uses (i.e., commercial and residential) within their boundaries, subarea TAZs should be used to isolate the major activity centers and/or large mixed-use developments within the subarea.

The separated TAZs should have highway facilities used as TAZ boundaries, which are incorporated into the subarea highway network. Following this general rule will result in the requisite TAZ highway network compatibility. Increasing the number of TAZs without increasing the number of highway facilities in the subarea network will result in erroneous traffic assignment results (i.e., highway facilities will be over assigned). Similarly, simply adding highway network to the model without adding TAZs will result in erroneous traffic assignment results (i.e., highway facilities will be under assigned).

In addition, the geometric characteristics of the regional travel demand model network need to be reviewed for consistency with the subarea highway network, including network lanes, classifications, speeds, turn penalties, etc. Future roadway facilities to serve future development also should be incorporated into the subarea highway network.

Combining Regional Models

In situations where the desired study area spans the jurisdiction of two regional travel demand models, the development of the subarea model is basically the extraction of the model portion from each regional model. The refinement of the subarea model is similar to the refinement of a subarea model near the regional travel demand model border. In this case, each portion of the subarea model initially is treated separately in terms of TAZ and highway network refinement. When each of the TAZs and highway networks has been refined, network geometry (network lanes, classifications, speeds, turn penalties, etc.) will need to be reviewed for consistency between the two subarea model components.

If the individual models have differing base or horizon years, the analyst should choose an appropriate common year for combining models. For base year, the more current year should be used and the “older” base year can be factored up to meet this year. For horizon year, the model with the “sooner” year should be used, and the later horizon year model can be scaled back to match.

The I-E/E-I trips of the two component subarea models can be combined using the I-E/E-I distributions of the component subarea model distributions. For example, the I-E trips from one component subarea model uses the E-I component of the other subarea model to develop the combined I-E/E-I trips for the overall subarea model. A similar procedure can be used to develop the combined subarea E-E trip table.

The Statewide Travel Demand Model was developed to address the longer-distance trips that take place at a regional level and to avoid situations where two regional models need to be stitched together. The statewide model can be used to conduct the study analysis over larger areas encompassing multiple regional models or, if necessary for a specific project, as the network to connect two regional subarea models.

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9 Traffic Forecasting and Alternatives Analysis

9.1 Alternatives Development

The project team should develop improvement concepts to satisfy the project objectives. Coordination between the project team and other key decision makers is essential for a successful and cost-effective development of viable improvement alternatives and the analysis of the preferred improvement alternatives. In some cases, the alternative improvements may have already been developed for the project and this traffic analysis may be required and/or requested to evaluate and support the decision-making process.

The following should be considered when developing and analyzing project alternatives:

- The "No-Build" alternative must be considered as one of the project alternatives. The No-Build alternative represents a benchmark for evaluating all improvement alternatives. Any project that is planned to be funded and constructed within the design year of the analysis should be included in the analysis of the No- Build alternative.
- All project alternatives should use the same boundary limits that were identified and approved in the project scoping. This is achieved by modeling networks for each alternative from the calibrated base network. However, some alternatives may have impacts beyond the base network, in which case, the analyst is required to include wider impacts in the analysis and document properly.
- Any build alternative considered for analysis should address the purpose and need for the project. In addition to considering traditional infrastructure improvements, alternatives should consider incorporation of transportation system management and operation strategies (e.g., ramp metering, traffic signal coordination, managed lanes and improved traveler information) as well as alternative transportation mode strategies such as improved transit service and multimodal accommodation.
- Traditionally, the most common solutions to intersection challenges involved stop-controlled, conventional signalization scenarios, or interchanges. Many of the performance metrics used to select between these common solutions focused on the movement of vehicles through the intersection. In recent years, a number of new or innovative intersection designs have been introduced across the

United States. These “alternative” intersection control types are enhancing safety and improving operations, along with varying degrees of other benefits. This reimagining of geometric design and traffic control has improved the movement of people and vehicles across and through intersections. Alternative intersections (including roundabouts, cross-over-based designs, and U-turn-based designs) often consider community needs, transportation needs, and control strategies to achieve multiple objectives. CDOT is currently in the process of developing the Intersection Control Evaluation (ICE) to consistently consider multiple context-sensitive control strategies when planning a new or modified intersection.

- Due to time and resources required for the traffic analysis effort, especially microsimulation approaches, and uncertainty of developing improvements concepts in the early stages of the project, it is beneficial to assess general feasibility of the concepts by using sketch-planning tools such as Cap-X or HCS. Both Cap-X and HCS software can quickly analyze both the conventional and alternative/innovative intersections/interchanges. This approach would use general performance measures such as v/c ratios to screen the concepts. Screening of concepts would generate viable improvement alternatives which may be carried forward for more detailed traffic analyses. Two or three viable improvement alternatives should be considered for detailed traffic evaluations. When v/c ratio is used, the analyst should make sure demand volume is used. All improvement concepts that were rejected from further considerations should be documented and included in the alternatives analysis report.
- Design standards and criteria published in the CDOT Roadway Design Guide, the American Association of State Highway and Transportation Officials (AASHTO) publication “A Policy on Geometric Design of Highway Streets” and FHWA policies on the National Highway System (NHS) should be followed when developing improvement alternatives. However, context-sensitive approaches that balance a broad range of project needs and environment are encouraged. When the design criteria cannot be met, the analyst should prepare background information sufficient to initiate a design exception or variation in the subsequent phases of the project development. Additionally, all improvement alternatives should be developed considering desired safety levels of the facility.
- Any assumptions (regarding traffic behavior) made during development of the improvement alternatives should be logical and their reasoning should be adequately documented and included in the final traffic analysis report and technical memorandums. Documentation of the alternatives development process, including the concepts screening process, is vital to the success of the traffic analysis since it helps the review of the final analysis report and supports informed decisions.
- To minimize errors in microsimulation analysis, the alternative analysis models should be built directly from the calibrated base microsimulation file.
- The analyst should refrain from switching analysis tools in the middle of a comparison between alternatives since each tool uses different methodologies to compute MOEs. It is prudent to consistently use one set of tools to evaluate MOEs across all alternatives.

- Safety considerations should evaluate existing safety issues and concerns in the analysis area through application of safety diagnostic analyses. Diagnosis analyses are useful to make informed decisions about development of improvement concepts. Existing safety profiles (in terms of crash type, frequency and severity) should be examined and crash causation determined before selecting crash countermeasures in the project improvement alternatives. Crash predictive methods can be used to estimate changes in the frequency of crashes that is associated with changes in traffic patterns, roadway geometrics, or traffic volume and control across different improvement alternatives. Future safety conditions and crash countermeasures should be established on the analysis boundary limit.

9.2 Travel Demand Forecasting

The traffic analysis for the project alternatives involves forecasting of the future demand for the base model, transferring demand forecast to the alternatives and evaluating performance of various improvement alternatives against the baseline future demand. This section provides guidance on travel demand forecasting using both the sketch planning tools and readily available travel demand models in Colorado.

Forecasting also supports predictive safety analysis by providing traffic volume for use in the safety prediction models (i.e., SPFs). Specifically, SPFs reflect the complex relationship between traffic volume (e.g., AADT), general roadway characteristics (e.g., area type, number of lanes, traffic control), and crash frequency. Traffic volume is a key predictor variable in almost all SPFs. By inputting traffic volume and possibly other roadway characteristics into the model, the SPF produces an estimate of the average crash frequency for similar facilities with those conditions. Under existing conditions, the traffic volume is typically available; however, future volumes are unknown and require traffic forecasting methods. If future predicted traffic volumes are available from a forecast model, then the analyst can enter these in the SPF to predict future crash frequency. The key to predicting future crashes is to use an SPF that represents the facility type of interest and to use traffic volumes from a reliable forecasting method.

9.2.1 Travel Demand Forecasting Method/Tool Selection

Selecting the appropriate forecasting method is based predominantly on whether a regional travel demand model is available, the planning timeframe for forecasts, and the project’s geographic scope.

Planning Timeframe

The timeframe of the analysis is a key indicator of the appropriateness of a Sketch Planning method versus a calibrated travel demand model. The timeframe of a study usually is dictated by the regulatory agency responsible for the study and varies by project type. As the timeframe increases, historical growth and approved land use changes provide less accurate depictions than the aggregated local land use plans and socioeconomic data included in the travel demand model. **Table 25** shows general timeframes for typical project types and the applicability of Sketch Planning methods or a travel demand model.

Table 25: Typical Analysis Timeframes

Common Project Types	Typical Analysis Timeframe	Sketch Planning (0-5 Years)	Travel Demand Model (Longer than 5 Years)
Signal retiming, construction, maintenance of traffic (MOT), safety projects, operational studies	0- to 2-year horizon	Sketch Planning tools use existing trends or approved developments and therefore are appropriate for forecasting traffic volumes in the short-term.	
TISs, corridor studies, prioritization studies, traditional intersection improvements	2- to 10-year for opening day analysis; TIS also includes a 20-year horizon analysis*		A travel demand model is designed to be consistent with long-range planning objectives and is developed using socioeconomic data and approved land use information. Therefore, a travel demand model is recommended for mid- to long-term assessments.
PELs, NEPA studies, road widening, new or reconfigured interchange, innovative or non-traditional intersection improvements, bridge widening, managed lanes	20- to 30-year horizon		

* See Chapter 10 for notes and exceptions when applying these guidelines to TISs

Geographic Scope

The geographic scope of an analysis plays a role in the appropriateness of a forecasting tool. In general, geographic scope can be defined as follows:

- Isolated location: limited study area, such as a single intersection or interchange
- Segment: linear or small-grid roadway network

- Corridor/small network: expanded study area that typically includes one major corridor with one or two parallel arterials and their connecting cross-streets
- Region: citywide or countywide study area involving all freeway corridors and major arterials

As shown in **Figure 16**, the recommended forecasting tool progresses with geographic scope. For localized applications, such as an analysis of an isolated intersection, the regional traffic patterns are not necessary; therefore, the historical growth or trip generation of approved developments within the immediate vicinity of the intersection will provide an appropriate forecast of future traffic volumes. Meanwhile, a larger regional project that affects several freeways and corridors must consider the existing and planned land use interactions throughout the city/county.

Figure 16: Forecasting Methods per Geographic Scope

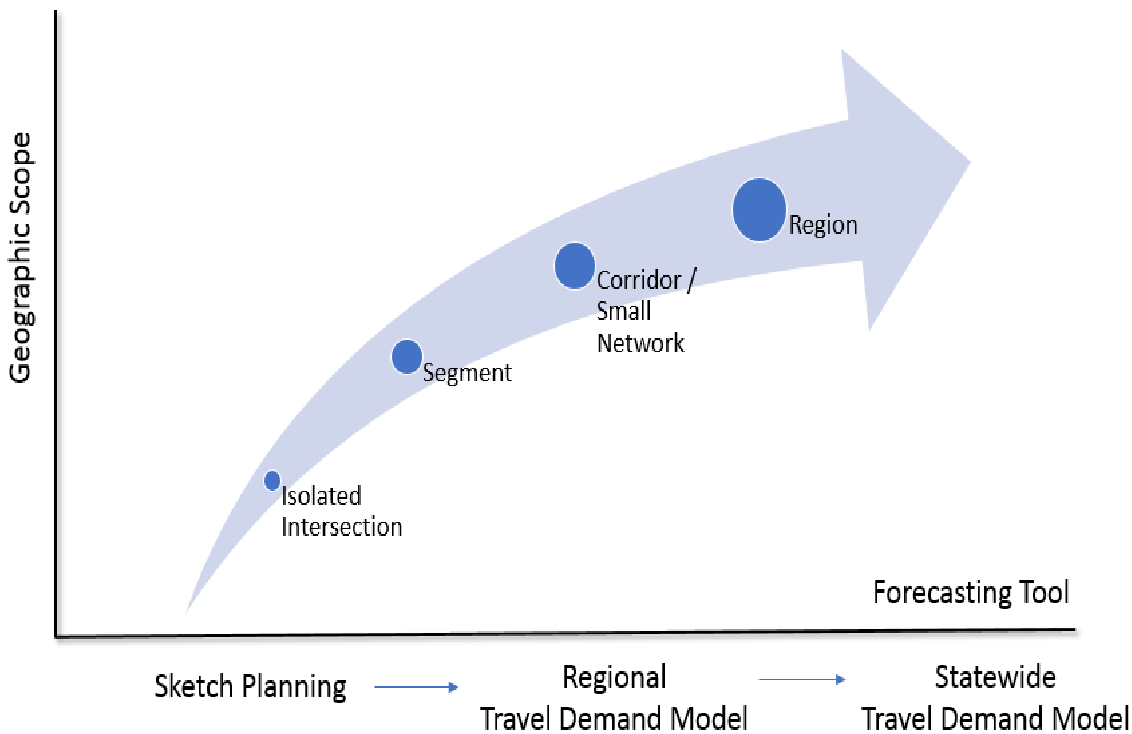

Figure 17 is a decision-making flowchart to determine a method for developing future estimates of demand volumes. The analyst's determination is largely based on whether a regional travel demand model is available, the time horizon of the project/study, and the geographic scope of the project. The flowchart indicates what specific Sketch Planning method should be used, along with what further travel demand model refinement or calibration may be necessary, consistent with the guidance provided for travel demand models later in this chapter.

