Traffic and Safety Analysis Procedures Manual

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Purpose

The Traffic and Safety Analysis Procedures Manual provides guidelines regarding traffic and safety analysis for Texas Department of Transportation (TxDOT) projects. It supports various project development stages, including planning, preliminary schematics, and final/approved schematics and design. Its primary purpose is to provide guidance regarding scoping, conducting, and reporting traffic and safety analyses.

Content

The Traffic and Safety Analysis Procedures Manual provides procedural guidelines for traffic and safety analysis, including intersection analysis. It is organized in the following four parts:

A. Part A consists of fundamentals. It includes Project Scoping, Data Collection, Traffic Volume and Forecasting, Traffic Analysis Methodology, Tools, and Measure of Effectiveness, Safety Analysis Concepts, and Safety Analysis, Methodologies, and Tools.

B. Part B presents general analysis types. It includes guidelines on Project and Corridor System Planning, Alternatives Analysis, Segment Analysis, Intersection Analysis, Interchange Analysis, and Roundabout Analysis. The purpose of this chapter is to provide guidance on conducting operational analysis, safety analysis and cost-benefit analysis of intersections. This part provides information on intersection and interchange types, including roundabouts, analysis tools, data requirements, Intersection Control Evaluations (ICE), and how to interpret analysis results for projects in various stages of project development.

C. Part C discusses additional analysis details. It includes procedures on Microsimulation Analysis, Multimodal Analysis, Transportation System Management and Operations (TSMO) and Transportation Demand Management (TDM) Analysis, and Traffic Impact Analysis (TIA).

D. Part D includes Reports and Documentation. It provides guidance on integrating analysis methodology, results, and recommendations into a comprehensive report.

The manual includes Appendices, which contain examples, links to helpful resources, and worksheets that support Parts A through D.

Instructions

The Traffic and Safety Analysis Procedures Manual applies to all projects requiring traffic and safety analysis beginning with the September 2024 Letting, and if project schematic or 30% plans have not been approved by November 1st, 2024. The Districts and Divisions are encouraged to use this manual prior to this date.

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Archives

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Chapter 0
Preface

0.1 Purpose

The Traffic and Safety Analysis Procedures (TSAP) Manual provides guidelines and best practices regarding traffic and safety analysis for Texas Department of Transportation (TxDOT) projects. It supports various project development stages (PDSs), including planning, preliminary schematics, and final/approved schematics and design. Its primary purpose is to provide guidance regarding scoping, conducting, and reporting traffic and safety analyses. Additional purposes of this manual include:

- Provide consistent and uniform direction regarding traffic and safety analysis methodologies
- Support TxDOT's Roadway Design Manual (RDM) and other traffic manuals
- Incorporate guidance found in the Transportation Research Board's (TRB's) Highway Capacity Manual (HCM)
- Incorporate guidance found in the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM)
- Focus on the needs of TxDOT transportation engineers and planners as the primary audience

0.2 Manual Organization

0.2.1 Overview

This manual is organized into four parts: fundamentals, general analysis types, additional analysis types and tools, and reporting. This manual generally follows the project process with the chapters in the manual corresponding to individual steps within the process. While the organization of this manual is linear, chapters in this manual may be used out of sequence based on project needs. The manual parts and chapter organization are shown below. Manual organization, chapter references, and recommended deliverables are shown in Figure 0-1.

0.2.2 Part A – Fundamentals

Part A describes the scoping process, data collection, traffic volume and forecasting, traffic analysis tools, measures of effectiveness (MOEs), and safety analysis. The chapters for Part A include:

- Chapter 1: Project Scoping – Scoping meeting agenda and guidance regarding project need, purpose, and limits
- Chapter 2: Data Collection – Resources for collecting traffic data
- Chapter 3: Traffic Volume and Forecasting – Guidance for projecting traffic volumes

- Chapter 4: Traffic Analysis Methodology, Tools, and MOEs – Method for tool and MOE selection
- Chapter 5: Safety Analysis Concepts – Guidance and resources for safety analysis concepts
- Chapter 6: Safety Analysis, Methodologies, and Tools – Guidance and resources for safety analysis, methodologies, and tools

0.2.3 Part B – General Analysis Types

Part B describes analysis types, corridor planning, alternatives analysis, and analysis for various facility types. The chapters for Part B include:

- Chapter 7: Project and Corridor System Planning – Guidance on the types of information and analysis methodologies to consider in corridor planning
- Chapter 8: Alternatives Analysis – Guidance regarding traffic and safety criteria for an alternative project analysis
- Chapter 9: Segment Analysis – An overview of tools, data requirements, input parameters, and MOEs recommended for a segment analysis
- Chapter 10: Intersection Analysis – Guidance on conducting operational, safety, and cost-benefit analysis of intersections
- Chapter 11: Interchange Analysis – Guidance on various interchange designs, evaluating interchange performance, and tools needed for interchange analysis
- Chapter 12: Roundabout Analysis – Guidance on performing a roundabout analysis for motorized vehicles, pedestrians, and bicycles

0.2.4 Part C – Additional Analysis Types and Tools

Part C describes the additional analysis types. The chapters for Part C include:

- Chapter 13: Microsimulation – Guidance on performing traffic analysis using microsimulation tools, including analysis of various facility types and multimodal considerations
- Chapter 14: Multimodal Analysis – Guidance on analysis of pedestrians, bicycles, freight, transit, and rail
- Chapter 15: Transportation System Management Operation (TSMO) and Transportation Demand Management – Guidance on performing analysis of various TSMO and/or Transportation Demand Management strategies
- Chapter 16: Traffic Impact Analysis (TIA) – Guidance on how to complete a TIA

0.2.5 Part D – Reporting

Part D describes the contents of report deliverables. The chapter for Part D is:

- Chapter 17: Reports and Documentation – A guide to develop consistent reports and documentation

Traffic and Safety Analysis Procedures Manual Organization

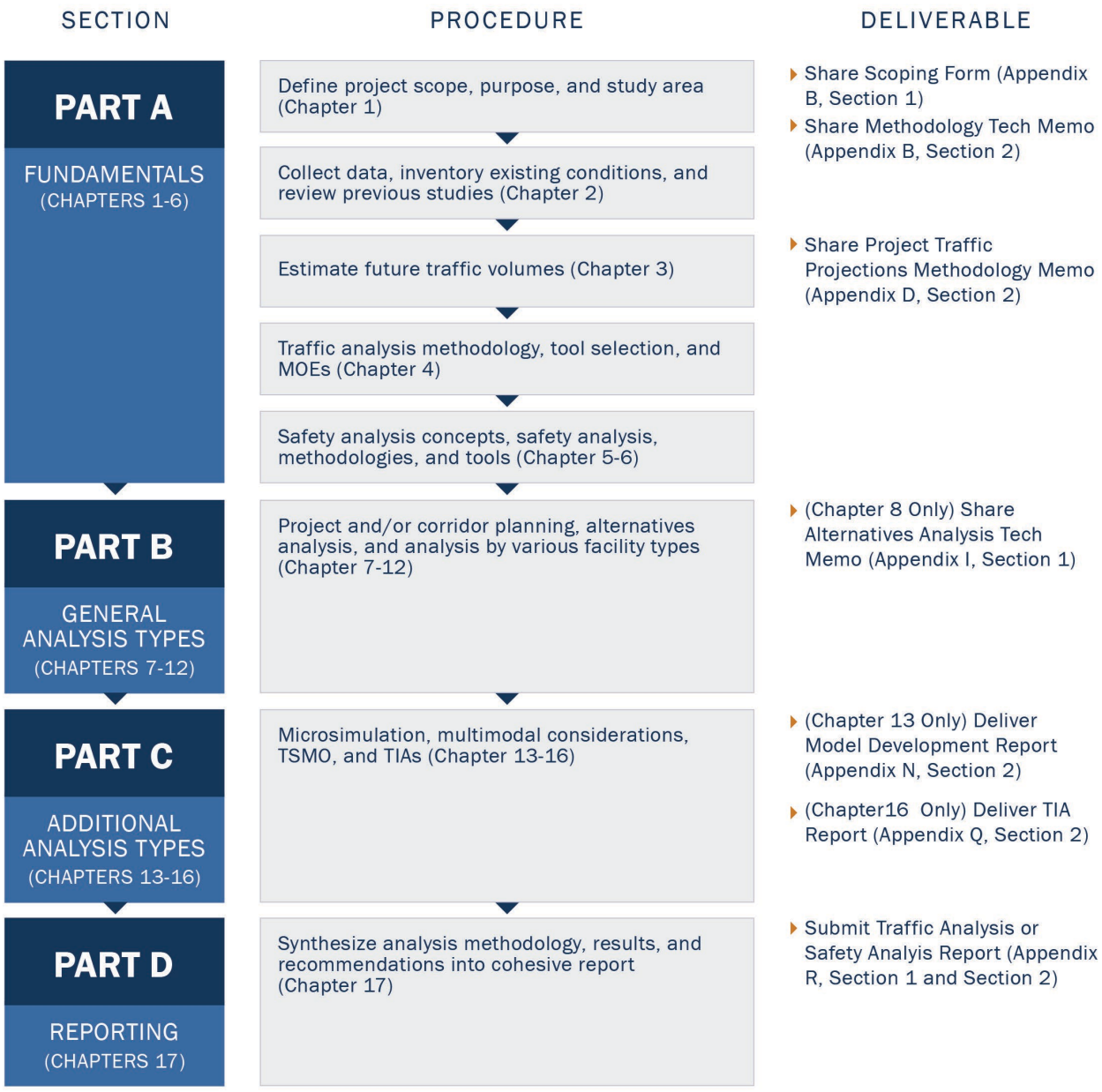


Figure 0-1: Manual Organization and Suggested Deliverables

0.3 Intended Use and Limitations

This manual is intended to guide scoping, conducting, and reporting traffic and safety analyses for projects. It is recommended that the guidance provided be used by TxDOT personnel, local agencies, consultants, and contractors working on "On-System" projects. This manual was developed using the following resources as references:

- The *Highway Capacity Manual* (HCM) by the TRB (see Appendix A, Section 1 – External References [Reference 1])
- The *Highway Safety Manual* (HSM) by AASHTO (see Appendix A, Section 1 – External References [Reference 2])
- The *Federal Highway Administration (FHWA) Traffic Analysis Toolboxes* (see Appendix A, Section 1 – External References [Reference 3])
- The *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) (see Appendix A, Section 1 – External References [Reference 4])
- Other documents developed by State Departments of Transportation and research institutions

This document is not a standalone manual. It does not include design standards and cannot be considered a substitute for engineering judgment. As a result, it is recommended these reference manuals and documents be referred to for detail. The tables from the HCM are credited to the Transportation Research Board, *Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis (2022).* They are reproduced with permission from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

The software programs stated in this manual are based on proven industry use and typical application of each program. They are for reference purposes only as examples of software programs to use. This manual does not advocate any specific software program.

Chapter 1
Project Scoping

1.1 Scoping Meeting

1.1.1 Overview

It is recommended that a scoping meeting be scheduled at the onset of a project to outline traffic and safety analysis procedures. The purpose of the scoping meeting is to affirm and refine the scope of work with the performing organization (e.g., TxDOT District/Division, consultant). It is suggested that all elements of analysis methodology be considered by the performing organization prior to the scoping meeting, which can be accomplished by filling out the scoping form (see Appendix B, Section 1 - Scoping Form). The **Scoping Form** is intended to serve as a project guidance document prepared by the performing organization prior to the onset of the project. Fill out the scoping form as completely as possible before the scoping meeting and update it throughout project development, as needed. This iterative process of updating the scoping form will create a living document representing applicable project details throughout the project development. The scoping form serves as common ground between the TxDOT project manager and the performing organization to help maintain consistency.

During the scoping meeting, discuss project information and methodology. See Table 1-1 for a sample scoping meeting agenda. It is recommended that analysis procedures be agreed upon by the TxDOT project manager, the performing organization, and other involved TxDOT groups, Divisions, and Districts. It is suggested that unresolved project scoping elements be documented during the scoping meeting and addressed later in **a Methodology Technical Memorandum**. The **Methodology Technical Memorandum** is intended to serve as a summary of the **Scoping Form** and provide additional information such as unresolved project scoping elements. It is recommended that the performing organization prepares the **Methodology Technical Memorandum** and shares it with the TxDOT project manager. An outline of a **Methodology Technical Memorandum** is found in Appendix B, Section 2 – Methodology Technical Memorandum. After the scoping meeting, it is recommended that the performing organization shares notes and the final **Scoping Form**, which reflect the revised methodology, with the TxDOT project manager.

1.1.2 Scoping Meeting Deliverables

- Before – **Scoping Form** (to be shared prior to the scoping meeting)
    - Prepared by the performing organization;
    - Shared with TxDOT project manager and other meeting attendees
- During – Discuss **Agenda** items (see Table 1-1) and update **Scoping Form**

- After – Share scoping meeting notes, final **Scoping Form**, and **Technical Memorandum**
- Technical memorandum outline is found in Appendix B, Section 2 – Methodology Technical Memorandum

Table 1-1: Scoping Meeting Agenda and Traffic and Safety Analysis Procedures Manual Chapter Reference

Item	Agenda Item	Chapter Reference
1	Introductions	Chapter 1 – Project Scoping
2	**Project Description and Goals**	Chapter 1 – Project Scoping
3	**Preliminary Data Review**	Chapter 2 – Data Collection
4	**Preliminary Alternatives Identification**	Chapter 8 – Alternatives Analysis
5	**Analysis Tools and Methodology**	Chapter 4 – Traffic Analysis Methodology, Tools, and MOEs
6	**Measure of Effectiveness (MOE) Selection**	Chapter 4 – Traffic Analysis Methodology, Tools, and MOEs Chapter 5 – Safety Analysis Concepts Chapter 6 – Safety Analysis, Methodologies, and Tools
7	**Traffic Forecasting**	Chapter 3 – Traffic Volume and Forecasting
8	Reports and Documentation	Chapter 17 – Reports and Documentation
9	Submittal Process	Agenda Only
10	Next Steps	Agenda Only

Legend: Analysis Elements in **bold**

1.2 Introductions and Project Descriptions

The introductions of a project include personnel involved in the project. It includes the TxDOT project manager, the project manager for the performing organization, and other TxDOT groups, Divisions, and Districts. FHWA may be involved in the process if the project involves an interstate. Specify these key personnel on the **Scoping Form**.

The project description serves as a defining set of characteristics that are either descriptive or serve to guide analysis methodologies. Characteristics in the project description include:

- Project name and control section job (CSJ) or Project ID;
- Location (i.e., City, County, and District of the project);
- Project overview;
- Analysis level and level of detail;
- Scope of work;
- Study limits;
    - Geographical limits (spatial);
    - Analysis time periods (temporal);
- Analysis years and peak periods;
- Background factors that may influence the project; and
- Project schedule

While some of the project descriptors are self-explanatory, more detailed information on some of the characteristics are in Sections 1.2.1 through 1.2.7. Specify the project descriptors on the **Scoping Form**.

1.2.1 Project Overview

The project overview section briefly describes basic elements of the project such as analysis type and the facility type. Include other descriptive information about the project in the project overview section. See Table 1-3 for an **example** of how to fill out this section.

1.2.2 Project Development Stage (PDS)

The PDS describes the position of a project in its life cycle. The three main PDSs are:

- Planning
    - A broad study that helps identify the needs and goals of future transportation. A process that involves alternatives analysis, where alternatives are considered, analyzed, compared, and selected. In the context of this manual, planning includes both the planning and programming of a project.
- Preliminary Schematics
    - The middle stage, where project information becomes more detailed and developed into a plan. In the context of this manual, preliminary design, environmental, right of way (ROW), and utilities are grouped into preliminary schematics.
- Final/Approved Schematics and Plans, Specifications, and Estimates (PS&E)
    - The end stage when all project details and plans are developed for construction or implementation.

The PDS can be considered multi-stage if it includes a combination of Planning, Preliminary Schematics, or Final/Approved PS&E. The PDS is one factor to determine which analysis tool will be used for a project. For more information about the PDS, see Chapter 4, Section 2. See Table 1-3 for an **example** of how to fill out this section.

1.2.3 Level of Detail

The level of detail is different than the PDS and describes the detail necessary to complete an analysis. Analysis tools are often categorized into varying levels of detail. The necessary level of detail for an analysis, as well as project scope and complexity, often influence tool selection. Level of detail is divided into three categories:

- Sketch-Level or Macroscopic
    - Sketch-level analysis tools may use less input and detail. This type of tool may be suitable for projects that have limited resources (data, budget, expertise, personnel, time, etc.), or projects that do not use high levels of detail. An example of a tool in this category is Capacity Analysis for Planning of Junctions (CAP-X).
    - Macroscopic tools, such as travel demand model (TDM) outputs, may be used for complex projects that have regional/sub-regional impacts. Analyses that use these types of tools often involve more resources than typical sketch-level tools. Coordination with TxDOT's Transportation Planning and Programming (TPP) Division or the local Metropolitan Planning Organization (MPO) may be necessary when travel demand outputs are used for a project.
- HCM-Based (Mesoscopic)
    - Analysis tools at this level involve a medium amount of input and detail or are HCM-based.
    - An example of this type of tool is the Highway Capacity Software (HCS).
- Microsimulation (Microscopic)
    - Analysis tools at this level likely involve the most input and detail. They are suitable for projects that are complex or use detailed operational analysis. Examples of these tools include Verkehr in Staedten Simulation (Vissim), Corridor Simulation (CORSIM), and SimTraffic.

Like the PDS, the level of detail can also be considered multi-resolution if the analysis includes a combination of Sketch-Level or Macroscopic, HCM-Based (Mesoscopic), and Microsimulation (Microscopic) tools. Use the PDS and level of detail to guide the selection of appropriate tools for analysis. Determination of level of detail (including multi-resolution modeling) for scoping is based on a variety of factors; work with the TxDOT project manager, TxDOT's Design Division (DES), and/or TPP to determine which level of detail fits for the

project. See Table 1-3 for an **example** of how to fill out this section.

Analysis tools typically used in safety-related projects include TxDOT's Safety Scoring Tool (SST), Safety Performance of Intersection Control Evaluation (SPICE), HSM for Rural Multilane, HSM for Urban/Suburban Arterials, HSM for Rural Two-Lane Roads, Enhanced Interchange Safety Analysis Tool (ISATe), Highway Safety Software (HSS), and Interactive Highway Safety Design Model (IHSDM). These tools are often used to achieve results varying in level of detail.

1.2.4 Scope of Work

The scope of work is an agreement on the work to be performed for a project. The basic scope of work is defined by the type of project (e.g., new roadway, adding capacity, operations analysis, signal analysis, corridor study, planning study, safety study, toll feasibility analysis, etc.) and is specified on the **Scoping Form**. Preventive Maintenance (PM) and resurfacing or restoration (2R) projects typically do not involve traffic analysis. Resurfacing, restoration, or rehabilitation (3R) projects may involve traffic analysis, especially if roadway geometrics are changed. Reconstruction (4R) projects typically involve traffic analysis. The level of detail depends on the project scope. It is recommended that a description of the scope of work be included and answer questions such as:

- *What is the purpose of the project?*
- *What are the project goals and objectives?*
- *What issues will the project address?*
- *What are the project milestones?*
- *What are the deliverables?*

During the project scoping meeting, refine the scope of work and modify it as agreed-upon.

1.2.5 Performance Based Practical Design (PBPD)

State within the Scope of Work if PBPD will be used. PBPD is a decision-making approach to better manage transportation investments and serve system-level needs and performance priorities with limited resources. PBPD uses performance evaluations during project development to guide alternative selections and, ultimately, geometric design decisions. During the planning stage, PBPD defines system and project purpose and need, develops concise project objectives from the purpose and need, considers project in the context of the system, and addresses all users. PBPD is based on quantitative analysis for system performance, operations, or safety, and allows for flexibility in design while still meeting project objectives. During preliminary engineering and design, PBPD develops solutions that meet the purpose and need and evaluates tradeoffs based on objective analysis of data. PBPD analysis includes a cost-benefit analysis. Table 1-2 shows operational and safety tools that incorporate PBPD. When used in planning and design, these tools can be used to compare and select alternative designs based on the operations and/or the number of predicted crashes for each alternative. Costs include cost of constructing or implementing improvements and cost of maintenance. Benefits are calculated in terms of delay

savings and crash reduction savings. For more information on Cost-Benefit Analysis, see Chapter 10, Section 10.3.6. Refer to TxDOT's RDM for additional information on PBPD.

Table 1-2: Operational and Safety Analysis Tools that Incorporate PBPD

Operations	Traffic Simulation Highway Capacity Manual Integrated Corridor Management	• Considers traffic volumes with various roadway and traffic data • Used to predict levels of service and/or delay
Safety	Highway Safety Manual -Crash Modification Factors Clearinghouse -Safety Analyst -Interactive Highway Safety Design Model (IHSDM) -NCHRP HSM Data Needs Research Digest -Interchange Safety Analysis Tool (ISATe)	• Considers traffic volumes with various roadway geometrics and features • Uses a predictive method to predict crash frequency, based on actual crash history

1.2.6 Geographic (Spatial) Limits

The geographic (spatial) limits include the project improvement locations (project area) and the area impacted by the project improvement (study area). Spatial limits for operation and safety are typically the same. For spatial limits, it is recommended to attach a map to the **Scoping Form**. For an **example** of the spatial limit map, see Figure 1-1.

Below are sample prompts that may provide guidance:

- Spatial Limits: *What is the overall project location? What intersections, interchanges, segments, or other facilities are to be included in the analysis? Is this an Interstate Access Justification Report (IAJR) that requires upstream and downstream interchanges to be included? For freeways, is it recommended that the main lanes and frontage roads be considered?*

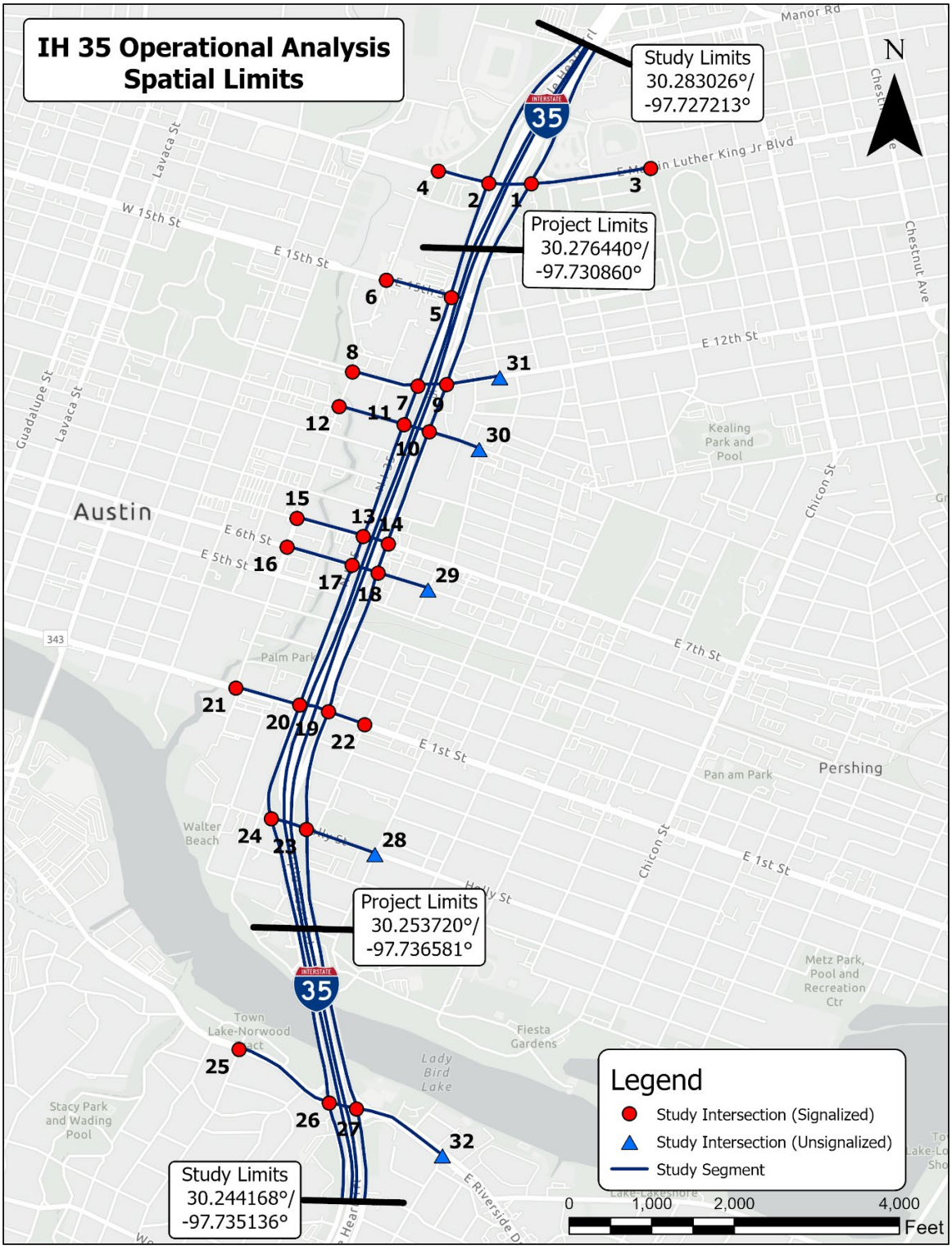


Figure 1-1: Spatial Limits Map Example

1.2.7 Analysis Years and Peak Periods

Time (temporal) limits for an operational analysis include the analysis years and analysis periods. Typical analysis years often include the following:

1. Existing Year – Existing year analysis represents the current conditions analysis and is typically completed using data less than three years old. If the project is using data more than three years old, include verification about how the volumes represent existing conditions.

2. Opening Year – The opening year is the first year in which the proposed improvements are expected to be open to traffic. If the project is proposed to be implemented in phases, the opening year is the year the first phase of traffic will be opened to traffic. The opening year is typically determined by project size, complexity, and schedule, with respect to the letting date. The let date is defined as the official receipt and opening of bids and determination of the apparent low bidder. It is dependent on the planning and programming of projects.

3. Interim Year – An interim year is the opening year of different phases of the project after the first phase. Interim years are sometimes used if the proposed improvements show failing level of service prior to the design year.

4. Design Year – Projects are planned and designed to meet the future, anticipated needs and characteristics of a certain year. This is referred to as the design year. Typically, the design year is 20 years after the anticipated project opening year.

The analysis years listed above are typical, but can vary based on project type (e.g., resurfacing, restoration, or rehabilitation projects often have analysis years of five to 10 years). Pavement design year is used for traffic projections but is not needed for traffic analysis. It is typically 10 years after the design year and represents useful life of the pavement. The analysis period is the time of day when the analysis will be conducted.

Typical traffic analysis time periods (temporal limits) include a weekday AM peak and a weekday PM peak. There are situations that warrant different analysis periods (e.g., analysis of a facility near a school, mall, or sports arena; analysis of a facility with heavy weekend traffic). Part of the scoping process is identifying the analysis day(s) and the analysis periods (e.g., AM Peak: Tuesday-Thursday, 7:15AM – 8:15AM).

Temporal limits for a historical safety analysis typically include the most recent three to five years. Temporal limits for a predictive safety analysis typically include the opening and design years. For projects that need FHWA approval, request Crash Records Information System (CRIS) data through TxDOT's Traffic Safety Division (TRF) or the Design Division.

Below are sample prompts that may provide guidance on selecting temporal limits:

- *What are the analysis years for each study area?*
- *What are the analysis periods for the study?*

1.2.8 Background Factors and Project Schedule

It is suggested that background factors which may influence the project are included on the **Scoping Form**. These background factors may include planned roadway improvements (geometric, operational, safety, etc.), planned developments (developments that change traffic patterns), input from various TxDOT groups, and other factors that have an influence on travel and safety.

It is recommended that a preliminary project schedule be attached to the **Scoping Form** when sharing the document with the TxDOT project manager. The project schedule establishes the start date and completion date of the project and includes major project milestones (e.g., project administration, data collection, traffic analysis, safety analysis, agency coordination, renderings, and work authorization termination date). For an **example**, see Appendix B, Section 3 – Example Project Schedule.

Table 1-3 is an **example** of a completed project description section on the **Scoping Form**.

Table 1-3: Scoping Form - Project Description Example

Project Description			
Project Name	IH-35 Capacity Analysis	Project CSJ or Project ID	1111-11-111
City, County	Austin, Travis	District	Austin
Project Overview	I-35 Capacity/Congestion Study		
Analysis Level	■ Planning ☐ Preliminary Schematics ☐ Final/Approved Schematics and Design ☐ Multi-Level ☐ Other		
Level of Detail (Select all that apply)	☐ Sketch-Level or Macroscopic ☐ HCM-Based (Mesoscopic) ■ Microsimulation (Microscopic) ☐ Multi-Resolution ☐ Other		
Scope of Work (Select all that apply)	☐ New Roadway ■ Add Capacity ■ Operations Analysis ☐ Signal Analysis ■ Corridor Study ☐ Feasibility Study ☐ Route Study ☐ Safety Study ☐ Toll Feasibility Analysis ☐ Other Operational analysis for multiple alternatives on 1.89 miles of IH-35 and operational analysis for multiple alternatives at 27 signalized intersections and five unsignalized intersections		
Spatial Limits	See Figure 1-1 (include project area and study area)		

Project Description	
Analysis Years and Peak Periods	Opening Year: 2030 Design Year: 2050 Pavement Design Year: 2060 AM Peak Hour/Period (weekday): 7:30 – 8:30 PM Peak Hour/Period (weekday): 5:00 – 6:00 Other Peak: Not Applicable Crash Data Analysis Year(s): Historical – Most recent 5 calendar years, Predictive – 2030, 2050
Background Factors that May Influence the Project	New BRT route addition adjacent to UT Austin
Project Schedule	See Appendix B, Section 3 – Example Project Schedule

1.3 Analysis Methodology

The preliminary analysis methodology consists of five categories: data review/collection, alternatives identification, analysis tool consideration and selection, MOE selection, and traffic forecasting.

Information regarding these elements will be filled out on the **Scoping Form** before the scoping meeting and will be updated during the scoping meeting as necessary.

Table 1-4 shows an **example** of a completed analysis methodology portion of the **Scoping Form**, which includes information on data review/collection, alternatives identification, analysis tool consideration and selection, MOE selection, and traffic forecasting.

See Chapter 8 for additional guidance on alternatives analysis.

Table 1-4: Scoping Form - Analysis Methodology Example

Preliminary Data Review	
Existing Traffic Data	■ STARS Historical Traffic Counts ■ K-Factors ■ D-Factors ■ T-Factors ■ Site Observations ☐ Travel Times ☐ National Performance Management Research Data Set (NPMRDS) ■ Big Data (e.g., 3rd party probe data) ☐ Other -
Field Data Collection Plan	**Attach map that specifies locations of applicable data to collect.** See Figure 1-2 ■ Turning Movement Counts ■ Segment Counts ☐ Classification Counts ■ Travel Time ☐ Speed ☐ Big Data (e.g., 3rd party probe data) ☐ High Occupancy Vehicle (HOV) Data ☐ Other -
Preliminary Alternatives Identification	
Alternatives to Consider	No-build, addition of general lane northbound and southbound, addition of managed lane northbound and southbound, on/off ramp relocation or closure
Analysis Tool Considerations	
Traffic Analysis Software Tools (Select all that apply)	☐ CAP-X ☐ HCS ☐ Synchro ☐ SIDRA ☐ Visum ■ Vissim ☐ Vistro ☐ Cube ☐ TransCAD ☐ SimTraffic ☐ CORSIM ☐ Other -
Microsimulation	Characteristics to calibrate: ■ Simulated Travel Time ■ Simulated Traffic Volume ☐ Simulated Queue Length ☐ Other -
	Important location(s) to calibrate: NB and SB on IH-35, intersection volumes
Initial MOE Selection	
Traffic MOEs (Select all that apply)	☐ v/c Ratio ■ Travel Time ■ Speed ■ Delay ■ LOS ☐ Queue Length ☐ Trip Reliability ☐ Other -
Traffic Forecasting	
Traffic Forecasting Methodology	Specify Option: ☐ TPP Led ■ District Led Specify Methodology: ☐ Traffic Projections from Nearby Projects ■ Travel Demand Model Outputs Forecasts ■ Traffic Projections from Historical Growth Rates ☐ Other -

1.3.1 Data Review and Collection

Data review and collection consists of three components:

- Gathering available data from existing sources (e.g., Statewide Traffic Analysis and Reporting System (STARS) traffic counts, the NPMRDS, multi-modal data such as TxDOT Comprehensive Accessibility Program (TCAP), CRIS crash reports, INRIX travel times and Origin-Destination (OD) data, and other big data sources that accomplish a similar purpose).
- Determining safety analysis and operational analysis data needs.
- Creating a field data collection plan to specify the location and types of data that will be collected.

To summarize, the data review process will be used to determine existing data availability, to determine additional data needed for the project, and to make a data collection plan. The data collection plan will be in map format and specify types of data and locations for all necessary data collection points (DCP). Figure 1-2 shows an **example** of the data collection map. Generally, 100 days of traffic data collection (segment counts) are recommended for FHWA approved projects. For other projects, 7 days are typically recommended for data collection and are to be based on coordination with the TxDOT project manager.

See Chapter 2 for additional guidance on data sources, collection, and summarization. See Chapter 5 and Chapter 6 for additional guidance on safety data.

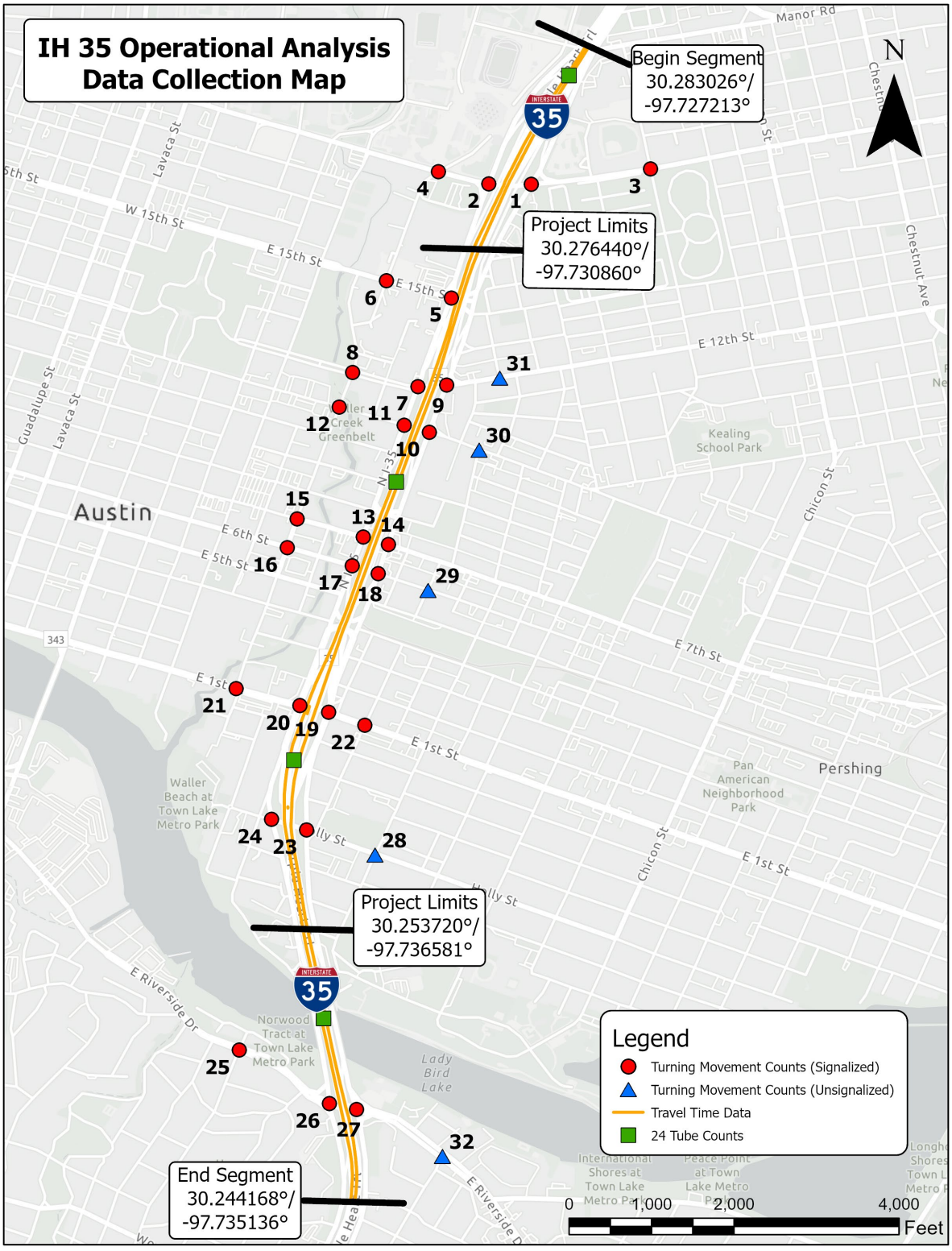


Figure 1-2: Data Collection Example Map

1.3.2 Alternatives Identification

Alternatives identification is the process of considering multiple alternatives that use different configurations to accomplish the same goal. After alternatives are selected, they are analyzed, and their results are compared to determine which option best accomplishes project goals and objectives.

While the outcomes for alternatives are not known before analysis begins, preliminary alternatives identification is critical because it leads to effective utilization of limited resources. Alternatives to be analyzed will be listed on the **Scoping Form**.

See Chapter 8 for detailed information on alternatives identification and analysis.

1.3.3 Analysis Tool Considerations and MOEs

Tool selection is based on many variables, such as project type, size, complexity, facility type, level of detail, analysis level, data requirements, desired metrics, tool functionality, and industry standards. Figure 4-1 in Chapter 4 can be used to gain a general understanding of tool selection based on level of detail, analysis level, and resource intensity. Some projects may need multi-resolution analysis, which could necessitate the selection of more than one tool for analysis. In these circumstances, refer to the Multi-Stage Analysis section of Chapter 4.

For further guidance on tool selection, see the following:

- Chapter 4 – Guidance on operational analysis tool selection for other modes, facility types, and project types;
- Chapter 6, Section 2 – Guidance on safety analysis tool selection;
- Chapter 14, Figure 14-1 – Guidance on tool selection for pedestrian analysis; and
- Chapter 14, Figure 14-3 – Guidance on tool selection for bicycle analysis

Calibration is the process of adjusting model parameters so that the model results accurately represent field conditions, which is necessary when developing a base conditions model using Microsimulation (Microscopic) tools such as Vissim. Typical characteristics to calibrate include traffic volumes, travel times, and queue length. It is recommended that calibration characteristics and critical calibration links (i.e., segments with weaving, bottlenecks, a volume-to-capacity (v/c) ratio > 1, etc.) be listed on the **Scoping Form** and a calibration map be attached to the **Scoping Form.** Other tools may necessitate calibration, and relevant calibration characteristics and important links to calibrate can be specified on the **Scoping Form**. See Chapter 13 for detailed information on calibration methodology and procedures.