Table 26 associates a project's analytical context and type, scoping considerations, desired MOEs, and necessary resources with applicable forecasting methods.

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Figure 17: Forecasting Decision Making Flowchart

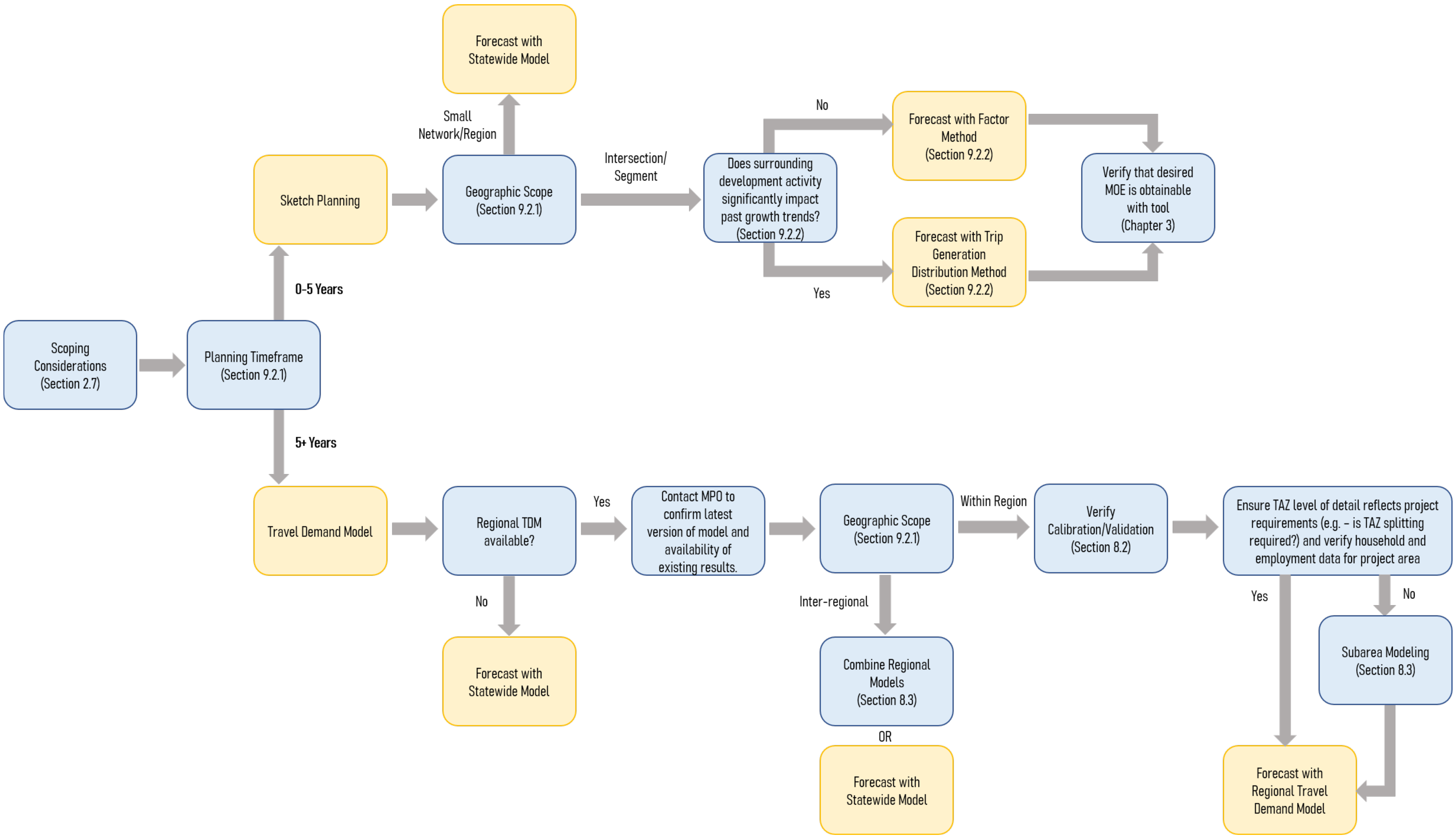

Table 26: Forecasting Tool Selection Matrix

		Selection Criteria	Forecasting Method			
			Sketch Planning	Travel Demand Model		
				Regional	*Statewide*	
Analytical Context and Project Type	*Planning*	General land use change	◐	●	◐	Historical growth rates can be used for high-level, information only, estimates of future traffic volumes
		New corridor/facility	○	●	◐	
		Travel demand management	○	○	○	Analysis typically based on existing travel patterns
		Prioritization	○	●	◐	
		Benefit/cost	○	●	◐	Safety benefits rely on the use of predictive models, which require traffic volumes as an input
		Site impact study	●	●	◐	Site impact studies can use both sketch planning for determining growth and travel demand models for distribution
		Air quality	◐	●	◐	
	Design	Road diet/cross-section modification	◐	●	◐	Corridor level analysis, but use of model recommended to determine diversion of traffic
		Lane widening	◐	●	◐	Long-term planning timeframe required for justification
		ESALs/load spectra	◐	○	○	Design traffic methodology applies
		Access management	◐	○	○	Trip generation distribution method can be utilized to reroute traffic based on access management revisions
	Operations	Tolling	○	●	●	
		Intersection design/signalization	◐	●	◐	Alternative intersection designs typically require a longer planning timeframe due to cost and complexity to implement
		Detour/diversion analysis, for lane closures, road closures or work zones	◐	●	◐	The decision to use sketch planning versus a travel demand model depends on the complexity of the detour
Scoping	*Budget*	Highly limited turnaround time or personnel	●	○	○	In some instances, where project specific modifications are not necessary, the MPO may be able to provide existing model results for interim/future years
		Moderately limited turnaround time or personnel	●	◐	◐	
		Ample budget, turnaround time and personnel	◐	●	●	
	Analysis Timeframe	Short-term (0-5 years)	●	◐	◐	Some site impact studies will require both short-term and 'information only' long-term assessments. Sketch planning is acceptable in these cases
		Mid to long-term (over 5 years)	○	●	●	
	Geography	Intersection	●	○	○	Alternative intersection designs typically require a longer planning timeframe due to cost and complexity to implement
		Segment	●	◐	◐	Engineering judgment necessary to determine if segment analysis will impact a larger set of facilities
		Corridor/small network	◐	●	◐	Larger study areas may be less feasible to forecast with the trip generation distribution method
		Region	○	◐	●	

● Applicable
◐ Generally Applicable
○ Not Applicable

Table 26: Forecasting Tool Selection Matrix Cont.

	Selection Criteria	Sketch Planning	Travel Demand Model		
			Regional	*Statewide*	
Desired Measures of Effectiveness	Average vehicle occupancy (AVO)	○	●	●	Obtainable with forecasting methods
	Delay	◍	◍	◍	Requires further traffic analysis
	Demand volume	●	●	●	Obtainable with forecasting methods
	Density	○	○	○	Low confidence level based on forecasting outputs
	Expected crashes	◍	◍	◍	Requires further safety analysis
	LOS	◍	◍	◍	Requires further traffic analysis
	LOSS	◍	◍	◍	Requires further safety analysis
	Mode split	○	●	●	Obtainable with forecasting methods
	Number of stops	○	○	○	Low confidence level based on forecasting outputs
	Predicted crashes	◍	◍	◍	Requires further safety analysis
	Queue length	○	○	○	Low confidence level based on forecasting outputs
	Ridership	○	●	●	Obtainable with forecasting methods
	Speed	○	◍	◍	Requires further traffic analysis
	Travel distance	○	●	●	Obtainable with forecasting methods
	Travel time	◍	◍	◍	Requires further traffic analysis
	Vehicle-hours of travel (VHT) or person-hours of travel (PHT)	◍	●	●	Obtainable with forecasting methods
	Vehicle-miles traveled or person-miles traveled	◍	●	●	Obtainable with forecasting methods
	Volume to capacity (v/c) ratio	◍	●	●	Obtainable with forecasting methods
Necessary Resources	Calibrated model	○	●	●	
	Completed OD matrix	◍	○	○	For trip generation distribution method
	Recent mainline traffic counts	●	◍	◍	
	Recent intersection counts	●	◍	◍	
	Recent speeds	○	◍	◍	
	Historical traffic counts, population growth rates	●	○	○	Historical growth rate is the primary resource for the factor method, however, population growth rate should be compared and utilized in some scenarios
	Existing and proposed geometry	○	●	●	
	Development characteristics within study area	●	◍	◍	For trip generation distribution method
	Network data	○	●	●	
	Demographic data organized by zones, districts, or places	○	◍	◍	This information is included in model but can be used for subarea modeling
	Locally calibrated trip generation rates or ITE trip rates	●	◍	◍	For trip generation distribution method and inputs into the travel demand model

Source: Adapted from the NCHRP Report 765

● Applicable
◍ Generally Applicable
○ Not Applicable

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Reinforcing with Project Examples:

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

- The study is within a large, densely populated region; therefore, a regional travel demand model likely is available.
- As a PEL, a long-range forecast will be necessary (20+ years).
- Forecasts should be prepared with the regional travel demand model.
- The model's developer (likely the area MPO) should have a calibration report available. Calibration more locally for the study area should be verified. If necessary, subarea modeling can be done to improve calibration in the study area.
- The model's forecasted demand volumes may differ from those developed using a factor method. There are no absolute rules as to which method produces a "right" forecast; rather, the analyst must provide fact- and data-based evidence upholding the forecasts.

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

- The study is within an isolated city generally surrounded by sparsely populated areas; it is unlikely that a travel demand model is available, but the analyst should verify with local transportation planning staff.
- As a future capacity needs analysis, a long-range forecast will be necessary (20+ years).
- Forecasts should be prepared with the Statewide Travel Model.
- CDOT will have a calibration report available. However, if evaluating a smaller geographic study area, the model should be locally calibrated. If necessary, subarea modeling can be done to improve calibration in the study area.
- The model's forecasted demand volumes may differ from those developed using a factor method. There are no absolute rules as to which method produces a "right" forecast; rather, the analyst must provide fact- and data-based evidence upholding the forecasts.

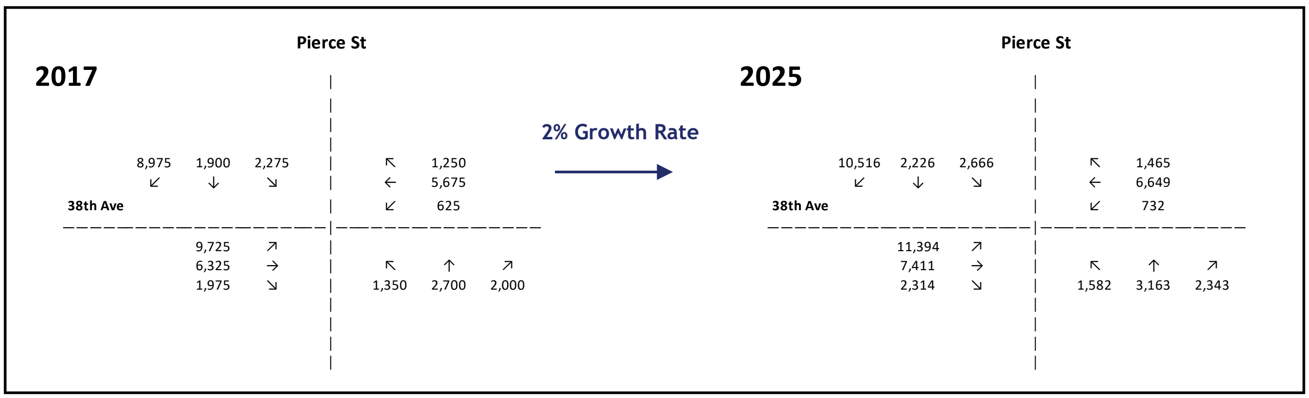
9.2.2 Sketch Planning Tool Guidance

There are two typical Sketch Planning forecasting methods used within the state: the Factor Method and the Trip Generation/Distribution Method. These inexpensive, fast-response approaches generally are easier to implement and less costly than travel demand models. Often, they are spreadsheet based. Because of their flexibility, these tools often are developed by agency staff or consultants for a specific project.

Factor Method (Growth Method)

The Factor Method forecasts future travel demand based on historical trends. Using historical traffic counts, a growth rate is established and applied to the existing demand volumes to project into the future year. The Factor Method can be completed using growth rates derived from historical traffic counts (the most common approach), population growth rates, or other area-specific trends. An illustration of applying the Factor Method is provided in **Figure 18**.

Figure 18: Illustration of Applying the Factor Method at an Intersection



The growth factor should be applied to the study area, up to the project's analysis year scenarios. Although a detailed analysis of surrounding approved development is not typically conducted with this method, the analyst will reasonably specify growth to account for increases in existing traffic due to other approved and pending, but not-yet-built, developments. Within a five-year timeframe, growth rates typically will be between 1 percent and 5 percent per year. Where limited historical traffic data exists, or when traffic growth rates are not within these thresholds, population growth rates should be examined and used as the growth factor based on engineering judgment.

Deriving future forecasts based on previous trends assumes the study area will continue to grow at a consistent rate. The forecasted traffic volumes are assumed to include the traffic generated by other surrounding development activity within the analysis timeframe. Therefore, if major surrounding development activity—which significantly increases the area’s historical growth or impacts the existing traffic patterns—is anticipated, the Trip Generation/Distribution Method should be considered.

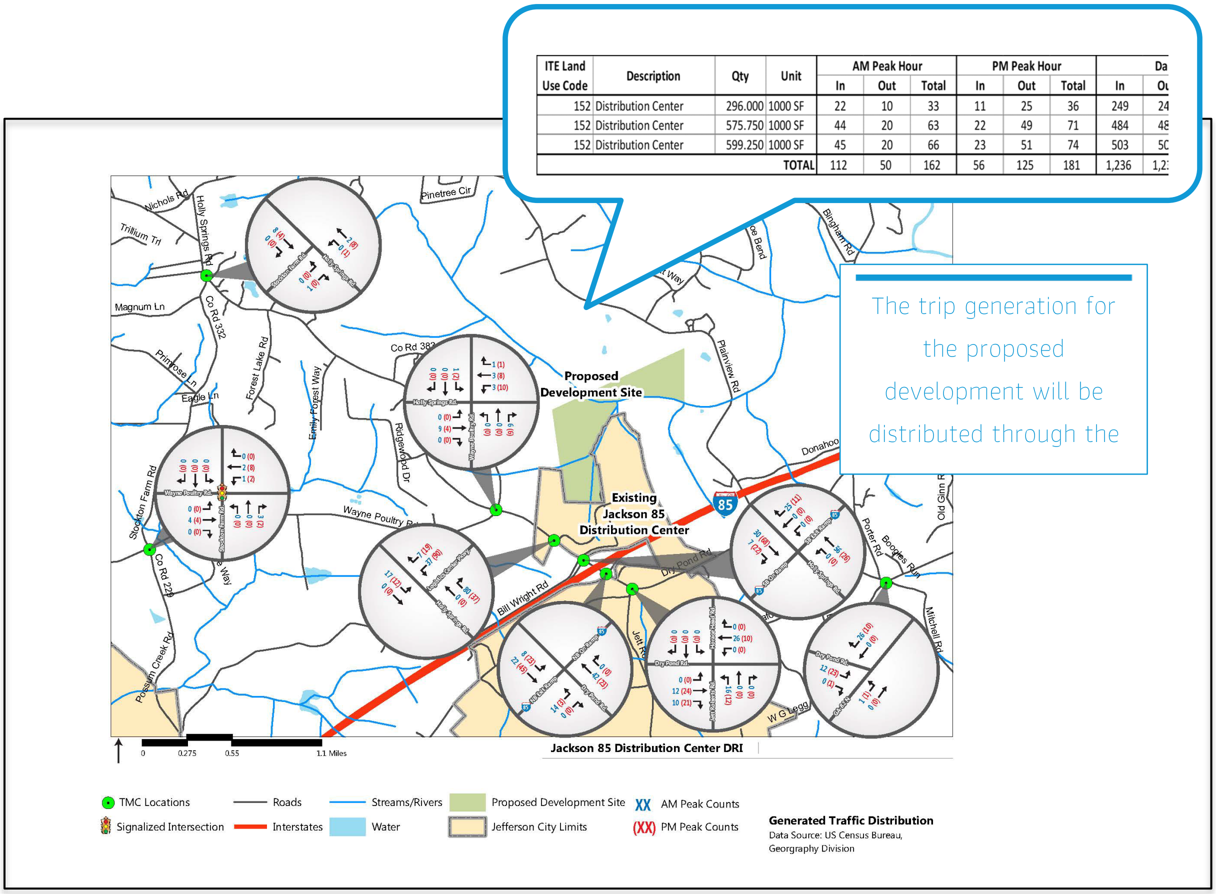
Trip Generation/Distribution Method

The Trip Generation/Distribution Method uses existing development characteristics within the study area to determine the short-term growth and/or distribution of anticipated traffic volumes. The known development characteristics can be based on planned development that is approved but not yet constructed or development with similar land use characteristics in the study area. A breakdown of the Trip Generation/Distribution Method is as follows:

- Trip Generation—future traffic volumes can be forecasted based on the amount of approved but not-yet-built development within the study area. Using this approach, the future traffic volumes would be derived by adding the planned development traffic volumes to the existing traffic volumes. For long-term projects it may be appropriate to add trips generated by the not-yet-built development to background traffic calculated using the factor method.
- Trip Distribution—distribution of proposed traffic can be determined based on existing traffic patterns, the anticipated distribution patterns of approved but not-yet-built developments, or the distribution patterns of similar land uses within the study area. Available travel demand models or Big Data also can inform trip distribution.

Figure 19 provides an illustration of a proposed development adjacent to a large existing development with similar land use characteristics. In this scenario, the trips of the proposed development will be distributed throughout the study area, based on the existing turning movement counts, which are largely the result of a similar land use.

Figure 19: Illustration of Trip Distribution Through Intersections



ITE Land Use Code	Description	Qty	Unit	AM Peak Hour			PM Peak Hour			Da	
				In	Out	Total	In	Out	Total	In	Ou
152	Distribution Center	296.000	1000 SF	22	10	33	11	25	36	249	24
152	Distribution Center	575.750	1000 SF	44	20	63	22	49	71	484	48
152	Distribution Center	599.250	1000 SF	45	20	66	23	51	74	503	5C
			TOTAL	112	50	162	56	125	181	1,236	1,2:

Factor Method or Trip Generation/Distribution Method?

The decision to forecast using the Factor Method or the Trip Generation/Distribution Method should be based on providing a conservative assessment of the area's growth and recent development activity. When conducting a TIS, some local jurisdictions will dictate the required approach; however, key questions to consider when selecting a Sketch Planning method are outlined below.

- Will surrounding development activity exceed historical growth patterns?
- Will surrounding development activity impact existing traffic distribution patterns?
- Is the historical growth rate negative?
- Does the local jurisdiction maintain trip generation and/or distribution information for previous land use changes?

If the answer to any of these questions is "yes," use the Trip Generation/Distribution Method. If no, the Factor Method is likely the most appropriate forecasting method.

Data Sources

Using a Sketch Planning method will require historical traffic counts or approved development traffic characteristics within the study area. Most of this information can be obtained through open data catalogs and coordination with the local agency. A few common data sources for completing the Factor Method and/or the Trip Generation/Distribution Method are as follows:

- **OTIS**—Information available through OTIS includes traffic counts (AADT, daily traffic counts broken down by hour, monthly summaries, capacity, v/c ratios), state highway attributes (speed limit, roadway classification, geometric information, etc.), roadway statistics, state highway video logs, demographics, geographic data, and maps. The extent of data availability may vary per location within OTIS.
- **Local Agency Data Catalogs**—Many local agencies maintain annual traffic count programs and publish the data in open data catalogs. These can be used as a resource when developing forecasts for non-state roadways.
- **ITE Trip Generation Manual**—ITE Trip Generation Manual provides the rates and equations for the full spectrum of land uses, with more than 1,700 data points. The ITE trip generation rates and equations can be applied to known development plans to determine the "new" trips within the study area. When using this manual, the analyst should follow the guidance provided in the ITE *Trip Generation Handbook*, Section 3.4: Recommended Procedure for Estimating Trip Generation.
- **Population Growth**—Population growth can be collected from the county demographer, based on U.S. Census data. When forecasting traffic using the Factor Method, population growth should be compared to the traffic growth obtained through historical counts or OTIS to ensure appropriate assumptions.

Additional information on data collection techniques can be found in Chapter 3: Data Collection.

Forecasting Inputs & Outputs

The typical inputs and outputs of the Sketch Planning method are provided in **Table 27**.

Table 27: Typical Inputs & Outputs for Sketch Planning Methods

Method		Typical Inputs	Typical Outputs
Sketch Planning	Factor Method	Historical traffic counts, existing traffic counts, population growth	Demand volumes
	Trip Generation/ Distribution Method	Known developments planned within the study area, O-D trip tables, locally calibrated trip generation rates or ITE trip rates, existing traffic counts	Demand volumes

Although Sketch Planning can be a cost-effective alternative to purchasing expensive, complex, and data-intensive software packages, it is important to keep in mind that estimates provided by Sketch Planning tools are generalized and dependent on the geographic data aggregation and other assumptions on growth and development activity.

9.2.3 Travel Demand Model Guidance

This section provides guidance for using a travel demand model to forecast future traffic volumes. If this forecasting method is deemed appropriate, the analyst should coordinate with the owner of the model (MPO, county, or CDOT) to confirm use of the most updated model. The analyst also should discuss the availability of existing model outputs with the MPO, if base information is necessary and project-specific inputs are not necessary. This section focuses on utilizing model output and post-processing results to generate future traffic forecasts. See chapter 8 of these guidelines for detailed documentation of travel demand models available in Colorado and model calibration, validation, and subarea analysis guidance.

Travel demand model volumes should be used only to calculate relative growth along corridors between the base year and future year. Only in limited circumstances should the direct model output be used as forecasted demand volumes (such as when a roadway with limited parallel capacity does not exist in a base year).

The output from a travel demand model can be used to predict future year turning movements and segment volumes in two different ways based on the relationship between the base year and future year volumes. This relationship can be applied to existing turning movement/counts to calculate future year turning movements. The details of these methods are outlined with example case studies in the National Cooperative Highway Research Program (NCHRP) Report 765. The growth rate calculated between two model outputs can be applied to existing traffic counts using one of the two methods described below.