Performance measures objectively report project conditions concerning specific criteria. Traffic analysis performance measures are often related to mobility and may include safety, accessibility, reliability, and others (see

Chapter 5 and Chapter 6 for Safety MOEs). Analysis tools selected for a project often determine which metrics will be used to evaluate project conditions. However, project-specific circumstances may merit the selection of a certain performance measures. Performance measures are selected based on the vision, mission, goals, and objectives of the project. Common performance measures and MOEs reported by common analysis tools are shown in Table 4-4 of Chapter 4.

For further guidance on MOE applications, see the following:

- Chapter 4 - Guidance on traffic analysis tools and MOEs;
- Chapter 5 and Chapter 6 - Guidance on safety analysis tools and MOEs; and
- Chapter 13 - Conditions and situations that use microsimulation

1.3.4 Traffic Volume and Forecasting

Traffic forecasting involves determining who will develop the traffic forecast, how the forecast will be developed (i.e., which forecasting methodology), and who will approve the traffic forecast. After determining who will develop and approve the forecasts, it is suggested that the choice is marked in the traffic forecasting section of the **Scoping Form** by checking TPP Led or District Led.

Depending on who is developing and approving the traffic forecast, selecting forecast methodology may be necessary. If the project lies within an MPO with a TDM, then the analyst can consider using the MPO's TDM. If the project is outside the MPO boundaries with a TDM, the analyst can consider using TxDOT's Statewide Analysis Model (SAM) outputs.

Other methods of traffic forecasting include historical trends and growth patterns. Typically, more than one method of traffic forecasting is used to cross-validate forecast results.

Document traffic forecasting assumptions on the **Scoping Form** and include information about which MPO's TDM will be used, where historical volumes will be taken to obtain a historical growth rate, or what planned land uses were used to develop growth patterns for traffic forecasting.

For additional guidance on traffic volume and forecasting, refer to the TxDOT TPP Traffic Forecasting Analysis Standard Operating Procedures (SOP). Coordinate with the TxDOT project manager to gain access to the latest SOP. An internal link to the SOP is also found in Appendix B, Section 4 – External References (Reference 1).

Chapter 2
Data Collection

2.1 Introduction

The purpose of this chapter is to provide guidance on the different types of data available for traffic and safety analysis, preferred methods of data collection, existing sources of data, and data needed for the different levels of analysis.

This chapter provides generalized data requirements for traffic operational analysis. There may be additional analysis-specific data requirements not covered in this chapter. For data specific to facility type or analysis type, such as intersections, interchanges, roundabouts, and microsimulation, see Chapters 10, 11, 12, and 13, respectively.

2.2 Types of Data

This section provides an overview of the different types of data that are used in traffic operational and safety analysis. It is important that all data is collected within the same timeframe to avoid any inconsistencies between the different data types. The different types of data, their collection methods, and resources mentioned in this section below are summarized in Section 2.5 in Table 2-1. Note that prior to beginning data collection, it may be useful to check the existing traffic operation data sources, which are listed in Section 2.3.

2.2.1 Geometric Data

Geometric data is related to the physical characteristics of the roadway facility. Below is a list of general geometric data that may be needed to perform traffic analyses. Additional data may be needed depending on the characteristics of the project study area; this is not an exhaustive list.

- Geographic coordinates (e.g., NAD 83);
- Number of lanes;
- Lane assignment;
- Lane, shoulder, and crosswalk widths;
- Presence of sidewalks and pedestrian elements;
- Type of lane (e.g., general purpose, managed lanes, bus-only lane, bike lane);
- Length of turn lanes or bays;
- Ramp spacing;
- Clear zone;
- Curvature of roadway (i.e., centerline alignment);
- Grade;
- Median width;
- Median type (e.g., divided, undivided, barrier);
- ROW;
- Driveway entries and location; and
- Location of railroad crossings

Geometric data can be gathered using TxDOT's Open Data Portal, online aerial imagery (e.g., Google Earth, Google Maps, Bing Maps, Nearmap), survey files, as-builts (i.e., plans that reflect the project as actually constructed), and other online resources. However, it is recommended that a field visit be performed, when possible, to verify the existing geometric conditions data gathered digitally. A field visit is necessary to verify geometric information in areas with limited or dated aerial imagery, or when as-builts are not available.

2.2.2 Traffic Operational Data

Traffic operational data is based on traffic control devices and roadway characteristics other than roadway geometry. Below is a list of general traffic operational data needed to perform traffic analysis. This is not an exhaustive list.

- Speed limits, operating speeds, and/or design speeds if available;
- Traffic control types and locations;
- Traffic signal timing plans;
- Driveway spacing/location;
- Parking occupancy (e.g., supply, temporal demand, turnover);
- Parking type (e.g., angled, parallel, back-in);
- Roadway functional classification;
- Area type (e.g., rural, urban, suburban);
- Driver behavior (e.g., rate of acceleration, rate of deceleration, lane changing behaviors, car following parameters);
- Lane utilization;
- School zones;
- Railroad preemption; and
- Signage types and locations (e.g., regulatory, warning, guidance signs)

Multiple sources of data may be needed to gather all the traffic operational data used to perform a traffic operational analysis. Data such as speed limits, intersection control, and roadway classification is available in the field or with online aerial imagery, a Geographic Information System (GIS) database, or other online resources. Other data, such as the timing for signals or the parking occupancy rate, may necessitate coordination with the governing public agency. Data such as lane utilization and driver behavior field observations to verify traffic operational conditions.

2.2.3 Traffic Counts

One of the fundamental data types needed to perform traffic operational analysis is traffic count data. There are several types of counts that may be needed based on the level of detail necessary for the analysis. It is recommended that traffic count data be collected on typical weekdays that represent a typical day's travel patterns. Avoid days with atypical traffic conditions, which can be caused by the following situations:

- On or around holidays;
    - Especially for areas that are retail-heavy, unless the study is specifically to analyze impacts during such time periods
- During inclement weather;
- During crashes or other major incidents affecting travel patterns;

- During construction or lane closures within the project limits;
- During construction or lane closures in the vicinity of the project that result in detours within the project limits;
- During summer break or other times when school is not in session; or
- Any other situations that may present atypical travel patterns (e.g., special events)

It is recommended that traffic counts be collected for atypical travel patterns based on project specifics. For example, if the purpose of the project is to study summer traffic due to an increase in tourism, game-day traffic at stadiums, holiday or event traffic, or other unique situations, an atypical traffic count could be necessary.

In general, collect traffic counts in 15-minute time intervals for the defined time period(s). It is suggested that traffic counts begin before the start of the congestion and end after congestion dissipates.

2.2.3.1 Turning Movement Counts (TMCs)

TMCs count vehicles, pedestrians, and bicyclists making a specific movement or turn at an intersection for all approaches during a defined period. Collect TMCs on a typical weekday and for a minimum of two consecutive weekdays, based on coordination with the TxDOT project manager. A typical weekday count is defined as a count occurring on a Tuesday, Wednesday, or Thursday. It is recommended that the traffic count data be collected in 15-minute increments and during the same period as the remainder of the data collection. TMCs may include vehicular, pedestrian, and bicyclist modes of travel.

Recommended TMC collection method:

- 15-minute increments;
- Typical weekday peak period (Tuesday, Wednesday, Thursday);
- Two consecutive weekdays; and
- Minimum of 2-hour period, which includes the peak hour

For atypical locations, it is suggested that the period of collection is based on the circumstances. Examples include corridors or roadways near malls, stadiums, or other land uses that generate large volumes of traffic at non-standard times of day.

2.2.3.2 Segment Traffic Counts

Segment traffic counts are conducted along a roadway during a typical week for a consecutive seven-to-14-day period for Interstate IAJR projects with microsimulation and one to two days for other projects. This is based on coordination with the TxDOT project manager and collected in 15-minute increments. Segment traffic counts are often separated by direction to analyze directional split. For analyses that use microsimulation as part of an IAJR, segment traffic counts are recommended to be conducted for a period of at least 7-to-14 consecutive days. Figure 2-1 is an example of a generic segment traffic count location.

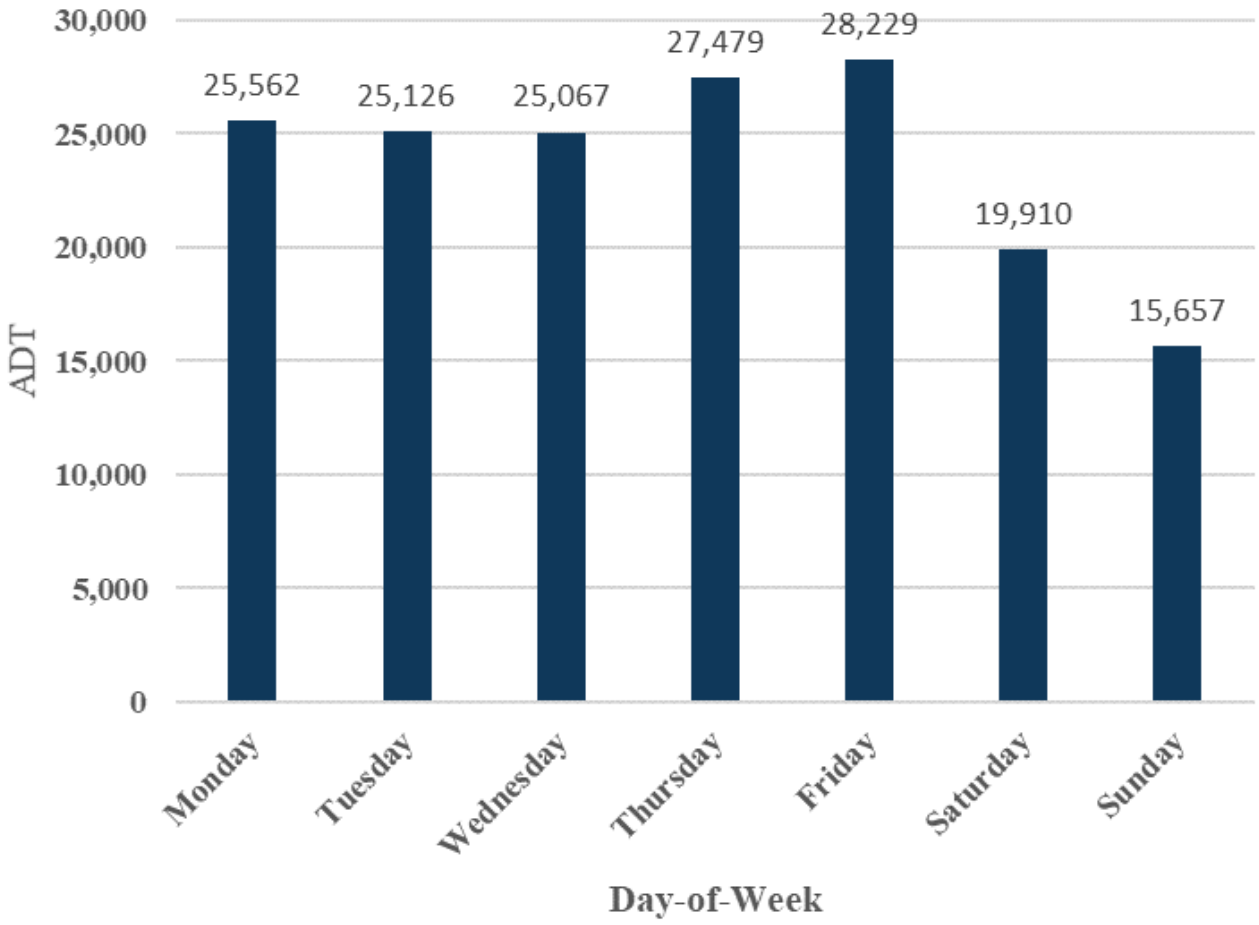


Figure 2-1: Example Segment Traffic Count Corridor Profile

Suggested segment traffic data collection method:

- 15-minute increments;
- Typical week; and
- Seven to 14 consecutive days for projects needing microsimulation on IAJR projects; one to two days for other projects

2.2.3.3 Classification Counts

Classification counts determine the breakdown of the 13 FHWA vehicle categories, per the *TxDOT Traffic Recorder Instruction Manual*. Classification counts are similar to segment traffic counts and include two-way traffic volumes on a roadway for a specified period of time greater than 24 hours but less than a year. Classification counts help determine the percentage of different vehicle categories using a roadway, which is important in performing traffic operational analysis and pavement design. It is suggested that classification counts be conducted during a typical week for a period of seven consecutive days for projects needing microsimulation on an IAJR project. Classification counts are to be conducted for a minimum of 48-hours for other projects, based on coordination with the TxDOT project manager. For locations where classification counts are performed in place of segment traffic counts, it is suggested the segment traffic collection method be used.

Suggested classification counts collection method:

- 15-minute increments;
- Typical week; and
- Minimum seven consecutive days for microsimulation on IAJR projects; one to two days for other projects

2.2.3.4 Oversaturated Counts

Oversaturated conditions occur when the demand for the facility exceeds the capacity. These conditions result in a significant drop in speeds and flow rate through a point or segment, depending on the severity of saturation. The HCM defines conditions as oversaturated when any of the following conditions are satisfied:

> "(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, oversaturated conditions result from a bottleneck on the facility. During oversaturated conditions, queues extend upstream from the point of the bottleneck.

It is recommended that traffic counts collected for oversaturated conditions span a time interval greater than just the peak hour or peak period. It is suggested that field observations are conducted, along with segment traffic counts, to determine the overall peak period and the shouldering effect of traffic or queue build up and dissipation. A shouldering effect occurs during a peak period when a facility is oversaturated and cannot process any additional demand, causing the peak period to extend longer than an hour. The effect can occur on both ends of the peak hour during a peak period, where the demand for the facility is higher than the capacity, allowing only a portion of the traffic volumes to process through the facility until the demand falls below capacity.

For oversaturated and bottleneck conditions, it is suggested that counts are started at least

one hour before congestion starts and end one hour after congestion has been cleared. Similar to TMCs, oversaturated counts are collected on a typical weekday and for a minimum of two consecutive days, based on coordination with the TxDOT project manager. Depending on how congested the study area is, collect counts at least one intersection or interchange upstream of the study area.

In addition to traffic counts, it is recommended that queue data is collected for oversaturated conditions, depending on the type of analysis being performed. See Section 2.2.4 - Queue Data for calculating demand in oversaturated conditions.

Recommended oversaturated counts collection method:

- 15-minute increments;
- Typical weekday peak period (Tuesday, Wednesday, Thursday);
    - Include the shouldering effect of traffic
    - Begin counts at a minimum one hour before congestion starts and end at a minimum one hour after congestion dissipates
- Collected at least one intersection or interchange upstream of the congested study area or other logical terminus determined through engineering judgement; and
- Collected for two consecutive weekdays

2.2.4 Queue Data

Queue data is recommended for oversaturated conditions. Traffic count data documents the volume processed at an intersection or at a cross-sectional point on a road but not necessarily the demand. In oversaturated conditions, the volume served at an intersection or at a cross-sectional point on a road may be lower than the overall demand. It is recommended that queue data be collected for oversaturated approaches or roadway segments within the study limits. If the queues extend past the study limits, collect data upstream, past the longest queues. For severely congested corridors with extremely long queues extending past the study area, engineering judgement would be used to determine where to set study limits and data collection locations for queues.

Queues are often measured in terms of arrival and departure volumes at a given facility. Counts are typically conducted in five-minute intervals, starting before the existence of any congestion or queues at the location and ending after all queues have been cleared from the facility. The resultant queue is defined as the difference between the five-minute arrivals and departures, and arrival data is counted upstream of the longest expected queue.

Complementary ways to determine queues include conducting license plate studies; using probe-based data to look at speeds, automated traffic recorders (ATR), segment counts, travel times, and bottleneck locations; and conducting field observations or scanning Google Maps for congestion. Google Maps provides live traffic data as well as typical historical congestion levels. This may be used to get a general understanding of queues. It is

recommended to perform field observations to supplement the data collected via Google Maps.

2.2.5 Speed, Travel Time, and Origin-Destination (OD) Data

Speed is a fundamental MOE for traffic operational analysis. Speed is measured in two ways: time-mean-speed (TMS) and space-mean-speed (SMS). TMS is calculated by recording the speeds of individual vehicles passing a point over a selected period of time. SMS is calculated by dividing the average travel time by the distance of that route. This is an important distinction, as some methods of collections use TMS, while others use SMS; this difference can lead to different speeds for the area of interest, if not carefully distinguished. TMS is typically used when the speed at a point is of most interest, and the SMS is used when the speed over a section of roadway is of most interest. SMS is also used when analyzing and reducing travel time data.

Travel time is the time to traverse a route from point A to point B and is a fundamental MOE for traffic engineering.

OD data is also another important traffic characteristic that may be helpful in determining travel patterns. OD datasets provide information on trips between user-defined geographic zones or roadways. These datasets may also have additional information related to the mode of transportation, such as organizing data by pedestrians, bicyclists, and freight.

Additional information about Probe-Based Data, Bluetooth Sensors Data, and Floating Cars Data is shown in this section. This additional information provides guidance on the different methods of collections for speed, travel time, and OD data.

2.2.5.1 Probe-Based Data

Probe-based data is collected from individual vehicles, or probes, over space and time, rather than collected at a specific place and time. The most common types of probe-based data collection methods are Automatic Vehicle Location (AVL), Global Positioning System (GPS) mobile devices, and third-party cell phone app data. This data is typically collected by third-party companies that parse through the data, anonymize it, and convert individual probe data into performance measures such as speed, travel time, and OD. This data is then used for traffic analysis. The data can also be used to determine OD of trips and queuing.

Floating car data (FCD) is a type of probe-based, timestamped, geospatial data that provides speeds and travel times. The data is collected by using an application or a GPS device that records timestamps and geospatial data while the application or device is driven through the area of interest. The driver attempts to “float” in the traffic stream, selecting a location in the traffic flow where the vehicle’s speed matches that of the surrounding vehicles to allow the probe to collect data of a typical vehicle along the facility during the analysis period. FCD is recommended to be collected on typical weekdays (Tuesday, Wednesday, Thursday) and

during the peak period. A minimum of five runs in each direction per peak period are typically performed for a more representative view of existing traffic conditions, as demonstrated by Figure 2-2. FCD provides a sample of the existing congestion, speeds, stops, and travel times for the study area during a peak period.

TxDOT has access to probe-based data, such as INRIX, which can be used for traffic analysis. See Section 2.3 Existing Traffic Operations Data Sources in this chapter for more information.

2.2.5.2 Bluetooth Sensors Data

Bluetooth sensor data is like probe-based data but is more localized and needs specialized hardware. Most vehicles manufactured today are equipped with Bluetooth devices, as are personal electronics such as phones, laptops, and tablets. Bluetooth sensors used for traffic engineering scan for other Bluetooth-enabled devices near the Bluetooth sensor device. Once a device is read by the Bluetooth sensors, it stores data related to the detected device. This data can be used to conduct OD studies, determine vehicular density, and conduct flow analysis. When using Bluetooth sensors for traffic engineering, the placement of these sensors is key. Placing these sensors under overpasses, or where multiple roadways are crossing over or under each other, may create challenges, such as not being able to identify the overpass or roadway on which the device was read. This can also occur at intersecting roadways with many pedestrians with cellphones. Post-processing of this data to minimize such issues is suggested. This method only gathers information for vehicles with Bluetooth devices present in the vehicle.

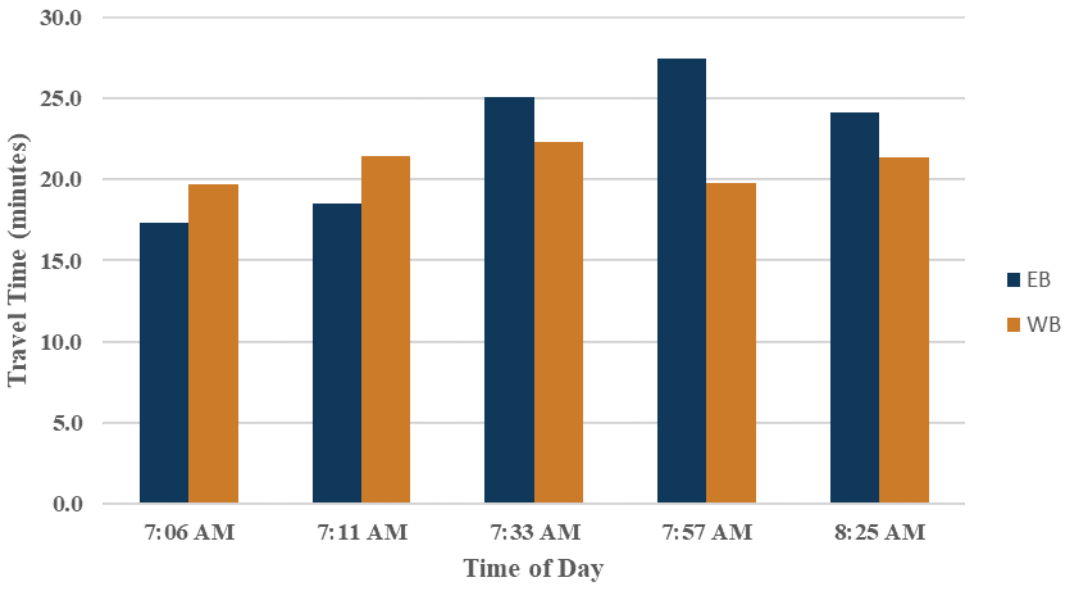


Figure 2-2: Floating Car Travel Time Runs

2.2.6 Multimodal Travel Data

Multimodal analysis involves considering other modes of transportation, such as pedestrians, bicyclists, transit, and freight. This subsection provides a list of the different data types that are often used to conduct analysis on different modes of transportation. For additional analysis-specific data requirements not covered in this subsection, see Chapter 14 – Multimodal Analysis.

Pedestrian and Bicycle Data Types

- Pedestrian counts taken at defined location;
- Bicycle counts;
- Scooter counts;
- Sidewalk location, length, and discontinuity, if any;
- Sidewalk width;
- Sidewalk and pavement condition;
- Buffer type;
- Posted speed;
- Type of facility (e.g., shared-use path, buffered bike lane);
- Pedestrian/bicycle facility surface type;
- Average Daily Traffic (ADT) on an adjacent roadway facility;
- Parking type (e.g., parallel, angled, back in);
- Adjacent land use; and
- Number of lanes on adjacent roadway facility

Transit Data Types

- Route;
- Service type (e.g., light rail, bus rapid transit);
- Number and location of stops (i.e., passenger boarding and alighting locations);
- Dwell time at stops; and
- Frequency and headway

Freight Data Types

- Passenger car equivalents;
- Truck traffic percentage;
- Tonnage;
- Commodity type;
- Freight warehouses, distribution facilities or ports that generate truck traffic;
- Location of railroad crossings; and
- Truck types

2.2.7 Safety Data

It is recommended that safety data is used to complete a safety analysis. Safety data often includes crash records, geometrical features of a roadway facility, proposed safety improvements to a roadway, and roadway characteristics such as ADT. Please see Section 2.2.1 and 2.2.3 for more information related to collecting geometric data and segment traffic counts. Additional information regarding data collection needs for safety and crash analysis is included in Chapter 5 and Chapter 6. The intent of gathering safety data is to complete a historical or predictive safety analysis that identifies potential locations to improve safety.

2.3 Existing Data Sources

There are several sources of existing traffic operational and safety data available online. Consider existing data for traffic operational and safety analysis to the extent practicable. Prior to beginning any analysis, determine the types of existing data that are already available that can be used for the project versus additional data that needs to be collected. Outlined below are several resources that TxDOT provides, along with references to other websites or tools the user can research for information on data collection.

2.3.1 Statewide Traffic Analysis and Reporting System (STARS II)

TxDOT on average collects 82,000 short-term counts and 1,000 vehicle classification counts statewide annually. In addition, TxDOT has many permanent count locations that collect data 24 hours a day, 365 days a year. This traffic data can be viewed on the STARS II database. A link to the database is found in Appendix C, Section 6 – External References (Reference 1).

TxDOT's STARS II is a data analytics and reporting platform with detailed traffic data and statistics. It provides an online web interface for viewing annually reported traffic data as well as additional traffic data that is not part of the annually validated data set. Annually reported traffic is submitted to the Highway Performance Monitoring System (HPMS), which has specific conditions set by FHWA regarding the collection and reporting method. HPMS data may be calculated differently than some of the other traffic data on the overall STARS II database. Detailed information on how to use the STARS II database is found in the TxDOT *Transportation Planning and Programming Traffic Forecasting Analysis Standard Operating Procedures* (SOP) document. Coordinate with the TxDOT project manager to gain access to the latest SOP document.

2.3.2 Other Sources of Traffic Count Data

Agencies may also have their own sets of traffic data. Cities and tolling authorities may have traffic management centers which often collect real time data about the transportation network.

Some MPOs and cities have their own traffic count databases. Cities may have an annual count program which can be a good resource for obtaining historical counts. Typically, these online databases only include ADT counts and not TMCs. Some MPOs combine counts from multiple sources such as cities and TxDOT STARS II and display it under one database. These counts may be used for planning or sketch level (macroscopic) analysis.

Some major cities, TxDOT urban areas, and cities that have traffic management centers may also have ADT or turning movement count data for their roadway facilities. These cities may conduct an annual traffic count program and collect traffic count data on their major roadways. The traffic management centers may also have data related to speed and travel time as part of their Intelligent Transportation System (ITS) network. As of 2024, the

suitability and availability of speed and count data is under review by TxDOT.

Tolling agencies may also be able to provide ADT counts for locations adjacent to the toll gantries. This information can be helpful for projects involving toll lanes or managed lanes.

Pedestrian and bicycle data can be obtained through Texas A&M Transportation Institute's (TTI's) Texas Bicycle and Pedestrian Count Exchange (BPCX). A link to BPCX is provided in Appendix C, Section 6 – External References (Reference 3). Cities and MPOs may also collect pedestrian and bicycle data. Coordinate with local jurisdictions to see what data is available.

2.3.3 Big Data

"Big data" in general refers to a large volume of information, the different types of data, the real-time nature of the data, and the tools and techniques to manage and analyze it. For transportation and traffic engineering, FHWA defines big data as having at least seven dimensions:

- Volume – the amount of data available;
- Velocity – how quickly the data is generated or gathered;
- Variety – how the data is structured;
- Veracity – how trustworthy is the data;
- Value – how meaningful is the data;
- People – refers to those who process and analyze the data; and
- Governance – how the data is gathered and processed

Big data has many advantages over traditional methods of collection. The data is readily available through third-party providers and does not involve infrastructure investment. Because the data is collected and stored by the provider, there is no need for local storage. Collecting the data does not involve manual and in-field methods. Data can be analyzed for an entire day, month, or year, not just during peak periods. The flexibility of data collection may enable a deeper understanding of travel patterns and other traffic operations-related issues.

There are some challenges and limitations associated with big data. Due to the automated nature of the data collection, there is a lack of information on field conditions, such as construction, detours, weather, or malfunctioning traffic signals. Typically, the data provider does not share its process for how the data is aggregated, processed, and analyzed, and the user relies on it and trusts the provider's methods. Other challenges may arise when the defined study area does not have a one-to-one relation within the defined limits of the provider's platform.

Additional detail about providers of big data (e.g., INRIX, Replica, and StreetLight) related to transportation planning and traffic engineering is provided in the sections below. As of 2024, TxDOT has subscriptions to INRIX and Replica, and the subscriptions are available to TxDOT employees and contractors working on TxDOT projects or initiatives. To access this data, consultants and external entities need a TxDOT sponsor and to fill out forms agreeing to terms

of use before access is granted. Sample forms are provided in Appendix C, Sections 2-5. Information regarding Replica data access can be found in Appendix C, Sections 6 (References 5 and 6).

Information regarding INRIX data access can be found in Appendix C, Section 6 (Reference 7).

2.3.3.1 INRIX

INRIX aggregates probe-based data from numerous sources, including crowd-sourced, public, and proprietary data. The data types include consumer devices (e.g., connected cars, mobile phones), local fleets (e.g., service, delivery), and long-haul trucks. All data types collected are GPS based. Historical data availability goes back three years. MOEs reported in the platform include travel times, speeds, congestion, and bottlenecks. INRIX data does not capture stops; therefore, that information is not available. The following data analysis tools are available to users:

- Real-Time Traffic Flow – provides speed and travel time data by roadway segment and is updated every minute for most roadways.
- Roadway Analytics – provides average speed and other data by roadway segment. The data can be organized into 15-minute bins and is available for dates from January 2018 onward.
- Historical Speed Profile – analytical tool that helps the user visualize, monitor, measure, and manage the performance of roadway networks.
- Trip Analytics – a tool that helps provide detailed data on trips such as origin-destination.

2.3.3.2 StreetLight Data

StreetLight data processes anonymized location records from various sources such as smart phones, navigation devices, and trucks. Additional context is added to this data by layering information from other sources such as parcel data and the roadway network. This data is then analyzed and aggregated into normalized travel patterns. Users can access this data via the StreetLight InSight platform.

StreetLight data primarily helps in analyzing origin-destination, annual average daily traffic (AADT) counts, segments, trip lengths, and route choice. StreetLight AADT counts are typically only used if no other data source is available. It is recommended that any traffic counts collected using the StreetLight platform be validated with permanent count stations or ADT where available. If there are no permanent count locations available, refer to temporary count locations or historical counts. It is important to note major differences between StreetLight counts and those collected from historical data, STARS II, or other resources.

2.3.3.3 Replica Data

Replica combines anonymized and aggregated data from a variety of sources, including census data, surveys, and location-based services, to create a synthetic vehicular dataset. From this synthetic vehicular dataset, users can derive OD flows, study freight patterns, analyze transit ridership, and perform link analyses, among other features.

2.3.4 TxDOT Open Data Portal

TxDOT's Open Data Portal is an online GIS database. The portal allows users to explore and download GIS datasets in various data formats. Users utilize queries and filters to view the information on a map on the portal. The database includes information regarding TxDOT's roadway inventory, mile markers, most congested roadway segments, District boundaries, legislative boundaries, bridges, and more. This data may help in a planning level analysis to get information regarding a corridor or study area. The data is also downloadable and may be used to create graphics and maps to convey information in a customizable way. Some of the information on this portal can also be found on other TxDOT online data sources such as the TxDOT Statewide Planning Map and TxDOT Project Tracker.

2.3.4.1 TxDOT Statewide Planning Map

TxDOT's Statewide Planning Map contains information on control sections, traffic counts, future traffic estimates, trunk systems, MPOs, and highways. The Statewide Planning Map displays a more selective portion of the information available on the Open Data Portal. It may be used to scan for AADTs on TxDOT roadways, determine congested areas, and find other planning level information.

2.3.4.2 TxDOT Project Tracker

TxDOT's Project Tracker includes information on planned projects in map format. These projects are differentiated by four phases; construction underway or begins soon, construction begins within the next 4 years, construction begins within the next 5 – 10 years, or projects that are in corridor study phase or 10+ years out. Additional information is included on the map such as estimated construction cost, funding sources, and type of project.

2.3.5 TxDOT Pavement Management Information System (PMIS)

TxDOT's PMIS is used for storing, retrieving, analyzing, and reporting pavement conditions for all of TxDOT's roadways. The PMIS is an internal database and information from the PMIS needs to be requested on a project basis. The request needs to go through the TxDOT Maintenance Division. A data request form for PMIS and a confidentiality agreement are provided in Appendix C, Section 3 – PMIS Data Request Form and Appendix C, Section 4 – PMIS Confidentiality Agreement, respectively.

2.3.6 TxDOT Traffic Management Centers

There may be datasets available through Traffic Management Centers in metro/urban Districts such as Austin, Dallas, El Paso, Fort Worth, and San Antonio. This data typically includes speed by lane, volume per lane, and occupancy per lane. This dataset can be used as a resource for traffic operations and safety analysis, especially for microscopic model development. See Appendix C, Section 7 – Traffic Management Center Data for more information about TxDOT's Traffic Management Centers. See Appendix C, Section 8 – Lonestar RVSD Detector Locations for locations the detectors. See Appendix C, Section 9 – Lonestar RVSD Detector Example Data Output for an example

of the Traffic Management Centers data outputs.

2.3.7 Travel Demand Model Outputs (TDM outputs)

Travel Demand Model outputs (TDM outputs) are used for determining future traffic volumes based on changes in land use, population, employment, and other demographical factors. TDMs also incorporate planned and approved future projects. MPOs have a TDM for their specific jurisdiction. TDM outputs may help with analyzing future growth of traffic, providing insight in travel patterns, and identifying areas for traffic improvements.

TxDOT also has a SAM which includes areas outside of the MPO TDM boundaries. The SAM encompasses all the State's major highways, ports of entry at the border with Mexico, and some freight corridors that tie in with the rest of the United States.

2.3.8 CRIS

Historical crash records are used to perform a safety analysis. Crash data can be obtained from TxDOT's CRIS database. Crash data available on CRIS are collected from reports from the Texas Peace Officer's Crash Reports (CR-3) and processed by TxDOT. The CRIS database has information related to the location of crashes, type of crash, conditions, date, and other pertinent information. This data can be queried and used in conducting various types of crash analysis. A CRIS database query allows the user to find crashes based on time and location. Once the user determines the location of interest and the range of years, they select attributes from three different fields: crash, unit, and person.

- The crash field has attributes related to roadway type and conditions, crash-related factors, crash severity, pedestrian and bicyclist-related crashes, contributing factors, traffic count, and location.
- The unit field has attributes related to vehicles (e.g., make, model), commercial motor vehicle-specific attributes, and damage associated with the vehicles.
- The person field has attributes related to the people involved in the crash, such as gender, ethnicity, and drug usage (related to the crash).

Users select the different attributes of interest, download the raw data, and analyze it in many ways, such as creating crash heat maps, generating graphs or infographics, identifying crash patterns based on certain criteria, and much more.

The user can also review queried results with preset data processing. These include a query results map, which has some predefined filters and map modes in place, such as:

- Standard view, which shows individual crashes denoted by different crash types;
- Cluster view, which combines crashes by area and shows an overall number of crashes by location; and

- Heat Map view, which shows color-coded crash areas based on density of crashes

These views are helpful for understanding where there is a higher frequency of crashes and the severities of these crashes, without having to download data or generate maps. The CRIS database also has a category of popular queries, which may be selected for screening and analysis purposes. For projects that need FHWA approval, it is recommended that crash data be obtained through the CRIS helpdesk or TxDOT's TRF Division. For projects that do not need FHWA approval, crash data may be downloaded through the CRIS website. A link to the CRIS website is shown in Appendix C, Section 6 – External References (Reference 4).

MicroStrategy (MSTR) is a business intelligence software connected to the CRIS database. MSTR is used to pull crash data, generate reports, and create dashboards. Access to MSTR can be requested through TxDOT's TRF Division.

2.3.9 Freight

TxDOT has access to Transearch, which is a tool that aggregates historical truck traffic and projects freight flows up to 30 years in the future. Freight information can be filtered by origin, destination, commodity, and transportation mode. It also has county-level freight movement data.

Transearch data is produced by IHS Markit, a company that oversees the software. To get access to the data, an IHS Markit data release form needs to be filled out and signed (see Appendix C, Section 5 – IHS Markit Data Release Form) and an email with the following information needs to be submitted to TPP:

- Project title;
- Project description;
- TxDOT project manager;
- Recipient company name and address; and
- Name, title, and email address of company representative with signing authority

2.3.10 Bike and Pedestrian

Bicycle and pedestrian traffic counts are often considered in traffic and safety analysis. If this data is unavailable from state resources, it may be available from the local MPO or city. Additionally, agencies can use the Texas Bicycle and Pedestrian Count Exchange. The Texas Bicycle and Pedestrian Count Exchange is a free statewide database that agencies can use to access bicycle and pedestrian counts. If counts for the location are unavailable, agencies can also submit a request for bike and pedestrian counts to be completed or request count equipment to conduct their own counts through the Bicycle and Pedestrian Counter Loan program. For more information about the loan program, use the online resource shown in Appendix C, Section 6 – External References (Reference 3)..

2.3.11 Regional Integrated Transportation Information System (RITIS)

RITIS is a large online database of the latest transportation-related data available from the public and private sectors. It was developed by University of Maryland's Center for Advanced Transportation Technology (CATT Lab) in 2006 with the intent to use data integration for improving traffic operations, incident management, and traveler information for the greater Washington D.C. area. Coordinate with TxDOT TPP Division for access to this data.

There are three main RITIS features that help with analysis: real-time data feeds, real-time situational awareness tools, and archived data analysis tools. RITIS data types are listed below and detailed information regarding each data type can be found on the RITIS website.

- Traffic volume, class, speed, and occupancy;
- Event, work zone, and incident;
- Crowdsourced Waze data;
- Weather;
- Signal status and signal timing
- Freight (OD for shipments, types of shipments, value, and quantity of goods, etc.);
- Travel time;
- OD;
- Routing (e.g., fastest route, shortest path, turning restrictions); and
- Parking (e.g., location of facilities, space utilization, restrictions)

2.4 Field Studies/Observations

Field observations are critical in understanding the complete picture of traffic operations. It is recommended that field observations are conducted on one of the same days as the other data collections to account for any nuances in traffic flows/patterns and how travelers use the facilities. Field observations are recommended but may be optional depending on the analysis and project scope. A field visit checklist is provided in Appendix C, Section 1 – Field Visit Checklist.

2.4.1 Existing Geometry

It is recommended that existing roadway geometry be verified during field observations. This is especially important for areas with new developments, locations that have dated aerial imagery, or locations with no as-builts available. Below is a list of items to note during field observations in addition the ones mentioned in Section 2.2:

- Sight distance at intersections;
- Driveway spacing;
- Lighting (e.g., intersection, safety, continuous);
- Signage (e.g., guide signs, speed limits, lane assignments);
- Pedestrian ramps;
- Pavement markings;
- Bicycle lanes/wide shoulders;
- Shared-used paths/sidewalks/worn dirt paths;
- Above-ground utilities;
- Other potential conflicts and environmental constraints;

- Condition of existing elements; and
- Traffic signals

2.4.2 Existing Operations

During field observations, verify operational items that could not be easily inferred from field traffic data. Below is a list of examples that may be noted during field observations:

- Existing roadway and traffic elements, including traffic control types;
- Speed limits (e.g., how often speed limits are changing, location of speed limit signs, operating speeds);
- Queuing and notable issues, such as queuing out of turn bays or on ramps;
- Traffic signal heads, including pedestrian signal heads;
- General operation of the traffic signal (e.g., sequence, phasing, cycle lengths, de facto cycle lengths if running free);
- Left turn phasing (permitted, protected [leading or lagging], protected-permitted, flashing yellow arrow);
- Land use and zoning in the vicinity of the project;
- Lane utilization along each approach;
- Turning movement speeds at non-conventional turning angles; and
- Atypical driver behavior, such as drivers making a right turn at an intersection, followed by immediate U-turns at a downstream location

2.4.3 Developments

It is suggested that adjacent developments around the project are noted during the field visit. It is also important to make note of all special traffic generators (e.g., office building, schools, mall, hospital, stadium, major employer, large parking garage/lot). This can provide insight into understanding traffic patterns within the study area and provide improved means for assumptions when balancing traffic volumes.

In addition to existing developments, Traffic Impact Analyses (TIAs) done for planned developments are another source of data for TMCs, trip generation, and additional traffic that may need to be layered into the analysis. Referring to past TIAs or ones that are in progress may provide an enhanced overall understanding of the future traffic and travel patterns.

2.4.3.1 Energy Sector

The Texas Railroad Commission (TRC) website is a good source for data related to the energy sector. For projects that take place in energy sector locations, such as the Permian Basin, the TRC website provides information such as drilling permits, energy-related infrastructure, production of oil and gas, and other useful information that may be helpful in determining future traffic impacts based on energy production. See Appendix C, Section 6 – External References (Reference 2) for a link to the TRC website.

2.5 Selection of Data Types

Not all data types will be needed for every operational study. Some data types are needed for planning stage studies, while other data types are necessary for the Preliminary Schematics or Final/Approved Schematics and

Design stages of projects. Table 2-1 provides guidance on which data types may be necessary versus optional for the different project development stages. Required (R) data types are needed to conduct the analysis. Project specific (PS) data types may be recommended, depending on the specifics of the project. Coordinate with the TxDOT project manager regarding the necessary and optional data to be collected for each project.

Table 2-1: Selection of Data Types

Data Type	Suggested Method of Collection	Resources	Analysis Type									
			Safety	*Alternatives*	*Segments*	*Intersection*	*Interchange*	*Roundabout*	*Alt Intersection or Interchange*	*Microsimulation (Microscopic)*	*Multimodal*	*TIA*
Roadway Geometry and Configuration	Aerial imagery, as-builts, and field verification, if needed	TxDOT's Open Data Portal, Google Maps, Bing Aerials, Nearmap, as-builts, and other online resources	R	R	R	R	R	R	R	R	R	R
Traffic Operational Data	Aerial imagery, as-builts, online databases, GIS, and field verification, if needed	Google Maps, Google Street view, Bing Aerials, Nearmap, as-builts, and other online resources	R	R	R	R	R	R	R	R	R	R
Turning Movement Counts (TMC)	Collected on a typical weekday (Tue, Wed, Thu) 2 consecutive days A minimum of 2-hour period, which includes the peak hour 15-minute increments	Traffic counting firms, MPO database, and previous studies	PS	PS	PS	R	R	R	R	R	PS	R
Segment Traffic Counts	Collected on a typical week 7 consecutive days 14 consecutive days (microsimulation) 24-hour period 15-minute increments 100 days of data for FHWA approved projects	STARS II, MPO database, previous studies, big data, and historical counts for FHWA projects	PS	PS	R	PS	PS	PS	PS	R	PS	PS
Classification Counts	Collected on a typical week 7 consecutive days 24-hour period 15-minute increments Includes FHWA Vehicle Types	STARS II, MPO database, and previous studies	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*
Oversaturated Counts	Collected on a typical weekday (Tue, Wed, Thu) 2 consecutive days A minimum of 3-hour period, will begin at a minimum 1 hour before and end at a minimum 1 hour after congestion Include shouldering affect 15-minute increments	CCTV cameras and previous studies	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	NA

Data Type	Suggested Method of Collection	Resources	Analysis Type									
			Safety	*Alternatives*	*Segments*	*Intersection*	*Interchange*	*Roundabout*	*Alt Intersection or Interchange*	*Microsimulation (Microscopic)*	*Multimodal*	*TIA*
	Collected at least one intersection upstream of the congested study area											
Queue Length	5-minute arrival and departure counts Probe-based data for speeds and bottlenecks, license plate studies, and field observations Will start before any queues exist and end after queues have cleared	CCTV cameras and previous studies	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	NA
Probe-Based OD	Project specific	INRIX, Replica, and StreetLight	NA	*PS*	*PS*	NA	*PS*	NA	NA	*PS*	*PS*	*PS*
Probe-Based Speed	Project specific	Coordinate with TxDOT project manager for access to INRIX platform	NA	*PS*	*PS*	NA	*PS*	NA	NA	*PS*	*PS*	*PS*
Bluetooth	Project specific	RITIS	NA	*PS*	*PS*	NA	*PS*	NA	*PS*	*PS*	*PS*	NA
Floating Car	At least 5 runs in each direction during the peak hour within the study limits	Mobile apps, gps data point collection instruments, and 3rd party vendors	NA	*PS*	*PS*	NA	NA	NA	NA	*PS*	*PS*	NA
Multimodal Data	Time frame of collection will be similar to the period of analysis	Transit agency, Texas Bicycle and Pedestrian Count Exchange, and Transearch database	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	**R**	PS

Data Type	Suggested Method of Collection	Resources	Analysis Type									
			Safety	*Alternatives*	*Segments*	*Intersection*	*Interchange*	*Roundabout*	*Alt Intersection or Interchange*	*Microsimulation (Microscopic)*	*Multimodal*	*TIA*
Crash	Minimum of previous 3 years of data	CRIS	**R**	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	NA	*PS*	NA
Field Studies and Observations	In person field visits Planned development studies such as TIAs	TIAs	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	*PS*	**R**	*PS*	**R**

R – Required, *PS* – Project Specific, NA – Not Applicable

2.6 Quality Assurance

Checking the quality and coherence of data is a critical part of the data collection process. The results of the analysis highly depend on the quality of data collected. It is recommended that field visits be made during the time when data is being collected. Field visits can help verify and ground truth any issues that could arise later when checking the data. They can also be helpful in documenting any atypical traffic patterns due to construction or road closures on adjacent projects, weather, debris on the road, or anything else that affects the data collection. It is recommended that the source of all data be documented, and a copy of the data be provided in the report appendix.

It is suggested that the following checks are performed once the data is collected and processed:

- Completeness – Check collected data for completeness. Does the data have all the necessary information needed for analysis? Were there errors in the data collection such as missing timing periods due to equipment malfunction or processing error? Were all modes considered?
- Accurate – Verify data is reasonable and matches field observations. Data may contain outlying or non-representative data due to equipment malfunction, post processing errors, incidents, or human errors. An example of an error that could occur with video counting equipment is U-turns being double counted at a roundabout due to the camera not being able to capture the entire roundabout.
- Discrepancy – It is recommended that all data collected such as traffic counts, speeds, or travel times be checked against other days of data collected for the same data type. If there are large variations, discrepancies, or outliers

based on the comparison or what was observed in the field, then it is important to determine the cause of the discrepancy and address it accordingly. If multiple days' worth of data is collected, it may be warranted to discard major outliers.

Chapter 3
Traffic Volume and Forecasting

3.1 Introduction

Traffic volumes are a critical component of any traffic analysis. A typical traffic analysis includes an existing conditions analysis using existing traffic volumes. Processing existing counts into meaningful analysis inputs facilitates an understanding of several concepts such as peak hour/period selection, local conditions, balancing, outlier data/disruptive events, and validation. Processing existing counts also uncovers several critical traffic characteristics such as the design hour (K-factor), directional distribution (D-factor), and percent trucks (T-factor). Future year traffic volumes are developed based on historical trends, growth patterns, and travel demand modeling and are developed in conjunction with TxDOT's TPP Division, the MPO, or others that perform this type of planning work. This chapter provides an outline of the traffic volume and forecasting processes. This chapter also provides procedures to analyze existing traffic volumes and develop future traffic projections. See Appendix D, Section 1 – Traffic Volume and Forecasting Checklist for a checklist that can be used during the forecasting process. For additional guidance on traffic volume and forecasting, refer to the *TxDOT TPP Traffic Forecasting Analysis SOP*. Coordinate with the TxDOT project manager to gain access to the latest documents. An internal link to the documents is also found in Appendix B, Section 4 – External References (Reference 1).

3.2 Existing Traffic Volumes

Existing traffic volumes are the foundation of traffic forecasts. See Chapter 2 for information on obtaining existing traffic volumes. It is recommended that existing traffic volumes are analyzed to extract traffic data factors and processed to provide consistent traffic forecasts. It is recommended that seasonal variation, historical factors, peak hour/period selection, outliers/disruptive events, balancing, and post processing be considered when using existing traffic volumes.

TxDOT's STARS II provides traffic volumes that are annualized to AADT. AADT estimates the mean traffic volume at a given location along a roadway across all days for a year. This data is used for both existing analysis and forecasting traffic volumes. Data, such as, the 30th highest hourly volume (K-factor), directional distribution (D-factor), percent trucks (T-factor), ADT, Design Hourly Volume (DHV), and vehicle classification can be obtained from STARS II. A graphic of the 30th highest hourly volume is shown in Figure 3-1.

Transportation Planning and Programming Division's
Statewide Traffic Analysis and Reporting System II

High Hourly Volumes for Year for 1/1/2018 - 12/31/2018
Criteria: Location ID = s17, Type = I-SECTION

District : Dallas **County :** Dallas **Community :** Balch Springs
Route: **On Road:** US0175
Location ID : S17 **Collection Type :** PERM **AADT:** 74,199
Roadbed : ML

Ordinal High Hour	Date	Day of Week	Hour	Volume	K Factor	Peak Direction	Directional Distribution
1	5/11/2018	Friday	4pm-5pm	6282	8.5	SB	59
2	4/6/2018	Friday	4pm-5pm	6244	8.4	SB	61
3	4/6/2018	Friday	5pm-6pm	6242	8.4	SB	61
4	1/26/2018	Friday	4pm-5pm	6218	8.4	SB	63
5	4/13/2018	Friday	5pm-6pm	6188	8.3	SB	62
6	2/9/2018	Friday	5pm-6pm	6176	8.3	SB	61
7	4/29/2018	Sunday	1pm-2pm	6158	8.3	NB	54
8	5/8/2018	Tuesday	5pm-6pm	6156	8.3	SB	63
9	9/21/2018	Friday	5pm-6pm	6142	8.3	SB	62
10	2/16/2018	Friday	5pm-6pm	6127	8.3	SB	61
20	9/21/2018	Friday	4pm-5pm	6073	8.2	SB	60
25	5/4/2018	Friday	5pm-6pm	6041	8.1	SB	62
30	5/18/2018	Friday	5pm-6pm	6018	8.1	SB	58
35	2/23/2018	Friday	4pm-5pm	5997	8.1	SB	60
40	5/15/2018	Tuesday	5pm-6pm	5978	8.1	SB	64
45	6/29/2018	Friday	4pm-5pm	5965	8	SB	61
50	4/30/2018	Monday	4pm-5pm	5955	8	SB	63
75	6/29/2018	Friday	5pm-6pm	5905	8	SB	61
100	10/5/2018	Friday	4pm-5pm	5865	7.9	SB	60
125	5/11/2018	Friday	3pm-4pm	5813	7.8	SB	58
150	4/22/2018	Sunday	12pm-1pm	5782	7.8	NB	51
175	4/29/2018	Sunday	2pm-3pm	5744	7.7	NB	53
200	2/8/2018	Thursday	5pm-6pm	5701	7.7	SB	61

K-Factor (8.1)

Directional Distribution (%) (58)

30th Highest Hour Data

Figure 3-1: 30th Highest Hourly Volume

3.2.1 Traffic Data Factors

Common traffic data factors include the K-factor, D-factor, and T-factor. The K-factor is the 30th highest hourly volume and is presented as a percentage of the ADT. The D-factor is the directionality of the 30th highest hourly volume of traffic. It is expressed as a percentage of the 30th highest hourly volume. The T-factor is the total percentage of single-unit trucks and multi-unit combination trucks. TxDOT uses vehicle classification data and overall traffic volumes to determine the T-factor. TxDOT uses this data to develop Equivalent Single Axle Load (ESAL) calculations for pavement design. Traffic data factors are obtained from STARS II.

3.2.2 Seasonal Factors

AADT is calculated using a volume count, axle factor, and seasonal factor. The seasonal factor measures the amount by which monthly traffic volume is above or below the annual average. Calculating the AADT allows direct comparison of short term traffic counts collected throughout the year.

3.2.3 Historical Factors

Historical growth rates are developed by calculating traffic growth rates between past years at multiple locations within and near the study area. It is suggested that historical growth rates are developed for as many years as there is available data. It is suggested that regression analysis be performed on historical counts to determine an average linear growth rate. Historical growth factor is determined based on the average growth rate. Check traffic data to assess whether it is necessary to exclude any outlier data from the analysis and document accordingly. An example of the historical growth rate calculation is provided in Appendix D, Section 4 – Regression Calculations.

3.2.4 Peak Hour/Period Selection

For roadway segments, 24-hour counts can be used to determine the time of day (e.g., AM, midday, or PM) peak hour or peak period. For intersections, segment counts or TMCs can be used to determine the peak hour or peak period. The peak hour is the hour in which the sum of vehicle volume during four consecutive 15-minute count intervals is the highest. Figure 3-2 shows an example of 24-hour traffic counts for a corridor, which can be used for AM and PM peak hour selection. This figure shows that the AM peak hour probably occurs sometime between 7:00am and 9:00am and that the PM peak hour probably occurs sometime between 3:30pm and 5:30pm.

Typically, the morning and evening peaks are used for analysis. Unique circumstances could necessitate the analysis of a midday peak, weekend peak, or other atypical peak. This is an important consideration near malls, commercial corridors, stadiums, schools, and unique land uses because these locations may cause sporadic or irregular traffic patterns. In oversaturated conditions, peak spreading may occur and necessitate a peak period selection rather than a peak hour. It is suggested that selection of peak hour/period be documented.

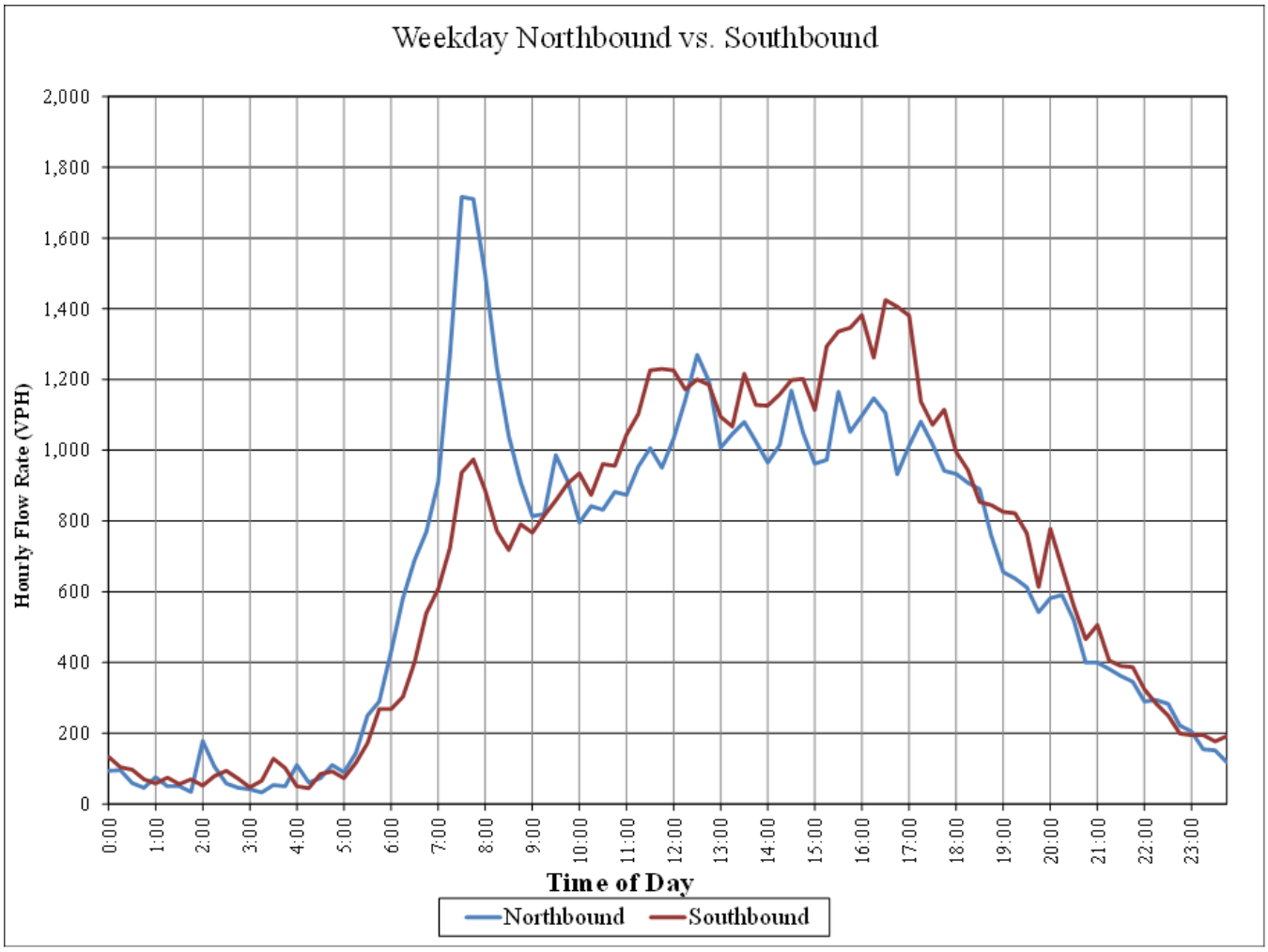


Figure 3-2: Peak Hour/Period Selection Using Count Data

3.2.5 Disruptive Events

Existing traffic volumes can be affected by disruptive events. During disruptive events (such as the COVID-19 pandemic or inclement weather conditions), data collected may need adjustment to account for anticipated impacts of the disruption and to remove outliers.

Options for obtaining data during a disruptive event vary based on the disruption type, duration, data availability, and data limitations. If data is less than two years old and was not collected during a recent disruptive event it can be used as is. In other situations, lack of recent counts could create the need for counts to be grown with historical growth rates or validated by big data. Big data uses geolocation services to sample the number of users on a transportation facility and their movements.

Figure 3-3 shows a decision tree to help decide what method to use for traffic analysis.

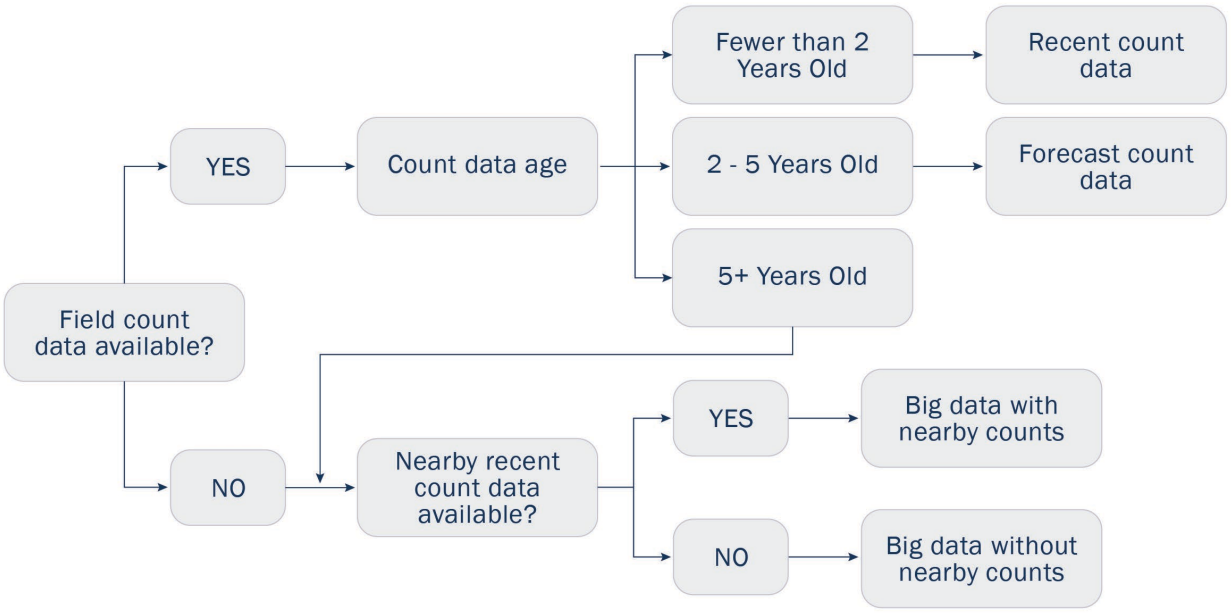


Figure 3-3: Traffic Volume Derivation Methodology Decision Tree for Disruptive Events

3.2.6 Traffic Balancing

Traffic volumes are considered balanced when no volume discrepancies exist between adjacent locations in the project area. Balancing typically begins at one extremity of the project and ends at the other extremity of the project until all discrepancies have been flushed out of the network. Include high-volume driveways that serve high-density developments. Balance base year volumes and traffic forecasts. It is recommended that counts are balanced before analysis begins, though there may be circumstances where counts will not balance due to land use and special traffic generators. Before balancing begins, round counts to the nearest determined interval unit. For standard rounding conventions, see Section 3.2.7 about post processing.

3.2.7 Post Processing

Traffic volumes are typically rounded up to the nearest 100 unit (e.g., vehicle, truck) but are rounded up to the nearest 50 if the traffic volumes are between 100-200. Traffic volumes are typically rounded up to the nearest 10 or 25 if traffic volumes are under 100. However, using numbers under 100 may cause balancing issues. It is recommended that identical volumes be rounded to the same value. Additionally, identical volumes typically result in the same values when forecasted.

3.2.8 Validation

Validate existing volumes by checking against field observations, historical traffic counts, traffic volumes from adjacent projects, adjacent land use, and the capacities defined in the HCM. Table 3-1 and Table 3-2 show the capacities of basic freeway segments, multi-lane highway segments, and ramps based on the *HCM 7th Edition*. If there are discrepancies between data points, validate with additional data sources.

Table 3-1: HCM's Basic Freeway Segment and Multi-Lane Highway Segment Capacities

Free Flow Speed (mi/h)	Capacity (pc/h/ln)	
	Basic Freeway Segment	Multi-Lane Highway Segment
75	2,400	N/A
70	2,400	2,300
65	2,350	2,300
60	2,300	2,200
55	2,250	2,100
50	N/A	2,000
45	N/A	1,900

Table 3-2: HCM's Ramp Capacities

Ramp Free Flow Speed (mi/h)	Capacity (pc/h)	
	Single-Lane Ramps	Two-Lane Ramps
>50	2,200	4,400
>40-50	2,100	4,200
>30-40	2,000	4,000
>=20-30	1,900	3,800
<20	1,800	3,600

3.3 Forecasting Traffic Volumes

Forecasting traffic volumes involves growing existing volumes at a given growth rate to a future year. This section discusses forecasting traffic volumes with the latest TDM outputs, without the latest TDM outputs, and a hybrid of TDM outputs/no TDM outputs. For projects within the boundaries of an MPO, the latest MPO TDM outputs can be referenced to

determine corridor growth rates for projects. For projects outside MPO boundaries, TPP's SAM can be referenced to determine growth rates. For forecasting without TDM outputs, growth patterns and historical trends are used as a means of estimating future volumes. Traffic analyses for highway designs from adjacent projects are an additional resource for traffic projections. See Figure 3-4 for the typical traffic forecasting process. It is recommended that the traffic growth rates from the various data sources be documented and submitted as part of the Traffic Projections Methodology Memo. An example outline for Traffic Projections Methodology Memorandum is provided in Appendix D, Section 2 – Traffic Projections Methodology Memorandum Outline. The growth rate for the first 20 years is typically higher than the growth rate for more than 20 years because the growth will taper down over time as the facility approaches capacity. For additional guidance on traffic volume and forecasting, refer to the *TxDOT TPP Traffic Forecasting Analysis SOPs.* Coordinate with the TxDOT project manager to gain access to the latest documents.

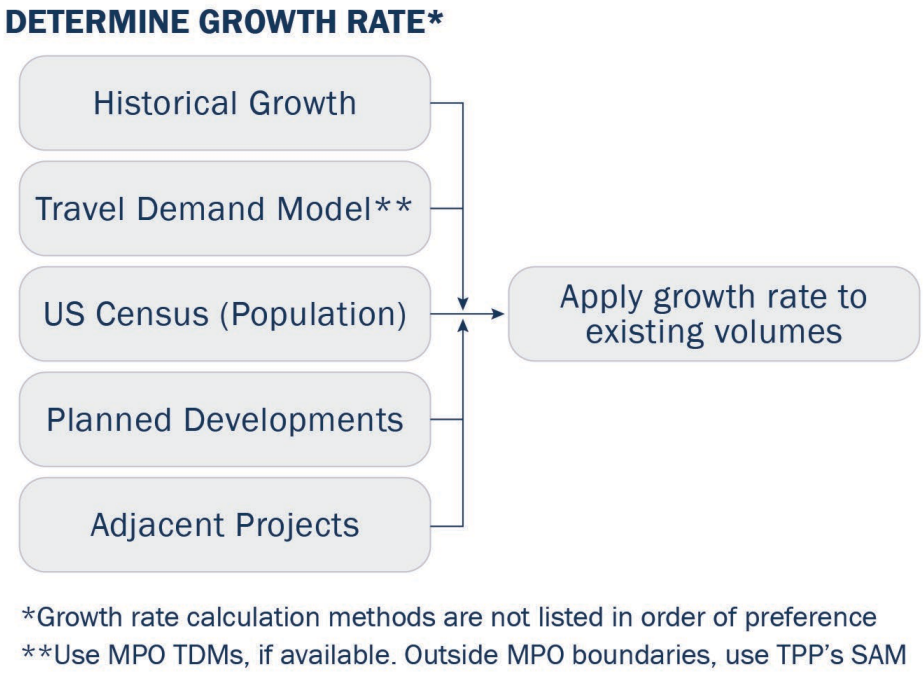


Figure 3-4: Traffic Forecasting Process

3.3.1 Traffic Volume Forecasting

TxDOT's forecasting analysis process is currently classified into two different categories: TPP-led and District-led. The District provides TPP Traffic Analysis Branch a notification of the District Led Traffic Analysis. TPP maintains the statewide system of records for traffic forecasting. For additional guidance on traffic volume and forecasting, refer to the *TxDOT TPP Traffic Forecasting Analysis SOPs*. Coordinate with the TxDOT project manager to gain access to the latest documents.

3.3.2 Future Year Selection

Typical traffic forecasts include the project opening year, the design year (i.e., opening year + 20 years), and the pavement design year (i.e., opening year + 30 years). Traffic forecasts may also include an interim year. An interim year occurs between the opening year and pavement design year. Interim years may be used if the proposed improvements show failing Level of Service (LOS) prior to the design year. The opening year is the first year in which the proposed improvements are expected to be open to traffic. If the project is proposed to be implemented in phases, the opening year is the year the first phase will be opened to traffic. Opening year is typically determined by project size, complexity, and schedule, with respect to the letting date. The let date is dependent on the planning and programming of projects.

3.3.3 AM and PM Peak Hour Traffic Projections

The AM and PM peak hours are not always inversely related. Peak hour percentages in terms of the percentage of total daily traffic that is occurring in the AM/PM peak hour are determined separately for both the peak hours. The percentages are intended to be a representation of the existing traffic patterns. Typically, traffic counts are collected in the form of TMCs and segment counts. Assuming traffic counts are taken on a typical weekday with no major events or disruptions, they represent peak hour percentages for the AM and PM K-factors. The peak hour percentages are then applied to the ADTs to develop projected AM and PM peak hour volumes. It is recommended that the traffic counts collected be validated against STARS data, previous counts, or traffic forecasts.

Turning movement traffic projections are estimated by applying existing TMC percentages at each approach to the ADT volumes. TMCs are typically rounded to 50-vehicle increments. This avoids an overestimation of traffic on side streets. The traffic projections are then balanced along the corridor.

For an example on calculating AM and PM peak hour traffic projections, see Appendix D, Section 3 – Peak Hour Projection Calculations.

3.3.4 Traffic Balancing

See Section 3.2.6 under Balancing for basic information on volume balancing. See Figure 3-5 for an example of balanced traffic projections. For an example calculation of volume balancing, see Appendix D, Section 5 – Balancing Traffic Volumes Example Calculations.

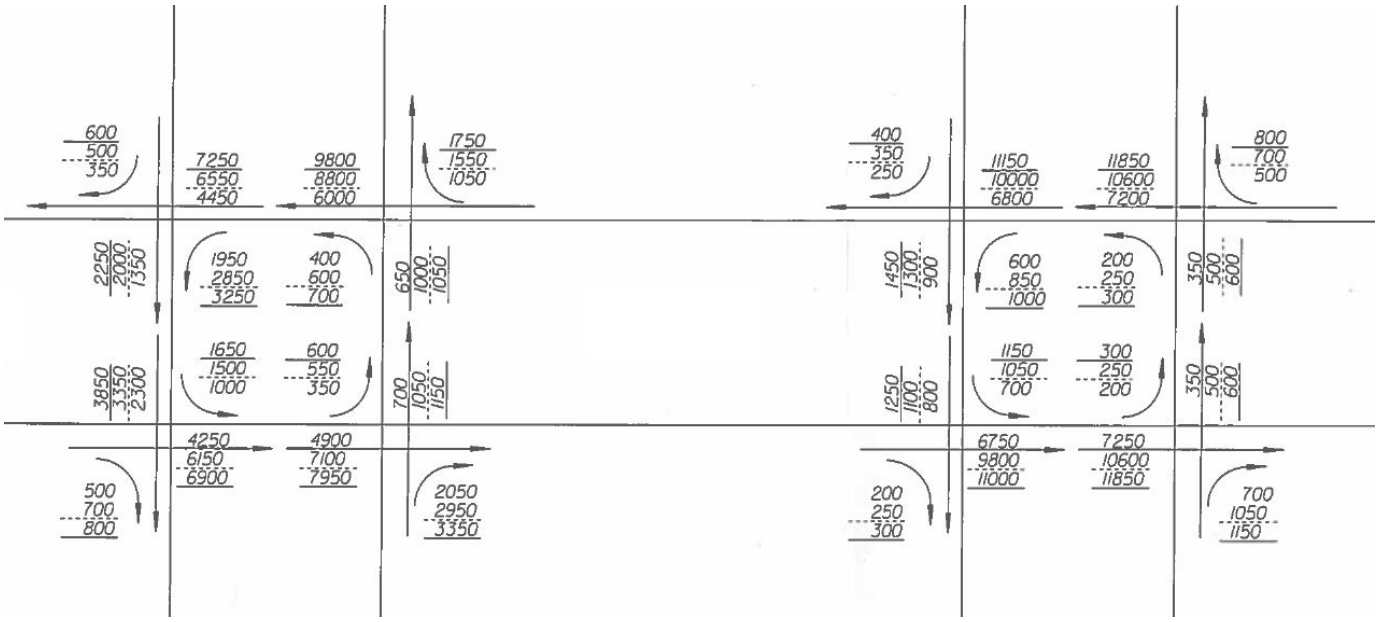


Figure 3-5: Example of a Balanced Network

3.3.5 Model Version Control

It is suggested that model versions used for no-build and build analysis are captured in terms of corresponding filenames and folder names. Typically, each version or revision is associated with a date or timestamp for efficient tracking. Versioning helps document changes to the model and helps control all changes applied to a model, allowing the identification and recovery of a previous version when needed. Model version controls are typically documented and include tracking of the changes and data inputs made in each model revision. See Chapter 7, Section 7.5.5 of this manual for definitions of no-build and build.

3.3.6 Forecasting with Travel Demand Model Outputs (TDM Outputs)

TxDOT and 23 MPOs collaborate in the transportation planning process and in the development of TDM outputs (TDM outputs) and their inputs. These 23 MPOs are listed on the following page. The MPO TDM outputs can be referenced to determine corridor growth rates for projects, if available. Outside these MPO boundaries, TPP's SAM can be referenced to determine growth rates for projects. SAM involves travel demand modeling at a statewide level. It includes different passenger and freight modes and the interaction among those modes. Access to the MPO TDM and the SAM needs a data request.

There are different types of TDM, which include 4-step/trip-based models and activity-based models (ABM). The traditional 4-step model includes trip generation, trip distribution, mode choice, and traffic assignment for a single OD pair from one traffic analysis zone (TAZ) to another. Conversely, ABMs examine continuing trips from one zone to another over time.

The TDMs available through an MPO are as follows:

- Abilene MPO
- Amarillo MPO
- Bryan-College Station MPO
- Capital Area MPO
- Corpus Christi MPO
- El Paso MPO
- Houston-Galveston Area Council
- Killeen-Temple MPO
- Laredo & Webb County Area MPO
- Longview MPO
- Lubbock MPO
- Permian Basin MPO
- North Central Texas Council of Governments
- Rio Grande Valley MPO
- San Angelo MPO
- Alamo Area MPO
- Sherman-Denison MPO
- South East Texas Regional Planning Commission
- Texarkana MPO
- Tyler Area MPO
- Victoria MPO
- Waco MPO
- Wichita Falls MPO

For non-attainment zones, only the approved TDM developed, calibrated, and validated by MPOs can be used. MPOs in the non-attainment zones are:

- El Paso MPO (El Paso area)
- Houston-Galveston Area Council (Houston-Galveston area)
- North Central Texas Council of Governments (Dallas-Fort Worth area)
- South East Texas Regional Planning Commission (Beaumont-Port Arthur area)

A TDM with project details is necessary for project level analysis for major investment type studies or a project that changes the MPO's approved plan. Forecasting with a TDM output is also applicable in special cases, such as for a new route location; where historical data is not available; or when considerable development and land use changes are expected in the project area in the future. Travel demand modeling includes the selection of an applicable model, calibration to local conditions, validation of model results, and revisions of forecast volumes. A TDM output is calibrated for regional trip generation, trip distribution, mode choice, and assignment. TDM outputs can have inconsistencies on a link-by-link basis since these models are not calibrated at the link level. Therefore, further adjustments or post-processing of the model's daily or peak-period outputs are typically applied prior to use in corridor or project analysis. Detailed travel demand modeling methodologies are described in *National Cooperative Highway Research Program (NCHRP) Report 716 Travel Demand Forecasting: Parameters and Techniques*.

It is recommended that TDM outputs and growth rates be compared with other sources, such as historical data, adjacent projects, past projects, state demographer forecasts, and US Census data population. Differences in volumes more than 10% for freeways, 15% for arterials, and 20% for ramps or low volume

roads may need to be further evaluated and documented to explain the discrepancy. If no model is available for the project, then see Section 3.3.7.

When forecasting volumes with a TDM, the existing year of a TDM coincides with the date the data was collected. For example, a TDM that uses census data for population information would have a base year that was the same as the census data year.

When forecasting traffic volumes for new locations (e.g., new routes through greenfield), it is recommended that a diversion analysis is conducted. Diversion analyses are typically conducted for a proposed highway or bypass, proposed frontage roads, ramp reversals, proposed Texas U-turns, and proposed land use development. TxDOT's *TPP Traffic Forecasting Analysis SOPs and Guide* outlines how to complete a diversion analysis. Coordinate with the TxDOT project manager to gain access to the latest documents.

TDMs forecast travel demand using the following traditional four-step model:

1. Trip Generation

Estimates the number of trips generated and attracted to a TAZ. The NCHRP *Report 716: Travel Demand Forecasting: Parameters and Techniques* document can be used for trip generation when developing a model. For validation, the analyst can use the *Travel Model Improvement Portal (TMIP) Travel Model Validation and Reasonableness Checking Manual*.

2. Trip Distribution

Estimates the number of trips TAZs. NCHRP 716 can be used for trip distribution when developing a model.

3. Mode Choice

Assigns each trip's mode of transportation. Typical modes include private vehicles, public transit, bicycle, and walking.

4. Trip Assignment

Assigns trips between zones to a route in the network.

3.3.7 Forecasting Without Travel Demand Model Outputs

Forecasting volumes without a TDM is a four-step process:

1. Obtain existing volumes
2. Determine the growth rate
3. Apply growth rate to the existing volumes
4. Other considerations

3.3.7.1 Obtain Existing Volumes

Existing volume considerations are discussed previously in this chapter, under Section 3.2. These considerations include traffic data factors, seasonal factors, historical factors, peak hour/period selection, disruptive events, traffic balancing, post processing, and validation.

Existing data can be obtained from various sources, including the TxDOT STARS database,

MPO counts, the statewide planning map, or big data. For more information on data collection, see Chapter 2.

3.3.7.2 Determine Growth Rate

The growth rate is a critical component needed to forecast traffic volumes. It can be determined using various methods. All methods listed in this section can be used to determine growth rate. The growth rate may vary from method to method, so it is recommended that multiple methods be checked for validation purposes. If needed, work with the District, TPP, and DES to develop interim growth rates.

Three methods of determining growth rate are as follows:

- Historical traffic growth data
    - Analyze traffic volumes over time at a particular location. Obtaining historical traffic volumes is discussed in Chapter 2.
    - Use of the linear regression spreadsheet provided in Appendix D, Section 4 – Regression Calculations is suggested to calculate historical traffic growth rates.
- Population growth data
    - Analyze population growth from multiple years to determine the traffic volume growth rate over time. Population data can be found in the US Census data or in the state demographer forecasts.

3.3.7.3 Apply Growth Rate to Existing Volumes

Apply the calculated growth rate to the existing volumes to develop traffic projections. The three components of the calculation are the existing volumes, the growth rate, and the number of years.

3.3.7.4 Other Considerations

- Planned developments
    - If there are developments planned near the project location, account for growth impacts of the developments.
- Adjacent projects
    - Adjacent roadway projects may impact traffic growth. Account for them during the traffic forecasting process.
- Complete the traffic projections methodology outline in Appendix D, Section 2 – Traffic Projections Methodology Memorandum Outline

For additional guidance on traffic volume and forecasting, refer to the *TxDOT TPP Traffic Forecasting Analysis SOPs and Guide.* Coordinate with the TxDOT project manager to gain access to the latest documents.

3.4 Forecast Using Hybrid Approach

The hybrid approach to forecasting volumes involves using historical growth data and a TDM output. There are two types of hybrid approaches discussed below. While both approaches use historical growth rates and a TDM output, the order the sources are used is different and create two distinct methods for forecasting volumes.

3.4.1.1 Historical + TDM Outputs

This hybrid approach involves historical traffic data and patterns. Growth rates are calculated from the TDM outputs and then applied to the historical data to develop traffic forecasts.

3.4.1.2 TDM Outputs + Historical

This hybrid approach involves obtaining TDM traffic data. Growth rates are calculated from historical data and then applied to the TDM volumes to forecast traffic volumes. This is applicable in cases where there is a new route location, historical data is not available, or considerable development and land use changes are expected in the project area in the future.

3.5 Connected and Automated Vehicles

Agencies are making funding plans to meet future roadway needs while anticipating impacts of connected and automated vehicles (CAVs). CAVs are anticipated to have substantial market penetration after year 2050. As of 2024, base capacity of a freeway lane is 2,400 vehicles per hour per lane (vphpl). Research has shown that at 100% market penetration rate, freeway capacity could increase by up to 33% to 3,200 vphpl due to smaller gaps between CAVs. Freeway capacity increases may be higher for lower base capacities. This is because an automated driving system is not affected by narrow lane widths, absence of shoulder, or other factors

that cause a human driver to maintain larger gaps. It is recommended that scenario planning analysis for the future considers the additional and independent impact of CAVs on lane capacities. Capacity adjustment factors (CAFs) for CAVs on basic freeway and freeway diverge segments are shown in Table 3-3. These adjustment factors come directly from the HCM 7th Edition.