Difference Method

In this method, the relative differences in model output turning volumes between the future year and base year can be applied to existing turning movements/counts. As described in NCHRP 765, the difference method is performed as follows:

FFdi = FAi + (BCi – BAi)

Where:

FFdi = future year forecast volume for turning movement i

FAi = future year model assignment volume for turning movement i

BCi = base year count for turning movement i

BAi = base year model assignment volume for turning movement i

Ratio Method

The ratio method involves using the relationship between base year and future year model output turning volumes as a multiplicative factor applied to the existing turning movements/counts. As described in NCHRP 765, the ratio method is performed as follows:

FFri = BCi * (FAi/BAi)

Where:

FFri = future year forecast volume for turning movement i

BCi = base year count for turning movement i

FAi = future year model assignment volume for turning movement i

BAi = base year model assignment volume for turning movement i

Choosing the Post-Processing Method

It is at the analyst's discretion which method to use when developing future year forecasts. The two methods can produce drastically different results depending on potential model errors or lack of network fidelity. According to the NCHRP 765 report, the ratio method is better to use over longer time horizons. This is based on the assumption that the relative relationship between base year and future year models should remain the same based on growth of the underlying land use and demographic data, regardless of the absolute volume assignments in the models. NCHRP 765 further explains:

A fundamental assumption of both the ratio and difference methods, as stated previously, is that future turning movements will be similar in nature to existing turning movements. This assumption can be extended to land use, general development patterns, and resulting traffic patterns within the area. NCHRP Report 255 discussed averaging the results from the ratio and difference methods as a means to reduce the extremes that may be reached by one of the individual methods. While averaging the results from the two methods may indeed reduce the extremes, it is also believed that averaging will reduce the accuracy of one method or the other. It is advised that the analyst evaluate the results from both methods within the context of existing traffic volumes and turning movements and select a preferred method.

Forecasting Beyond a Model's Future Year

In some cases, it may be necessary to develop future traffic forecasts beyond the available horizon year of the travel demand model. The following text details the two methods for extrapolating volumes beyond the horizon year.

Scenario A: Desired future year is within five years of available model year, or v/c ratio for the available future year model on the study corridor is less than 1.0.

In this scenario, the user can calculate the volume growth rate on the study corridor between the available base year and future year models. This growth rate then can be extrapolated out the desired number of years, up to five years beyond the future year, to calculate future year volumes.

This method is preferred for the given scenario because it assumes that the growth within five years of the model future year remains consistent based on the model trends. A v/c ratio of less than 1.0 also is required to assume that additional growth will not be reassigned or redistributed to other corridors in the region. If the study corridor v/c ratio is 1.0 or greater, or if the desired future year is beyond five years of the model year, then the analyst should apply Scenario B.

Scenario B: Desired future year is beyond five years of available model year or v/c ratio for the available future year model on the study corridor is equal to or greater than 1.0.

In this scenario, the analyst should extrapolate the socioeconomic data input to the desired future year, and rerun the full travel demand model. The extrapolation of the population and employment data can be based on the growth rate of the data between the base year and future year of the model.

This method is preferred for the given scenario because it assumes that additional long-term growth in demographics may cause demand that far exceeds a corridor's capacity to handle the associated volumes. In addition, a corridor that is already at a v/c ratio of 1.0 will not be able to handle much additional traffic. Therefore, the full travel demand model should be run to reflect regional changes in trip distribution, mode choice, or assigned trip path.

9.2.4 Forecasting Documentation

(Adapted from NCHRP Report 765 and the Florida Department of Transportation Traffic Analysis Handbook)

When forecasting is necessary as a part of the project analysis, the forecasting methodology and process should be identified clearly within the analyst's report. At a minimum, the following topics should be addressed:

- **Description/purpose of forecast.** Documentation should include a description of the project and the specific purpose for which the forecasts have been developed. The description also should indicate the MOEs that will be used.
- **Data types and sources.** All data and sources that were used to develop the forecasts should be provided. The data should be summarized in tables and/or graphics, with the source of the data identified. Common data used in the development of traffic forecasts include traffic counts (24-hour directional counts, peak-hour intersection turning movement counts, and vehicle classification counts), population and employment summaries and projections, descriptions of roadway characteristics, land use and development plans, and planned/programmed projects that will influence future travel patterns and demand.
- **Forecasting method used.** A key component of a traffic forecast report is the discussion of tools and methods used. The discussion should justify the use of specific tools and methods, their application in developing the forecasts, and their limitations.
- **Model assumptions and checklist (Appendix E).** Any assumptions or modifications made during development of the forecasts should be logical and their reasoning adequately documented and included in the report. To assist in this section, a travel demand model checklist can be found in Appendix E of this guidance document.
- **Final forecasted volumes (graphically depicted).** The results section should provide maps, tables, graphs, and diagrams to accompany the text. The results should be drafted in a manner that allows the reviewer to clearly understand the future traffic volumes and their method of derivation.

If forecasting was used to develop MOEs that require further traffic or safety analysis, see Chapter 5: Traffic Modeling and Analysis Tools for guidance on future conditions and alternatives analyses.

9.3 Evaluation of Alternatives

Evaluation of project alternatives should proceed only after a general consensus with the project team on viable alternatives has been reached. This will avoid redoing the analysis if new alternatives are suggested later on. The evaluation of project alternatives is performed by assessing all selected MOEs for the project using proper analysis tools as approved in the traffic analysis methodology. In most cases, the same MOEs and analysis tools used to evaluate the existing conditions should also be used for the project alternatives, including the No-Build alternative. MOEs are computed and compared for each project alternative for each analysis year. No-Build alternative MOEs are used as the baseline for comparison. This process results in recommendation of the best alternative that meets the project objectives.

The following is additional guidance that the analyst should review when evaluating the alternatives using microsimulation analysis:

- The simulation model of the project alternative should be created directly from a calibrated base model. The model parameters adjusted in the calibration process are typically carried forward without change during the alternative analysis stage, assuming traffic characteristics in the base model do not change. However, future change in the facility type or proposed improvements with design exceptions may dictate modification of some of the calibration parameters. When such modification is necessary, documentation should be provided. <u>Documentation should be provided and prior concurrence by CDOT and appropriate stake holders should be engaged.</u>
- Model verification/error checking is required to verify there are no coding errors in the model development process that could affect the accuracy of the model. The analyst should review the model input data for the alternative in question and may make adjustments to driver behavior and physical design elements as needed (such as lengths of acceleration/deceleration lanes in an attempt to improve operations.
- The number of runs and random seeds that were used to calibrate the base model should be used to simulate alternative models.

10
Application of Guidelines

10.1 Traffic Impact Studies

CDOT's *Recommended Outline for Traffic Impact Study* (2008) identifies the procedure and format for TISs on the State Highway System. The *State Highway Access Code* (2002) also identifies items that should be included in a TIS.

These guidelines do not replace either the *Recommended Outline for Traffic Impact Study* or elements of the *State Highway Access Code*. However, analysts and engineers completing TISs on the State Highway System are expected to apply these guidelines to their studies. Specifically:

- TISs on the State Highway System must include 20th year projections (also referred to as future projected "background" traffic volumes). Analysts and engineers will apply the methods of Chapter 9: Forecasting in developing 20th year projections.
- TISs on the State Highway System must provide a figure of the project's trip distribution. Where available, travel demand models are recommended to inform the assumed trip distribution. Big Data, including cellular-based O-D data, is an appropriate data source for trip distribution both in areas with and without travel demand models. Engineering judgment should be used to refine trip distributions based on these data sources and should be validated with CDOT data where available.
- When completing capacity and LOS analysis, analysts and engineers should use a traffic analysis tool or tools consistent with the recommendations of Chapter 5: Traffic Modeling and Analysis Tools. CDOT may reject analysis completed with non-approved tools.

The utility of the 20-year horizon assessment varies throughout the state.

- In some scenarios, the 20-year horizon assessment is used to establish development agreements in which developers fund improvements for future-year impacts, prior to receiving an approval for a connection to the state highway network.
- In other cases, the 20-year horizon assessment is used "for information only," as the local owner of the project (City or County) may approve developments that have impacts to the state highway system that do not require an access permit. The traffic numbers forecasted to be generated by

potential phases of large scaled developments then are used by the MPO for traffic modeling forecasting.

- The 20-year horizon forecast may be sought by reviewing agencies, such as FHWA.
- The 20-year horizon forecast should be used as design parameter by the access permitting authority to determine the minimum geometry for the proposed access connection along with assessing operational and safety impacts.

The selection of a forecasting method should consider these scenarios when determining if a Sketch Planning method or use of a travel demand model is most appropriate.

A travel demand model's forecasted demand volumes and/or project trip distribution may differ from those developed using a Sketch Planning method. There are no absolute rules as to which method produces a "right" forecast; rather, the engineer must provide fact- and data-based evidence upholding the forecasts. Variations in the recommended forecasting methodology should be agreed upon in writing with CDOT's project manager and, when applicable, Region Traffic Engineer and Access Manager.

10.2 Traffic Safety Studies

CDOT's *Highway Safety Improvement Program (HSIP) Manual* (2016) identifies the data and procedures to support traffic safety studies on all public roads. The *AASHTO Highway Safety Manual* (2010) provides additional information on how to diagnose crash contributing factors and how to select countermeasures to address or mitigate those contributing factors.

This section describes how these guidelines support the procedures set forth in CDOT's *HSIP Manual* and AASHTO's *Highway Safety Manual*. Specifically, these guidelines support the following components of safety analysis:

- Project Identification: CDOT uses two methods for identifying locations with potential for crash reduction: LOSS and Diagnostic Analysis. LOSS is based on the use of SPFs, which require traffic volume as an input. For historical analyses, traffic volumes are typically known. For analysis of future conditions, it is necessary to use forecasted future volumes. While LOSS describes the magnitude of the safety problem, it does not indicate the nature of the problem. The nature of the problem is determined through Diagnostic Analysis, including direct diagnostic and pattern recognition techniques. Refer to CDOT's Highway Safety Improvement Program Manual for further details on diagnostic analysis. CDOT's Safety Engineering and Analysis Group develops a statewide summary of locations with high potential for crash mitigation (LOSS III and IV) and locations with identified crash patterns. The summary is stratified by region and distributed to the CDOT Regions for consideration in project identification.
- Candidate Safety Projects: Each Region reviews the initial candidate listing of locations with higher potential for crash mitigation. The Regions may perform additional traffic and safety analysis to

diagnose underlying issues and determine the most feasible and cost-beneficial candidate safety projects. The Regions then submit candidate safety projects to CDOT's S&TE Office for further consideration.

- Technical Evaluations: CDOT HQ performs technical evaluations of candidate projects, including the calculation of a benefit-cost (B/C) ratio based on the economic analysis of crash reduction for candidate projects. This economic analysis relies on accurate estimates of future traffic volumes as well as other information on the cost and safety effectiveness of the proposed project. Refer to Appendix B of CDOT's Highway Safety Improvement Program Manual for a detailed description of the B/C calculation procedure.

The selection of a forecasting method should consider these scenarios when determining if a Sketch Planning method or use of a travel demand model is most appropriate. When conducting a traffic analysis, the analyst should consider performing a more detailed safety analysis if the study area includes a location identified on the statewide summary of locations with high potential for crash mitigation. If a Safety Assessment is required, please contact the Safety Engineering and Analysis Group for assistance.

10.3 Dynamic Traffic Assignment

The Dynamic Traffic Assignment (DTA) is an evolving technique in transportation modeling. The benefits of applying DTA in transportation analysis increase with network size and level of congestion. Both DTA modeling process and software capabilities are rapidly changing, the major benefit of using DTA is the capability of the modeling method to take into account the spatial and temporal effects of congestion in determining route choice, time of departure choice, and mode choice.

When to Use Dynamic Traffic Assignment

DTA modeling methods provide the practitioner with extensive capabilities in transportation modeling. Travel demand models dynamically assign traffic at various levels of technical sophistication. Recent activity-based models generally are sophisticated regarding time of departure and mode choice; however, their assignment still relies on average link speeds rather than incorporating node delay associated with intersection congestion. A microsimulation model is highly capable of estimating node delay associated with intersection congestion, but assumes fixed-route choice, time of departure choice, and mode choice. DTA aims to combine the strengths of each.

DTA is useful when the analyst's study area includes a congested transportation facility as well as its parallel facilities (or parallel capacity). Typically, DTA is applied to better understand traffic volume patterns over a large area. It may inform whether to implement a project on one corridor versus another. Or, it may inform how much traffic redistribution to expect from one facility to another. DTA's assignment methods is more sophisticated than a traditional travel demand model as it accounts for bottlenecks. DTA also allows for temporal spreading (peak-hour spreading). If well calibrated, a DTA can avoid multiple iterations of a travel demand model with standalone microsimulation. However, DTA does have limitations. DTA is generally best as an alternatives analysis or subarea planning tool to inform the demand volume's shifted temporal and spatial pattern. It does not replace detailed microsimulation for producing location-specific MOEs.