Table 3-3: HCM's CAFs for CAVs for Basic Freeway and Freeway Diverge Segments

Proportion of CAVs in Traffic Stream	Adjusted Segment Capacity		
	2,400 pc/h/ln	2,100 pc/h/ln	1,800 pc/h/ln
0	1.00	1.00	1.00
20	1.02	1.02	1.15
40	1.07	1.10	1.27
60	1.13	1.25	1.40
80	1.22	1.37	1.60
100	1.33	1.52	1.78

Chapter 4
Traffic Analysis Methodology, Tools, and MOE

4.1 Introduction

The tools, methodologies, and MOEs used to analyze roadway facilities have a critical impact on decision-making and perceived performance. Each tool and methodology necessitate a varied level of effort and produces results with varying degrees of detail and reliability. As such, it is suggested that the selection of tools, methodologies, and MOEs are carefully considered. Additional information about analysis methodology, tools, and MOEs can be found in Appendix E, Section 1 – Additional Resources.

4.1.1 Purpose and Intended Use

The purpose and intended use of this chapter is to provide guidance on the selection of analysis tools, methodologies, and MOEs. This chapter does not provide guidance on how to use analysis tools (such as a software user manual) or procedures for calculating MOEs. Further guidance is available in facility-specific chapters (e.g., segments, intersections, interchanges, roundabout analysis).

4.2 Project Development Stage (PDS)

Traffic and safety analysis procedures are applied to a wide range of projects. The PDS refers to a project's position on the project timeline (i.e., is the project in the beginning, middle, or end stage?). The PDS defines the level of effort necessary to complete an analysis and could also influence the analysis tools used, depending on project complexity, scope, schedule, and cost. A project's PDS can be classified as either the Planning stage, Preliminary Schematics stage, or Final/Approved Schematics and Design stage. General characteristics of each PDS are provided later in this chapter. The general impact of PDS on tool selection is shown in Figure 4-1. This figure generally describes the impact that the PDS has on tool selection but may not be applicable to every project.

Analysis with a low amount of detail calls for accurate input data but is not as finely detailed or coded as that necessary for highly detailed analysis. In terms of network, a low-detail analysis typically involves general link-node representation and longer segments with lane and posted speed information. Highly detailed analysis calls for accurate input data that is finely detailed or coded. It involves longer segments broken up into multiple segments. It depicts lane variations, geometric configuration, curvature, turning movement, and additional details.

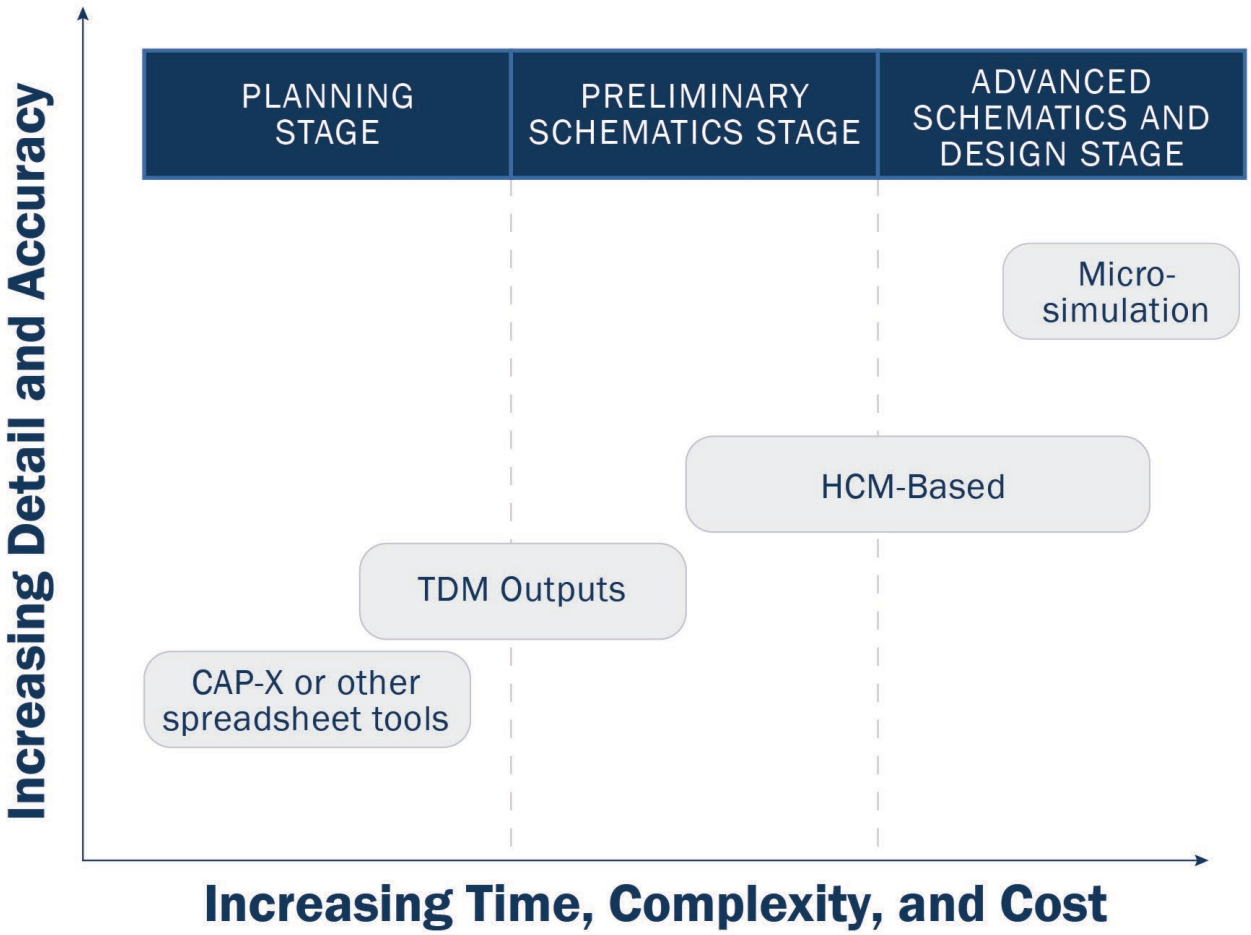


Figure 4-1: Tool Selection by Project Development Stage

4.2.1 Planning-Stage

A Planning-stage analysis is typically a low-detail analysis applied to projects at an early development stage. While a Planning-stage analysis is low-detail, it uses accurate data and as much data as available for the study. Per the HCM, Planning-stage analyses are "directed toward broad issues such as initial complication identification, long-range analyses, and regional and statewide performance monitoring." While Planning-stage analysis is often applied to high-level projects and large areas, it could also be applied to specific locations and projects that use many data inputs.

Planning-stage analyses:

- Are conducted for projects such as short- or long-range studies, master plans, strategic plans, and alternatives analyses;
- Help estimate high-level project cost;
- Identify questions to be answered in later stages of analysis;

- Rely on available data sources and supplement unknown inputs with default values; and
- Use screening tools, TDM outputs, or other planning stage tools to select viable alternative for further analysis
    - Screening tools that can be implemented include general service volumes, CAP-X, and other spreadsheet-based tools

4.2.2 Preliminary Schematics-Stage

Preliminary Schematics-stage analysis is a medium-detail analysis applied to projects at a middle development stage. Per the HCM, Preliminary Schematics-stage analyses are "conducted to support planning decisions related to roadway design concept and scope and when alternatives analyses are performed." Compared to a planning-stage analysis, the preliminary schematics-stage may have the project broken down into smaller components for individual analysis. Projects in the preliminary schematics-stage may also include more data that was not included in the planning-stage analysis.

Preliminary Schematics-stage analyses:

- Are conducted for projects such as alternatives analyses, preliminary design, and existing intersection/corridor evaluation;
- Answer key questions to determine scope and benefits of further study, if needed;
- Use tools that may need more detail input;
- May use tools that are deterministic (report same results, given same inputs) and macroscopic (evaluate traffic stream as compared to individual vehicles); and
- May use tools that are stochastic (account for randomness) and mesoscopic (evaluates both traffic flows/streams and individual vehicles)

4.2.3 Final/Approved Schematics and Design Stage

Final/Approved Schematics and Design-stage analysis is a high-detail analysis that is often performed with more data than projects in other stages of development. While study limits for projects in this stage could be broad or narrow, they are well defined.

Final/Approved Schematics and Design-stage analyses:

- Are conducted for projects beyond the preliminary design stage;
- Answer questions generated by previous stages of analysis;
- Often necessitate substantial amounts of data to be collected; and
- May use tools that are stochastic (account for randomness) and microscopic (evaluate individual vehicles). The use of microsimulation (microscopic) tools depends on the scope, complexity, traffic operational conditions, and MOEs of the project

4.2.4 Multi-Stage Analysis

Multi-stage analysis is a combination of analysis stages, often applied in sequence. As with alternatives analysis, study limits are well-defined and narrowed to permit increased detail. For example, if a project used CAP-X (a Planning-stage analysis tool) to determine intersection configurations and then modeled in Vissim (a design stage analysis tool) to determine the preferred intersection configuration, that would be considered a multi-stage analysis.

Multi-Resolution Modeling (MRM) involves tools with different traffic analysis resolutions (Sketch-level or macroscopic, HCM-based (mesoscopic), and microsimulation (microscopic)). It could include assessing a sketch-level or macroscopic trip table to determine overall trip patterns. It could also include using HCM-based (mesoscopic) analysis to understand impact of mitigation strategies on groups of vehicles at a lane-by-lane level or packets of vehicles in large networks. Lastly, a multi-stage analysis could potentially include microsimulation (microscopic) analysis of individual driver behavior and the impacts of traffic control strategies. Figure 4-2 shows the MRM framework.

Partial multi-resolution models, involving macroscopic and microscopic models for networks experiencing medium to low levels of congestion, may not be able to model large-scale traffic demand reroutes. This could result in macroscopic/TDM output results that may not properly represent the congestion for the various alternatives and could require further analysis using engineering judgement or different analysis techniques.

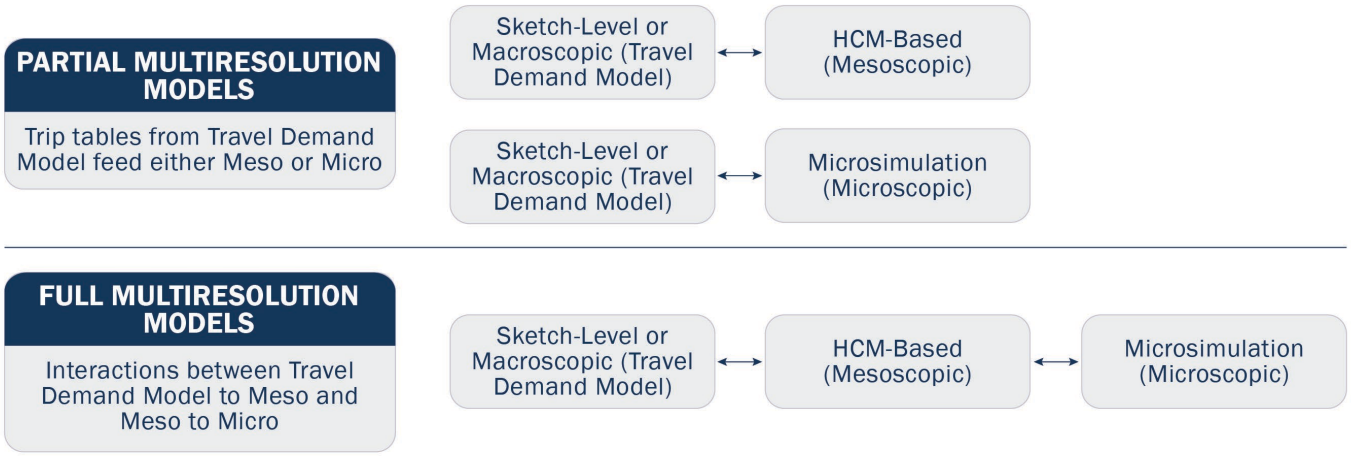


Figure 4-2: Multi-Resolution Modeling Frameworks

4.3 Analysis Tool Description and Selection Methodology

Analysis tools are typically selected based on the tool's ability to satisfy the project need and purpose as well as project-specific constraints (e.g., project objectives, traffic operational conditions, complexity of geometry, MOEs, availability of data, level of effort, budget, and schedule). The Analysis Tool Selection Process, a flow chart which graphically demonstrates tool selection methodology, is provided in Appendix E, Section 2 – Traffic Analysis Tool Selection Process. It is recommended that users review the appended methodology and consider project-specific constraints, as well as local preferences, before selecting analysis tools.

Generally, based on the appended tool selection methodology, analysis stage and project facility type are used to inform the selection of analysis tools. A simplified analysis tool selection is provided in Table 4-1, for use if facility saturation level, project-specific limitations, or other information necessary to complete the flow chart is unknown. TxDOT does not promote the use of any specific analysis tool, product, or vendor. Analysis tools named within Table 4-1 are intended to represent a tool category (or type) where several tools are acceptable.

All tools discussed in this chapter are examples of software used by industry experts and do not reflect preferences of TxDOT.

Table 4-1: FHWA Traffic Analysis Tools Vol II: Needs and Analysis Tools/Methods

Transportation Planning Needs	Operational Analysis Tools/Methods						
	Sketch-level or Macroscopic Tools	Deterministic Models	Travel Demand Forecasting Models	Simulation	Archived Operations Data	Operations-Oriented Performance Metrics	Traffic Signal Optimization Tools
Needs Assessments / Deficiency Analysis		✓	✓	✓	✓	✓	✓
Preliminary Screening Assessments	✓						
Alternatives Analysis	✓		✓	✓		✓	
Strategic ITS Planning	✓		✓			✓	

Transportation Planning Needs	Operational Analysis Tools/Methods						
	Sketch-level or Macroscopic Tools	Deterministic Models	Travel Demand Forecasting Models	Simulation	Archived Operations Data	Operations-Oriented Performance Metrics	Traffic Signal Optimization Tools
Project Scoring/ Ranking/ Prioritizing		✓	✓			✓	
Corridor and Environmental Analysis		✓	✓	✓		✓	✓
Planning for Nonrecurring Congestion	✓		✓	✓	✓	✓	
Performance Monitoring		✓			✓	✓	✓
Evaluations of Developed Projects	✓		✓	✓	✓	✓	

4.3.1 CAP-X

CAP-X is an example of a planning-stage, spreadsheet-based tool developed by FHWA to evaluate junctions (conventional intersections, alternative interchanges, and roundabouts). CAP-X inputs include turning movement volumes, truck percentages, and volume growth percentages. CAP-X outputs include critical lane volume and volume to capacity (v/c) ratio for various junctions (conventional, quadrant roadway, displaced left turn (DLT), etc.). CAP-X reports include a graphic of each junction-type with corresponding inputs and outputs. For more information about CAP-X, refer to the FHWA's CAP-X webpage.

4.3.2 Travel Demand Models (TDM)

TransCAD, Visum, and Cube are three examples of software that are used for travel demand modeling. These types of tools are typically GIS-based planning-stage tools used for travel demand modeling. Inputs include analysis zones and network of links (roadways and zone connectors). Most models are based on static traffic assignment, with static travel times for calculating the shortest path. Analysis zones include attributes such as land use, population, trip origins and destinations by mode, and employment data. Links include attributes such as facility type, number of lanes, posted speeds, capacity, distance, and travel time. Analysis follows the four-step model to output projected traffic volumes. When using TDMs, tool selection is based on model availability (i.e., if the TDM used was developed in Cube, then it is recommended that Cube is used as the analysis tool for the project). The content in this chapter focuses on TDM

outputs, not on the development of TDMs. Typical outputs for a TDM are the Vehicle Miles Traveled (VMT), Vehicles Hours Traveled (VHT), Vehicle Hours of Delay, volume-to-capacity ratio, and speed.

4.3.3 DynusT

A mesoscopic simulation model that uses dynamic traffic assignment (DTA) that is used for planning- and schematic-level projects. DynusT is a stochastic tool that uses the HCM fundamentals. It is a hybrid of microsimulation models and HCM-based models because it can model traffic flows and individual vehicles at intersections. It considers saturated and unsaturated conditions, capturing queues and diverted traffic. It also calculates shortest paths based on experienced travel delay.

4.3.4 HCM/HCS

HCS is a Preliminary Schematics-stage tool used to evaluate uninterrupted flow (freeway) and interrupted flow (urban and rural) facilities. HCS performs the HCM equations/operations and includes methodologies for vehicle and non-vehicle (pedestrian, bicycle, transit) modes. HCS inputs and outputs vary by facility and mode; inputs include volume, roadway, and signal timing parameters. HCS outputs include traffic operations MOEs LOS, delay, queue lengths, facility travel speed, etc.). HCS reports static output by intersection or roadway segment. HCS results are most reliable when typical geometric locations are analyzed at locations with traffic volumes under capacity (undersaturated conditions). HCM/HCS is traditionally used for undersaturated conditions and rural facilities. HCS can be calibrated to local conditions by adjusting default inputs.

4.3.5 Synchro

Synchro is a Preliminary Schematics-stage tool used to evaluate urban roadways and rural/urban intersections. Synchro performs the HCM calculations and includes proprietary equations particularly useful for optimizing signal timing parameters along signalized arterials within a static model. Synchro inputs include volume, roadway, and signal timing parameters. Bing maps are embedded in Synchro and Environmental Systems Research Institute (ESRI) shapefiles (or other georeferenced files/aerials) and can be imported into Synchro such that links/nodes are mapped correctly. Synchro can be calibrated to local conditions by adjusting default inputs.

Synchro outputs include traffic operations MOEs and environmental MOEs (fuel consumption and emissions). Synchro reports the HCM calculation results or Synchro static model percentile delay results for each location or network. The HCM results can be reported for intersection analyses, except for signal timing optimization projects. The Synchro proprietary delay calculations employ a percentile delay method, where delays are calculated for the 10^{th}, 30^{th}, 50^{th}, 70^{th}, and 90^{th} percentile traffic volumes and then averaged to provide the reported delay values. Additionally, Synchro is capable of multi-file comparisons and TIA reporting.

4.3.6 Signalized And Unsignalized Intersection Design And Research Aid

Signalized and unsignalized intersection design and research aid (SIDRA) is a Preliminary Schematics-stage tool used to evaluate intersections, mainly roundabouts. SIDRA inputs include volume and roadway parameters. SIDRA outputs include LOS and delay reported by lane. SIDRA provides outputs for each location.

4.3.7 FREeway EVALuation (FREEVAL)

FREEVAL is a Planning-stage tool that is based on the HCM methodology and used to perform a capacity analysis for undersaturated and oversaturated conditions. In addition to a basic capacity analysis, it performs work zone impact analysis, managed lane analysis, and travel time reliability analysis. FREEVAL can be downloaded from the FREEVAL website, which also has links to user guides, instructive videos, and links to other resources.

4.3.8 Verkehr in Staedten Simulation (Vissim)

Vissim is a tool used to evaluate uninterrupted and interrupted facilities. Vissim inputs need a more granular level of detail than macroscopic or mesoscopic models. Vissim is a microsimulation modeling program that simulates the movements of individual vehicles throughout a predefined network. A sketch-level or macroscopic modeling tool aggregates vehicle behaviors between decision points. Vissim, by contrast, tracks every movement that every vehicle makes from the moment it enters the network until the moment it exits the network.

Vissim inputs include volume, roadway, and signal timing parameters. Vissim outputs include traffic and environmental MOEs. Vissim accounts for randomness and factors not included in the HCM calculations, including driver behavior and how delays in one part of the network impact every other part of the network. This makes Vissim more accurate, particularly when evaluating oversaturated conditions. Vissim reports simulation output by location. Vissim simulations can be exported as video files to demonstrate the conditions to expect in the field. Vissim is typically used to analyze complicated or unusual geometry, oversaturated conditions, alternative intersections, and complex urban facilities/networks.

Vissim (or an alternative microsimulation tool) is often used to analyze locations with the following characteristics:

- Oversaturated conditions (traffic volumes over capacity);
- Multilane or two-lane rural roads where traffic signals or stop signs significantly impact capacity and/or operations;
- Climbing lanes for trucks;
- A short through-lane is added or dropped at a signal;
- Two-way left-turn lanes;
- Roundabouts of more than a single lane;
- Tight diamond interchanges; or
- Atypical conditions

4.3.9 Corridor Simulation (CORSIM)

CORSIM is a Final/Approved Schematics and Design-stage tool used to evaluate complex or oversaturated freeway and urban roadway facilities. CORSIM is a Microsimulation (Microscopic) traffic simulation that models freeways, highways, networks, including segments, weaves, merges/diverges, and unsignalized and signalized intersections. CORSIM inputs are similar to Preliminary Schematics-stage tools, with the addition of user-defined driver characteristics (dwell time, driver familiarity, etc.). CORSIM outputs include traffic and environmental MOEs.

4.3.10 SimTraffic

SimTraffic, a companion tool for Synchro, is a microscopic and Final/Approved Schematics and Design-stage tool used to evaluate intersections and networks. SimTraffic inputs are similar to Preliminary Schematic-stage tools, with the addition of driver behavior parameters (deceleration rates, reaction time, gap acceptance factor, etc.). Driver behavior parameters are modified for each of 10 driver types. As vehicles are added to the simulation, they are randomly assigned a driver type. SimTraffic outputs include traffic and environmental MOEs. SimTraffic simulations can be exported as video files. Typical applications of SimTraffic include analyzing signalized and unsignalized intersections.

4.4 Analysis Tool Evaluation

Project-specific constraints may merit the selection of analysis tools different from tools prescribed per the Analysis Tool Selection Process provided in Appendix E, Section 2 – Traffic Analysis Tool Selection Process. Tool limitations are reviewed when considering project constraints such as project complexity, schedule, and budget. Analysis tool limitations, provided in Table 4-2, are described in terms of complexity and data requirements; each criterion is classified as either low, medium, or high. Analysis tool method is described as deterministic (reports the same results given the same inputs) or stochastic (reports different results given the same inputs due to the presence of randomizing factors). See the Section 4.4.2 subsection for more information on deterministic and stochastic analysis types. Analysis time is presented as a comparative factor. Bigger time factors indicate longer time for analysis, while smaller factors indicate shorter times.

Table 4-2: Analysis Tool Limitations

Analysis Tool	Method	Time	Complexity	Data Requirements
Spreadsheet-based Tools	Deterministic	Varies	Varies	Varies
TDM	Deterministic	2x	Low to Medium	Medium
CAP-X	Deterministic	1x	Low	Medium
HCS	Deterministic	2x	Low to Medium	Medium
DynusT	Deterministic/ Stochastic	4x	Medium to High	Medium to High
Synchro	Deterministic	2x	Medium	Medium
SIDRA	Deterministic	3x	Medium	Medium
Vissim	Stochastic	5x	High	High
CORSIM	Stochastic	4x	High	High
SimTraffic	Stochastic	3x	Medium to High	Medium

4.4.1 General

Analysis results are the most reliable when typical geometric configurations are analyzed. All analysis tools have some limitations. Below are some examples of the limitations of deterministic tools:

- Network affect caused by congestion;
- Traffic flows will not adjust travel routes due to congestion;
- Interference caused by roadside parking;
- HOV, High-Occupancy Toll (HOT), or other managed lanes;
- Tight diamond interchanges;
- Impacts of multiple closely spaced driveways along a street segment;
- Interactions between bicycles, pedestrians, and vehicles sharing the same roadway;
- Impacts of on-street parking, commercial vehicle loading, and double parking;
- Impacts of changes in roadway environment (or other violations of driver expectation);
- Impacts of tolling on travel patterns;
- Driver behavior;
- Two-way left-turn lanes; and
- v/c does not capture spatial congestion

The following are some examples of the limitations of stochastic tools:

- Models may have difficulty capturing the effects of a continuous two-way left-turn lane;
- It is recommended to run models multiple times to capture randomness or average travel experience; and

- Impacts of driver behavior (obstruction of visibility, roadway distractions, etc.)

4.4.2 Method

Analysis tools may be classified as either deterministic or stochastic. Stochastic tools account for randomness, while deterministic tools do not. Because of this, stochastic tools more accurately represent variability present in a traffic network (e.g., varying speeds among drivers, varying reaction times, and varying acceleration and deceleration rates). Microsimulation-based (microscopic) tools are typically stochastic, while the HCM-based and spreadsheet-based tools are deterministic.

4.4.3 Level of Effort

Level of effort refers to the duration necessary for model development and application. Level of effort is critical to understand for all projects and particularly for projects with set letting schedules. If constrained by time limits, PS&E projects may select Planning-stage or Preliminary Schematics-stage analysis tools. FHWA's *Guidance on the Stage of Effort Required to Conduct Traffic Analysis Using Microsimulation* presents estimates of typical microsimulation (microscopic) traffic analysis projects based on the project size.

Table 4-3 shows estimated level of effort in terms of a range of percentages by task for microsimulation (microscopic) projects based on the FHWA guidance. For small- and medium-sized projects, level of effort is similar across different tasks, as the modeling complexity is still comparable. For large models, calibration efforts need extensive data collection. Although it could seem that effort is lower for developing and calibrating the base model and performing alternatives analysis, the small difference in percentages could represent hundreds of hours of effort. For example, a small project that has a duration of six months will need approximately 15 days of data collection efforts.

Table 4-3: Level of Effort

Task	Project Size		
	Small	Medium	Large
Data Collection	5-10%	5-10%	15-20%
Base Model Development and Calibration	25-30%	30-35%	25-30%
Alternatives Analysis	50-55%	45-50%	25-30%
Documentation/Presentations	5-10%	5-10%	15-20%
Project Management	5-10%	5-10%	10-15%

4.4.4 Complexity

Complexity indicates the level of effort necessary to develop, calibrate, and validate a model for it to achieve its intended purpose. Complexity varies by project type, project size, and the analysis tool, among other things. Due

to the variability in project complexity, it is suggested that the analyst give careful consideration to selecting the correct tool for the project.

4.4.5 Data Requirements

Data requirements vary by project type, analysis tool, and selected MOEs. Review Chapter 2 for detailed information on data requirements. *FHWA Traffic Analysis Toolbox, Volume III* (2004) guidance may be followed for TxDOT projects that do not involve FHWA approval. Average day traffic analysis may be performed for these projects. Follow *FHWA Traffic Analysis Toolbox, Volume III* (2019) guidance for projects that involve IAJRs or FHWA approval.

4.5 MOEs

MOEs objectively report project conditions involving specific criteria. Traffic analysis MOEs are often related to mobility and may also include safety, accessibility, reliability, or other

s (see Chapter 5 and Chapter 6 for Safety MOEs). Analysis tools selected for a project often determine which MOEs will be used to evaluate project conditions. However, project-specific circumstances could merit the selection of a certain MOE, in which case analysis tool selection could be MOE-dependent. Common MOEs reported by common analysis tools are provided in Table 4-4. MOEs can be selected when completing a quantitative analysis. The number and type of MOEs selected are dependent on the goals and objectives of the project.

Table 4-4: MOEs by Analysis Tool

MOEs Reported	Units	CAP-X	TDM	FREEVAL	HCS	Synchro	SIDRA	Vissim	CORSIM	SimTraffic
Control Delay	Sec/veh	✓	✓	✓	✓	✓	✓	✓[a]	✓	✓
Density	Pcpmpl		✓	✓	✓			✓	✓	
Percent of Free-Flow Speed	%		✓		✓			✓		
Percent Time Spent Following	%				✓					
Queue Length	veh or ft				✓	✓	✓	✓	✓	✓
Reliability				✓						
Travel Speed	mph		✓	✓	✓	✓	✓	✓	✓	✓
Travel Time	Sec		✓	✓	✓			✓	✓	✓
Volume-to-Capacity Ratio	#	✓	✓	✓	✓	✓	✓			
Service Measure (LOS)	A-F	✓	✓	✓	✓	✓		✓	✓	✓
Vehicle Miles of Travel	VMT		✓					✓		

Vehicles Hours of Travel	VHT		✓					✓		
Vehicle Hours of Delay	VHD		✓					✓		
Freeways: Percent Breakdowns	%		✓	✓	✓			✓		
Throughput	Veh/hr					✓	✓	✓	✓	✓

The checkmarks represent the MOEs a certain tool can output

[a]Vissim's control delay is calculated differently than the Highway Capacity Manual

4.5.1 Control Delay

Control delay is expressed as seconds per vehicle (sec/veh). Per the HCM, control delay is defined as "delay brought about by the presence of a traffic control device, including delay associated with vehicles slowing in advance of an intersection, the time spent stopped on an intersection approach, the time spent as vehicles move up in the queue, and the time needed for vehicles to accelerate to their desired speed."

4.5.2 Density

Density is expressed as passenger cars per mile per lane (pcpmpl) or vehicles per mile per lane (vpmpl). Per the HCM, density is defined as "the number of vehicles occupying a given length of a lane or roadway at a particular instant." Truck volume can be converted to passenger car volume by using a passenger car equivalent factor.

4.5.3 Percent of Free-Flow Speed (PFFS)

Free-flow speed is defined as "the average speed of vehicles on a given segment, measured under low-volume conditions, when drivers are free to drive at their desired speed and are not constrained by the presence of other vehicles or downstream traffic control devices." PFF) is expressed as a percentage. Per the HCM, PFFS is defined as "the average travel speed (ATS) divided by the free-flow speed."

4.5.4 Percent Time-Spent-Following

Percent time-spent-following (PTSF) is expressed as a percentage. Per the HCM, PTSF is defined as "the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of the inability to pass." A platoon consists of vehicles or pedestrians that travel together as a group, either because of traffic control devices, roadway geometry, or other factors.

4.5.5 Queue Length

Queue length, often reported in terms of 95th-percentile or as a queue-to-storage ratio, is typically expressed as feet but can also be reported as the number of vehicles queued. Per the HCM, queue length is defined as "the distance between the upstream and downstream ends of the queue." A queue length in the 95th percentile indicates the length which has a five percent probability of being exceeded during a given analysis period.

Queue-to-storage ratio is a numeric value equaling the ratio of 95th-percentile queue length to the storage length of the corresponding movement. Queue-to-storage ratios greater than one indicate incomplete storage.

4.5.6 Reliability

Reliability, specifically travel time reliability, quantifies the variation of travel time. Per the HCM, reliability is defined as "the entire range of travel times for a given trip for a selected time period and over a selected horizon." Reliability is expressed in terms of variability or in terms of success or failure with respect to a specific target. To measure reliability, a history of travel times over a selected horizon (for example, a year) is necessary to create a travel time distribution.

4.5.7 Speed

Speed, specifically SMS, is expressed as miles per hour (mph). Per the HCM, SMS is defined as "an average speed based on the average travel time of vehicles to traverse a length of roadway."

4.5.8 Travel Time

Travel time is expressed as seconds (sec). Per the HCM, travel time is defined as "the average time spent by vehicles traversing a highway segment, including control delay."

4.5.9 Volume to Capacity Ratio

Volume to capacity (v/c) ratio is a numeric value equaling the ratio of traffic volume to facility capacity. v/c ratios greater than one indicate capacity failure.

4.5.10 Freeways: Percent Breakdowns

Percent breakdowns is expressed as a percentage. Per FHWA's Traffic Analysis Toolbox Volume VI, breakdown is defined as "a density of vehicles per lane greater than the density at capacity flow rate." Percent breakdown can be computed both geographically, as a percent of directional freeway miles, and temporally, as a percent of analysis period. A higher percent breakdown indicates more congested freeway operations.

4.5.11 Throughput

Per the HCM, throughput is defined as "the number of persons or vehicles passing a point on a transportation facility during a given time period." Per FHWA's Traffic Analysis Toolbox Volume VI, the throughput of different alternatives is compared "to determine the relative productivity of each alternative."

4.5.12 Level-of-Service (LOS)

LOS is expressed as letter grades A through F. Per the HCM, LOS is defined as "a quantitative stratification of a performance measure or measures representing quality of service." Service or performance measures are specific MOEs selected for the project which will be classified into LOS grades. Typically, LOS grades of A-D represent acceptable MOE values, LOS E represents near the failure range of the MOE, and LOS F represents conditions which are failing or past the failing threshold of the specific MOE.

4.5.13 Vehicle Hours Traveled (VHT)

VHT is the total time it takes for all vehicles in a network to finish their trips. VHT includes

congested travel time and is commonly used to measure overall network delay.

4.5.14 Vehicle Miles Traveled (VMT)

VMT is the amount of distance traveled by all vehicles in a geographic region over a given period. VMT is important for Planning-stage analysis because it shows travel pattern changes over time. VMT measures travel demand and is useful for determining infrastructure needs. High VMT values in a TDM may be indicative of circuitous trips in a network, which could be reduced by adding thoroughfares or by providing more connectivity.

4.5.15 Vehicle Hours of Delay (VHD)

VHD is calculated by taking the difference between travel times at free-flow speed and travel times at average speeds. This measure of effectiveness quantifies the extra time it takes vehicles to travel through the network due to congestion.

Chapter 5
Safety Analysis Concepts

5.1 Introduction

5.1.1 Overview

Chapter 5 provides background information on the purpose of the safety chapter; the intended users and limitations of the safety analysis concepts; and overviews of TxDOT safety policies and programs, AASHTO HSM, and Crash Modification Factors (CMFs).

5.1.2 Background and Purpose

TxDOT has adopted the aspirational target, referred to as Road to Zero of zero traffic fatalities on Texas roadways by 2050. A variety of approaches are being taken to facilitate the potential reduction of fatal crashes and improve the overall safety for all road users. The application of proven safety countermeasures is key to reaching the Road to Zero target. One of the objectives of this manual is to promote safe-by-design practices by integrating safety analysis during project development, analyzing existing safety conditions, comparing alternatives, and predicting safety performance for future conditions. This manual also promotes consistency and standardization in safety analysis across the State and advances general transportation safety knowledge. Each District prepares annual safety plans to improve safety within their District.

5.1.3 Intended Users

The safety analysis concepts, methodologies, and tools presented in this chapter and Chapter 6 are intended for engineers, planners, modelers, and designers who perform safety-related analyses for TxDOT projects. A safety practitioner is defined as a TxDOT employee and/or consultant who is tasked with performing, reviewing, and/or approving safety analyses. The safety methodologies and tools in this chapter may also be appropriate for use by local agencies and MPOs.

5.1.4 Limitations

It is not possible to cover all the ever-changing safety analysis processes, procedures, methods, approaches, and tools in this chapter. Safety practitioners are aggressively working to develop new research to fill in existing gaps and limitations in the application of safety analysis methodologies. Some of these gaps include (but are not limited to):

- Data unavailability, including lack of necessary data inputs for crash analysis;
- Traditional crash rate analyses assumed a linear relationship between traffic volume and crash frequency;
- Lack of consideration for variability of driver population from one location to another;
- Lack of consideration for traffic variability throughout the day (current safety analysis procedures use ADT volumes);

- Changes in existing tools and versions of those tools — some methods and tools do not consider variables that may be important to roadway design, creating the potential for statistical bias and uncertainty;
- Randomness, natural variations in crash data, and/or changes in site conditions; and
- Safety analysis approaches or predictive methodologies have not been developed for all facility types, alternative intersections, or roadway designs

Due to these limitations, professional judgement is necessary when performing safety analysis.

5.2 An Overview of TxDOT Safety Policies and Programs

5.2.1 Overview

One of TxDOT's goals is to promote safety. TxDOT identifies and develops proven countermeasures, strategies, and programs to improve safety. TxDOT's objective is to reduce crash severity and total crashes by implementing a data-driven approach to engineering solutions. TxDOT's Road to Zero goal includes systemic safety, the integration of safety analysis into project development, and promotion of safe-by-design practices. TxDOT's highway safety engineering programs use crash data to research, design, and implement safety projects that save lives and reduce the severity and number of crashes on roadways. The National Safety Council (NSC) developed the KABCO crash severity scale to classify crash injuries. TxDOT uses the KABCO scale to identify crash severity. The KABCO scale is summarized here:

- K – Fatal injury
- A – Suspected serious injury
- B – Suspected minor injury
- C – Possible injury
- O – Property damage-only

The Texas Transportation Institute has compiled a list of safety tools that may be used for screening, evaluation, and design. A link to these tools can be found at Appendix F, Section 3 – External References (Reference 7).

This section provides a brief overview of TxDOT's current safety policies and programs. TxDOT's key safety initiatives include the Strategic Highway Safety Plan (SHSP), Highway Safety Improvement Program (HSIP), and the Statewide Systemic Safety Widening Program (SSWP).

5.2.2 Safe System Approach

The safe system approach is accepted by FHWA as an effective way to eliminate fatal and serious injuries for all road users. This method of addressing safety focuses on human mistakes/vulnerability and emphasizes shared responsibility, redundancy in safe design, and proactive safety. A link to the Safe System Approach on the FHWA website is provided in Appendix F, Section 3 – External References (Reference 8).

5.2.3 Strategic Highway Safety Plan (SHSP)

Texas' SHSP aims to reduce traffic crashes, fatalities, and injuries and is structured around Emphasis Areas (EAs). The EAs direct resources to where they can most effectively and efficiently improve road safety. A link to the SHSP website is provided in Appendix F, Section 3 – External References (Reference 1).

5.2.4 Highway Safety Improvement Program (HSIP)

As described by the FHWA, HSIP is a core federal aid program that aims to significantly reduce traffic fatalities and injuries on all public roads, including on-system roads, off-system roads, and roads on tribal land. The HSIP involves a data-driven, strategic approach to improving highway safety on all public roads with a focus on safety performance. HSIP-funded projects either address historical crashes or focus on high-exposure roadway features (systemic safety). HSIP-funded projects are also evaluated for cost-effectiveness. The benefit-cost (B/C) analysis uses the Safety Improvement Index (SII) formula. The SII is the ratio of the annual savings in preventable crash costs to the cost of constructing the proposed improvement. A sample SII calculator is provided in Appendix F, Section 1 – SII Calculators. A link to TxDOT's Highway Safety Engineering Website (including the SII calculator spreadsheet) can be found in Appendix F, Section 3 – External References (Reference 6).

5.2.5 Statewide Systemic Safety Widening Program (SSWP)

The TxDOT SSWP focuses on rural two-lane, two-way highways that are less than 24 feet in paved surface width and have an ADT of at least 400 vehicles per day (vpd). This program involves the widening of on-system narrow roads, along with adding edgeline and centerline rumble strips to improve safety. Projects are evaluated and selected using total safety factor weights. A link to TxDOT's Highway Safety Engineering Website (including information about SSWP) can be found in Appendix F, Section 3 – External References (Reference 6)

5.2.6 Education and Outreach

TxDOT employs education and outreach methods to promote safe driving, bicycling, and pedestrian activities. TxDOT has several traffic-safety focused policies and programs, some of which are described below.

5.2.6.1 Safety and Laws

Texas legislators have enacted traffic laws on the following subjects to enforce public safety:

- Cell phones;
- Collisions;
- Crash reports and records;
- Flashing yellow lights;
- Road signs;
- Speed limits;
- Seat belts (Click It or Ticket); and
- Stop and yield to pedestrians

5.2.6.2 Drive Safe Texas

DriveSafeTexas.org offers a mobile-friendly platform and an extensive library of videos on the following safe-driving topics:

- Bicycles and pedestrians;
- Distracted driving;
- Drowsy driving;
- Energy sector safety;
- Highway driving;
- Impaired driving;
- Motorcycle videos;
- Move-over law;
- Seat belts and safety seats;
- Signage and signals;
- Speed and speed limits;
- Teen drivers;
- Weather and adverse conditions; and
- Work zone safety

5.2.6.3 Share the Road

This program emphasizes being considerate of all modes of transportation beyond passenger vehicles, including large trucks, motorcycles, bicycles, pedestrians, and people in work zones. This program covers the following:

- Aggressive drivers;
- Bicycle safety;
- Talk. Text. Crash.;
- Highway driving;
- Motorcycles;
- Pedestrians;
- Railroad crossings;
- Work zones;
- Be Safe. Drive Smart.; and
- Move over or slow down

5.2.6.4 Sober and Safe

TxDOT has the following public involvement campaigns to encourage responsible driving:

- Football: Make Your Game Plan;
- Holiday: Plan While You Can;
- Faces of Drunk Driving;
- Memorial signs;
- Driving while intoxicated (DWI);
- Underage drinking and driving;
- College and young adult impaired driving prevention; and
- Labor Day

5.2.6.5 End the Streak

Texas has also created the public involvement campaign #EndTheStreak to bring awareness to traffic-related fatalities on Texas roads and to encourage responsible driving. Print materials, photos, videos, and testimonials about this campaign are available on TxDOT's website.

5.2.6.6 Road to Zero

The Road to Zero initiative was developed by TxDOT to reduce the number of deaths on Texas roadways by half by the year 2035 and to zero by the year 2050. This goal places emphasis on the SHSP, bridge safety systems, design manual updates with safety-driven improvements, and other initiatives that influence safety.

5.2.6.7 Behavioral Traffic Safety Program Manual

The purpose of this manual is to establish program and project management procedures for subgrants and contracts in support of the

Texas Behavioral Traffic Safety Program. The mission of this program is to implement traffic-safety education and enforcement strategies to reduce traffic fatalities in Texas by half by the year 2035 and to zero by 2050.

5.3 AASHTO's Highway Safety Manual (HSM)

5.3.1 Overview

The HSM was developed by AASHTO. The first edition of the HSM was published in 2010 and is the premier guidance document for incorporating quantitative safety analysis in the project planning and development processes. With an emphasis on using analytical methods to quantify safety, the HSM helps practitioners understand the safety effects of decisions in planning, design, operations, and maintenance efforts. This science-based approach is intended to take the guesswork out of safety analysis. A supplement to the HSM was published in 2014 to provide additional guidance on performing analysis on freeways. The HSM is for practitioners at the State, county, MPO, local agency, tribal, and consultant level.

This section is intended to be an introduction into the HSM, not a comprehensive overview. Reference the HSM or the HSM website for additional detailed information.

The most recent HSM, 1st Edition, 2010, consists of three volumes and a supplement. It is divided into four parts, which are further described in the following sections:

- Part A – Introduction, Human Factors, and Fundamentals (Volume 1);
    - Chapter 1 – Introduction and Overview
    - Chapter 2 – Human Factors
    - Chapter 3 – Fundamentals
- Part B – Roadway Safety Management Process (Volume 1);
    - Chapter 4 – Network Screening
    - Chapter 5 – Diagnosis
    - Chapter 6 – Select Countermeasures
    - Chapter 7 – Economic Appraisal
    - Chapter 8 – Prioritization
    - Chapter 9 – Safety Effectiveness Evaluation
- Part C – Predictive Method (Volume 2 and Supplement); and
    - Chapter 10 – Predictive Method for Rural Two-Lane, Two-Way Roads (Volume 2)
    - Chapter 11 – Predictive Method for Rural Multilane Highways (Volume 2)
    - Chapter 12 – Predictive Method for Urban and Suburban Arterials (Volume 2)
    - Chapter 18 – Predictive Method for Freeways (2014 Supplement)
    - Chapter 19 – Predictive Method for Ramps (2014 Supplement)
- Part D – CMF (Volume 3)
    - Chapter 13 – Roadway Segments
    - Chapter 14 – Intersections

- Chapter 15 – Interchanges
- Chapter 16 – Special Facilities and Geometric Situations
- Chapter 17 – Road Networks

Figure 5-1 shows these HSM parts and chapters in flowchart format.

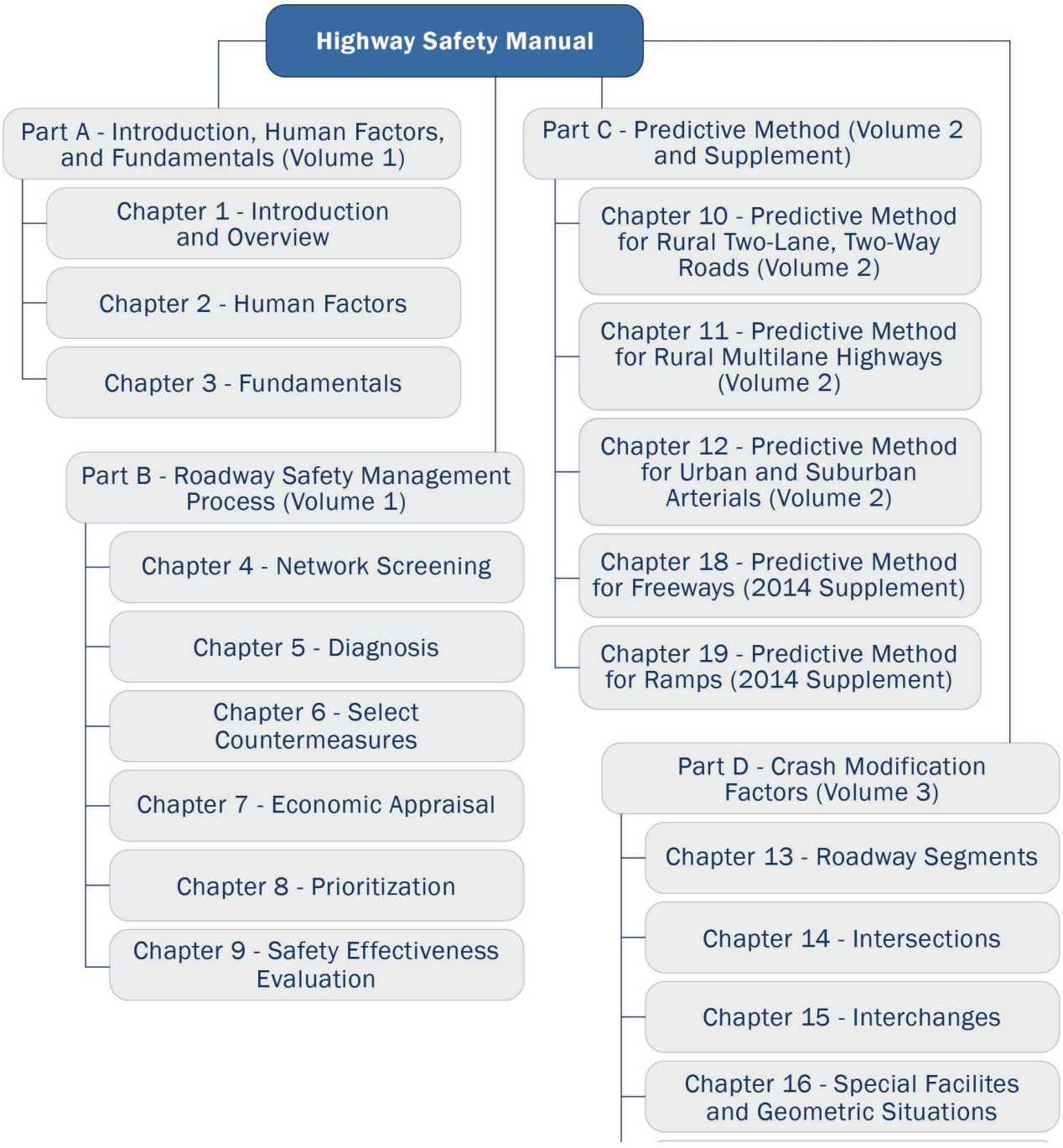


Figure 5-1: HSM Parts

The information contained within the HSM is not a legal standard of care and is intended to aid agencies in their efforts to integrate safety into their decision-making processes. The HSM was not created to replace or substitute the exercise of sound engineering judgement. The HSM does not supersede publications such as the TMUTCD, the AASHTO *A Policy on Geometric Design of Highways and Streets* (Green Book), or other AASHTO and agency guidelines, manuals, and policies.

5.3.2 HSM Part A – Introduction, Human Factors, and Fundamentals

Part A describes the purpose, scope, and intended audience of the HSM. The HSM exists to provide analytical tools, techniques, and processes for quantifying the potential effects that decisions made in planning, design, operations, and maintenance have on overall crashes. The information in the HSM intends to help agencies integrate safety into their decision-making processes. When used properly, the HSM can be integrated into all facets of the project development process. It also provides a brief introduction into the core elements of human factors that affect the interaction between drivers and the roadway. Although there is no specific design guidance provided in the HSM related to human factors, the information related to human factors is intended to support the information provided in Parts B, C, and D. A more detailed discussion on human factors is available in the NCHRP

Report 600: *Human Factors Guidelines for Road Systems*.

The last chapter in Part A introduces the fundamental concepts needed to understand the roadway safety management techniques and crash estimating methods presented in the subsequent parts of the HSM. This chapter includes an overview of the following fundamental concepts:

- Differences between objective safety and subjective safety;
- Key definitions for crash-related terms;
- Overview of crashes as random and rare events;
- Contributing factors of crashes;
- Reducing crashes by changing the roadway and environment;
- Data needed for crash analysis; and
- Evolution of crash estimation methods

For greater understanding of Part A, please refer to the HSM.

5.3.3 HSM Part B – Roadway Safety Management Process

Part B of the HSM presents procedures and information that is useful in monitoring and reducing crash frequency and severity on existing roadway networks. This includes the following six steps of the Roadway Safety Management Process:

- Network Screening – Reviewing the existing transportation network to identify and rank individual sites based on the potential for reduction in average crash frequency.
- Diagnosis – Evaluating individual sites based on crash data, historic site data,

and field conditions to identify crash patterns.

- Select Countermeasures – Selecting possible countermeasures to reduce the average crash frequency at the site based on the identified factors that may contribute to the crashes.
- Economic Appraisal – Identifying individual projects that are cost-effective or economically justified by evaluating the benefits and costs of the possible countermeasures.
- Prioritize Projects – Identifying and prioritizing the set of improvement projects that meet the agency's objectives, including safety, by evaluating the list of economically justified improvements at a specific site or sites.
- Safety Effectiveness Evaluation – Evaluating the effectiveness of a countermeasure or improvement project at one site or multiple sites in reducing average crash frequency or severity.

The Roadway Safety Management Process is an iterative process to improve the overall safety of the existing roadway network by implementing economically justified projects through data-driven processes. The basic outline of the Roadway Safety Management Process is demonstrated in Figure 5-2.

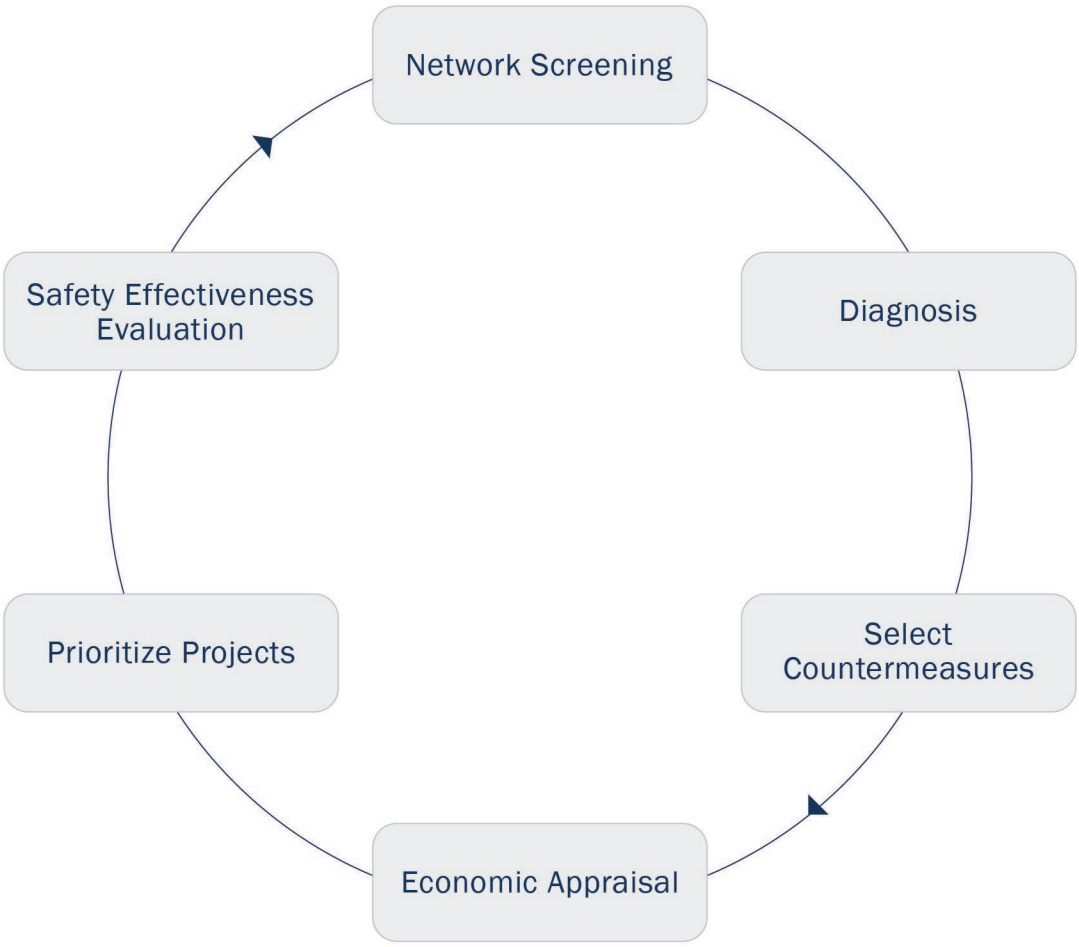


Figure 5-2: Road Safety Management Process

5.3.4 HSM Part C – Predictive Method

Part C of the HSM provides a predictive method to estimate average crash frequencies for both existing and proposed future conditions of a roadway network, facility, or individual site. This predictive method not only estimates total crashes over a given time but can also be used to estimate average crash frequencies by crash severity and collision type. It is recommended that these estimates be determined for existing conditions, alternatives to the existing conditions, or for proposed new roadways. A roadway network can be divided into individual sites of either homogenous roadway segments or intersections to run the predictive method.

The estimated average crash frequency of an individual facility type is based on the traffic volumes, geometric design features, and traffic control type for that site. Predictive models were developed to estimate average crash frequencies for a variety of facility types using regression models. These regression models were developed from data of similar sites across the country and are known as safety performance functions (SPFs) in the HSM. SPFs have been developed for specific facility types under what are referred to as "base conditions," the most common conditions for similar sites across the country. For example, Table 5-1 shows a sample of the base conditions for rural multilane highways.

Table 5-1: Rural Multilane Highway Base Conditions

Undivided Roadways	Divided Roadways	Intersections
Lane width: 12 feet	Lane width: 12 feet	Intersection skew angle: 0 degrees
Shoulder width: 6 feet	Right shoulder width: 8 feet	No intersection left-turn lanes except on stop-controlled approaches
Shoulder type: Paved	Median width: 30 feet	No intersection right-turn lanes except on stop-controlled approaches
No lighting	No lighting	No lighting

The HSM has developed the SPFs for the following facility types:

- Rural two-lane, two-way roads;
- Rural multilane highways;
- Urban and suburban arterials; and
- Freeways and ramps (2014 supplement)

Table 5-2 and Table 5-3 demonstrate the various facility types that SPFs were developed for as part of the HSM.

Table 5-2: SPFs by Roadway and Arterial Facility Types

Facility Type	Undivided Roadway Segment	Divided Roadway Segment	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			3-Leg	4-Leg	3-Leg	4-Leg
Rural Two-Lane, Two-Way Road	✓		✓	✓		✓
Rural Multilane Highways	✓	✓	✓	✓		✓
Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

Table 5-3: SPFs by Freeway and Ramp Facility Types

Facility Type	Classification	Rural	Urban
Freeway Segment	Four-Lane	✓	✓
	Six-Lane	✓	✓
	Eight-Lane	✓	✓
	Ten-Lane		✓
Ramp Segments	One-Lane Entrance Ramp	✓	✓
	One-Lane Exit Ramp	✓	✓
	Two-Lane Entrance Ramp		✓
	Two-Lane Exit Ramp		✓
Collector-Distributor Road (C-D)	One-Lane C-D Road	✓	✓
	Two-Lane C-D Road		✓
Ramp Terminal	One-Way Stop-Controlled Two-, Three-, or Four-Lane Crossroad	✓	✓
	Signalized Two-Lane Crossroad	✓	✓
	Signalized Three-Lane Crossroad	✓	✓
	Signalized Four-Lane Crossroad	✓	✓
	Signalized Five-Lane Crossroad		✓
	Signalized Six-Lane Crossroad		✓

A simplified example of how SPFs were developed for the HSM is illustrated in Figure 5-3. This figure illustrates how crash data from across the country was used in the development of the SPFs located in the HSM.

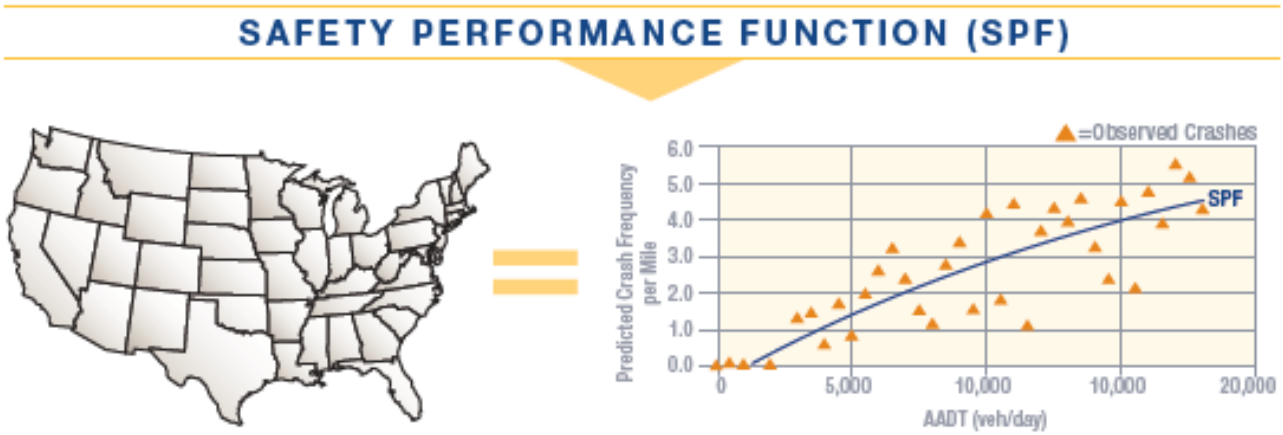


Figure 5-3: Example SPF Development

Adjustments to the predicted crashes, determined by using an SPF, may account for the differences between the base conditions used in developing the SPF and the site-specific conditions.

Part C CMFs are used to account for these differences when site-specific conditions vary from the base conditions. These CMFs were developed specifically for individual SPFs and are intended to be applied only to the crash prediction results of that particular SPF. The SPF-related CMFs are different than the CMFs on the CMF Clearinghouse website. The Highway Safety Manual 2nd Edition (HSM2) is expected to rename SPF-related CMFs to AFs to reduce the confusion between Part C CMFs developed for a specific SPF and CMFs located on the Clearinghouse website.

A calibration factor (C) may also be used to make agency-specific adjustments to the predicted crash totals. This accounts for the differences between the agency or agencies for which the models were developed and the agency/agencies for which the predictive model is being applied. Calibration factors to the HSM predictive method calculations should be applied whenever possible. Each agency is responsible for developing their own calibration factors for specific facility types.

The HSM Part C predictive method is summarized in the following general equation:

$$N_{Predicted} = N_{SPFx} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{nx}) \times C_x$$

Where:

$N_{predicted}$ = predicted average crash frequency for a specific site type

N_{SPFx} = predicted average crash frequency for the base conditions of the SPF for a specific site type

CMF_{1x} = CMF specific to the SPF for a specific site type

C_x = calibration factor to adjust the specific SPF to the local conditions for a specific site type

x= specific site type

Because crash totals fluctuate over time, it is difficult to know whether changes in the observed crash totals are due to changes in site conditions or are due to natural fluctuations. A period with a high number of observed crashes is statistically likely to be followed by a period with a low number of observed crashes. The opposite of this tendency also applies; it is probable that a period with low crash totals will be followed by a period with high crash totals. This tendency to regress to the mean or average is known as regression-to-the-mean (RTM). Failure to account for the effects of RTM introduces the potential for RTM bias, also known as selection bias. RTM bias results in overestimating or underestimating the effectiveness of a treatment. The effects of RTM bias are illustrated in Figure 5-4. For existing sites, facilities, or roadways, the Empirical Bayes (EB) method can be applied within the predictive method to account for both the predicted average crash frequency and the observed crash frequency. This method accounts for the reliability of a particular SPF and RTM bias.

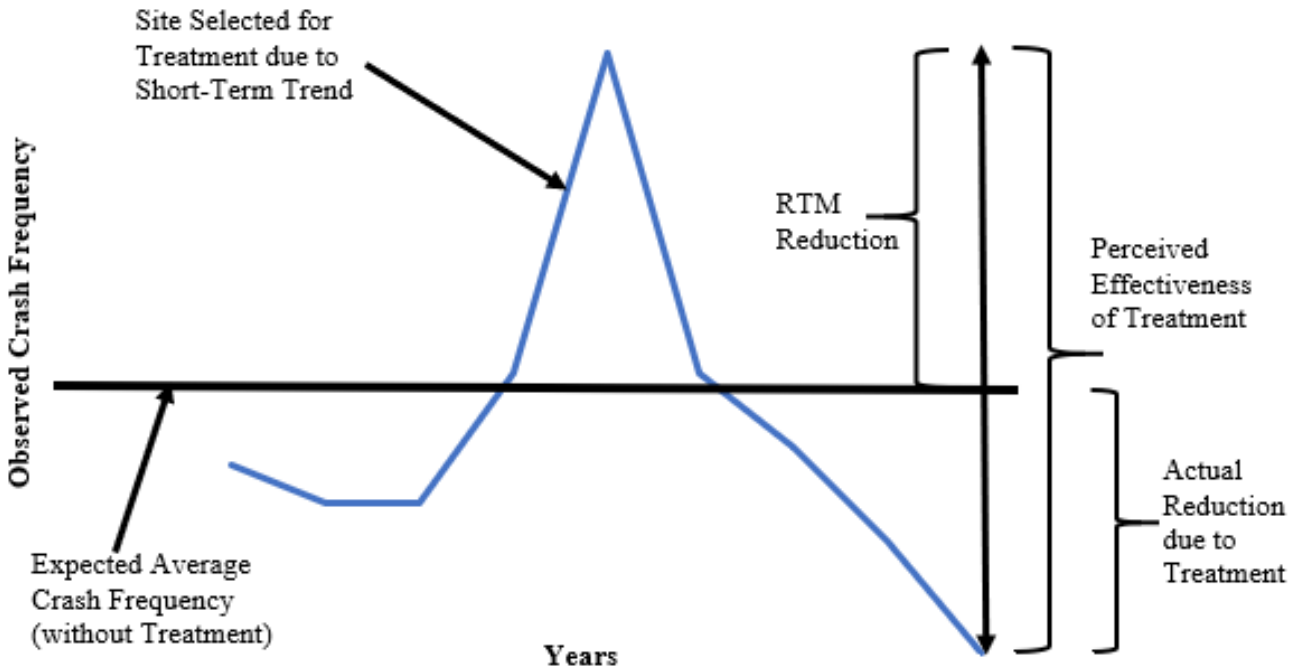


Figure 5-4: Regression to Mean Bias

The application of the EB method within the predictive method results in an expected average crash frequency. Figure 5-5 illustrates the relationship between observed, predicted, and expected crashes when performing the predictive method for a particular SPF. See Appendix F, Section 2 – NCHRP 17-50 Project Example of HSM in Design for more details on how expected crashes can be estimated.

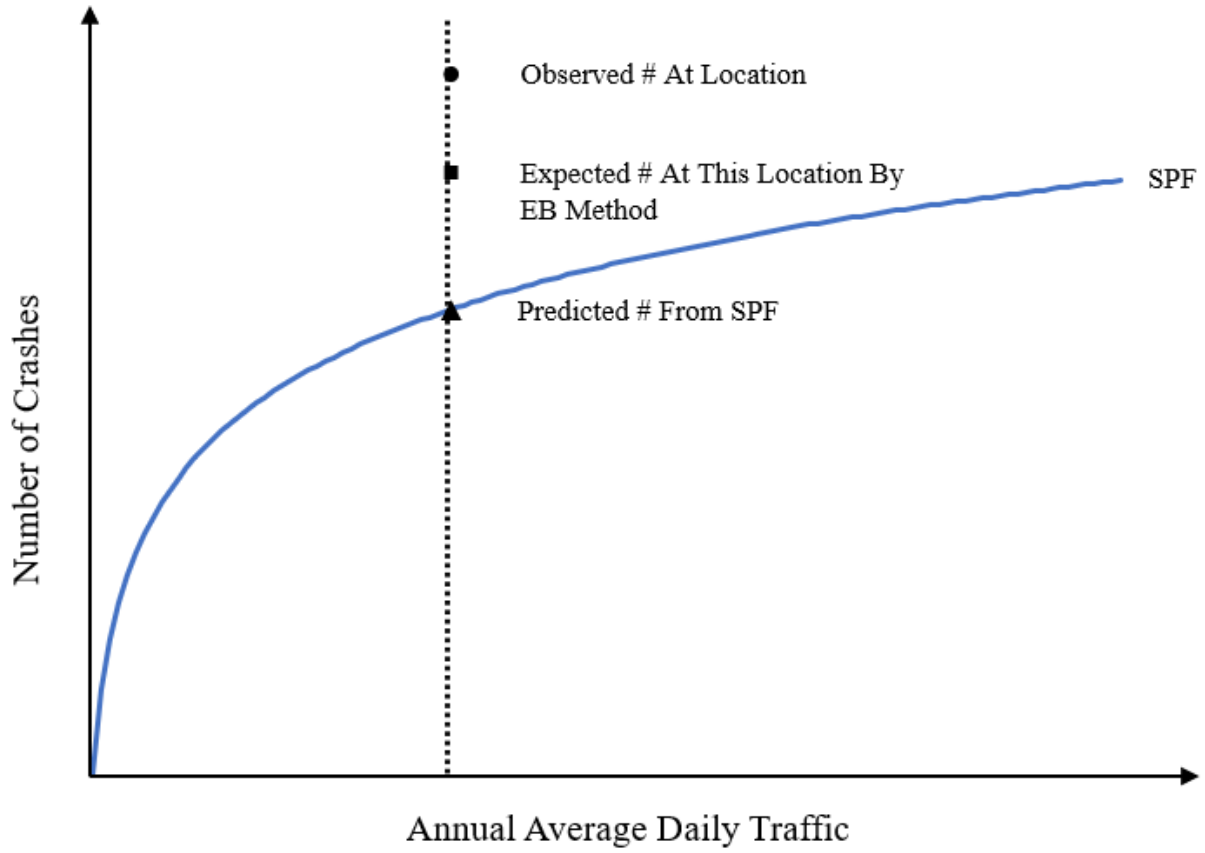


Figure 5-5: Relationship of Observed, Predicted, and Expected Crashes within the Predictive Method

Table 5-4 identifies the scenarios when the EB method is applicable and not applicable, as identified in the HSM.

Table 5-4: Applicability of the EB Method

EB Method is Not Applicable (Predicted Crashes)	EB Method is Applicable (Expected Crashes)
EB method is not applicable for the following types of situations: • New alignments for a substantial proportion of the project length • Change in the basic number of intersection legs or traffic control type	EB method is applicable for the following situations: • Geometrics and traffic control features are not changed (for example the "do-nothing alternative") • Where the roadway cross-section is modified but the basic number of through-lanes remains the same • Minor changes in alignment are made while keeping most of the alignment intact • A passing lane or short four-lane section is added to a rural two-lane, two-way road • Any combination of the above improvements

The HSM predictive method is summarized as an 18-step process used to estimate average crash frequencies for a roadway network, facility, or site and is illustrated in Figure 5-6.

An example of applying the HSM Part C predictive method is provided in Appendix F, Section 2 – NCHRP 17-50 Project Example of HSM in Design.

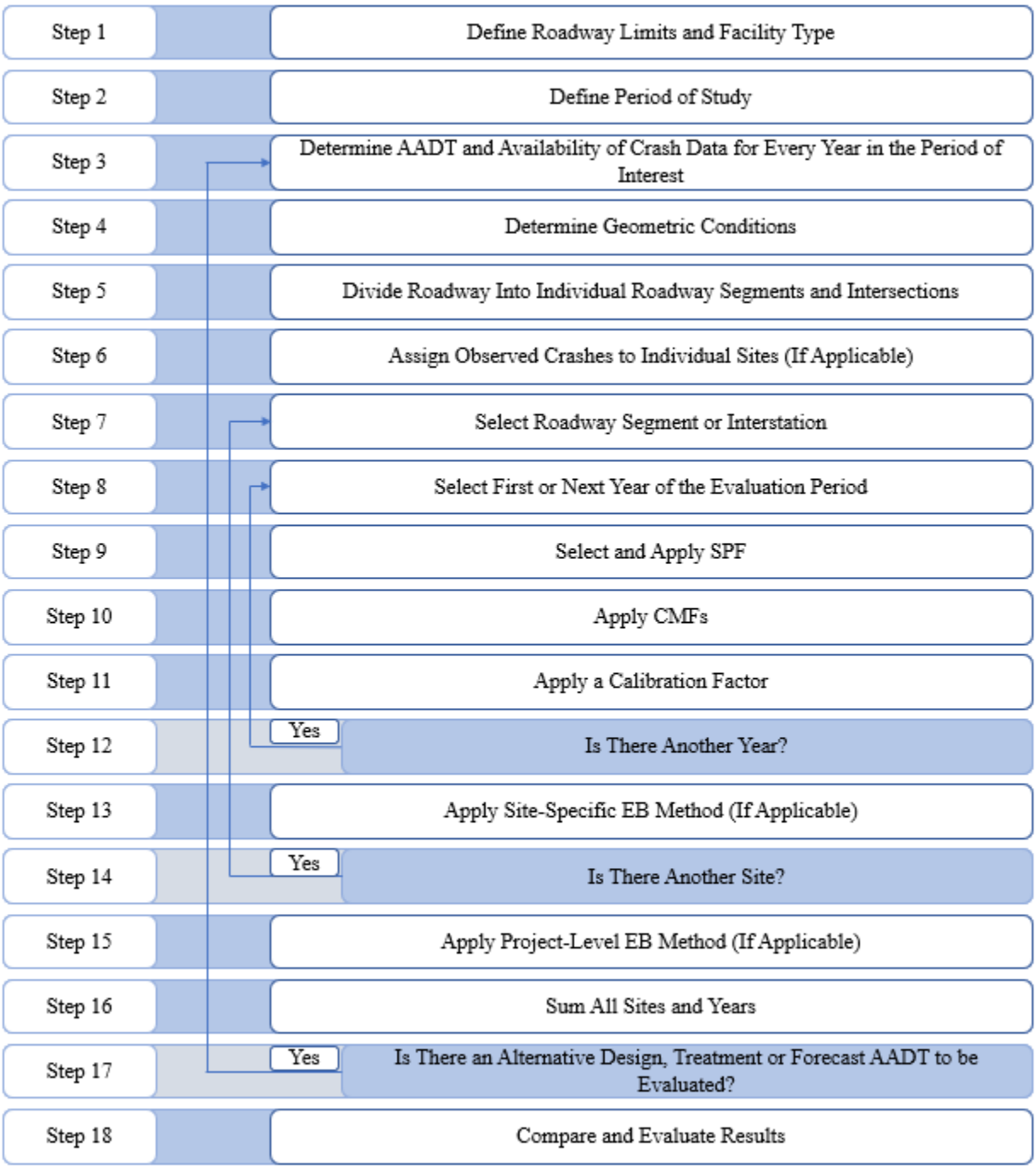


Figure 5-6: HSM Predictive Method 18-Step Process

5.3.5 HSM Part D – Crash Modification Factors

Part D of the HSM presents information regarding the effects of various safety treatments or countermeasures. This information is intended to estimate how effective a particular countermeasure or set of countermeasures will be in reducing crashes at a specific location in the form of a CMF. Most of the information in Part D of the HSM manual is now located on the CMF Clearinghouse website. It is anticipated that, with the publication of the HSM2, Part D will focus on the methodologies for selecting, applying, and developing CMFs and will no longer list individual CMFs. The CMF Clearinghouse website will become the sole repository of CMFs.

5.3.6 HSM 2nd Edition

It is anticipated that the second edition of the HSM (or HSM2) will expand upon the methodologies in the first edition of the HSM, incorporate new models and research that has been completed, and modify practices based on user experiences and needs. New or additional content is expected to be included in the areas of human factors, bicycle and pedestrian safety, systemic safety, SPF calibration, additional crash prediction models, and CMF development. It is the responsibility of the users of the manual to incorporate any relevant information when the HSM2 becomes publicly available. Additional information about the HSM2 is available on the AASHTO website related to the HSM. A link to the website can be found in Appendix F, Section 3 – External References (Reference 4).

5.4 Crash Modification Factors (CMFs)

5.4.1 Overview

This section provides a general overview of CMFs, their relation to Crash Reduction Factors (CRFs), and an introduction to the CMF Clearinghouse.

5.4.2 General Overview of CMFs

A CMF is an estimate of the anticipated change in crash frequency that can be expected because of implementing a particular countermeasure at a specific site. A CMF is a multiplicative factor that can be multiplied by the number of observed or predicted crashes at a specific site to compute the number of anticipated crashes after a given countermeasure is implemented. CMF calculations are presented in Figure 5-7.

$$\text{CMF} = \frac{\text{Anticipated Crashes } \mathbf{With} \text{ Treatment}}{\text{Anticipated Crashes } \mathbf{Without} \text{ Treatment}}$$

CMF = 1.0	Anticipated to have no impact on safety
CMF < 1.0	Anticipated to reduce crashes
CMF > 1.0	Anticipated to increase crashes

Figure 5-7: CMF Calculation

A CRF is similar to a CMF but stated as the percent reduction in crashes after a given countermeasure is implemented at a specific site. The CRF calculation based on the CMF is presented in Figure 5-8.

$$\mathbf{CRF} = (1 - \mathrm{CMF}) \times 100$$

Figure 5-8: Crash Reduction Factor Calculation

5.4.3 CMF Clearinghouse

CMFs are located on the CMF Clearinghouse website, which is a central, web-based repository of CMFs. This website is a searchable database maintained by FHWA with the intent of serving three roles related to the transportation safety field: to educate CMF users, house CMF data for use, and facilitate continued CMF research. The CMF Clearinghouse website includes search features for CMFs applicable to the various countermeasures under consideration. A link to the CMF Clearinghouse is available in Appendix F, Section 3 – External References (Reference 2).

All CMFs in the Clearinghouse are evaluated and rated using the defined star rating system. CMFs are given a star rating from one to five stars. The star rating indicates the reliability and quality of a CMF, with five stars being the most reliable. The star rating system considers various factors from the study research that produced the CMF. These factors include data used, study design, study methodology, sample size, statistical significance, and location(s) where the data was collected. An updated star rating system was developed and implemented in February 2021 as part of the NCHRP) 17-72 project. As a result, many CMFs received a new star rating based on the updated evaluation criteria. CMF summary reports printed prior to February 2021 may contain star ratings that differ from their current star rating. Additional information about the star rating system's evaluation criteria and the changes to the evaluation criteria are on the CMF Clearinghouse website.

Whenever possible, only CMFs with a star rating of three or higher may be used in analysis. If the best available CMF has a star rating lower than three, it can only be used if accepted by the TxDOT project manager assigned to approve the completed analysis. A CMF's ID number and star rating is suggested to be documented if used for safety analysis.

5.4.4 Selecting CMFs

Special attention is necessary when selecting CMFs for use in safety analysis to make sure that the practitioner is selecting appropriate CMFs. The primary goal is to select a CMF that was developed under the same (or very similar) conditions as the location for which it is being applied. When selecting CMFs, consider the following characteristics:

- Countermeasure type;
- Crash type;
- Crash severity;
- Roadway or intersection type;
- Area type (rural vs. urban);
- AADT ranges;

- Prior conditions; and
- Similarity to locality where data is used

If multiple CMFs are available and appear to be similar or equally applicable, it is suggested that the following items related to the quality of the CMFs are reviewed to determine the best possible match:

- Star rating;
- Score details; and
- Age of data or study

When selecting CMFs for use in analysis from the CMF Clearinghouse, the CMF IDs are recommended to be documented, and the CMF detail summary page can be provided. This information can be saved as a PDF and included as an appendix or attachment to the analysis documentation.

It is critical that sound engineering or professional judgment be used when selecting CMFs. Additional guidance on selecting CMFs is available in the following link: Appendix F, Section 3 – External References (Reference 3).

5.4.5 Applying Multiple CMFs

In many cases, the application of multiple safety-related improvements results in greater crash reduction benefits. This results in the possibility of multiple CMFs being applicable. The interaction between various safety treatments is complicated and can make it difficult to determine the true effectiveness of multiple treatments when used together. This is because CMFs are not always independent of one another, and it is possible to overestimate or underestimate the potential for crash reduction when applying the effects of multiple CMFs. A CMF is considered independent of another CMF if there is no overlap in their crash type and/or crash severity. For example, the installation of a pedestrian signal would be relatively independent of the installation of a left-turn phase at an adjacent intersection, because one addresses pedestrian-vehicle crashes while the other addresses left-turn opposite-direction crashes. An example of overlapping or non-independent CMFs would be multiple treatments focused on reducing nighttime crashes or multiple treatments focused on reducing run-off road crashes.

When applying multiple treatments, no more than three CMFs can be applied because it may overestimate the reduction of crashes. The following subsection provides an overview of four different methods that can be considered when applying multiple CMFs.

5.4.5.1 Dominant Effect Method

The dominant effect method applies the CMF for only the most effective treatment. The most effective treatment is the treatment with the lowest CMF value. This method is intended to be the simplest and most conservative approach. Typically, this method would be applied when the applicable CMFs are not independent of one another and have extreme overlap in the crash type and/or severity that are affected. The primary limitation of this method is that it is likely to underestimate the combined treatment effect if the additional treatments also improve safety.

5.4.5.2 Additive Effects Method

The additive effects method adds the effects of the CMFs together and presumes that the CMFs are independent and do not have overlapping effects. The following is an example of how to calculate the combined CMF value for the additive effects method:

$$CMF_{Combined} = 1 - [(1 - CMF_1) + (1 - CMF_2) + (1 - CMF_3)]$$

The primary limitation to this approach is the possibility that the combined effects may exceed 100 percent reduction in crashes or a CMF value less than zero.

5.4.5.3 Multiplicative Method

The multiplicative method estimates the combined effect of the various treatments being applied. Individual CMF values for each treatment are multiplied together to determine a combined CMF value. This is the most common method used at this time because it is identified in the HSM. The following is an example of the multiplicative method:

$$CMF_{Combined} = CMF_1 \times CMF_2 \times CMF_3$$

The primary limitation of this method is that it is likely to either underestimate or overestimate the combined effects of the overall safety treatments if their effects are not independent of one another. This method can only be applied when it is presumed that all the CMFs are independent and there is no overlap.