The capabilities of changing start times and using alternative route choices based on congestion and other information within the model allow for the testing of a multitude of transportation conditions. Applying DTA methods may require more effort than other static transportation modeling techniques; therefore, the need for DTA methods should be considered carefully, taking into account data needs, model building time, and calibration. The FHWA TAT Volume XIV provides the following list of potential project evaluations in which DTA could be an appropriate tool to include.

- Bottleneck removal studies;
- Active Transportation and Demand Management (ATDM) strategies;
- Integrated Corridor Management (ICM) strategies;
- Intelligent Transportation Systems (ITS) strategies;
- Operational strategies;
- Demand management strategies;
- Additional capacity;
- Incident management response scenarios;
- Special events;
- Work zone impacts and construction diversion; and
- Managed lanes and tolling projects.

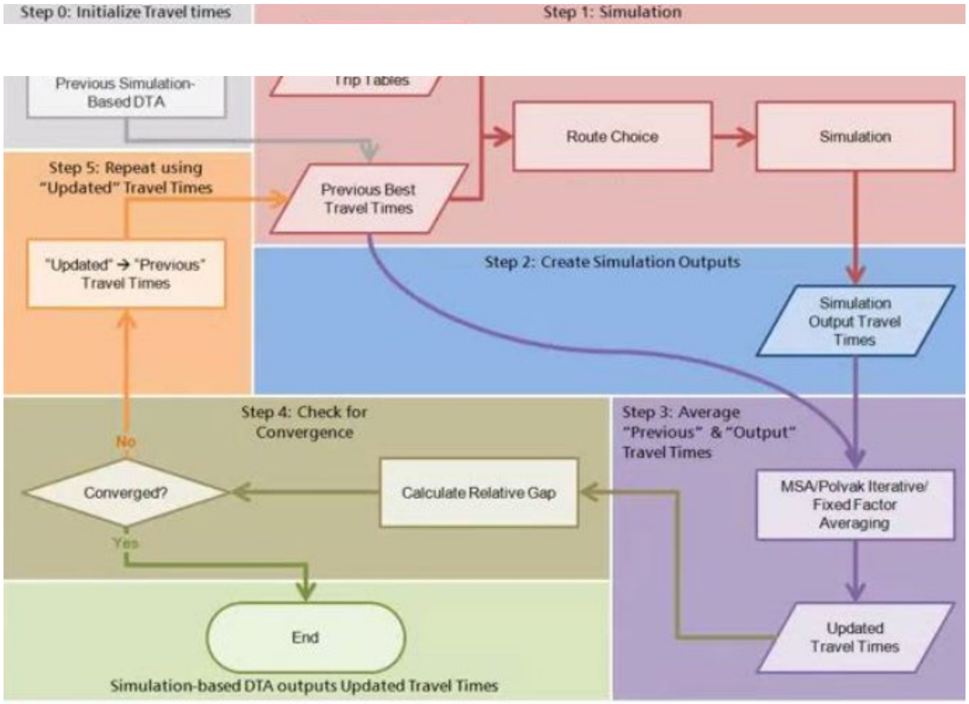
10.3.1 Basic DTA Requirements

The requirements for preparing and applying DTA consist of traffic modeling software capable of handling DTA, adequate and sufficient data for the development and calibration of a model, and the knowledge and skills to apply the tools. The FHWA TAT Volume XIV provides a brief overview of the key requirements to apply a DTA.

- **Regional Travel Demand Model –** The development of a DTA model requires O-D data as inputs. Building a DTA model without this type of information is very difficult. Ideally, the travel demand model for a region should be stratified into peak periods or individual hours. Daily regional models (24-hour assignments) are too coarse for a DTA modeling approach that examines congestion and traffic assignments at a time increment of less than 1 hour. Additional O-D Data, if desired, can usually be obtained through third party vendors, i.e. AirSage, and StreetLight.

- **Robust Data Collection –** In order to build and calibrate a DTA model, sufficient amounts of data collected in the field should be available so that the variation of traffic and congestion is understood and quantified. The types of temporal-based data to be collected include traffic counts, speeds, congestion, and geographic data such as base mapping and lane geometry.
- **Traffic Modeling Tool with DTA Capability –** The traffic analysis tool used must have DTA capabilities with the desired resolution needed for the analysis, such as VISSIM and TransModeler.
- **Transportation Modeling Skills –** The application of DTA is another layer on top of existing transportation modeling techniques. Having fundamental knowledge of travel demand modeling and micro/mesoscopic simulation modeling techniques and working knowledge of model calibration and statistical analysis is needed to apply DTA successfully. An example is provided below.

Figure 20 illustrates the steps of running a travel demand model.



Source: Caliper

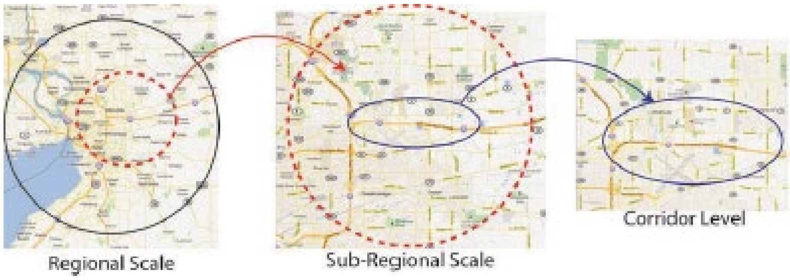
10.3.2 Model Size and Resolution

The size of model networks can vary greatly when DTA is applied. Since route choice is a major element of DTA, the size of the model network at a minimum should include alternative routes to allow route choice to occur.

Improving software and computing capabilities are making it possible to apply DTA at different scales. **Figure 21** visualizes the difference model scales. DTA may be incorporated into the following models.

- **Macroscopic** - Macroscopic models refer to regional travel demand models for both traditional trip-based models and Activity-Based Models (ABM).
- **Mesoscopic** - These models use aggregated flow relationships and include more precise representation of traffic operations than travel demand models. DTA applications are strongly associated with mesoscopic type modeling software.
- **Microscopic** - These models simulate individual vehicle-to-vehicle interactions and traffic control strategies. DTA applications in microscopic models provide the most complex analysis of all the model types.

Figure 21: Model Scales



Traffic modeling often involves a combination of some or all of these model types. This concept is referred to as *Multi-Resolution Modeling (MRM)*. Multi-resolution modeling (MRM) is an effective method for linking analysis tools with different resolutions to enhance DTA. Within the MRM framework, results from one model are fed to another in an iterative process so that overall analysis results are improved and consistency between model assumptions is maintained.

10.3.3 Model Timeframes and Analysis Contexts

DTA can be applied for various time periods and time intervals. DTA also can be applied to near-term and future long-range plans, to fine tune travel demand estimates, and to conduct operational analysis on design improvements.

11 Analysis Documentation

The purpose of this chapter is to provide guidance on the requirements for analysis documentation. Documentation is the process of making a clear and concise presentation of analytical findings which is a critical element of a successful analysis. Clearly show how alternatives differ in both intent and in what specific model parameters or methods were used to capture those differences. The final report should include the following:

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

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Glossary

Analytical/Deterministic Tools—Most analytical/deterministic tools implement the procedures of the *Highway Capacity Manual* (HCM). These tools quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities. These tools are equation based, with the analyst inputting the data and parameters into the equation and the HCM procedures producing a single answer. These tools are intended for analyzing the performance of isolated or small-scale transportation facilities, but are limited in their ability to analyze network or system effects.

Big Data—Big Data describes vast data sets that are so voluminous and complex that traditional data-processing application software is inadequate to deal with them. In transportation, Big Data is generated through numerous devices, including probe data, smartphones, and traffic sensors and is available for purchase from third-party vendors.

Calibration—Process where the analyst selects the model parameters that cause the model to reproduce field-measured local traffic operations conditions the best. (FHWA TAT: Vol III, 2019)

Capacity—The theoretical maximum number of vehicles that can be carried on a street or highway under given conditions.

Crash Frequency—A quantitative measure of safety performance representing the number of crashes estimated to occur at a particular site, facility, or network based on crash history, traffic volume, and other site characteristics. There are three specific terms used to define crash frequency: 1) observed crashes, 2) predicted crashes, and 3) expected crashes.

Crash Severity—The level of most serious injury or property damage due to a crash, commonly divided into categories based on the KABCO scale.

Demand Volume—The measurement of how many people or vehicles need to get through a transportation network over a studied period of time.

Expected Crashes—An estimate of the long-term average safety performance based on the weighted average of observed and predicted crashes using the Empirical Bayes method. If the observed crash history is not available or applicable, then the weight assigned to the observed crashes is zero and the expected crashes is based solely on the predicted crashes. If a reliable SPF is not available for the facility type of interest and the crash history is available and applicable, then the weight assigned to the SPF is zero and the expected crashes is based solely on the observed crashes.

Forecasting—The prediction of travel demand. Its focus may be predicting traffic flow along the highway network, or a more detailed focus such as destination choice, mode choice, time-of-day travel choice, or route choice.

Interrupted Flow—Flow is regulated by external means, such as a traffic signal. Vehicle-vehicle interactions, as well as interactions between vehicles and the roadway, play a secondary role in defining the traffic flow. For example, vehicles traveling on an urban arterial with traffic signals are participating in interrupted flow.

Level of Service (LOS)—A qualitative measure used to relate the quality of motor vehicle traffic service. LOS scores are assigned on an A to F scale. LOS A represents unrestricted flow conditions, while LOS F represents over-saturated conditions.

Level of Service of Safety (LOSS)—A quantitative measure of safety performance used to compare the expected safety performance of a given roadway or intersection to the average safety performance of roadways or intersections with similar geometric and operational characteristics. LOSS-I indicates low potential for crash reduction, LOSS-II indicates low to moderate potential for crash reduction, LOSS-III indicates moderate to high potential for crash reduction, and LOSS-IV indicates high potential for crash reduction. Refer to Appendix A of CDOT's Highway Safety Improvement Program Manual for further details and calculation of LOSS.

Macroscopic Models—Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as the microscopic models. (FHWA TAT: Vol I, 2004)

Mesoscopic Models—Mesoscopic simulation models combine the properties of both microscopic (discussed below) and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Movement, however, follows the approach of macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques. (FHWA TAT: Vol I, 2004)

Measures of Effectiveness (MOE)—The purpose of computing traffic performance measures of effectiveness is to quantify the achievement of a project's traffic operations objectives. (FHWA TAT: Vol VI, 2007)

Metropolitan Planning Organization (MPO)—A federally mandated and federally funded transportation policy-making organization in the United States that is made up of representatives from local government and government transportation authorities.

Microscopic Models—Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small-time intervals (e.g., one second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed. (FHWA TAT: Vol I, 2004)

Model—The combination of modeling software and analyst-developed input/parameters for large statewide, regional, sub regional or local study areas to determine transportation-specific MOEs. A single model may be applied to the same study area for several time periods and several existing and future improvement alternatives. (Adapted from FHWA TAT: Vol III, 2019)

Observed Crashes—The number of reported crashes at a specific location during a defined time period.

Over-Saturated Conditions—This occurs when traffic flow rate approaches or exceeds the capacity of a transportation facility. For most facility types, this corresponds to LOS E or LOS F conditions. Symptoms of an over-saturated condition include irregular flow rate, variable speed, or traffic queues on freeways; vehicles waiting more than one cycle or significant traffic queues at a traffic signal; and significant traffic queues at a roundabout.

Predicted Crashes—The estimated number of crashes from a safety performance function.

Safety Performance Function (SPF)—An equation that represents the statistical relationship between safety and roadway characteristics for a given facility type. A facility type represents a group of similar segments or intersections, typically defined by geometric and operational characteristics such as traffic control (signalized, stop-controlled, uncontrolled), area type (urban or rural), number of lanes, and number of approaches.

Service Volume—The amount of travel demand served by a given amount of capacity over a studied period. Service volume is less than demand volume when a transportation network is over capacity.

Sketch Planning—Sketch Planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. They allow for the evaluation of specific projects or alternatives without conducting an in-depth engineering analysis.

Software—Set of computer instructions for assisting the analyst in the development and application of a specific model. Several models can be developed using a single software program. These models will share the same basic computational algorithms embedded in the software; however, they will employ different input and parameter values. (Adapted from FHWA TAT: Vol III, 2019)

Spatial Limits—The geographic extents/boundary limits of the study area or model that the analyst includes in the analysis. The spatial limits of a transportation network should be sufficient to encompass all the traffic congestion present in the primary influence area of the project.

Subarea Model—An area within a large-scale (typically, regional) travel demand model that is further refined to produce more detailed travel forecasts for the study area.

Temporal Limits—The target analysis period during which the analyst studies a transportation facility. The temporal limits should be sufficient to include all congestion related to the base case and each alternative. Otherwise, the model will not measure all the congestion associated with an alternative, resulting in under-reporting the benefits because the demand volume has not been captured. The temporal limits need to capture traffic volumes from an uncongested condition to an uncongested condition.

Travel Demand (or Demand Volume)—The measurement of how many people or vehicles need to get through a transportation network over a studied period. Travel demand often is based on the demographic data of the region and the available routes between origins and destinations. When a transportation network is at or over capacity, not all travel demand will be served. Service volume is the amount of travel demand served by a given amount of capacity over a studied period.

Traffic Analysis—The quantifiable evaluation, simulation, or optimization of the operations of transportation facilities and/or systems. Traffic analysis can include the modeling of existing operations and predicting probable outcomes for proposed design alternatives or land use scenarios.

Traffic Analysis Zone (TAZ)—A geographical subdivision of the travel demand model area containing information about population, households, and employment. TAZs typically are derived from U.S. Census boundaries to make tabulating the socioeconomic data easier.

Under-Saturated Conditions—Traffic flow rate is below the theoretical capacity of the transportation facility. For most facility types, this corresponds to LOS A through LOS D.

Uninterrupted Flow—Flow is regulated by vehicle-vehicle interactions and interactions between vehicles and the roadway. For example, vehicles traveling on a freeway are participating in uninterrupted flow because there are no traffic control devices to interrupt that flow.

Validation—Process where the analyst checks the overall model-predicted traffic performance to predict future behavior. Model validation is performed based on field data not used in the calibration process. (FHWA TAT: Vol III, 2019)

Vehicle Classification—A range of vehicle types, such as motorcycles, passenger cars, buses, and heavy vehicles or trucks. FHWA classifies vehicles into 13 categories, including motorcycles, passenger cars, buses, single-unit trucks, and trailer trucks.

Verification—Process where the software developer checks the accuracy of the software implementation of traffic operations theory. (FHWA TAT: Vol III, 2019)

QSG
Quick Start Guide

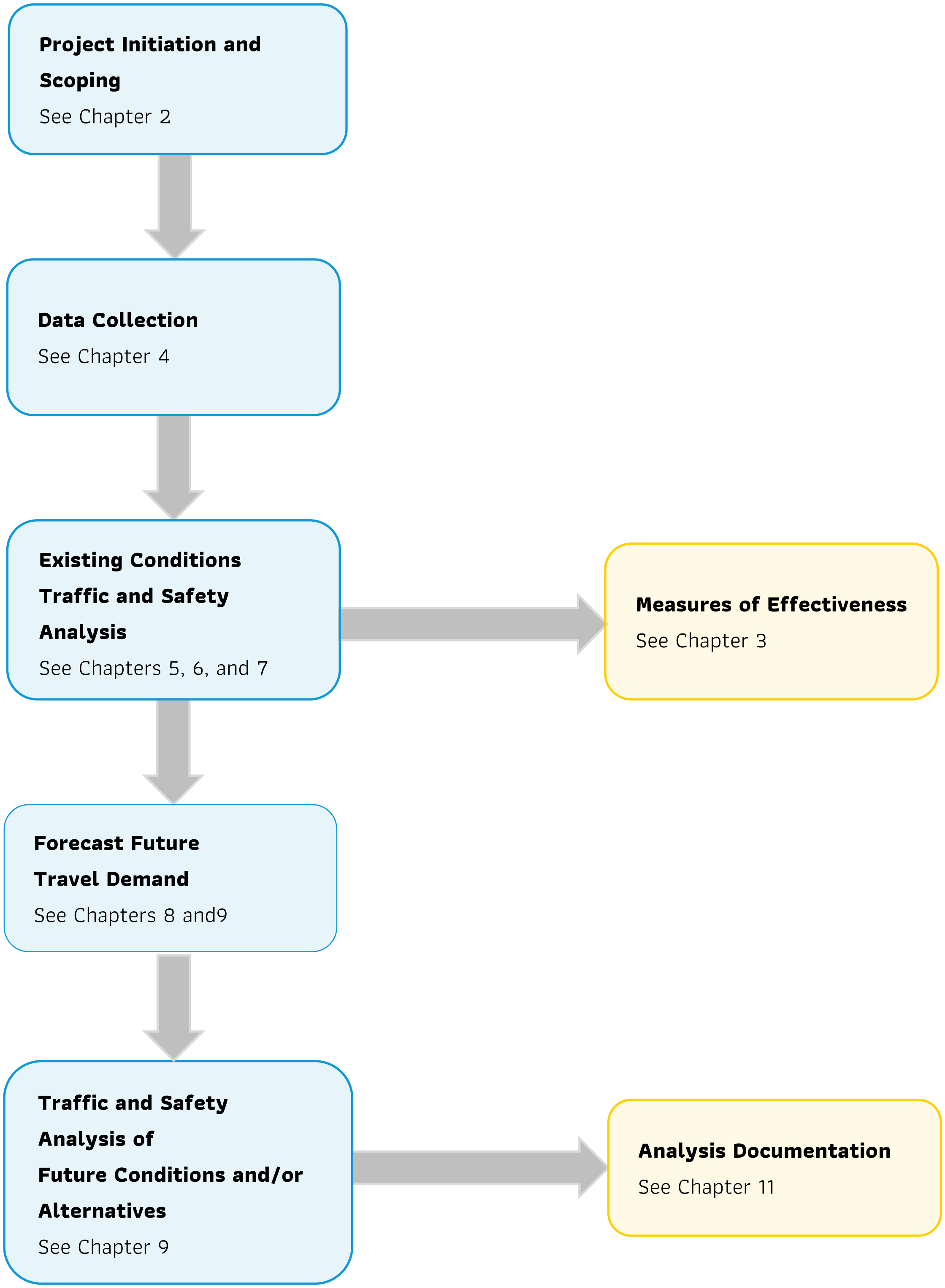
Overview

This Quick Start Guide provides the analyst with a quick summary of the required steps for a typical traffic analysis and forecasting process for a project on the State Highway System. This Quick Start Guide addresses a typical traffic analysis and forecasting project that includes:

- Data collection
- Existing conditions traffic and safety analysis
- Forecasting of future travel demand
- Traffic and safety analysis of future conditions and/or alternatives

Not all projects follow this typical pattern. The Quick Start Guide identifies common exceptions and where the guidelines address those exceptions. **Figure 22** shows the process of a typical traffic and safety analysis and forecasting process for a project on the State Highway System.

Figure 22: Typical Traffic and Safety Analysis and Forecasting Process Flowchart



Project Initiation & Scoping

The project's scope, which defines the extent or range of the project's effort, needs to account for every step of the traffic analysis, safety analysis, and forecasting process. Scoping happens at the project's initiation; however, coordination and interim checks throughout the project's progression to completion help ensure successful outcomes. The Quick Start Guide provides high-level scoping considerations; Chapter 2 includes detailed information on project scoping. For CDOT-funded projects, variations in a project's scope from these guidelines should be agreed upon in writing with CDOT's project manager and documented in the project's deliverables. Analysts preparing a TIS also may wish to collaborate with CDOT up-front to agree on any variations to the study's scope. The project's schedule and budget will be designed to accommodate this scope. The project scope should not be scaled to meet a predetermined schedule and budget.

Data Collection

Upon initiating the project, the analyst first collects data pertaining to:

- Roadway geometrics (segment lengths, lane configurations, etc.)
- Traffic controls (control type, signal timings, etc.)
- Vehicle characteristics (vehicle classification)
- Demand (entry volumes, per-lane volumes, O-D data, etc., per the established temporal limits)
- Performance (travel speeds/times, queue lengths, lane utilization, crash history, etc.)

Data Collection
Notes and Exceptions:

OTIS and COGNOS may be acceptable data sources for CDOT projects.

Big Data may substitute for detection-based data or add value where other data cannot. Chapter 4 includes more detail regarding data collection.

The analyst also will complete field observations to verify that the MOEs resulting from the existing conditions traffic and safety analysis match conditions observed in the field. These field observations also may be used to calibrate a microsimulation model.

Existing Conditions Traffic and Safety Analysis

When the data collection is complete, the analyst will perform the existing conditions traffic and safety analysis. The analyst will select the appropriate tool according to **Table 8**: Traffic Analysis Tool Selection Matrix or the list of safety analysis tools following **Table 6**: Deterministic Safety Software Strengths & Weaknesses. Based on the existing conditions traffic and safety analysis, the analyst then chooses the MOEs, such as LOS or LOSS and its associated measures (delay, density, speed, expected crashes, predicted crashes, etc.). The existing conditions MOEs are compared later with the MOEs resulting from traffic and safety analysis of future conditions and/or alternatives.

Existing Conditions Traffic and Safety Analysis

Notes and Exceptions:

Chapter 5 includes more detail regarding traffic and safety analysis.

Traffic analysis MOEs most commonly include LOS and its associated measures (delay, density, speed, etc.). While these MOEs often are pertinent to a project, additional MOEs typically are necessary to understand the pros and cons of a project. Additional or alternative MOEs are to be determined by the analyst.

Safety analysis MOEs most commonly include LOSS and its associated measures (observed, predicted, and expected crash frequency). While these MOEs often are pertinent to a project, additional MOEs may be necessary to understand the pros and cons of a project. Additional or alternative MOEs are to be determined by the analyst.

Forecasting MOEs most commonly include demand volume. Chapter 3 identifies additional MOEs that should be considered for use in projects. The analyst must confirm that the selected method/tool supplies the desired MOEs and must collect the data necessary to derive each MOE.

Analyzing under-saturated facilities using deterministic tools usually requires a lesser level of effort than over-saturated facilities using microsimulation. Chapter 2 includes detail regarding the scoping of these projects.

If using microsimulation, analyst must follow the guidance in Chapter 7.

Forecast Future Travel Demand

The analyst forecasts future travel demand using the methods identified in Chapters 8 and 9. This will determine whether the analyst will use a Sketch Planning method, a regional travel demand model, or the Statewide Travel Model. Traditionally, this step follows the existing conditions traffic and safety analysis; however, the two steps can be completed in parallel.

Forecasting Future Travel Demand

Notes and Exceptions:

Chapter 9 includes more detail regarding forecasting.
Some projects, such as signal retiming studies, are based on existing traffic conditions. In these projects, the forecasting of future travel demand is not necessary.

Traffic and Safety Analysis of Future Conditions & Alternatives

The analyst will complete traffic and safety analysis of future conditions and/or alternatives, applying future demand volumes to the traffic or safety analysis tool. The analyst will produce MOEs for the future conditions and/or alternatives. The MOEs from each alternative will be compared against each other to derive findings and conclusions.

Reinforcing with Project Examples:

This section provides only a summary of findings related to each project example. See Chapter4: Data Collection, Chapter 5: Traffic Modeling and Analysis Tools, and Chapter 9: Forecasting for more detailed findings related to each project example.

Project 1: PEL for an Urban Freeway Segment within a Large Region

Project 1 is a Planning & Environmental Linkages Study for an urban freeway segment within a large, densely populated region. A new freeway interchange is being considered along this freeway segment. Currently, the freeway segment is congested, and congestion is anticipated to increase in the future.

- A variety of roadway geometric, traffic control, vehicle characteristic, and demand volume data must be collected. Microsimulation will be performed given the over-saturated condition; therefore, O-D data and detailed performance data also are needed (travel speeds/times and queue lengths). Field observations should be completed.
- TransModeler and VISSIM are appropriate traffic analysis tools for this study as the study area includes both uninterrupted flow and interrupted flow facilities in over-saturated conditions.
- Forecasts should be prepared with the regional travel demand model.

Project 2: Capacity Needs Analysis for an Urban Arterial in an Isolated City

Project 2 is a study to identify future capacity needs on an urban highway in an isolated city generally surrounded by sparsely populated areas. There is no congestion currently on the highway, although a few turning movements experience high delay during peak hours. While these movements may worsen over time, it is unlikely that the highway will become congested.