5.4.5.4 Dominant Common Residuals Method

The dominant common residuals method is similar to the multiplicative method, except that the CMFs are non-independent of one another or slightly overlapping. The combined effect of the various treatments being applied is calculated by multiplying the individual CMF values together for each countermeasure and then raising that value to the power of the most effective or lowest CMF value. The following is an example of how the dominant common residuals method's combined CMF value is calculated:

$$CMF_{Combined} = (CMF_1 \times CMF_2 \times CMF_3)^{CMF_1}$$

This method is more conservative than the multiplicative method, but it is not appropriate for CMFs with values greater than 1.0 or if the most effective treatment has a CMF value greater than 1.0. A combined CMF value that is raised to a power greater than 1.0 intensifies the effects of the combined CMF rather than dampening its effects.

5.4.5.5 Examples of Applying Multiple CMFs

Table 5-5 provides examples of the various methods outlined in this section of the manual related to the various methods for applying multiple CMFs. The hypothetical CMF values of 0.95, 0.65, and 0.80 were used in the example calculation table.

Table 5-5: Methods for Applying Multiple CMFs

Method	Calculations	Resulting CMF Value
Dominant Effect	$CMF = 0.65$	0.65
Additive Effects	$CMF_{Combined} = 1 - [(1 - 0.65) + (1 - 0.80) + (1 - 0.95)]$	0.40
Multiplicative	$CMF_{Combined} = 0.65 \times 0.80 \times 0.95$	0.494
Dominant Common Residuals	$CMF_{Combined} = (0.65 \times 0.80 \times 0.95)^{0.65}$	0.632

Chapter 6
Safety Analysis, Methodologies, and Tools

6.1 Safety Analysis Methods

6.1.1 Overall

Chapter 6 provides a detailed overview into the safety analysis methodologies and the tools used to implement safety analysis. Chapter 6 also covers the application of safety analysis methodologies and tools, guidance on safety analysis documentation, and safety analysis applications. An overview of various safety analysis methods is provided in this section. These methods are broken down into existing and future conditions analysis. Figure 6-1 highlights the safety analysis methods covered in this section of the manual.

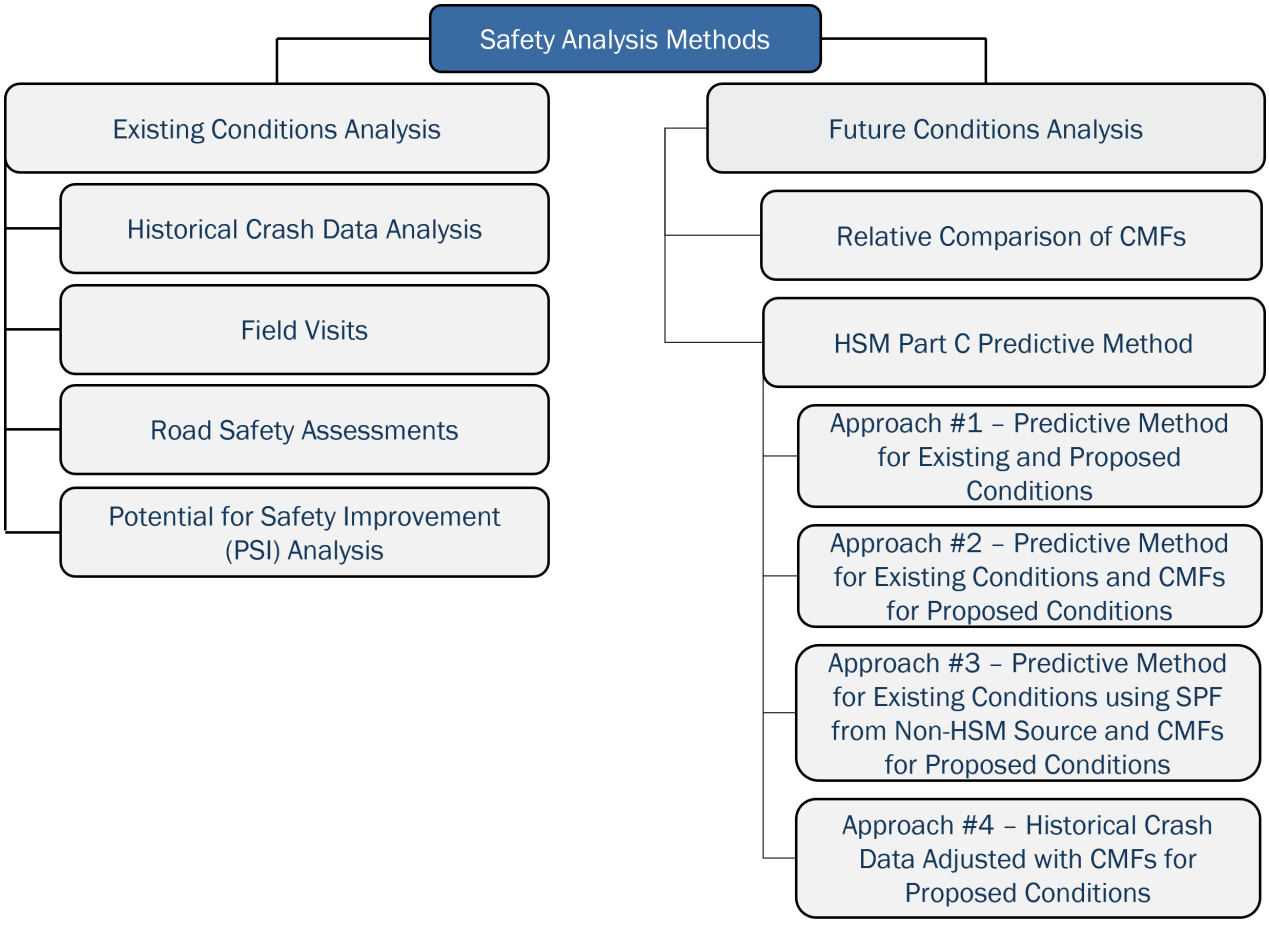


Figure 6-1: Safety Analysis Method

6.1.2 Safety Analysis Study Area

The safety analysis study area includes all roadway elements (segments, intersections, and interchanges) in the area impacted by the proposed project. The traffic analysis study area is a starting point, but the safety analysis area also depends on additional safety impacts of the proposed project. The safety analysis study area limits will be the same for all alternatives for consistency and comparability of the analysis results. Intersections typically include 300 feet on each approach but can be adjusted for intersections where longer queue lengths affect approaches.

6.1.3 Existing Conditions Analysis

The purpose of safety analysis for existing conditions is to identify safety issues that exist and provide the information needed to mitigate those issues. Existing conditions safety analysis methods include the following:

- Historical crash data analysis;
- Field visits;
- Road Safety Assessments (RSAs); and
- Potential for Safety Improvements (PSI)

6.1.3.1 Historical Crash Data Analysis

The purpose of a historical crash data analysis is to identify safety issues through the review of crash trends, patterns, and rates. For projects that need FHWA approval, request CRIS data through TxDOT's Traffic Safety Division (TRF) or the Design Division. For other project types, crash data can be obtained through the CRIS website. CRIS allows users to run queries on historical crash data, based on a variety of selection criteria. The CRIS query builder can be used to create a new query, load a saved query, or browse queries authored by TxDOT.

It is recommended that the most recent and complete five calendar years (January 1 through December 31) of crash data be used to conduct a standard historical crash data analysis. It is possible to use less than five years of crash data in the analysis if study area conditions experienced significant changes, resulting in the historical crash data no longer being relevant to the current conditions. For example, a traffic signal installed at an intersection five years ago would result in only four complete calendar years of crash data (beginning after the installation of the traffic signal). In this situation, only use four years of historical crash data for analysis. A minimum of three years of crash data is necessary to perform a historical crash data analysis. If a shorter study period is necessary, pre-approval by the TxDOT Project Manager who will be approving the completed analysis is recommended. The following are situations when a shorter study period may be acceptable:

- Recent construction project in the study area;
- Before and after study with less than five years of after data; and
- Significant land use changes resulting in a significant change in traffic volumes and crash patterns

More than five years of crash data can be used in analysis in certain circumstances. This would be applicable when very little or no historical

crash data is available for a study area of interest or when the analysis is focused on a particular subset of crash data that occurs less frequently. For example, using more than five years historical crash data may be applicable when performing historical crash analysis in rural areas with sparce crashes, performing a detailed pedestrian and bicycle crash analysis, or preparing a commercial vehicle crash analysis. When a situation warrants the use of more than five years of crash data, eight years of historical crash data is recommended to be used in the analysis. When a longer study period is necessary, it is to be accepted by the TxDOT Project Manager who will be approving the completed analysis. Table 6-1 shows the recommended years of data recommended for safety analysis on various project types.

Table 6-1: Typical Data Recommendations for Various Project Types

Project Characteristics	Years of Data
• Recent construction in the crash area • Significant land use changes resulting in change in traffic volumes • Performing a before and after study	Review a minimum of 3 years of crash data
• Typical historical crash data analysis	Review 5 years of crash data
• Analysis of a rural area with few crashes • Detailed bicycle and pedestrian analysis • Commercial vehicle crash analysis	Review 8 years of crash data

When analyzing historical crash data to determine trends, patterns, and rates, many characteristics should be evaluated and the results can be displayed using a variety of methods. These methods result in the creation of crash summary tables, figures, charts, or maps. The following is a list of minimum characteristics to be included in a historical crash data analysis:

- Highway;
- Year;
- Road part;
- Crash location;
- Crash severity;
- Manner of collision;
- Crash rate (include comparison to statewide average for similar facility types);
- Segment versus intersection-related;
- Pedestrian and bicycle-related; and
- Contributing factors

Additional analysis results or characteristics that could be evaluated include, but are not limited to the following:

- Weather condition;

- Lighting condition;
- Road surface condition;
- First harmful event;
- Vehicle type;
- Collision diagrams;
- Crash density/heat maps;
- Driver age;
- Time of day;
- Day of week;
- Time of year;
- Work zone;
- Alcohol or drugs;
- Speed;
- Animal-related; and
- Distracted driving

There are methods that can be used to analyze historical crash data and determine crash patterns and trends. Historical crash data analysis includes calculation of crash rates and the comparison of those crash rates to statewide averages for similar facility types. A link to the statewide traffic crash rates is in Appendix G, Section 5 – External References (Reference 11). Crash rates are intended to normalize the number of crashes relative to traffic or exposure. When a location or study area is determined to have a crash rate significantly higher than the statewide average (more than five crashes per million entering vehicles for intersections or 5 crashes per 100 million vehicle miles of travel for segments), further analysis may be needed. Crash rates are determined for roadway segments or intersections and can be calculated for total crashes, fatal crashes, injury crashes, and/or fatal and injury crashes.

The equation for determining a crash rate for a roadway segment is:

$$R = \frac{C \text{ x } 100{,}000{,}000}{L \text{ x } V \text{ x } N \text{ x } 365}$$

R = Crash rate for the road segment expressed as crashes per 100 million vehicle miles of travel (MVMT)

C= Total number of crashes in the study period

V= Daily traffic volume

L = Length of roadway segment in miles

N = Years of data

The equation for determining an intersection crash rate is:

$$R = \frac{C \text{ x } 1{,}000{,}000}{V \text{ x } N \text{ x } 365}$$

R = Crash rate for the intersection expressed as crashes per 1 million entering vehicles (MEV)

C= Total number of intersection crashes in the study period

V= Traffic volumes entering the intersection daily

N = Years of data

Roadway segment crash rates are calculated per 100 MVMT

. Intersection crash rates are typically calculated per MEV. Both MVMT and MEV are traffic exposure variables. For example, if a

two-mile long corridor segment has an AADT or ADT of 20,000 vehicles per day and 50 crashes from 2016 through 2020, the segment crash rate is calculated as follows:

$$R = \frac{50 \text{ x } 100{,}000{,}000}{2 \text{ x } 20{,}000 \text{ x } 5 \text{ x } 365}$$

R = 68.5 Crashes per 100 MVMT

Table 6-2 presents an example of a comparison of crash rates by year for road type and highway system. Crash rates higher than the statewide average indicate the need to further analyze crashes to develop countermeasures and recommend safety improvements. An additional table provided in Appendix G, Section 4 – Example Crash Data Summary shows crash comparisons by collision type and crash severity. This table is recommended to be used to check whether any aspect of the crash data stands out (e.g., overrepresented crash types or severity, crash rates greater than the statewide average, or patterns of fatalities and suspected serious injuries). Further analysis may be necessary if crash severities are higher than expected, the manner of collisions are different than expected, or if there are issues in unexpected locations. Further analysis can include viewing CR-3 and evaluating crash diagrams.

Table 6-2: Example Crash Rate Comparison

Corridor	Crash Year	Length of Section (mile)	Total Crashes	ADT	Crash Rate	Statewide Average by Road Type (4 or more lanes, undivided)	Statewide Average by Highway System (State Highway)
Main Street	2016	3.0	19	11,934	145.40	104.31	92.43
	2017	3.0	13	12,404	95.71	101.36	90.95
	2018	3.0	17	12,943	119.95	98.43	91.63
	2019	3.0	13	13,755	86.31	95.90	89.17
	2020	3.0	18	14,521	113.20	87.76	79.92

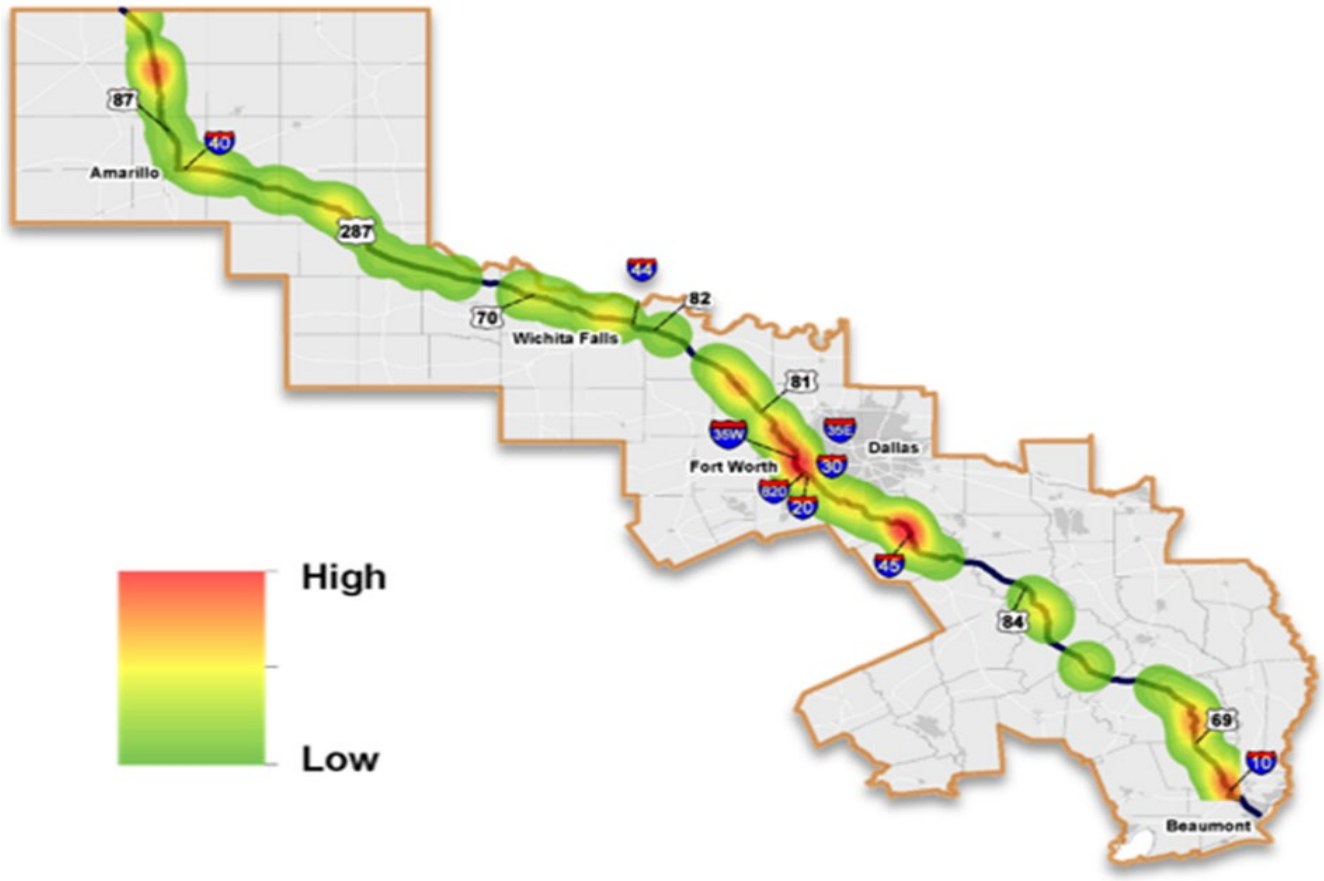


Figure 6-2: Crash Heat Map

Figure 6-2 presents a color-coded crash heat map showing crash concentrated locations (i.e., areas where the density of crashes is high), where green represents a low crash density and red represents a high crash density. These maps are typically created using crash data and a GIS mapping software. They can be helpful in visualizing locations with a high occurrence of crashes. The CRIS query tool also provides an option to view crashes as clusters to visualize crash concentrations. The cluster view combines crashes by area and shows an overall number of crashes.

6.1.3.2 Countermeasures

Proven countermeasures are a collection of strategies that are effective at reducing roadway fatalities and serious injuries. Countermeasures have been developed by FHWA and TxDOT and are shown in Appendix G, Section 5 – External References (Reference 12) and Appendix G, Section 5 – External References (Reference 15). These countermeasures are designed to reduce preventable crashes that share specific characteristics. The TxDOT countermeasures consider crashes with the following characteristics:

- Part of the roadway the crash occurred on;
- First harmful event;
- Vehicle movements and manner of collision; and
- Type of object struck

Countermeasures are typically used to select strategies to reduce crashes on roadways.

6.1.3.3 Field Visits

A key aspect of performing an existing conditions analysis are field visits. Field visits are used to confirm the existing roadway and traffic operation conditions and can also be used to review the results from the historical crash data analysis. It is recommended that the particular focus of these field visits is to capture information that typically cannot be obtained through the review of historical crash data and predictive analysis. This additional information related to safety can include driver behavior, speed issues, lane utilization, potential conflict issues, and the current conditions of the facility. For example, field visits may be conducted to understand the interaction between vehicles and pedestrians/bicyclists to identify potential safety issues related to these vulnerable user groups. Field visits are usually performed at times specific to the project and may include peak period, off-peak, dusk/dawn, and nighttime visits.

Field visits are recommended to provide additional insight in terms of the local conditions and potential safety issues that could otherwise be missed when only reviewing historical crash data or looking at aerial imagery. The review of aerial imagery or street-level photo logs is intended to supplement field visits and are not to be used as a replacement.

6.1.3.4 Road Safety Assessments (RSAs)

One method of supplementing field visits is to follow the formal RSA process as defined in the FHWA *Road Safety Audit Guidelines Report (Publication No. FHWA-SA-06-06).* The typical RSA includes the following eight steps:

- Step 1 – Identify project or road to be audited.
- Step 2 – Select an interdisciplinary RSA team that is independent from the project team.
- Step 3 – Conduct a pre-assessment meeting to review project information.
- Step 4 – Perform field observations under various conditions.
- Step 5 – Conduct assessment analysis and prepare report of findings.
- Step 6 – Present assessment findings to the project owner.
- Step 7 – Project owner prepares formal response.
- Step 8 – Incorporate findings into the project, when appropriate.

RSAs can be performed for both existing conditions and proposed design. Generally, projects with the following characteristics benefit from an RSA:

- Projects (intersection or road segment) with a low record of safety performance;

- Projects with safety issues from stakeholders;
- Projects identified during network screening as having lower than expected safety performance; and
- Projects using context-sensitive design principles

Additional information about the RSA process is available on the FHWA RSA website, which can be found in Appendix G, Section 5 – External References (Reference 2).

6.1.3.5 PSI Analysis

PSI analysis is conducted using the HSM predictive method. The purpose of PSI analysis is to evaluate the existing conditions of the area of interest to determine the potential to reduce crashes at that location. PSI analysis uses the observed crash data at a site to apply the EB method and determine the expected average crash frequency. The difference between the expected average crash frequency and the predicted average crash frequency is the potential reduction in crashes at that site when compared to similar facility types. If the PSI is a positive value (expected crashes are more than predicted crashes) then the site experiences more crashes than would be expected and has the potential to improve safety at that location. Figure 6-3 provides a visual representation of the relationship between observed, predicted, and expected crashes when performing PSI analysis.

The following are the basic analysis steps for performing PSI analysis:

- Determine study area;
- Determine crash analysis years;
- Obtain historical crash data for study area and analysis years;
- Calculate predicted average crash frequency using the HSM predictive method for the study area site(s);
- Calculate expected average crash frequency by applying the EB method within the HSM predictive method for the study area site(s);
- Determine the difference between the expected and predicted crash frequency; and
- Document analysis methodology, assumptions, and analysis results

Figure 6-4 contains an example of one approach for graphically documenting the PSI analysis results.

6.1.4 Future Conditions Analysis

The purpose of safety analysis for future conditions is to consider safety implications of design decisions in the project development process. Future conditions analysis is conducted in a variety of different forms and analysis methods. Future conditions safety analysis methods may include:

- Relative Comparison of CMFs for future conditions analysis; and
- HSM Part C Predictive Method for future conditions analysis (various approaches)

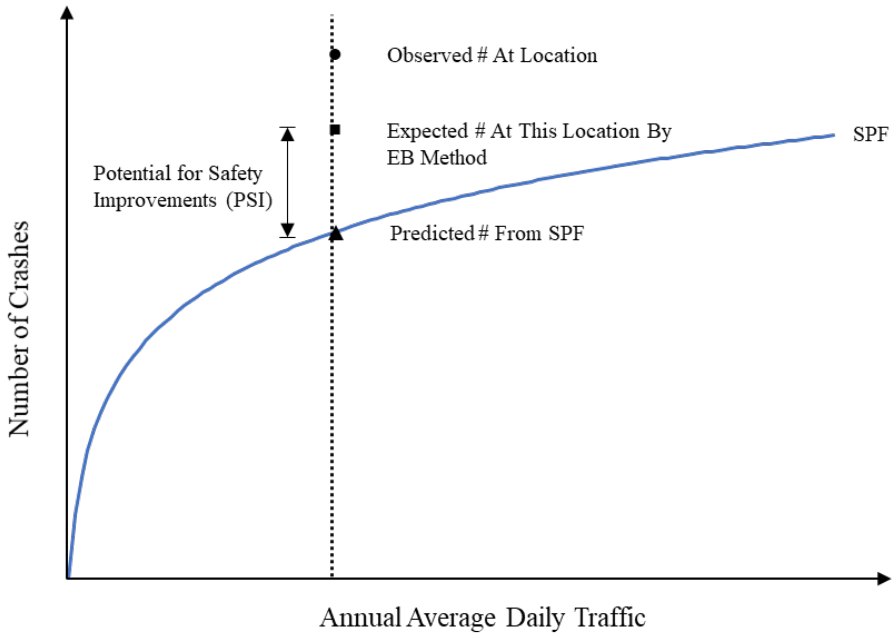


Figure 6-3: Relationship of Observed, Predicted, and Expected Crashes within PSI Analysis

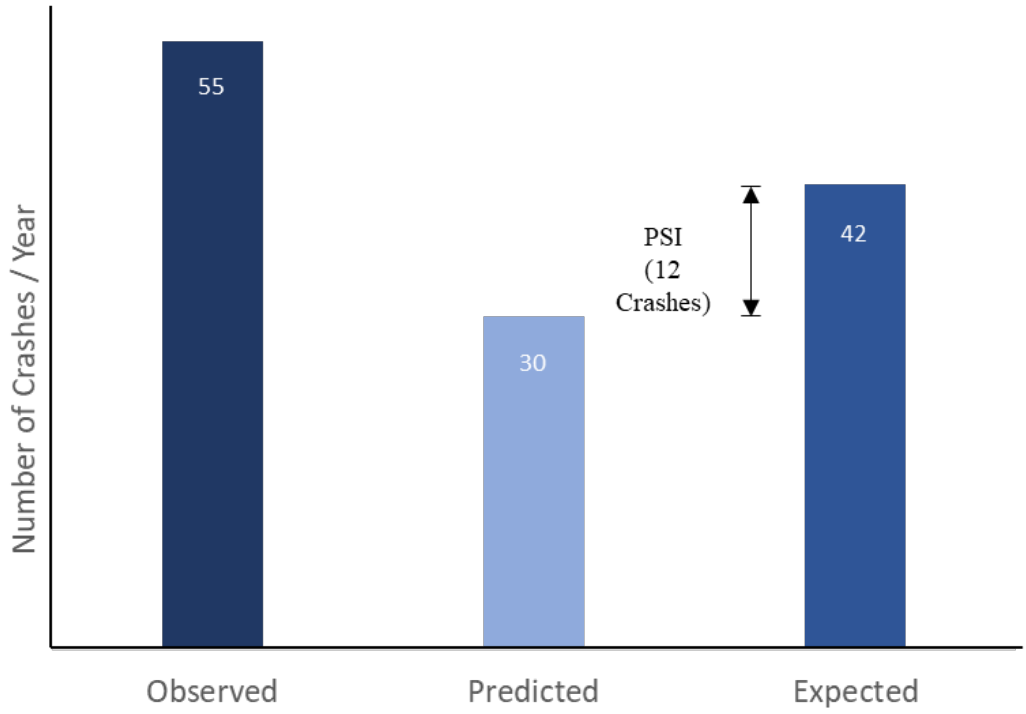


Figure 6-4: Potential for Safety Improvement Example

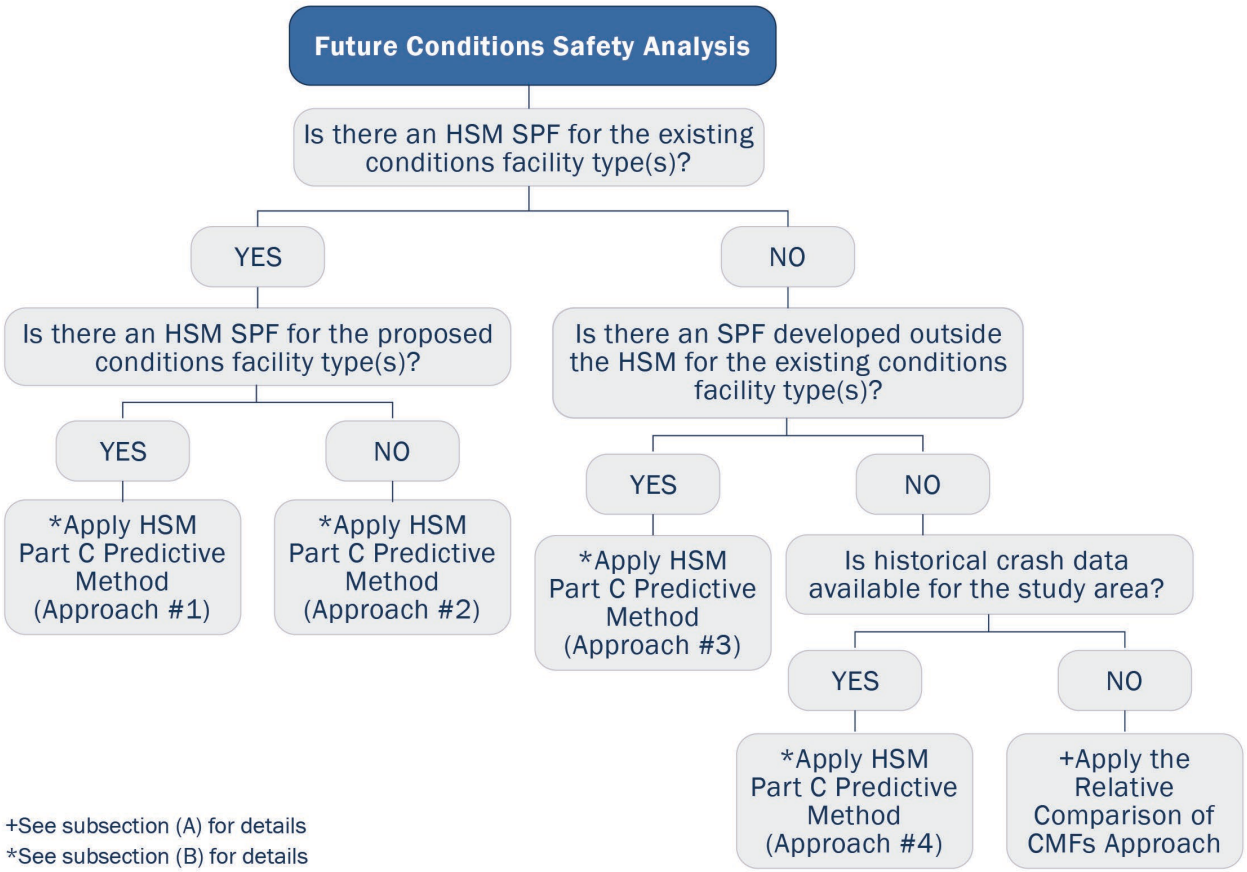


Figure 6-5: Future Conditions Analysis Decision Tree

The decision tree flowchart in Figure 6-5 can be used to determine which of the future conditions safety analysis approaches is best suited for the project. Additional details about the various approaches are provided in the subsequent subsections.

6.1.4.1 Relative Comparison of CMFs

The relative comparison of CMFs method is used to compare the potential safety impacts of alternatives by comparing the CMF values for each of the proposed alternatives or countermeasures. Comparing CMFs involves verifying that the comparisons are of identical crash types and other details. This method is typically used when historical crash data is not available. This method is the simplest method to apply and involves careful selection of CMFs. The relative comparison of CMFs method is most suitable for the initial screening of viable countermeasures before performing a more detailed analysis.

The basic analysis steps when performing a relative comparison of CMFs analysis are as follows:

- Determine the safety study area;
- Identify the existing conditions and proposed countermeasure(s) or alternative(s);
- Determine and document the appropriate CMF(s) for each countermeasure or alternative;and
- Use the results to determine next steps for additional analysis, if needed

Table 6-3 provides an example of how the relative comparison of CMFs analysis method could be applied. This example considers various alternatives for pedestrian facility modifications using CMFs located on the CMF Clearinghouse website. A general overview of CMFs is provided in Chapter 5, Section 5.4.

6.1.4.2 HSM Part C Predictive Method

The purpose of the HSM Part C predictive method is to provide a structured method for determining predicted or expected average crash frequencies for both existing and proposed future conditions of a roadway network, facility, or individual site. A detailed introduction into the HSM Part C Predictive Method is provided in Chapter 5, Section 5.3.

There are four analysis approaches for applying the HSM Part C predictive method to estimate the safety effectiveness of proposed projects or alternatives. Not all analysis methods have the same order of reliability when investigating the results of the potential safety impacts of proposed improvements or alternatives. It is important for practitioners to determine which analysis method is most applicable for the given analysis scenario. Figure 6-5 presents a flowchart for where the HSM Part C predictive method analysis falls within the future conditions analysis. The following are the four HSM Part C predictive method analysis approaches in order of highest to lowest predictive reliability:

- Approach #1 – Apply the Part C predictive method to estimate the average crash frequency for both the existing and proposed conditions.
- Approach #2 – Apply the Part C predictive method to estimate the average crash frequency for the existing conditions. Apply the appropriate CMF(s) related to the proposed condition to the existing condition results to estimate the

Table 6-3: Example of the Relative Comparison of CMFs

Alternative	CMF Description	CMF ID	CMF Value	Star Rating
Alternative #1 – Pedestrian Hybrid Beacon	Install pedestrian hybrid beacon (PHB) with advanced yield or stop markings and signs	9021	0.432	4 Star
Alternative #2 – Raised Median	Install raised median with marked crosswalk (uncontrolled)	175	0.54	3 Star
Alternative #3 – Raised pedestrian crosswalks	Install raised pedestrian crosswalks	136	0.55	3 Star
Alternative #4 – Rectangular Rapid Flashing Beacon (RRFB)	Install RRFB	9024	0.526	3 Star

safety performance of the proposed condition. Approach 2 is typically applied when the proposed conditions do not apply directly to a predictive model located within the HSM. The CMF located on the CMF Clearinghouse needs to be applied to the results from the predictive method for the existing conditions to generate predictive results for the proposed conditions.

- Approach #3 – Use a SPF developed outside of the HSM to estimate the average crash frequency for the existing conditions, then apply the appropriate CMF(s) related to the proposed condition to the existing condition results to estimate the safety performance of the proposed condition.
- Approach #4 – Use historical crash data to estimate the average crash frequency of the existing condition and then apply the appropriate CMF(s) related to the proposed condition to the historical crash data to estimate the average crash frequency for the proposed condition.

The basic analysis steps when performing HSM Part C predictive method analysis are as follows:

- Determine the safety study area based on project type, complexity, and impact of proposed improvements;
- Determine the analysis years;
- Determine which of the four approaches is the most appropriate;
- Apply the HSM predictive method 18-step process, where applicable;
- Determine appropriate CMF(s), where appropriate;
- Document analysis methodology, approach, and assumptions; and
- Summarize and document analysis results

6.2 An Overview of Predictive Safety Analysis Tools

6.2.1 Overview

A variety of tools have been developed to help practitioners implement safety analysis. This section provides an overview and introduction to the following safety analysis tools:

- HSM Spreadsheets;
- IHSDM;
- ISATe;
- SPICE;
- HSS; and
- Other TxDOT-specific tools such as SSTs

The data requirements and level of effort to operate these safety analysis tools varies greatly depending on the tool and facility types being analyzed. In general, the data requirements to perform the HSM Part C predictive method are located in the various Part C chapters within the HSM. Table 6-4 summarizes the applications of the various safety analysis tools.

It shows the gaps of certain tools in analyzing certain facilities.

Qualitative safety analysis such as field visits and RSAs are described under Section 1 of this chapter. The following sub-sections provide an overview of the various quantitative safety analysis tools.

Table 6-4: Safety Analysis Tool Application

Tools	Application					
	HSM Predictive Analysis (SPF-based)	HSM Predictive Analysis (CMF-based)	Rural Roadways	Urban Roadway	Ramps and Freeways	Intersection Evaluations
HSM spreadsheets	✓		✓	✓		✓
IHSDM	✓		✓	✓	✓	✓
ISATe	✓				✓	
SPICE		✓				✓
HSS	✓		✓	✓	✓	✓
TxDOT-specific tools	✓	✓	✓			✓

6.2.2 HSM Spreadsheets

As part of the NCHRP research studies used to develop the HSM crash prediction models, several spreadsheet tools were developed to assist in the implementation of the HSM Part C predictive method. The HSM Spreadsheets are Microsoft Excel-based tools maintained by AASHTO that were created for the purpose of simplifying the implementation of the HSM Part C predictive method. The following four HSM Spreadsheets related to the various chapters in the HSM have been developed:

- Rural Two-Lane, Two-Way Roads Spreadsheet – HSM Chapter 10;
- Rural Multilane Highways Spreadsheet – HSM Chapter 11;
- Urban and Suburban Arterials Spreadsheet – HSM Chapter 12; and
- ISATe – HSM Chapter 18 and Chapter 19

The use of the HSM Spreadsheets allows the user to manually enter data and determine the segmentation of the safety study area. The latest version of these tools, along with additional information, is available on AASHTO's HSM website, which is located in Appendix G, Section 5 – External References (Reference 3).

Several agencies have expanded and modified the HSM Spreadsheets to meet their specific needs. These changes include automation, increased flexibility, and additional features. These modified spreadsheets are not designed for general use in Texas but may be a useful resource for very specific application needs. Several of these modified tools are located on the HSM website. The use of modified spreadsheets can be accepted by the TxDOT Project Manager that will be approving the completed analysis prior to use.

6.2.3 Interactive Highway Safety Design Model (IHSDM)

IHSDM is a suite of software analysis tools developed to evaluate the safety and operational effects of geometric design decisions on roadways. IHSDM is meant to be used as a decision-support tool by providing estimates of the expected safety and operational performance of a roadway design. It checks existing or proposed roadway designs against relevant design policy values. The results of the IHSDM support decision-making in the roadway design process. This software is intended to be used by project managers, designers, and traffic safety reviewers in State and local agencies and by engineering consulting firms. As of 2024, the IHSDM software is available for free from the FHWA software overview site, but FHWA no longer supports development of this software. A link to the software is located in Appendix G, Section 5 – External References (Reference 4), and includes the following six evaluation modules:

- Crash Prediction;
- Design Consistency;
- Intersection Review;
- Policy Review;
- Traffic Analysis; and
- Driver/Vehicle

The crash prediction module was developed to help support the implementation of the HSM Part C and is considered a faithful implementation of the HSM predictive method. The crash prediction models in Chapter 10, Chapter 11, Chapter 12, Chapter 18, and Chapter 19 are included in IHSDM, along with other crash prediction models developed since the publication of the HSM. IHSDM crash prediction modules can be used to do the following:

- Predict crash frequency for roadway segments, intersections, and interchanges;
- Evaluate the safety effects of roadway improvements and treatments;
- Compare relative safety performance of design alternatives; and
- Assess the safety and cost-effectiveness of design decisions

The following facility types can be analyzed with IHSDM:

- Rural Intersections and Two-Lane, Two-Way Segments;
- Rural Multi-Lane Segments and Intersections;
- Urban/Suburban Arterial Segments and Intersections;
- Roundabouts; and
- Freeways, Ramps, and Interchanges

Data entry and segmentation can be done manually, as in the HSM spreadsheets. The software also has the capability to import alignment files to automate parts of the data entry and segmentation process. Data can also be copied and pasted in from another spreadsheet to increase the usability. Data can be entered either based on milepost or station. Additional information about facility types and data considerations is available in the help feature of the IHSDM software.

6.2.4 Enhanced Interchange Safety Analysis Tool (ISATe)

ISATe is another HSM Excel-based spreadsheet tool developed by FHWA to help practitioners implement the HSM Part C predictive method for freeways, ramps, interchanges, and collector-distributor (C-D) roads, as identified in Chapter 18 and Chapter 19 of the HSM. ISATe is intended to help agencies make informed decisions related to the safety performance of design alternatives and changes to existing freeway systems. The ISATe spreadsheet and user manual can be downloaded from AASHTO's HSM website, which is located in Appendix G, Section 5 – External References (Reference 3). Data entry and segmentation for ISATe is very similar to the HSM Spreadsheets.