- A variety of roadway geometric, traffic control, vehicle characteristic, and demand volume data must be collected. Microsimulation will not be performed given the under-saturated condition and lack of unique geometry; therefore, minimal performance data is needed (only queue lengths). Field observations should be completed.
- HCS, Synchro, and Vistro are appropriate traffic analysis tools for this study involving interrupted flow facilities in under-saturated conditions.
- Forecasts should be prepared with the Statewide Travel Model (no regional travel demand model is available and a long-range forecast is necessary).

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Appendix A: Scoping Checklist

Scoping Checklist

Colorado Department of Transportation

GENERAL INFORMATION	
Date:	
Reviewed by:	

TRAFFIC MODEL DESCRIPTION		
Project Name/Description	Region	Highway/Roadway(s)
Traffic Model Name/Description	Analysis Scenario/Alternative	Analysis Year(s)

Scoping Checklist

Item	Description	Check	Remarks
Study Objective	What is the study objective, purpose and need, and location?		
Technical Guidance and Standards	Which guidelines or standards will be applicable to conduct the study?		
Analysis Area Boundary Limit	What is the anticipated spatial and temporal limits?		
Analysis Tool(s) Selection and Analysis Approach	What approach has been used in the past within similar studies? Is this approach acceptable?		
Data requirements and data collection plan	What data collection requirements are anticipated? (sources, techniques, schedule, calibration/validation requirements)		
Project Traffic Forecasting	Will future traffic volumes be necessary? What is the anticipated forecasting approach?		
Analysis Output	What are the desired Measures of Effectiveness (MOEs)? Does the anticipated tools produce these MOEs?		
Project Alternatives	How many alternatives will be required?		
Traffic Analysis Report and Technical Documentation	What documentation will be required with the study?		
Project Schedule	What is the anticipated project schedule?		
Estimate of Work Effort	Include an estimate of the level of analysis effort.		

Appendix B: Signal Timing Objective, Strategy, Tactic Matrix

CONTEXT		OBJECTIVES	CONTEXT		STRATEGY	CONTEXT		TACTIC
Uncongested	Typical Conditions	Intersection — Equitable Distribution of Green To provide access equity, **the demand for all phases will be handled equitably** by serving all movements regularly and **not providing preferential treatment to coordinated movements** to the extent that delays and stops of other movements are significantly increased. To do this objective function is to balance delays. Strategies to prevent queue overflow on minor movements may be needed.	Isolated	Light flow	Minimize phase failures			Design passage time and max green to reduce phase failures
				Moderate flow	Reduce wait time			Design passage time and max green to reduce wait time
			In network	Moderate flow	Minimize delay			Webster's Method
								Highway Capacity Manual's Quick Estimation Method
								Critical Movement Analysis
				Mobility > Access	Maximize coordinated split	Some spare capacity at signal		Design minimum split for non-coordinated phases
		Network — Smooth Flow This objective seeks to **provide a green band** along an **arterial road**, in **one or both directions**, with the relationship between the intersections arranged so that **once a platoon starts moving it rarely slows or stops**. This may involve holding a platoon at one intersection until it can be released and not experience downstream stops. It may also involve **operating non-coordinated phases at a high degree of saturation** (by using the shortest possible green), within a **constraint** of preventing or **minimizing phase failures and overflow of turn bays** with limited length, and with **spare time in each cycle generally reverting to the coordinated phases.**	Design Network Cycle Length					
			Linear arterial	Predominantly one way flow	One-way progression	Any intersection spacing		Consensus cycle length
				Two way flow	Two-way progression	Even intersection spacing		Resonant cycle length
						Uneven intersection spacing	Sufficient left turn phases	Resonant cycle length using average spacing
							Few/no left turn phases	Consensus cycle length
			Grid	One way streets	Four-way progression	Even intersection spacing		Quarter cycle
			Design Intersection Splits					
			Any network		Progression	Travel to the area more important than travel through the area		Use equitable distribution of green
						Travel through the area more important than travel to the area		Maximize coordinated splits
			Design Offsets					
			Linear arterial	Predominantly one way flow	One-way progression	Minimal side street turning traffic		Design offsets for first car
						Moderate side street turning traffic		Design offsets for first car with queue clearance
				Two way flow	Two-way progression	Equal/favorable intersection spacing		Resonant offsets
						Unequal/unfavorable intersection spacing	Sufficient left turn phases	Resonant offsets with lead-lag phasing
			Grid	One way streets	Four-way progression	Even intersection spacing		Quarter cycle
			Design Phase Sequence					
			Arterials and grids	Signals without left turn phases	Progression			Use default phase sequence (no options)
				Signals with left turn phases	Two- and four-way progression	Excellent bandwidth		Use default phase sequence
						Poor bandwidth		Use lead-lag phasing to maximize bandwidth
	Special Condition	Intersection — Equitable Treatment by Mode	Isolated		*(not covered)*			
		Network — Programmed Stop	In Network		*(not covered)*			
		Many Other Objectives			*(not covered)*			

CONTEXT		OBJECTIVES	CONTEXT		STRATEGY	CONTEXT	TACTIC
Congested	Typical Conditions	Intersection Throughput This objective seeks to **provide a green split** that provides the **maximum throughput** at the stop bar **maintaining** a **high degree of saturation without causing unacceptable congestion** or delay on the non coordinated movements. The **non-coordinated** phases would typically be **vehicle actuated** and operated at a **high degree of saturation** (by using the shortest possible green), within a constraint of preventing or minimizing phase failures and overflow of turn bays with limited length, and with spare time in each cycle generally reverting to the coordinated phases.	Inappropriate timing		Fix timing		As needed (meet OST)
			Failed equipment		Fix equipment		As needed (meet functionality)
			Problematic geometry	Storage bay spillback	Mitigate problematic geometry		Short bay method
				Storage bay blocking	Mitigate problematic geometry		Lead/Lag phasing
				Both spillback and blocking	Mitigate problematic geometry		Phase reservice
			Excess demand		Minimize unused green	Try this first	Aggressive passage times
						Early phase terminations	Variable gap times (with aggressive minimum gap)
						Phase stays green too long	Cap the max greens
					Improve lane flow	Flows inconsistent with lanes	Change lane striping
						In coordinated network	Drop out of coordination
						Multilane approaches	Lane-by-lane detection
						Any/all	Think like HCM adjustment factors
		Network Manage Queues Where there are closely spaced intersections, such as at a diamond interchange or within a tight grid network, and especially when a short block is fed by movements from various phases, **the primary objective is to ensure that queues do not block upstream intersections or movements** (such as occurs when a left turn bay spills over into adjacent lanes, or left turn queues exceed the intersection spacing at a tight diamond interchange). **This often requires constraints on cycle lengths and phase lengths to ensure that a large platoon does not enter a short block** if it must be stored within that block and wait for a subsequent green phase. **It may also involve "gating" a movement, so that a movement is stored at an intersection simply to hold it in a location that has sufficient queuing capacity**, even though other movements at the intersection may not require the green time. **Phase reservice** may also be an effective tool in management of queues, especially for minor movements where queue overflows can cause problems for major movements.	Operational issues from queue spillback	Two way flow	Gating	Bottleneck Intersection(s)	OSTs from Intersection – Throughput
						Upstream of the Bottleneck	Cycle/Splits/Offsets for bottleneck queue relief
				Predominately one way flow	One-way gating	Light Side/Midblock Turns	Last car
						Moderate Side/Midblock Turns	Simultaneous offsets
						Heavy Side/Midblock Turns	Negative offsets
			Safety issues from queue spillback		Prevent unsafe queues		Cycle/Splits/Offsets to serve priority movements
	Special Condition	Intersection Preferential Distribution of Green			*(not covered)*		
		Network Priority to Arterial			*(not covered)*		
		Many Other Objectives			*(not covered)*		

Appendix C: Microsimulation Model Review Checklist

Microsimulation Model Review Checklist

Colorado Department of Transportation

GENERAL INFORMATION

Date:

Reviewed by:

MICROSIMULATION MODEL DESCRIPTION

Project Name/Description	Region	Highway/Roadway(s)
Traffic Model Name/Description	Analysis Scenario/Alternative	Analysis Year(s)
Describe how the Temporal Limits of the Model were determined:		

Analysis Time Period(s)

Analysis Time Period(s)

□Weekday AM Peak	□Weekday Midday	□Weekday PM Peak	□Friday Peak	□Sat Peak	□Sun Peak	□Other:
Hours:	Hours:	Hours:	Hours:	Hours:	Hours:	Hours:

Description of Data Collection Plan (Verification/Validation):

Software/Tool(s) Utilized:

Microsimulation Model Review Checklist

Colorado Department of Transportation

Purpose & Scope of Review:

Spatial Limits of Model:

Other Notes:

Item	Guidance	Comment
Microsimulation Model Calibration Targets	Documentation shall be provided to verify that the model is calibrated according to the calibration targets in Section 4.5.1 of the CDOT Traffic Analysis and Forecasting Guidelines.	
Microsimulation Model Review	Visually review the microsimulation model for the following settings below:	
	- Lanes - lane configurations, link speeds, lane widths, roadway grades	
	- Volumes - vehicle volumes shall be balanced; vehicle routing should follow existing patterns	

REVIEW ITEMS (Continued)		
Item	**Guidance**	**Comment**
Microsimulation Model Review	Signal timings (if applicable) - should match existing signal timings or reasonable plus project or future year signal timings.	
Microsimulation Parameters	Documentation shall be provided to verify that model parameter adjustment to achieve model calibration was done in compliance with Section 4.5.1 of the CDOT Traffic Analysis and Forecasting Guidelines.	
Microsimulation Post-processing	Verify that at least 10 runs within the standard deviation of simulated volume served and simulated network delay were used.	

Appendix D: CDOT *StateFocus* Travel Model Release Agreement

Colorado Department of Transportation
***StateFocus* Travel Model**
Release Agreement

This Release Agreement is made and entered into by and between the undersigned recipient and the Colorado Department of Transportation (CDOT) with respect to CDOT's release to recipient of a copy of CDOT's *StateFocus* statewide travel model for use in association with the specific project identified below.

Project Name: ____

The recipient hereby acknowledges and agrees as follows:

1.0 Current version of StateFocus

1.1 CDOT has released the latest version of its statewide travel model *StateFocus,* version indicated below, based on the TransCAD software platform. *StateFocus* is calibrated to run using TransCAD version indicated below and initialed by an authorized representative of CDOT:

StateFocus: ____
____
TransCAD: ____
____

Initials of CDOT representative: ______________

1.2 *StateFocus* is not calibrated to operate accurately using any other versions of TransCAD than those indicated above, due to ongoing updates made by Caliper Corporation to the software platform. Recipients wishing to use *StateFocus* with other versions of TransCAD, shall be responsible for insuring the model's calibration against various observed travel measures. CDOT reserves the right to review such calibration efforts.

1.3 *StateFocus* software package, which includes StateFocus EXE, GISDK scripts, and model parameters, is stored on CDOT's modeling server, and will be made available to the signatories of this Release Agreement, upon execution of this Release Agreement.

1.4 This Release Agreement gives recipient solely a non-exclusive revocable license to access and use, as limited herein, *StateFocus* and the data therein. Recipient agrees that *StateFocus* is the sole property of CDOT and that the data therein is the sole property of CDOT and/or third-party providers of data.

2.0 Conditions for Release

As consideration for the release to recipient of *StateFocus* and the technical assistance provided by CDOT described below, the recipient agrees to all terms and conditions of release described in this Release Agreement.

2.1 The recipient is responsible, at its own expense, for purchase and maintenance of TransCAD from Caliper Corporation. The recipient agrees to abide by all copyright use restrictions, and other conditions of sale of TransCAD by Caliper Corporation.

2.2 The recipient will not distribute *StateFocus* to any party in any form without the prior written consent of CDOT. CDOT authorizes recipient to distribute *StateFocus* as received from CDOT to the parties explicitly identified below as contractors or agents of recipient for the specific project(s) identified below, as initialed by an authorized representative of CDOT.

These contractors and agents agree to be bound by the same terms of this release as the recipient. Authorized representatives of contractors and agents will execute a copy of this Release Agreement providing the same information requested of recipient. Any additional parties interested in using *StateFocus* will be referred by recipient directly to CDOT.