6.2.5 Safety Performance for Intersection Control Evaluation (SPICE)

The SPICE tool is a macro-based, Microsoft Excel spreadsheet that was developed to provide practitioners the ability to evaluate the anticipated safety performance of various control types or intersection types within one tool during the scoping and screening stages of the project development process. This tool was specifically developed to help practitioners performing Intersection Control Evaluations (ICE) to identify alternatives to consider for additional analysis. The SPICE tool can be applied to the following intersection control types:

- Traffic Signal;
- Minor Road Stop;
- All-Way Stop;
- One-Lane Roundabout;
- Two-Lane Roundabout;
- Displaced Left-Turn (DLT);
- Median U-Turn (MUT);
- Signalized Restricted Crossing U-Turn (RCUT);
- Unsignalized RCUT;
- Continuous Green-T (CGT) Intersection; and
- Jughandle

The SPICE tool is a static tool that does not allow for the flexibility that is available in some of the other crash prediction tools. The purpose of the SPICE tool is to allow the practitioner to

evaluate a wide variety of intersection control types and select the most applicable control types that are then further evaluated using one of the more detailed tools like IHSDM or the HSM Spreadsheets. The SPICE tool can be used in conjunction with the CAP-X tool to perform preliminary analysis of intersection control types. Links to download the SPICE tool and user guide can be accessed on AASHTO's HSM website, which is located in Appendix G, Section 5 – External References (Reference 3), or the CMF Clearinghouse resources website, which is located in Appendix G, Section 5 – External References (Reference 5).

6.2.6 Highway Safety Software (HSS)

The HSS performs crash prediction evaluations for roadway facilities based on the developed HSM methodologies. Similar to IHSDM, the HSS is another safety software tool developed to implement the HSM predictive method. The HSS software can be used to evaluate the following facility types:

- Rural Two-Lane Highways and Intersections;
- Rural Multi-Lane Highways and Intersections;
- Urban and Suburban Arterials and Intersections;
- Freeway Ramps and Interchanges; and
- Roundabouts

The HSS software is distributed as part of McTrans HCS and comes with a comprehensive user's guide to provide the needed references for the user along with the data requirements.

6.2.7 Comparison of Predictive Safety Analysis Tools

The HSM Spreadsheets were developed as part of the NCHRP Project 17-38 to implement the HSM Part C predictive methods for rural two-lane two-way roads, rural multilane highways, and urban and suburban arterials.

IHSDM is typically used more frequently by practitioners for analysis of complex or larger projects. Segmentation is automated if LandXML files are available to import. The crash module for the IHSDM includes a "site-based analysis tool" that can be used without having to include the detailed horizontal and vertical alignment and cross-section data.

ISATe is a spreadsheet-based tool that implements the HSM predictive methods for freeways and ramps. Its application is very similar to the developed HSM Spreadsheets.

The SPICE tool was developed to evaluate the anticipated safety performance of intersection control strategies within a single tool. The SPICE Tool uses the SPFs in Part C of the HSM (and subsequent NCHRP Reports) to select high-quality CMFs from Part D of the HSM and CMF Clearinghouse. The SPICE tool automates many of the decisions necessary for selecting the appropriate SPF or CMF to apply. The SPICE Tool only provides predicted crash frequencies and severities for intersections. The SPICE Tool is not intended to replace the functionality of other tools, including the HSM spreadsheets, ISATe, or IHSDM.

The HSS performs crash prediction evaluations in roadway facilities based on the HSM Part C crash prediction models. SPF and the CMFs are presented for the various facility types. HSS can conduct a standalone evaluation of a segment and intersection or analyze corridors composed of a series of segments and intersections. Each of the crash prediction tools is considered to faithfully implement the HSM Part C crash prediction models. The difference between these various tools is in their approach to allow the user to input the data needed to run the predictive analysis.

FHWA requirements surrounding predictive crash analysis only apply in situations to which the predictive tool can analyze the project.

A summary of the predictive safety analysis tools is shown in Table 6-5. This table shows the types and applications of predictive safety tools.

Table 6-5: Predictive Safety Analysis Tools

Analysis Tool	Application
HSM spreadsheets	• Rural two-lane roads • Rural multilane highways • Urban and suburban arterials
IHSDM	• Roadway facilities found in HSM Part C • Complex or large projects • New research conducted since HSM
ISATe	• Freeways • Freeway ramps • Interchanges • C-D Roads
SPICE	• Intersections
HSS	• Roadway facilities found in HSM Part C

6.2.8 Other TxDOT Specific Tools

TxDOT has SSTs for two-lane rural roadways, multi-lane rural roadways, and urban intersections. Information regarding these tools can be found in Appendix G, Section 7 – Safer By Design. Static versions are also included in Appendix G, Section 1 – Rural Multi-Lane Road Segment Safety Scoring Tool, Appendix G, Section 2 – Rural Two-Lane Road Segment Safety Scoring Tool, and Appendix G, Section 3 – Urban Intersection Safety Scoring Tool. TxDOT also has an Eligibility Matrix used as guidance for determining when the SST is applicable to a project. The Eligibility Matrix for the Rural Highways is shown in Appendix G,

Section 5 – External References (Reference 14) and the Eligibility Matrix for Urban Intersections is shown in Appendix G, Section 5 – External References (Reference 13). The goal of the SSTs is to understand safety effects of design elements and optimize safety before a project is constructed. There is no specific safety score to aim for. The intent is to get the highest score for a particular project, given the constraints. These tools make use of several SPFs and CMFs. The tools can be used for all phases of project development, however, the most value is in using it during the initial scoping stages. Scores from the initial scoping phase and at final PS&E are necessary for reporting purposes. Safety scorings are necessary for PM, 2R, 3R and 4R projects. These project types are defined in TxDOT's RDM.

6.2.9 Local Safety Performance Functions (SPF) and Calibration Factors

HSM models were developed based on the data from States other than Texas. It would be logical to develop new models to address the HSM limitations and calibrate existing HSM models to Texas conditions. TxDOT has completed a couple of research projects which provided local SPFs or calibration factors for all types of facilities. These methods are incorporated into spreadsheet tools to be implemented in the new models. The implementation phase is currently underway which would provide hands-on trainings to TxDOT practitioners. Information regarding local SPFs and calibration factors can be found in Appendix G, Section 6 – Safety Prediction Models.

6.3 General Guidance for Safety Analysis Documentation

Proper documentation of safety analysis methodologies, processes, and procedures is critical to ensure that any safety analysis was performed correctly and in accordance with the latest and best practices. The following identifies general guidance when providing documentation for any safety analysis performed:

- Relate predicted safety performance of the project to existing conditions or observed known safety performance issues of the existing conditions.
- Consider any factors not included in the quantitative analysis.
- Explain safety analysis outputs and check that they are reasonable with what is expected.
- Provide a written summary of the analysis results along with all appropriate tables, graphs, and/or figures to help summarize the results.
- Provide a brief description of the analysis approach and methodology.
- All assumptions used to perform the analysis and resulting decisions made are recommended to be documented in the analysis summary.
- Document the source of all data used in the analysis and provide a copy of all analysis data in an appendix.

- Include the input and output files from any tool used to assist in the safety analysis (both in native and PDF formats).
- Provide a copy of any historical crash data used in the analysis and include native electronic file; excel spreadsheet, text file, etc.
- Include a PDF summary of any CMF used from the CMF Clearinghouse website.
- Crash data is recommended to include raw data with appropriate attributes including, but not limited to, highway name/number, crash year, location (latitude, longitude, Distance-from-Origin (DFO), mile point), severity, manner of collision, etc.
- Location-based analysis may include a Google Earth KMZ file with applicable data (horizontal alignment with stationing, proposed geometric design, Area of Influence with DFO, etc.), if available.
- Input data is recommended to correspond with design plans (horizontal and vertical alignment, stationing, etc.).
- Explain why the proposed design is the right engineering solution for the project.

6.4 Safety Analysis Applications

6.4.1 Interstate Access Justification Report (IAJR)

IAJR involves an evaluation of a change in access along Interstates. One of the evaluation criteria is safety. The safety analysis may conclude that the proposed change in access does not have a significant adverse impact on the safety of the Interstate facility or on the local street network based on the current and the planned future traffic projections. The scope and methodology for safety analysis is typically based on the project type, location, complexity, crash history, and need and purpose. Safety analysis for IAJRs includes one of the following options:

- Option A - Historical Crash Analysis and HSM Predictive Method; and
- Option B - Historical Crash Analysis and evaluation of CMFs

Option A is the preferred methodology. If the HSM predictive method cannot be used, option B may be allowed as per the IAJR methodology, assumptions, coordination, and project scoping.

The safety analysis study area for an IAJR is suggested to be the area impacted by the proposed project. The traffic analysis study area is a good starting point, but the safety analysis study area depends on the safety impacts of the proposed project and may be more encompassing than the traffic analysis study area. The safety analysis study area along the Interstate includes at least the adjacent interchanges on either side of the proposed access change. Along the crossroad, it extends at least one-half mile from the ramp terminal and includes the first major intersection.

Historical crash analysis is typically conducted for five complete calendar years (January 1st to

December 31st). The results of the analysis are used to identify or confirm safety issues within the project study area. The analysis includes:

- Crash frequency by facility type for each year;
- Crash rates and comparisons with statewide average for similar facilities;
- Crash severity by facility type for each year;
    - Mainlanes
    - Frontage roads
    - Ramps
- Crash contributing factors;
- Manner of collision for each year by time of day; and
- Crash diagrams such as heat maps, bar charts or other maps graphically showing the high crash locations along the study area roadways or at the interchanges

Predictive Crash Analysis (Predictive, or quantitative safety analysis) involves using HSM based methods that use SPFs and CMFs to estimate the anticipated change in crashes from existing conditions to the proposed design. It is recommended that predictive analysis be performed for no-build and build conditions for the design year. Typical applications for safety analysis tools are detailed in Section 6.2 of this chapter. For additional details on safety analysis for IAJRs, please see TxDOT's IAJR SOPs and SOPs FAQ in Appendix G, Section 5 – External References (Reference 7). See Appendix G, Section 8 – IAJR SOP FAQ Webinar Slides for additional information about the Standard Operation Procedures.

6.4.2 Design Exceptions

A design exception is necessary whenever the controlling criteria specified for the different categories of construction projects (such as, 4R, 3R, 2R, Special Facilities, Off-System Historically Significant Bridge Projects, On-System Park Road Projects, and on-street Bicycle Facilities) are not met. Design exceptions add flexibility to meet project needs (i.e., balancing costs, ROW, environmental considerations, modal access, and performance). A design exception is comprised of multiple comparisons, with the safety analysis being just one part of the process. The request for design exceptions is recommended to include a summary and analysis of the crash history at the location. An explanation is suggested to be provided on how crash history relates to design exceptions and predicted safety performance of the project under development. For the latest guidance on design exceptions, refer to the TxDOT RDM. Safety analysis for design exception requests include the following:

- Need;
    - Project description
    - Project location map
    - Location of design exceptions
    - Alternatives
- Description of Anticipated or Proposed Design Exceptions;
- Area of Influence;
    - Mainlane
    - Crossroads

- Analysis Years (if applicable);
  - Existing
  - Opening
  - Design
  - Interim
- Data Collection;
  - Historic crash data
  - Traffic volumes
- Safety Analysis;
  - Historical crash data analysis for the latest three to five years
  - Predictive/Expected number of crashes (if applicable)
  - Safety analysis of alternatives
- Analysis Tools; and
  - Predictive Crash Analysis – See Section 6.1 of this chapter for application of predictive crash analysis
- Safety Analysis of Possible Mitigation/Countermeasures

For more information on design exceptions see TxDOT's request for a design exception form. The design exception form can be found on Appendix G, Section 5 – External References (Reference 6). As of May 2024, TxDOT has also developed draft Design Exception SOP for Interstate projects, which will be available online later.

Chapter 7
Project and Corridor System Planning

7.1 Introduction

7.1.1 Overview

Corridor planning shapes a long-term vision for a corridor with the comprehensive analysis of a transportation corridor from a multimodal approach (passenger vehicles, commercial vehicles, railroad, transit, aviation, maritime, and bike/ped). It focuses on a mix of transportation needs as they relate to the complex economic, demographic, and social characteristics of communities within the corridor. TxDOT uses three main types of studies to identify transportation needs related to the State system: Feasibility, Route, and Corridor studies. The following sections are consistent with Chapter 11 of the TxDOT Transportation Planning and Programming manual.

7.1.1.1 Feasibility Studies

When a solution is unknown, a feasibility study is performed to determine possible alternatives and their viability. A feasibility study is part of the Planning phase of the project development process and is intended for limited project development. Feasibility studies establish design concepts, general ROW requirements, and associated project impacts. The typical elements of a feasibility study include evaluating alternative project solutions/concepts, analyzing current and future traffic, evaluating potential environmental red flags and fatal flaws, and developing planning-level cost estimates.

7.1.1.2 Route Studies

Route studies are typically conducted in an area around one or two cities/towns currently experiencing, or forecasted to experience, adverse traffic congestion that have safety issues due to outdated roadway design or need to determine routes for freight traffic. These studies typically follow-up a feasibility study. The purpose of a route study is to identify a preferred route that meets the local and regional travel needs. A route study is part of the Planning phase of the project development process and documents transportation needs for the purpose of subsequent detailed schematic and environmental studies.

7.1.1.3 Corridor Studies

Corridor studies provide agency-wide planning, programming, and implementation activities for a 25-year to 30-year outlook. A corridor study is critical to the Planning phase of project development as it provides direct linkage from the Statewide Long Range Transportation Plan (SLRTP) vision. TxDOT uses corridor studies as sources of projects for the Metropolitan Transportation Plan (MTP), the Rural Transportation Plan (RTP), and the Unified Transportation Program (UTP).

Such studies establish a shared vision and consensus by allowing stakeholders and communities to set goals and objectives. Corridor studies vary in length and can be evaluated either from a regional perspective or statewide perspective. Corridor studies are effective tools in examining a transportation corridor's existing conditions, developing multi-modal future conditions, and providing interim solutions for corridors as they evolve.

7.1.2 Purpose and Intended Use

The purpose and intended use of this chapter is to provide guidance on the type of information and analysis to include in a feasibility, route, or corridor study. This chapter includes details on defining overall scope for a corridor planning project, an overview of existing conditions data collection, and a process to identify and analyze existing and future traffic and safety conditions along the corridor. The rest of this chapter provides information on key considerations of corridor planning.

7.1.3 Limitations

The chapter is written from a traffic and safety analysis perspective for the three types of corridor planning projects (feasibility, route, and corridor studies), and does not include information regarding other aspects of the corridor planning process or details on next steps. This chapter does not include a step-by-step procedure for how to complete a corridor planning process. Components related to environmental documentation, pavement design, and other items not pertaining to traffic operations and safety analysis are not included in this chapter. For more information, refer to TxDOT's TPP manual. See Appendix H, Section 1 – External References (Reference 1), for a link to the TPP manual.

7.2 Define Scope and Effort

7.2.1 Scoping Elements

When scoping out corridor planning projects, it is important to understand that the nature of corridor planning makes it hard to apply a "one size fits all" solution. Instead, it is important to have a set of guiding principles and understanding of general content needed for each type of study when approaching the three types of corridor planning projects.

Feasibility studies are performed when the project is in the early stages of development. The study helps determine whether the project can move forward to more in-depth schematic design, environmental analysis, public involvement, and ROW mapping. General contents of a feasibility study include but are not limited to:

- Potential alternative alignments for a corridor;
    - General ROW footprint of alternative alignments
- High-level safety analysis and traffic analysis;
    - Recommendations for improving safety and mobility
- High-level construction costs; and
- Feasibility study report:
    - Purpose and need
    - Alternative alignments graphics and maps

    - Summary of stakeholder engagement and public outreach
    - Summary of traffic and safety analysis

Route studies are performed to identify build option(s) for further detailed schematic design and/or environmental impact analysis. Route options may include construction of roadways on new alignments or providing improvements along existing facilities to increase capacity, enhance mobility, and improve safety. General contents of a route study include but are not limited to:

- Summaries of meetings with stakeholders and public;
- Feasibility studies previously performed on the route;
- Maps and graphics that show study area limits, environmental features, route options, etc.; and
- Technical memoranda related to:
    - Traffic analysis methodology, existing and future traffic conditions, crash analysis (crash rate, concentrated areas)
    - Engineering considerations, including design criteria, typical section(s), route option evaluation, and preliminary cost estimates (construction, ROW acquisition, utility relocations and adjustments)
    - Other subject matter as warranted
- Route study report
    - Purpose and need;
    - Correspondence/resolutions from coordination with public agencies (cities, counties, metropolitan and rural planning organizations);
    - Summary of stakeholder engagement and public outreach;
    - Inventory of existing transportation infrastructure and conditions (traffic operations, safety, and geometric);
    - Environmental features and land use – Water resources, natural resources, historical landmarks, parks, schools, first responder facilities, future land uses;
    - Summary of traffic and safety analysis;
    - Route options and evaluation process and results; and
    - Findings based on the overall process, which could include recommending a route option(s) or course of action

Corridor studies are typically conducted along a State system route that is analyzed from a regional or statewide perspective. The general contents of a corridor study include but are not limited to:

- Maps and graphics that show study area limits, environmental features, and conceptual plans;
- Summaries of meetings with stakeholders, public, and other groups/individuals; and

- Technical memoranda related to:
    - Traffic analysis methodology, existing and future traffic conditions, crash analysis (crash rate, concentrated areas)
    - Engineering considerations, including design criteria, typical section(s), route option evaluation, preliminary cost estimates (construction, ROW acquisition, utility relocations and adjustments)
    - Other subject matter, as warranted
- Corridor Study Report
    - Background information such as previous studies conducted on the corridor;
    - Purpose and need;
    - Inventory of existing transportation infrastructure and conditions (traffic operations, safety, and geometric);
    - Correspondence/resolutions from coordination with public agencies (cities, counties, metropolitan and rural planning organizations);
    - Environmental features and land use – Water resources, natural resources, historical landmarks, parks, schools, first responder facilities, future land uses;
    - Description, development process, and evaluation of alternatives;
    - Implementation plan of prioritized projects; and
    - Other findings and recommendations, as warranted

7.2.2 Develop Goals and Objectives

Prior to starting any corridor planning process, it is important to develop a set of goals and objectives that serve as guidelines throughout the corridor planning process. Goals and objectives are helpful when trying to decide between alternatives. They aid in selecting the alternative that best aligns with the needs of the client.

When developing goals and objectives, it is important to ask key questions such as**, what are the issues the study is trying to solve?** Answering open-ended questions helps develop goals and objectives and establishes an overall vision for the project. Examples of potential goals and objectives of a corridor study include:

- Improving multimodal mobility for passenger vehicles, commercial vehicles, railroad, transit, aviation, maritime, and bike/pedestrians;
- Improving safety for vulnerable users such as pedestrians and bicyclists; and
- Managing access to provide safety improvements

The goals and objectives set for a corridor planning project are developed and refined based on input from various stakeholders. At first, goals and objectives can be set by the Steering Committee. These goals may be introduced at a public meeting to get input and make sure they align with the interests of other stakeholders and the public. The goals will be updated accordingly, so both the stakeholders

and Steering Committee are working toward the same outcome.

Goals and objectives are recommended to be set in a clear and concise manner. Avoid general statements such as “Improve mobility and safety through this corridor”; rather, use more specific statements such as “Achieve a safe multimodal mobility environment consistent with road to zero principles”. Measurable goals are recommended when performing traffic and safety analysis. Compare each corridor planning alternative to determine how each alternative meets the performance measures for each goal.

7.2.3 Assemble Steering Committee

Depending on the type of study, one of the initial steps for corridor planning could be to assemble a Steering Committee or a team that provides direction from a technical and policy standpoint. This committee may consist of representatives from TxDOT Districts and Divisions, MPOs, active transportation stakeholders cities, transit agency, consultant team, and other agencies that could be part of the corridor planning process. It is important to make sure the group does not become too large, as a large committee may impede efficiency of the planning process. The purpose of this group is to have regularly scheduled meetings to help establish goals and objectives, make sure the project is on track, communicate any outstanding needs and information, and develop solutions. Frequency of these meetings is based on the project scope of work and the committee’s role and involvement. Not all corridor planning projects warrant a Steering Committee.

Note that the Steering Committee is different than the stakeholders. Stakeholders may include the individuals from the Steering Committee as well as residents, business owners, developers, commuters, elected officials, advocacy groups, and whoever else could be applicable or have an interest in the study.

7.2.4 Define Study Limits

The study limits are set based on the issues the corridor planning project is trying to address. It is suggested to consider the overall project location and intersections, interchanges, segments, or other facilities (frontage roads, parallel routes) that will be included in the analysis. The broader study area often includes the corridor/route/parallel routes that are being studied, along with larger demographical areas such as cities, counties, and TxDOT Districts. The purpose of the larger area surrounding the corridor/route is to provide additional context on the characteristics of the area, such as traffic patterns, environmental features, population, Gross Domestic Product (GDP), land use, employment, industries served, freight movement, and other points of interest.

7.2.5 Data Collection

Prior to evaluating existing conditions and conducting any analysis, it is important to determine the type of data needed to perform the corridor study. The data types needed vary from project to project. Some data types are readily available on online sources such as the

TxDOT Open Data Portal, TxDOT Project Tracker, STARS II, Texas Natural Resources Information System (TNRIS), Texas Bicycle and Pedestrian Count Exchange, and others. Other data, such as traffic counts, may need to be collected. Check DCP in the STARS II database for the corridor to determine whether the available data is recent and if it can be used for the corridor study. Historical traffic growth is a strong datapoint to determine future traffic. Traffic counts are necessary for the existing conditions analysis and for traffic projections. It is important to have counts conducted at all the necessary locations where data is not available. A Travel Demand Model output (TDM) is a datapoint to determine future traffic and can be obtained from TxDOT or the MPO. Some data sources that TxDOT has access to needs a signed licensing or non-disclosure agreement with TxDOT before receiving access. More information on how different data types are used for corridor studies is presented under Section 7.3.

7.2.6 Stakeholder Engagement and Public Involvement

Active engagement and participation of internal and external stakeholders is critical for the corridor planning process. Depending on the scale of the corridor study, holding multiple rounds of public meetings could be a lengthy process requiring extensive time and resources to conduct. Develop a Public Involvement Plan (PIP) early on to determine how to best involve the stakeholders and the public in providing feedback. More information related to public involvement is presented in Section 7.4.

7.2.7 Existing and Future Conditions Analysis

Performing existing and future conditions analysis is a critical part of the corridor planning process. It is recommended that evaluation criteria and MOEs used for the analysis are aligned with the goals and objectives of the project. More information related to Existing and Future Conditions Analysis is presented in Section 7.5.

7.3 Existing Conditions Data Collection

Existing conditions analysis is the basis of any traffic and safety analysis. The purpose of assessing existing conditions is to provide an overview of the current state of the route or corridor. The assessment helps to determine the type of infrastructure that currently exists, identify gaps in infrastructure, understand characteristics of the corridor, identify environmental constraints, note ongoing projects, etc. Evaluating existing conditions provides a narrative for the overall corridor from which concepts are developed.

Data types for existing information include land use, demographics, roadway characteristics, planned projects, crash data, economic analysis and development, environmental impacts, external agencies, historical traffic counts, existing traffic counts, freight, travel demand model outputs, speed, travel time, and OD data. Additional data types are often needed to fully evaluate and analyze the corridor based on the project scope. Sources for information related to each data type are listed below.

Present the existing data in a report. Data can be presented in the form of maps, charts, tables, and text. Discussion of the how the data is relevant to the corridor is recommended. Additional data can be gathered from stakeholders through the outreach process. This data is often valuable, revealing specific details at a local level.

7.3.1 Land Use and Demographics

Land use and demographic information is typically available on the local jurisdiction's GIS database website. Some agencies have this data shown in a web interface format, but it may not be available for download. In those cases, reach out to the corresponding jurisdiction to request access to the data. The data usually contains zoning case number, tract size, and the type of zoning.

Demographic data can be found on the Texas Demographic Center (TDC) website and the U.S. Census Bureau website. These websites contain information related to population size, age, sex, commuting characteristics, households, income, means of transportation, and more. This information can be broken down by specific geography such as State, county, and census tract. See Appendix H, Section 1 – External References (Reference 2 and 3), for a link to the TDC website and the Census Bureau website.

Another source for land use and demographic data is MPOs. MPOs have TDM for the region, which include information on baseline and future forecast year population, employment, and other demographic characteristics. MPOs typically update these on a rolling three- to five-year basis and gather information from cities within the MPO to update their land use and thoroughfares according to what the cities have planned for the future.

Land use and demographic data could also be helpful in determining the growth rates for the overall corridor. Land use maps often show the planned developments near the corridor and the corresponding increase in population and traffic. It is recommended to compare this data to historical growth rates, TDC data, U.S. Census Bureau data, and other related items to check that growth rates are consistent.

7.3.2 Roadway Characteristics

Information regarding the geometrics of the roadway segment is typically obtained from field visits, as-builts, survey files, the agency's GIS database, or online maps. TxDOT's Statewide Planning Map and Open Data Portal are good sources for finding information on bridge crossings, vertical clearances, shoulder widths, and other important roadway-related elements. When collecting information from online maps, it is crucial to check the date of the aerial and verify it is not outdated. Field verification of geometry may be necessary depending on the date of the aerial. See Appendix H, Section 1 – External References (Reference 4) for a link to the Statewide Planning Map and Appendix H, Section 1 – External References (Reference 5) for a link to the Open Portal website.

7.3.3 Planned Projects

When performing a corridor planning project, it is important to consider projects that affect the study area. Sources for this information include

TxDOT's Project Tracker website, TxDOT Connect, and the UTP. Furthermore, TxDOT Districts within the study area may have more detailed and up-to-date information on projects. It is recommended to check these resources to determine whether any projects on or adjacent to the corridor could affect the study. Present any relevant projects to the Steering Committee, incorporating and accounting for any identified improvements in the corridor study. To better understand previous active transportation planning efforts in an area, engineers and planners can reference the Active Transportation Plan Inventory. This interactive reference map allows users to identify locations across Texas where Active Transportation Plans (ATPs) Texas have been completed. ATPs are stakeholder-influenced plans that help guide active transportation projects, programs, and policies within a jurisdiction. See Appendix H, Section 1 – External References (Reference 6), for a link to the Project Tracker website and Appendix H, Section 1 – External References (Reference 7) for a link to the UTP website.

MPOs also have a regional transportation plan, which is a long-term (20-year) plan that includes projects, programs, and policies aimed at addressing various issues such as mobility, sustainability, maintenance, and funding.

7.3.4 Border Data

For corridor planning projects that involve interaction with border crossings, border towns, or facilities adjacent to the border, it is important to get information on the flow of goods and people between United States and Mexico. The Bureau of Transportation Statistics (BTS) provides data and statistics on multimodal freight (highway, rail, aviation, maritime, etc.), transportation economics, commercial aviation, and border crossing data. Information related to the import and export of commodities can be found on the website by port of entry and can be filtered by different time frames and mode of transportation. Data related to Mexico is available on the website for the National Institute of Statistics, Geography, and Informatics (INEGI). This website has information related to demographics (education, employment, population), economy and productive sectors (trade, manufacturing, GDP, transport), geography and environment (maps, environment), and government-related information. This data may be downloaded in a spreadsheet format and broken down by geography and year. See Appendix H, Section 1 – External References (Reference 8) for a link to the INEGI website.

7.3.5 Crash Data

TxDOT's CRIS database has crash-related information that can be queried by year and location. This data is typically acquired for the corridor planning analysis to determine crash concentrated areas. It is recommended to identify crash countermeasures to reduce the severity and number of crashes. For projects that need FHWA approval, obtain crash data through the CRIS helpdesk or TxDOT's TRF Division. For projects that do not need FHWA approval, crash data can also be downloaded through the CRIS website. See Appendix H, Section 1 – External References (Reference 9) for a link to the CRIS website.

7.3.6 Economic Analysis and Development

The State's highway system is seen as a crucial part of not just the movement of people, but also goods and services. Depending on the type of corridor planning process being performed, a preliminary economic analysis of existing conditions in the study limits could be needed.

The Bureau of Labor Statistics (BLS) provides information on employment, productivity, pay and benefits, inflation, prices, and much more. Data from BLS can be used to determine earnings by demographics or by industry, or employment within the study limits. See Appendix H, Section 1 – External References (Reference 10) for a link to the BLS website.

The United States Bureau of Economic Analysis (BEA) provides information on GDP, international trade and investment, industries, employment, and other topics. Data can be broken down by geographies and industries. See Appendix H, Section 1 – External References (Reference 11) for a link to the BEA website.

The Texas Demographic Center and the United States Census Bureau also has information related to population and socioeconomic related information.

TxDOT also has access to IHS Markit data, which breaks down employment, income, population, GDP, and other socioeconomic data by county. It includes historical data as well as data projected out 20 to 30 years.

7.3.7 Environmental Features

The Texas Historical Commission (THC) is a state agency that has a GIS database that includes information related to historical sites, historical markers, cemeteries, county courthouses, and more. Another useful resource for environmental-related data is TNRIS. This online database has information regarding natural resources such as flood areas, culverts, bridges, low points, ground covers, and the Federal Emergency Management Agency (FEMA) zones.

Environmental data related to US Fish and Wildlife Service (USFWS) and US Army Corps of Engineers (USACE) can be reviewed as well. While information related to these resources is tied more to the Environmental Assessment (EA) process, avoiding areas such as wetlands, critical habitats, and superfund sites could help prevent untimely changes that affect the design, cost, and schedule.

7.3.8 Other External Agencies

Assets of other external agencies could play a decisive factor in the evaluation of alternatives. It is recommended to consider the impacts of railroads, irrigation/water resource entities, navigable waterways (US Coast Guard-regulated waters), Environmental Protection Agency superfund sites and concentrated areas (e.g., abandoned underground storage tanks), and Federal Aviation Administration (FAA) airport vicinity restrictions. Significant utilities such as interstate pipelines, fiber optic backbones, and overhead transmission lines can be considered as well. Mitigating impacts

for such complications can be a costly and lengthy process.

7.3.9 Historical Counts

Collect historical traffic counts for multiple locations on the corridor and the surrounding area. These counts can be gathered from the STARS database or other publicly available count databases from regional MPO, county, or city websites. Once all the count locations are determined and the count data is gathered, linear regression analysis is typically performed for the individual locations to determine historical growth rates. It is recommended to check historical counts for any outliers and removed if necessary. Determine historical growth rates for up to 20 years' worth of data, if available. After determining historical growth rates for individual roadway segments, an overall historical growth rate is typically calculated for the corridor. An example of the historical growth rate calculation is provided in Appendix D, Section 4 – Regression Calculations. More detailed information regarding the overall process can be found in Chapter 3 and the TPP Traffic Forecasting Analysis SOP. Use engineering judgement to determine if the overall historical growth rate is reasonable. To help in the decision process, evaluate proposed developments, land use data, demographics, and future growth trends (see Traffic Demand Model section below) to see if the calculated projected growth rate needs to be adjusted.

7.3.10 Traffic Counts

In addition to historical counts, segment counts and classification counts may be collected at key locations on the corridor. TMCs may be conducted at all study intersections. These traffic counts form the basis of the existing conditions traffic analysis, safety analysis, and traffic projections.

7.3.11 Freight

Truck freight can be an important part of the overall characteristics of a corridor. Data related to truck freight could be helpful in determining future needs for the corridor. The following sources could be used to determine truck freight traffic:

- New classification counts;
- Truck percentage from TxDOT's Statewide Planning Map;
- Classification counts from TxDOT's STARS II database;
- TxDOT's Weigh-in-Motion System. TxDOT has developed a statewide network of stations that collects data on vehicle classification and weights. This data also includes date, time, vehicle length by axle spacing, axle weight, and speed. This information can be valuable for evaluating the movement of truck traffic and freight flows along a route/corridor;
- Transearch. TxDOT's Transearch data from IHS Markit can be used to determine historical truck traffic and projected freight flows for up to 30 years into the future. Freight information can be filtered by origin, destination, commodity, and transportation mode. Transearch has county-level freight-movement data. The data is classified by:

    - Inbound, outbound, intrastate, and through traffic
    - Tonnage and value
    - Commodity type
- Bureau of Transportation Statistics. This agency provides data and statistics on commodity flow surveys, freight indicators, freight transportation, and much more

Additional information regarding freight analysis and data types is presented in Chapter 14. Some of these data sources may need a licensing agreement or non-disclosure agreement from TxDOT to allow the requester access.

7.3.12 Travel Demand Model Outputs

A TDM is another useful tool in determining future traffic projections and growth rates. Reference MPO TDM outputs to help determine growth rates for a corridor, if available. Outside of MPO boundaries, TPP's Statewide Analysis Model (SAM) may be referenced to determine growth rates for corridors.

7.3.13 Speed and Travel Time

Speed and travel time data may be useful for corridor planning projects to determine areas of bottlenecks. Give additional attention to bottlenecks to determine different types of mitigations that may relieve congestion. Mitigations might include widening the roadway or adding intersection capacity by adjusting signal timing or providing turn lanes.

Another MOE of interest for corridors is travel time reliability. Travel time reliability helps measure the extent of unexpected delay. Most drivers traveling during peak hours expect some amount of delay. An expected delay is typically accounted for and drivers often adjust their schedules accordingly to get to where they are going on time. The frequency and extent of unexpected delays cause driver's greater frustration. Travel time reliability is the consistency or dependability in travel times, as measured from day to day and/or across different times of day.

TxDOT has subscriptions with vendors that provide speed, congestion, travel time, and travel time reliability data. For more information regarding the vendors or accessing this type of data, see Chapter 2, Section 2.3.3.

7.3.14 OD Data

OD data can be helpful in determining useful travel behaviors and patterns, such as:

- Percentage of drivers using the corridor as a cut-through versus a destination;
- Percentage of corridor drivers that are local versus regional;
- Route choice of drivers using this corridor;
- Potential conflict locations between different routes; and
- Areas the drivers using this corridor are going to and coming from

For more information on accessing OD data, see Chapter 2, Section 2.3.3.

7.4 Stakeholder Engagement and Public Involvement

Stakeholder engagement and public involvement are fundamental parts of corridor planning projects. Depending on the type of the corridor planning project, different levels of stakeholder engagement and/or public involvement could be needed to satisfy the needs of the project.

Stakeholder engagement and public involvement are two separate processes. It is important to draw the distinction between two, which is summarized and then explained below.

Stakeholder engagement involves:

- Key stakeholders;
- Feedback throughout the study; and
- Necessary for all corridor planning projects

Public involvement includes:

- General public; and
- Fosters two-way communication

Stakeholder engagement is the process of developing a list of key stakeholders including agencies, elected officials, business representatives, and private citizen groups, and engaging them throughout the project for feedback and information regarding the different issues associated with the study.

Stakeholder engagement is necessary for all three types of corridor planning projects (feasibility, route, and corridor) at various levels of commitment. Stakeholder engagement can be done on an individual basis with each individual group/stakeholder, as part of a Steering Committee, or both. The process varies, depending on the depth and detail of the study. Getting feedback from the stakeholder group is an important part of the corridor planning process and helps guide the direction of the planning study.

Public involvement is the process of engaging citizens and fostering two-way communication between TxDOT and the general public. The purpose of public involvement is to incorporate the input, issues, and matters of the public into the decision-making process.

Public involvement and outreach are important elements for route study and feasibility study. The feedback TxDOT receives from these meetings helps make informed decisions about the project development. However, for corridor studies, public meetings can be optional, especially for high-level planning studies.

TxDOT has extensive resources on public involvement on its website and in TxDOT's Environmental Handbook – Public Involvement manual regarding general guidelines and process for public involvement. Other resources also are available on TxDOT's public involvement toolkit website.

7.5 Existing and Future Conditions Analysis

Existing conditions analysis provides a baseline or overview of the current state of a route or corridor. Future conditions analysis helps determine the state of a route or corridor in the horizon year.

Traffic projections are a key element of a planning study and for future conditions analysis. TxDOT's forecasting analysis process is currently classified into two different categories: TPP-led and District-led. The District provides TPP Traffic Analysis Branch a notification of the District Led Traffic Analysis. TPP maintains the statewide system of records for traffic forecasting. For additional guidance on traffic volume and forecasting, refer to the TxDOT TPP Traffic Forecasting Analysis Standard Operating Procedures. Coordinate with the TxDOT project manager to gain access to the latest documents.

More detailed information regarding the overall process can be found in Chapter 3, Section 3.1. The following subsections discuss information regarding traffic projections.

7.5.1 Traffic Projections

Existing traffic volumes are the basis for traffic projections. Existing traffic volumes are developed from traffic counts that are typically collected as part of the overall data collection effort.

Historical traffic data can be obtained from STARS. Growth rate is typically determined for a corridor based on 20-year historical growth rates, while considering the travel demand model outputs and planned developments. Depending on the type of corridor and the overall length, a corridor may have different growth rates along its segments. Prior to developing future traffic projections, a Traffic Projections Methodology Memorandum is typically prepared outlining the growth rate and approach to develop traffic projections. Include any assumptions regarding the development of growth rates in the memorandum. This memorandum is submitted to TPP or the reviewing District for approval prior to proceeding with traffic projections. An example outline for Traffic Projections Methodology Memorandum is provided in Appendix D, Section 2 – Traffic Projections Methodology Memorandum Outline.

Future traffic projections are developed based on traffic data factors and approved growth rates. Typical traffic forecasts include the project opening year, the design year (i.e., opening year plus 20 years), and the pavement design year (i.e., opening year plus 30 years). Once traffic projections are estimated, they need to be balanced throughout the corridor. More detailed information regarding the development of growth rates, volume balancing, and future traffic projections is provided in Chapter 3.

After traffic projections are approved, the Traffic Analysis for Highway Design (TAHD) table is developed in coordination with TPP. See Chapter 3, Section 3.2 for more information on the traffic data factors and the TAHD table.

7.5.2 AM and PM Peak Hour Traffic Projections

Determine the peak hour percentages in terms of the percentage of total daily traffic that is occurring in the AM/PM peak hour for both the peak hours. The percentages are intended to be a representation of the existing traffic patterns. Typically, traffic counts are collected in the form of TMCs and/or tube/camera counts. Assuming traffic counts are taken on a typical weekday with no major events or disruptions, they represent peak hour percentages for the AM and PM K factors. The peak hour percentages are then applied to the ADT to develop projected AM and PM peak hour volumes. Validate the traffic counts collected against STARS data, previous counts, or traffic forecasts. Please note that AM and PM peak hours are not always inversely related.

Turning movement traffic projections are estimated by applying existing turning movement count percentages at each approach to the ADT volumes. The TMCs are typically rounded to 50-vehicle increments, to avoid an overestimation of traffic on side streets. Traffic projections are then balanced along the corridor.

7.5.3 Analysis Tools and Performance Measures

A corridor planning project involves evaluating and comparing different alternatives to determine how closely they meet the study goals and objectives. Table 7-1 lists objectives for a typical corridor planning project. The performance measures quantify how objectives perform when compared to existing or future conditions. Note that the table does not include all objectives, performance measures, sources of data, or tools for analyzing a corridor planning project.

Table 7-1 is provided as a first step and guide for establishing basic objectives and how to measure them. The table provides sources of data as well as tools that can be used to evaluate the performance measures. Scoring metrics are generally developed to rank the different performance measures based on stakeholder feedback, public involvement, and the goals and objectives of the study.

In addition to the performance measures listed in Table 7-1, other evaluation criteria could be considered, such as ROW availability, environmental impacts, and public input.