1. ____
2. ____
3. ____
4. ____

Initials of CDOT representative: _______________

2.3 The recipient will not make any changes to StateFocus software or parameters without the prior written consent of CDOT, other than minor software customizations necessary to allow *StateFocus* to operate on the recipient's hardware (such as software installation paths, or number of processing cores available), and any modifications explicitly listed below and initialed by an authorized representative of CDOT.

____
____
____
____

Initials of CDOT representative: _______________

Any request for further modifications shall be limited to the changes as presented in writing by the recipient to CDOT for its consent. No consent for changes not outlined herein is given or implied by this Release Agreement.

2.4 To the extent permitted by law, the recipient shall indemnify and hold harmless CDOT, its officers, employees and agents, against any and all claims, damages, liability and court awards, including all costs, expenses, and attorney's fees, arising out of recipient's performance or non-performance of this Release Agreement or from the recipient's use of *StateFocus* and any data or information therein.

2.5 The recipient agrees to strictly limit the use of the *StateFocus* travel model to the following project: ____ for the client:______________________. The recipient must not use *StateFocus* for any other project for which a separate release agreement has not been executed. Violation of this term may be grounds for termination of this Release Agreement.

2.6 At CDOT's option, all results of recipient's modeling will be submitted to CDOT for review and concurrence before release of the results to any other parties. CDOT will, at its option, re-run any of the recipient's models to verify proper use of the travel model.

2.7 In the event that CDOT has authorized modifications to *StateFocus* software or parameters, recipient agrees to provide to CDOT, upon request, electronic versions of such modifications and/or technical documentation describing such modifications.

3.0 Technical Assistance; No Warranty

3.1 CDOT will provide to the recipient copies of CDOT network, zone system, demographic data set, program control batch files, user guide materials, and any other files necessary to operate *StateFocus.*

3.2 CDOT retains the right to change, update, or withdraw permission to use *StateFocus* and to terminate this Release Agreement, with with ten days (10) written notice, , at any time for any or no reason. In the event of termination, recipient shall return to CDOT all copies of *StateFocus* and any other files and information released pursuant hereto without penalty or right to cause of action or recourse against CDOT.

3.3 CDOT MAKES NO WARRANTY OR REPRESENTATION AS TO THE ACCURACY OR SUITABILITY FOR A PARTICULAR PURPOSE OF *StateFocus* OR DATA PROVIDED FOR USE WITH *StateFocus*, AND CDOT DISCLAIMS ALL WARRANTIES, SPECIFICALLY THE WARRANTIES OF MERCHANTABILITY AND PARTICULAR PURPOSE. RECIPIENT RELEASES CDOT FROM ANY CLAIMS, JUDGEMENTS, OR DAMAGES, CONSEQUENTIAL OR DIRECTLY ARISING FROM ANY ERRORS OR OMISSIONS CONTAINED WITHIN *StateFocus* AND THE DATA PROVIDED, OR ANY PART THEREOF, OR ARISING FROM ANY RELIANCE UPON THE *StateFocus* MODEL OR DATA OR OMISSIONS THEREFROM.

3.4 Any opinions expressed by the recipient or representations made by the recipient based upon *StateFocus* output data are the sole responsibility of the recipient. Should recipient make any modification to the transportation networks, demographic data sets, software, or model parameters, recipient shall not characterize the resulting forecasts as originating from, belonging to, or being endorsed by CDOT, unless such modifications are formally adopted by CDOT. Instead, recipient shall characterize such results as based on recipient's modifications of CDOT's *StateFocus* model.

4.0 Confidential Information

4.1 Recipient acknowledges that the *StateFocus* statewide travel model released to recipient includes certain Quarterly Census of Employment Wages data (QCEW Data) collected by the Colorado Department of Labor and Employment (DLE), specifically total employment numbers by business class, and latitudinal and longitudinal location. Recipient agrees to maintain the QCEW Data as confidential and to use the same, and any part thereof, solely to assist the recipient's Project. Recipient's use of QCEW Data shall be consistent with all terms hereof and the provisions of any applicable state or federal regulations.

4.2 Recipient shall restrict access to the QCEW Data to only those employees or agents of the recipient whose access is necessary to assist the recipient's Project. Upon request of CDOT or DLE, recipient shall provide, in a timely manner, a listing of all individuals who have access to *StateFocus* and the QCEW Data therein. Except in the event it is necessary for the recipient to utilize a third-party to format, process or use the QCEW Data for recipient's Project, the recipient shall not copy or permit others to copy or access the QCEW Data, or any part thereof. In the event the recipient must utilize a third-party to format, process, or use the QCEW Data, the recipient shall not allow the third-party to use the same, or any part thereof, for any purpose other than the recipient's Project. The recipient shall ensure the QCEW Data is adequately secured from non-authorized access or publication, and that any such third-parties are bound to terms identical to this Release Agreement.

4.3 Recipient shall not publish, sell, or disclose the QCEW Data, or any part thereof, to the extent that the information published of any area, industry, federal department or federal agency level contains fewer than three (3) reporting units (as defined in C.R.S. 8-70-103(9), 1987 Rep. Vol., as amended), or eighty percent (80%) of the total employment of the applicable reporting level is made up by a single reporting unit.

4.4 If requested by CDOT or DLE, recipient, and any third-party that the recipient engages, shall permit the DLE, the U.S. Department of Labor, or any other duly authorized agent or governmental agency, to monitor all activities conducted by the recipient or third- party related to the use of QCEW Data provided within the *StateFocus* model. Such monitoring may consist of internal evaluation procedures, examination of program data, special analyses, on-site checking, formal audit examinations, or any other reasonable procedures. All such monitoring shall be performed in a manner that shall not unduly interfere with recipient's work on the Project.

4.5 In the event of recipient's breach of the QCEW Data's confidentiality, breach of QCEW Data confidentiality by any third-party engaged by recipient, or any of the recipient's duties specified herein, the recipient shall, to the extent permitted by law, indemnify, save and hold harmless the CDOT, and its employees and agents, against any and all claims, damages, liability and court awards including costs, expenses, and attorney fees incurred as a result of any act or omission by the recipient, or its employees, agents, subcontractors, or assignees, and the recipient shall return all QCEW Data to the CDOT and pay any penalty imposed upon CDOT by DLE as a result of such breach, act or omission by recipient, or its employees, agents, subcontractors, or assignees.

5.0 Miscellaneous Terms and Conditions

5.1 All terms and conditions of this Release Agreement shall be binding upon recipient and any employee, agent or third-party of recipient. Any breach of any QCEW Data confidentiality or any other duties or obligations specified herein by any of recipient's employees, agents or third parties shall be deemed to be a breach on the part of the recipient.

5.2 The laws of the State of Colorado and any applicable rules and regulations issued pursuant thereto shall be applied in the interpretation, execution and enforcement of this Release Agreement. The terms of this Release Agreement are severable, and should any term or provision hereof be declared invalid or become inoperative for any reason, such invalidity or failure shall not affect the validity of any other term of provision hereof.

5.2 This Release Agreement is intended as the complete integration of all understandings between the parties. No prior or contemporaneous addition, deletion, or other amendment hereto shall have any force or effect whatsoever, unless embodied herein in writing. No subsequent novation, renewal, addition, deletion, or other amendment hereto shall have any force or effect unless embodied in a written amendment signed by both parties. Any

CDOT waiver of any alleged breach of confidentiality by the recipient or third-party agents of the recipient is not to imply a waiver of any subsequent breach.

5.3 All notices, except for a termination notice which is discussed elsewhere, required and permitted pursuant to this Release Agreement shall be in writing and shall be deemed given when personally served or five days after deposit in the United States Mail, postage prepaid, registered or certified, return receipt requested, and addressed to the party to whom notice is intended to be given.

5.4 The recipient warrants that it possesses the legal authority to enter into this Release Agreement. The undersigned also warrants that she/he is duly authorized to enter into this Release Agreement on behalf of the recipient and to bind the recipient to its terms and conditions.

6.0 Remedies

6.1 In the event of breach of this Release Agreement, the sole and exclusive remedies are termination of this Release Agreement upon ten days (10) written notice to Recipient, or CDOT may seek an injunction or pursue an action for damages in the event that CDOT believes that Recipient's use of the Data is not in accordance with the terms of this Release Agreement.

____
Authorized StateFocus model recipient NAME and TITLE

____
SIGNATURE

____

____

____
Recipient Company name, address and phone number

____
Date

____
CDOT Approval Signature

____
Approval Date

Appendix E: Travel Demand Model Review Checklist

Travel Demand Model Checklist

Colorado Department of Transportation

GENERAL INFORMATION

Date:

Reviewed by:

Project Name/Description	Region	Highway/Roadway(s)
Traffic Model Name/Description	Analysis Scenario/Alternative	Analysis Year(s)

Analysis Tool(s) Utilized:

SCOPE OF STUDY

Purpose & Scope:

Description/Limit of Model:

Other Notes:

REVIEW ITEMS

Scope of Study

___ Is the study area identified by the consultant wide enough to cover the area significantly impacted by the project? (If not, recommend that the study area be expanded)

___ Are there any other programmed improvement projects in the area that need modeling/forecasting information in the near future?

___ Have you checked to see what modeling efforts have been done in the study area in the past? (Please check for air quality conformity analyses, traffic studies, or Environmental Impact Statements done for any project in the study area within the last few years).

REVIEW ITEMS (Continued)

Model Assumptions

___ Has the consultant obtained a calibration/validation document from the MPO

___ Has the consultant reviewed the study area land use and network assumptions in the model? ______ Base Year | ______ Future Year

___ Does the consultant have better information or has the consultant chosen different assumptions than the available model? If yes, describe:

___ Has the consultant reviewed the new information with staff?

___ Has the consultant documented the differences?

___ Has the consultant reviewed area improvement assumptions and reached agreement with staff on the projects and configurations to be included in future scenarios?

Study Area Enhancements to Model

___ Has the consultant provided better land use / network information or chosen different assumptions that the model within the study area? (The consultant needs to expand network detail, review and modify land use as needed, and modify the zone system within study area as needed). If yes:

___ Has the consultant reviewed the new information with staff?

___ Has the consultant documented the differences?

___ Has the consultant reviewed the TAZ structure in the model, and provided additional detail where necessary?

___ Has the consultant provided land use comparisons of any new TAZs (if any) for validation?

___ Has the consultant reviewed the following model network components, but not limited, within area impacting the study area? ___ Speeds, ___ Centroid locations, ___ Centroid connectors, ___ Capacities, ___ Local streets, ___ Turn penalties

___ Has the consultant provided a list and a map identifying locations of all changes?

___ Has the staff reviewed and agreed with the proposed changes?

___ Has the consultant changed the following model assumptions?

___ Trip rates,

___ Special generators,

___ Peak factors.

___ Has the consultant made any new recommendations?

___ Has the consultant reviewed these new recommendations with staff?

___ Has the consultant documented these new recommendations?

___ Has the consultant made changes to any network attributes which affect modeled travel times? ___ Link Length, ___ Speed, ___ Capacity, ___ Volume/Delay functions, ___ Others (specify)

___ Has the consultant provided a list and a map identifying locations of all changes?

___ If yes, did the consultant rerun the trip distributions? (This includes base year calibration as well as all future year alternatives).

___ Did the consultant rerun the traffic assignment? (This includes base year calibration as well as all future year alternatives).

___ Has the consultant review resulted in any land use changes and if so, has the trip generation model been rerun?

Post-processing of Results

Were forecasted demand volumes developed using difference method of ratio method?

___ Will turn movements be adjusted by link or individual turn movement counts?

___ Are intersections balanced to match link forecasts?

___ Will the post-processing ensure consistent forecasts along intersections in the same corridor?

Forecasts Beyond the Model Year

___ Will the growth factor be calculated by area or by link?

___ Has the consultant discussed this with CDOT staff?

___ If link based, how will factors be calculated for links that are not in the model?

___ Has the consultant provided any documentation?

Additional Comments

___ Has the consultant provided an overall evaluation of the model and calibration results for reasonableness?

___ Has the consultant checked to see if results from the new study are consistent with the work done in the past in the same study area?

___ If the results are different, has the consultant documented the reasons why?

___ How will the model be used to analyze the impacts of non-capacity related projects?