Table 7-1: Corridor Planning Performance Measures

Objectives	Performance Measures	Sources and Types of Data	Tools[1]
Mobility	• LOS and Delay • Travel time • Free flow speed vs. peak period speed • Travel time reliability • V/C Ratio	• INRIX, StreetLight, Replica, Wejo, NPMRDS, American Transportation Research Institute (ATRI), and Geotab • Traffic counts • Aerial imagery • Online database	• Travel demand model outputs • Deterministic analysis • CAP-X • HCM analysis
Safety	• Number of fatal or serious injury crashes • Crash rate compared to statewide average for a similar facility type • Number of pedestrian and bicycle related crashes • Number of similar types of crashes	• CRIS • Aerial Imagery • As-builts	• GIS software • HSM spreadsheets • IHSDM • ISATe • HSS • TxDOT HSM Spreadsheet Tools
Pedestrians and Bicyclists	• Number of marked crossings within a corridor • Width of bike lane or sidewalk • Length of crosswalks • Crosswalk lighting	• Big Data • Field visit • Aerial imagery • Strava	• HCM analysis • Pedestrian and bicycle assessment inventory
Transit	• Person throughput versus vehicular throughput • Number and spacing of transit stops on corridor • Service frequency • Ridership • On-time service (reliability)	• Transit agency • Aerial imagery	• Microsimulation • Travel demand modeling
Freight	• Vehicle classification and percentage • Truck flows into and out of areas	• Commodity Flow Surveys (CFS) • Vehicle Travel Information System (VTRIS) • Transearch • Geotab	• Freight Analysis Framework (FAF) • Sketch Level or Macroscopic analysis • Travel demand modeling • Transearch

Table 7-1: Corridor Planning Performance Measures

Objectives	Performance Measures	Sources and Types of Data	Tools[1]
Access Management	• Driveway spacing and access density • Number of median openings • Conflicting driveways on a two-way left turn lane	• As-builts, CAD drawings, and survey files • Aerial imagery	• Microsimulation • HCM analysis
Economic Analysis and Development	• Providing connectivity • Population • GDP • Total Employment • Industries Served	• Agency GIS database • U.S Census Bureau • IHS Markit • Texas Demographic Center • US Bureau of Labor Statistics • US Bureau of Economic Analysis	• GIS software • Travel demand modeling

[1]The tools presented here are general tools used for various levels of analysis. Depending on the level of analysis, different tools could be needed. Individual analysis chapters have more information regarding the type of tool to use for different levels of analysis.

7.5.4 Existing Conditions Analysis

Existing conditions analysis is a key step in evaluating a corridor. An existing conditions analysis provides a baseline condition to compare future improvements. It also helps determine if the overall improvements being recommended provide a benefit and meet the study goals. The existing conditions analysis includes various types of analysis, depending on the type of corridor planning project. The analysis level for corridor studies is typically planning-stage and the types of tools to be used for the analysis are typically sketch-level or macroscopic tools. This may include tools such as CAP-X, GIS, or TDM outputs, depending on the extents of the analysis and scope of work. Ultimately, the type of tool and analysis is determined based on the objectives and the corresponding MOEs that quantify the corridor study goals. These objectives and MOEs may be selected from Table 7-1 above. The same analysis tools and MOEs are typically used for evaluating both existing and future conditions. The chapters from this document listed below provide more detail on the types of analysis that may be performed to evaluate existing conditions.

- Traffic Analysis Methodology, Tools, and MOE (Chapter 4);

- Segment Analysis (Chapter 9);
- Intersection Analysis (Chapter 10);
- Interchange Analysis (Chapter 11);
- Roundabout Analysis (Chapter 12);
- Microsimulation (Chapter 13); and
- Multimodal Analysis (Chapter 14)

7.5.5 Future Conditions Analysis

A future conditions analysis is developed using the traffic projections and analyzing future no-build and build conditions using the projected traffic volumes. Traffic analysis of future conditions is typically based on opening year and/or design year. Typically, traffic volumes for future no-build and build conditions analysis remain the same. However, there could be some exceptions for new alignment routes, access modifications, and existing facilities with oversaturated conditions. Discuss and document any exceptions.

The No-build analysis is developed using the existing conditions plus any committed projects that could be built between the existing year and future analysis year. This analysis determines the impact of future traffic growth on MOEs if existing conditions and committed projects remain in the future. It also provides a comparison between the current conditions (existing conditions analysis) and traffic conditions in the future if no further action is taken.

The Build conditions analysis is developed by analyzing improvements based on issues observed in the existing conditions and future no-build conditions. Build conditions analysis includes alternatives analysis, which is a decision-making process where multiple alternatives are evaluated to select a preferred alternative. When evaluating future conditions, it is important to have several mitigation options, as some could be more favorable than others, based on stakeholder input, ROW impacts, the B/C ratio, or environmental factors. To evaluate multiple alternatives, develop a screening process and an evaluation matrix based on MOEs, stakeholder inputs, and other constraints. See Chapter 8 for more information on developing alternatives, screening process, and evaluating alternatives.

7.5.6 Safety Analysis

There may be instances where a corridor does not have congestion-related issues, but safety is an issue due to roadway geometry, incomplete traffic control, faulty pavement markings, low quality signage, or other reasons. Rural segments of corridors are often more inclined to have safety-related issues than congestion-related issues.

Similar to traffic analysis, safety analysis is performed for two conditions, existing and future. The purpose of safety analysis for existing conditions is to identify existing safety issues and develop safety countermeasures for those issues. Existing conditions safety analysis methods include:

- Historical crash data analysis;
    - This includes crash types, contributing factors, crash rates,
    - crash severities, crash heat maps, and other crash data-related analysis to help

understand safety-related issues on the corridor.

- PSI Analysis; and
- Identifying countermeasures

The purpose of the future safety conditions analysis is to consider safety implications of alternatives that have been developed. Future conditions analysis can be conducted in a variety of methods, some of which are listed below.

- Relative comparison of CMFs; and
- HSM Part C Predictive Method

More information regarding how to perform existing and future safety analysis is presented in Chapter 5 and Chapter 6.

Table 7-2: Corridor Planning Components

Description	Feasibility	Route	Corridor
Purpose and need	X	X	X
Existing Infrastructure and transportation features	X	X	X
Traffic analysis (methodology, existing conditions, alternatives, no-build/build analysis, etc.)	X	X	X
Safety analysis (crash data, crash heat maps, crash rates, etc.)	X	X	X
Demographic analysis	X	-	X
Economic data and analysis	-	-	X
Engineering considerations	X	X	X
Typical sections	X	X	X
Evaluation criteria and metrics	X	X	X
Preliminary cost estimates	X	X	X
ROW acquisition	X	X	X
Utility adjustments	-	X	-
Environmental data and documentation	-	X	-
Stakeholder engagement	X	X	X
Public involvement	X	X	X
Summary of stakeholder and working group meetings	X	X	X
Implementation Plan	-	-	X

7.6 Report Content

The corridor planning process has many parts. Documenting all information succinctly is important to delivering an overall successful project. Table 7-2 above summarizes the general content for the different types of corridor planning projects.

Chapter 8
Alternatives Analysis

8.1 Introduction

8.1.1 Overview

An alternatives analysis is a decision-making process where multiple alternatives are evaluated and a preferred alternative selected. This chapter describes three important aspects of the alternatives analysis process (criteria definition, alternative development, and alternative evaluation), and provides a sample report outline. General characteristics of an alternatives analysis, as well as general steps, are provided below.

Alternatives analyses includes:

- Defining evaluation criteria, such as safety, mobility, and environmental performance measures;
- Developing project alternatives, defining evaluation criteria, and selecting a preferred alternative through a detailed screening process; and
- Evaluating, comparing, and prioritizing alternatives based on evaluation criteria

The alternatives analysis process involves the following steps. This is represented in the flow diagram in Figure 8-1.

1. Determine purpose and need
2. Set goals and objectives
3. Define overall project scope and study area
4. Define evaluation criteria
5. Establish performance measures
6. Develop alternatives
    a. Refine project scope, study area, and performance measures as needed
7. Evaluate alternatives
8. Score, rank and select preferred alternative

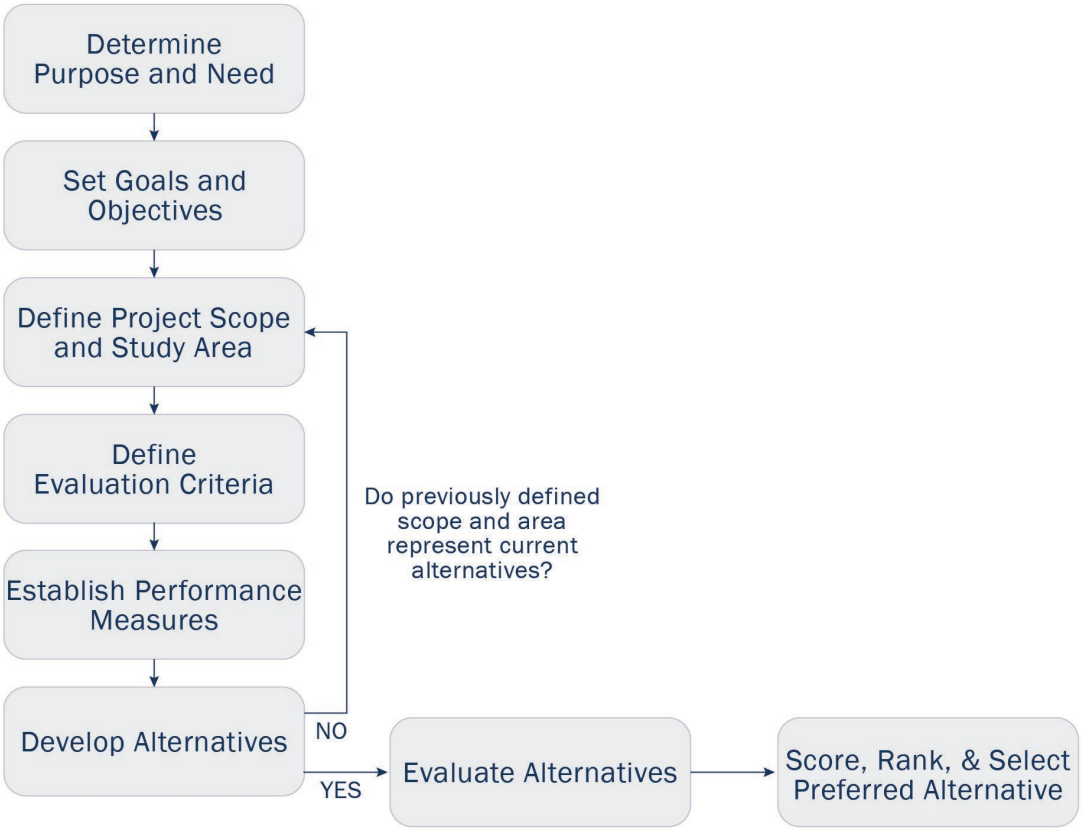


Figure 8-1: Alternatives Analysis Process

8.1.2 Purpose and Intended Use

The purpose of this chapter is to provide a general guidance to conduct alternatives analysis. It includes procedures to screen and evaluate alternatives in terms of traffic and safety analysis, such as reduction in delay or travel time and reduction in crash severity and frequency. This chapter is intended to be used as a resource and informational guide for alternative development, criteria definition, and presentation of alternatives analysis results (alternative evaluation). Procedures for conducting traffic analyses, necessary to evaluate alternatives, are detailed in Chapters 4, 9, 10, 11, 12, 13, and 14. This chapter emphasizes developing alternatives and evaluating alternatives.

8.1.3 Limitations

This chapter does not cover all aspects of alternatives analysis; it is limited to the traffic and safety aspects of alternatives analysis. If National Environmental Policy Act (NEPA) is pertinent or will be pertinent, such as in the creation of an Environmental Impact Statement (EIS) or an EA, the NEPA guidance for alternatives analysis needs to be followed. Most projects are deemed Categorical Exclusion (CE) and do not involve the NEPA process.

8.2 Alternatives Analysis Elements

8.2.1 Analysis Tools and Methods

Typical analysis tools and methods for alternatives analysis include:

- **Sketch-level or macroscopic tools:** Used for high-level alternatives analysis for general order-of-magnitude estimates of travel demand and traffic operations. Examples are CAP-X and HCM service volume tables.
- **TDM:** Used for alternatives analysis to compare scenarios or screen alternatives at a high level.
    - TDM outputs are typically used to determine the benefits and impacts of major highway improvements. Common outputs include origin and destination data, route choice, v/c, and vehicle miles traveled. Examples are TransCAD and Cube.
- **Deterministic tools:** Used in alternatives analysis to quickly determine the LOS (e.g., density, speed, and delay) of isolated or smaller-scale facilities. They are limited in their ability to analyze network or system effects. Examples are Synchro and Highway Capacity Software.
- **Traffic signal optimization tools:** Used to optimize signal timings for intersections, corridors, or networks. These tools can incorporate items such as intersection capacity, cycle lengths, splits, and signal coordination and offset. They are used to perform alternatives analysis for intersections or interchanges. Examples are Synchro and PASSER.
- **Simulation tools:** Used to simulate the traffic flows and movement of individual vehicles and pedestrians. These tools produce detailed outputs, need higher levels of effort, and can either be deterministic or stochastic in nature. They are best suited for alternatives analysis that involve oversaturated conditions, complex geometric configurations, and alternative intersections. Examples are Vissim, CORSIM, and DynusT.
- **Safety analysis and tools:** Safety analysis can be performed in terms of historical crash analysis or predictive safety analysis. Historical crashes (in terms of crash type, frequency and severity, contributing factors) are typically examined to select crash countermeasures in the alternatives analysis. Crash predictive methods can be used to estimate changes in the number of crashes associated with alternatives analysis. CMF are typically used as a multiplicative factor to estimate the expected number of crashes.

8.2.2 Define Evaluation Criteria

Selecting evaluation criteria demands engineering judgement and is typically coordinated with project stakeholders prior to proceeding with alternatives evaluation. Evaluation criteria are quantitative (MOEs) or qualitative indicators that enumerate impacts (good and bad) of an alternative. Figure 8-2

presents a flow diagram of potential evaluation criteria.

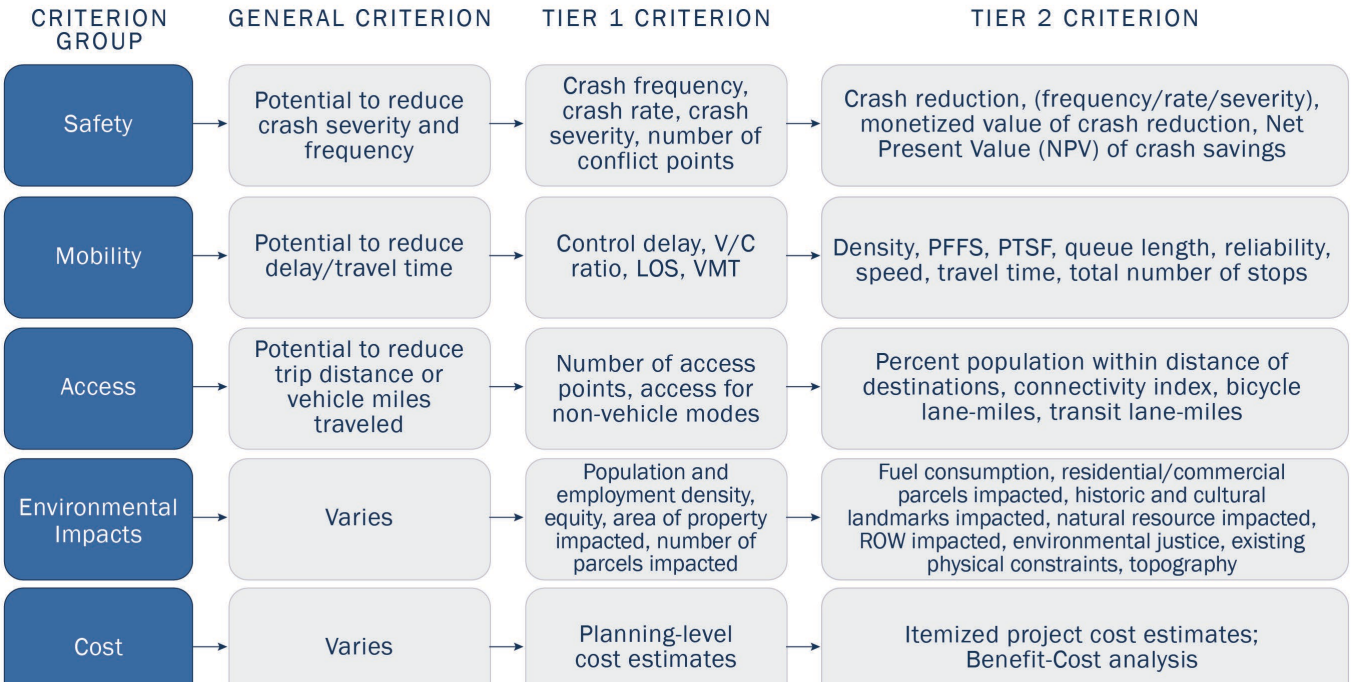


Figure 8-2: Evaluation Criteria

Criteria Definition Guidance:

- **Objectivity:** It is suggested that evaluation criteria aim to be objective and without bias.
- **Criteria groups:** Evaluation criteria that represent a range of project impacts and reflect all project goals/objectives selected. Common criteria groups include safety, mobility, access, environmental, and cost (see Figure 8-2).
- **Quantitative criteria:** Quantitative criteria are preferred and can include the MOEs discussed in Chapter 4. Common quantitative criteria include crash rate, crash frequency, LOS, impacted residential parcels, and OD travel times.
- **Qualitative criteria:** For high-level evaluations where MOEs may not be feasible, qualitative criteria can be precisely defined and criterion scoring can be annotated. Examples of qualitative criteria are conflict points and driver expectancy. Conflict points help identify potential safety issues. Driver expectancy is another qualitative criterion that relates to a driver's readiness to respond accurately and promptly to situations, events, and information while driving.
- **Quantitative comparison:** Quantitative metrics can be reported for each alternative and then qualitatively "scored" to compare impacts between criteria.
- **Trade-offs:** A wide range of criteria can be employed to highlight benefits and costs of each alternative. This certifies trade-offs, or specific costs associated with selected benefits, are evaluated as part of the decision-making process.
- **Weighting criteria:** Trade-offs can be plainly demonstrated by weighting criteria; weights are assigned in proportion to the importance of each criterion. However, weighting criterion, as with assigning exact values to qualitative criterion, may misrepresent project impacts or over-complicate the alternatives analysis.
- **Redundant criteria:** It is recommended that redundant criteria (such as intersection LOS and control delay) be valued appropriately to avoid double-counting impacts.
- **Multi-tier alternatives analysis:** Evaluation criteria can differ between evaluation tiers (see Table 8-1). For example, a Tier 0 (fatal-flaw) analysis can evaluate twelve Planning-level alternatives using sketch-level or macroscopic tools. A Tier 1 (preliminary) analysis can evaluate six Preliminary Schematics-level alternatives using HCM-based (mesoscopic) tools. A Tier 2 (detailed) analysis can evaluate three Advanced Schematics and Design-level alternatives using microsimulation (microscopic) tools.

Table 8-1: Multi-Tier Alternatives Analysis Objectives and Sample Criteria

Analysis Tier	Objective	Sample Criteria
Tier 0 (Fatal Flaw)	Develop viable alternatives that satisfy the project's purpose and need. Often evaluated using sketch-level or macroscopic tools based on a high-level sketch of the alternative.	• Includes multi-modal infrastructure • Within existing ROW
Tier 1 (Preliminary)	Refine viable alternatives for further evaluation. Often evaluated using a TDM output or HCM-based (mesoscopic) tools.	• Expected to reduce crash frequency (assessed qualitatively) • V/C ratio reduced within study area
Tier 2 (Detailed)	Select the alternative that best satisfies the project's purpose and need. Often evaluated using microsimulation (microscopic) or HCM -based (mesoscopic) tools.	• Net present value (NPV) of crash savings • Delay and travel time • Initial construction cost

8.2.3 Alternative Development Guidance

- **Number of alternatives:** Varies by project scope and level of detail. A large number of alternatives are refined using a multi-tier screening process. Generally, three to five alternatives are evaluated in detail as the final analysis tier.
- **Level of Analysis:** Alternatives are developed with sufficient detail to adequately evaluate benefits and costs. Alternatives typically increase in detail (additional attributes characterizing each alternative) as the number of alternatives is reduced.
- **Timeframe:** Alternatives can be short-, mid-, or long-term. Short-term alternatives are often developed in more detail, while long-term alternatives have less detail (sketch-level).
- **Type:** Alternatives include infrastructure improvements, Transportation Demand Management improvements, and Transportation System Management (TSM) improvements (see Section 15.2.2 and 15.5 in Chapter 15).
- **Nomenclature:** Name alternatives to be easily understood and distinguishable. Improvements for each alternative are directly stated.
- **Description:** Alternatives are often depicted graphically and described narratively, denoting key aspects (see Figure 8-3). If alternatives vary by specific elements (such as ROW, cross section, etc.), it is recommended they be represented in a matrix (see Table 8-2).

No Build

- West of First Street, Main Street is a six-lane roadway with two-way operation
- East of First Street, Main Street is a four-lane roadway with two-way operation
- Washington Avenue is a two-lane roadway with two-way operation

Alternative 1 – Extend Widening to Third Street

- West of Third Street, Main Street is a six-lane roadway with two-way operation
- East of Third Street, Main Street is a four-lane roadway with two-way operation
- Washington Avenue is a two-lane roadway with two-way operation

Alternative 2 – One-Way Couplet

- West of First Street, Main Street is a six-lane roadway with two-way operation
- East of First Street, Main Street is a three-lane roadway with one-way operation
- Washington Avenue is a three-lane roadway with one-way operation

Alternative 3 – Two-Lane Elevated Bypass

- West of First Street, Main Street is a six-lane (at-grade) roadway with two-way operation
- Between First Street and Second Street, Main Street has two-way operation and is a four-lane roadway (at-grade) and a two-lane roadway (above grade)
- East of Second Street, Main Street is a four-lane (at-grade) roadway with two-way operation
- Washington Avenue is a two-lane roadway with two-way operation

Figure 8-3: Narrative Description of Alternatives Example

- No-Build Alternative: A no-build (base condition) alternative that represents future conditions without proposed project improvements is typically included as a benchmark for comparison. A no-build alternative typically considers existing conditions with committed projects. Any project expected to be complete prior to the analysis build year and included in a fiscally constrained funding program may be included in the no-build alternative. The no-build alternative serves as the baseline for analyzing other alternatives, so it is recommended that particular care be given when developing the no-build alternative.
- Traffic Projections: Baseline and future year traffic projections for the no-build scenario are typically used for each build scenario. However, it is recommended the build alternatives selected for evaluation be reviewed to determine whether new traffic projections are mandatory to represent the proposed improvements. This is common for access changes, new alignments, and locations where the existing corridor is capacity-constrained, resulting in detours. These detours are

captured using the DTA routing methodology found in some microsimulation models. For regional and larger study areas, TDM outputs are often used to determine changes in travel patterns. For smaller corridor- or intersection-level studies, these changes can be assigned manually.

- **Multi-tier alternatives analysis:** Complex projects could necessitate alternatives to be developed and evaluated in sequence, with increasing levels of detail. Alternatives evaluated in subsequent tiers are typically based on evaluation results of prior tiers.

Table 8-2: Matrix Description of Alternatives Example

Nomenclature		Main Street Characteristics			Washington Avenue Characteristics		
Alt.	Description	Lanes	Traffic Flow	Grade	Lanes	Traffic Flow	Grade
No Build	Widening terminates at First Street	4/6	Bi-Directional	At-Grade	2	Bi-Directional	At-Grade
1	Extend Widening to Third Street	6	Bi-Directional	At-Grade	2	Bi-Directional	At-Grade
2	One-Way Couplet	3	Westbound	At-Grade	3	Eastbound	At-Grade
3	Two-Lane Elevated Bypass	6 (2 by.)	Bi-Directional	At and Above	2	Bi-Directional	At-Grade

8.2.4 Develop Alternatives

Prior to developing alternatives, the project team defines the scope and study area, determines the purpose and need, and sets project goals and objectives (see Chapter 1 for guidance). Developing alternatives demands understanding the issues. Coordination with project stakeholders is necessary to establish that an appropriate range of alternatives is considered. The number of alternatives acknowledged varies by project scope and level of detail; three to five alternatives are generally evaluated at each "tier." Potential solutions to be considered include:

- Transportation System Management and Operations (TSMO) strategies;
- Transportation demand management improvements;
- Transportation system management improvements;
- Access control and local circulation changes;
- Multimodal and intermodal improvements;
- Safety solutions;
- Segment improvements;
- System improvements;
- Intersection improvements; and
- Interchanges

Consider developing alternatives with enough detail to adequately evaluate benefits and costs.

8.2.5 Evaluate Alternatives

After alternatives and evaluation criteria have been defined, each alternative is assessed based on selected criteria. For example, for the safety evaluation criteria, safety performance of the alternatives is evaluated. Design elements should be modified to optimize safety. Alternatives are analyzed using a well-defined, developed, calibrated, and validated baseline model.

Sensitivity analysis is used in the decision-making process for choosing among alternatives or for determining which alternatives maintain a certain level of mobility or safety. For example, sensitivity analysis could be performed by increasing traffic projections by 5 to 15 percent to determine how the study area would operate with increased traffic. Procedures for conducting traffic analyses are detailed in Chapters 4, 9, 10, 11, 12, 13, and 14.

Alternative Evaluation Guidance:

- **Levels of Alternatives Analysis:** Different levels of alternatives analysis are performed based on the scope, size, and complexity of the project. Network/corridor-level alternatives have a bigger scale and regional impact; these alternatives can use sketch-level or macroscopic tools or TDM outputs to assess alternatives. Intersection or interchange-level alternatives analysis are more localized and location-specific, so deterministic tools, traffic signal optimization tools, or simulation tools can be used to compare alternatives. Comparing alternatives includes comparing different build scenarios to the no-build scenario.
- **Evaluation Results Narrative:** It is recommended that evaluation results comprehensively describe the benefits and costs of each alternative. Evaluation results are typically described narratively and organized such that the preferred alternative is evident. Provide justification explaining how the preferred alternative meets project evaluation criteria and satisfies the project's purpose and need.
- **Evaluation Results Matrix:** Evaluation results are typically summarized in a matrix (alternatives versus evaluation criteria). Table 8-3 (quantitative evaluation results example) and Table 8-4 (qualitative evaluation results example) present examples of evaluation results.
- **Discarded Alternatives:** Evaluation results clarify why non-selected alternatives were discarded. Discarded alternatives are documented.
- **Scoring:** Generally, quantitative analysis results are converted to qualitative scores that are then compared to identify the preferred alternative.

Table 8-3: Quantitative Evaluation Results Example

Criterion Type	Criterion	Unit	Alternatives			
			No Build	Extend Widening	Couplet	Bypass
Safety	Predicted crash frequency	Crashes per Year	60	60	50	40
	NPV of crash savings	Dollars	$-	$-	$10,000,000	$20,000,000
Mobility	LOS - Intersection 1	Grade	C	B	F	C
	Delay - Intersection 1	sec/veh	25	18	87	21
	LOS - Intersection 2	Grade	B	B	D	C
	Delay - Intersection 2	sec/veh	14	10	51	26
Access	Bicycle lane-miles	Miles	-	3	6	-
	Transit lane-miles	Miles	-	3	6	8
Other	Proposed ROW Acquisition (Actual)	Square Feet	105,037	105,037	91,016	121,489
	*Residential Parcels Impacted	Number	19	19	25	104
	*Commercial Parcels Impacted	Number	-	-	1	-
	Cost	Dollars	$1,000,000	$8,000,000	$12,000,000	$15,000,000

*Impacted is defined as parcels with ROW is impacted by the alternative design

Table 8-4: Qualitative Evaluation Results Example

Criterion	Measures	Alternative with *Rating (1-5)							
		No-Build		Extend Widening to Third Street		One-Way Couplet		Two-Lane Elevated Bypass	
Safety	Conflict points and driver expectancy	2	Merge, no access management	4	No merge, installed access management	4	Two-to-one-way conversion, introducing uncommon operation, fewer conflict points at intersections	2	High speeds, introducing uncommon operation
Mobility	Travel speed, roadway capacity, and intersection capacity (Delay and LOS)	1	No increased capacity	3	Increased capacity	4	Increased capacity, fewer phases at traffic signals	5	Increased capacity
Access	Property entry/exit points and local route distance	4	No access management	3	Restricted access (raised median)	2	Limits access, increases trip distance	1	Access controlled
Property Impacts	Environmental and historic impacts	5	No ROW necessary	3	50-foot ROW necessary	5	No ROW necessary	1	100-foot ROW necessary
ROW Cost	Cost of ROW expected to be purchased	5	No ROW necessary	3	50-foot ROW necessary	5	No ROW necessary	1	100-foot ROW necessary
Construction Cost	Cost of materials to construct improvements	5	No improvement	3	Widening Main Street	3	Reconstructing Main Street, widening Washington Avenue	1	Elevated structure, widening Main Street
Development Potential	Potential economic benefits	2	None	3	Increased volume	5	ROW made available for social/aesthetic improvements	1	None

*Rating scale is from 1-5. 1 signifies the best rating and 5 signifies the worst rating

- **B/C Analysis:** Benefits and costs of each alternative are typically monetized so that alternatives can be compared economically. HSM procedures are typically used to monetize safety impacts. TxDOT's Road User Cost (see Appendix I, Section 2 – External References (Reference 2)) can be used to monetize vehicle operating impacts.

8.3 Alternatives Analysis Report

The purpose of an alternatives analysis is to identify an alternative that best satisfies the project's purpose and need. The alternatives analysis report articulates a clear connection between the project's purpose and need and the preferred alternative, in terms of evaluation results. Documenting dismissed alternatives is key and will prevent them from being reintroduced. See Appendix I, Section 1 – Alternatives Analysis Tech Memo Sample Outline for a suggested outline for an Alternatives Analysis Technical Memorandum.

Chapter 9
Segment Analysis (Freeways, Multi-Lane Highways, Two-Lane Highways, Arterials, and Frontage Roads)

9.1 Introduction

9.1.1 Overview

This chapter covers the following types of segment analysis: basic freeway segments, basic multi-lane highways, weaving segments, merge and diverge segments, two-lane highways, arterial segments, and frontage roads. Definitions of the various facility types are provided later in this section. Three levels of detail are used to describe tools recommended for segment analysis:

- Sketch-level or macroscopic tools are typically used for projects in the Planning stage or for projects with a large geographic scope. These tools include:
    - TDM
    - Service volume tables
- HCM-based (mesoscopic) tools are typically used for projects in the Preliminary Schematics stage or for projects that need moderate levels of detail. These tools include:
    - HCS, FREEVAL, and HCM-CALC
- Microsimulation (microscopic) tools consider individual vehicles and their movements and are typically used for projects in the Final/Approved Schematics and Design stage. These tools include:
    - Vissim and CORSIM

The tools available to perform each type of analysis are shown in Table 9-1 based on segment type and level of detail.

9.1.2 Facility Definitions

9.1.2.1 Freeways

A freeway has two or more lanes in each direction access-controlled via ramps. Freeway facilities are typically broken up by “sections” or “segments.” Sections of a freeway are defined as the areas between two ramp gore points. The HCM defines several segment types, including basic, weaving, merge, and diverge segments. See Figure 9-1 for an illustration of a merge, diverge, and weaving segment. Freeway facilities are typically composed of more segments than sections. Analyzing freeway facilities by sections, by segments, and in its entirety are covered in this chapter.

Table 9-1: Segment Analysis Tools

Segment Type	Sketch-level or macroscopic	HCM-based (mesoscopic)	Microsimulation (microscopic)
Freeways (Basic)[1]	Travel Demand Model output, Service volume tables	HCS, Freeval, HCM-CALC	Vissim, CORSIM
Multi-lane Highways (Basic)[2]	Travel Demand Model output, Service volume tables	HCS, Freeval, HCM-CALC	Vissim, CORSIM
Weaving[3]	Travel Demand Model output	HCS, Freeval, HCM-CALC	Vissim, CORSIM
Merge and Diverge[4]	Travel Demand Model output	HCM method, HCS, Freeval, HCM-CALC	Vissim, CORSIM
Two-lane Highways	Travel Demand Model output, Service volume tables	HCS, Freeval, HCM-CALC	Vissim, CORSIM
Arterial Facilities	Travel Demand Model output, Service volume tables	Synchro, HCS, Freeval, HCM-CALC	Vissim
Frontage Roads	Synchro or other HCM-based tool	TTI Procedures[5]	Vissim

[1]A segment of freeway outside the influence area of any merge (1,500 feet), diverge (1,500 feet), weaving segments (500 feet), or any signalized intersections (2 miles).
[2]A segment of highway outside the influence area of any merge (1,500 feet), diverge (1,500 feet), weaving segments (500 feet), or any signalized intersections (2 miles).
[3]The crossing of two or more traffic streams traveling in the same direction along a significant length of highway without the aid of traffic control devices. Often formed when merge segments are followed by diverge segments.
[4]Primarily occurs at on-ramp and off-ramp junctions with a freeway mainlane.
[5]TTI procedures are deterministic but are not HCM-based (mesoscopic). These procedures are discussed in section 3 of this chapter.

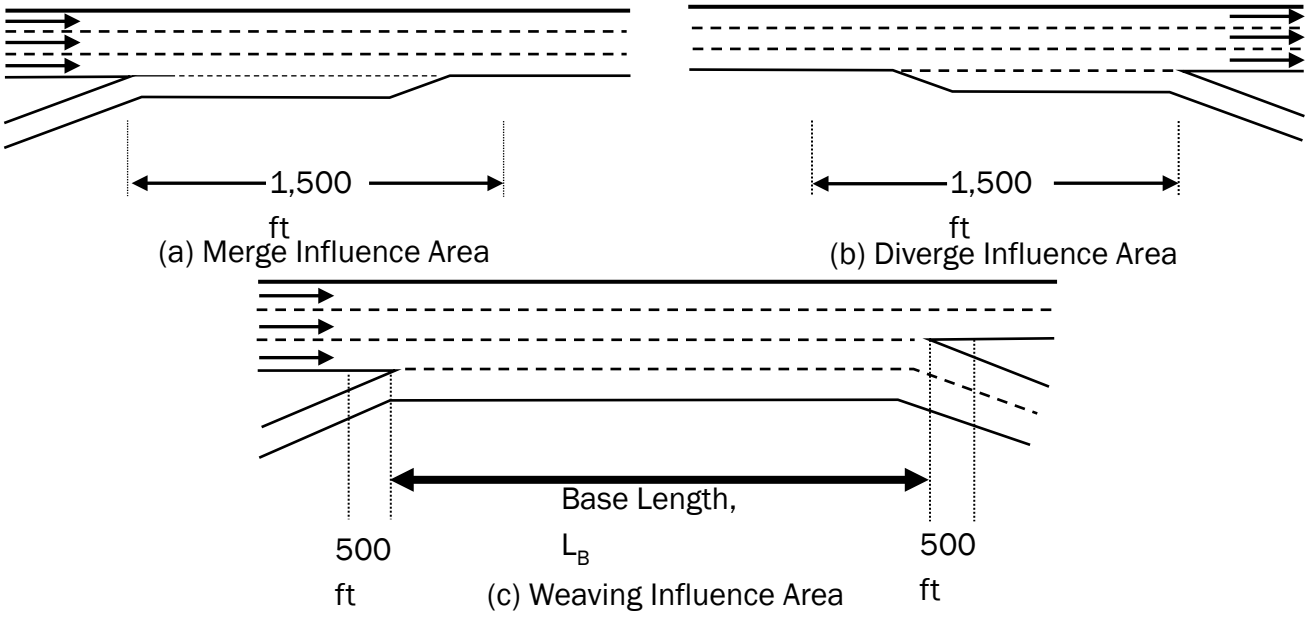


Figure 9-1: Illustration of Merge, Diverge, and Weaving Segments from the HCS7 User Guide (Segment Length subsection)

9.1.2.2 Highways

Two types of highways are covered in this chapter: multi-lane (two or more lanes in each direction) and two-lane highways (one lane in each direction). Multi-lane highway segments are analyzed similarly to basic freeway segments. In some instances, multi-lane highways are like freeway segments or arterials, based on the access density and speed.

For two-lane highways, vehicles pass using the opposing lane of traffic. Two-lane highways can include intercity connectors, regional connectors, intracity connectors and may pass through scenic areas or areas with challenging terrain.

9.1.2.3 Arterials

Arterial/urban street segments are bounded by intersections or ramp terminals where the through-movement for the segment is signalized, stop-controlled, or yield-controlled. If these boundary intersection control types do not exist, the segment can be bounded by a two-way stop controlled (TWSC) intersection with stop control on the cross street. Arterial facilities made up of multiple arterial segments can also be analyzed.

9.1.2.4 Frontage Roads

Frontage roads, or service roads, run parallel to a controlled-access facility, serving as connectors between ramps of the higher-speed facility and intersections of lower-speed local streets. Their primary purpose is to provide access to local properties and allow the mainlane users to bypass intersections and driveways. They can either have one-way or two-way operation. Frontage road segments are typically bound by ramps, signalized intersections, or intersections with stop or yield control.

9.1.3 Purpose and Intended Use

The purpose of this chapter is to provide an overview of the tools, data requirements, input parameters, and MOEs for three levels of segment analysis: Sketch-level or macroscopic, HCM-based (mesoscopic), and Microsimulation (microscopic). Each tool corresponds to a different level of precision and accuracy. This chapter is intended to be used as a resource and informational guide for practitioners and covers the latest methodologies, practices, and procedures for analyzing segments. This chapter generally follows the HCM but also recommends different tools and methodologies where limitations exist.

9.1.4 Limitations

As of 2024, there is only one published methodology to analyze frontage road operations. This chapter does not address freeway work zones, managed, or toll lanes. More information can be found in HCM 7th Edition, Chapter 10.

This chapter does not cover freeway to urban street interactions. For information on urban street interactions, refer to NCHRP 15-57 HCM Methodologies for Corridors Involving Freeways and Surface Streets (2020). It has information on evaluating operations and impact of spillback on networks that include both freeways and urban streets. This method evaluates freeway performance by lane, as spillback affects each lane of the freeway

differently. The resulting trip-based performance measurement framework provides travel time estimates for given OD pairs within a highway network.

Safety aspects of segment operations are also not covered in this chapter. See Chapter 5 and Chapter 6 of this manual for segment safety analysis information.

9.2 Sketch-Level or Macroscopic Analysis

9.2.1 Overview and Intended Use

Sketch-level or macroscopic analysis looks at deterministic relationships between traffic variables such as flow, speed, and density to evaluate segment operations (*FHWA Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools*). Deterministic means that for a set of inputs, there is only one answer. In this context, it means the characteristics of individual vehicles are not tracked on the system-wide level. Performance measures are aggregated for platoons of vehicles over specified time intervals. Network details are approximated or based on averages.

Sketch-level or macroscopic analysis is supported by observed patterns of traffic variables. Sketch-level or macroscopic analysis tools typically need the least amount of input and detail and are often used for projects in the planning stage of project development or for projects that do not need high levels of detail. Sketch-level or macroscopic analyses are typically used for analyzing a large network, or screening multiple alternatives. It is not well-suited for analyzing unique transportation networks. If a network is considerably modified from the original demand or network attributes, obtain new OD tables before analyzing it.

The purpose of this section is to provide an overview of the tools available to complete a Sketch-level or macroscopic analysis and provide guidance on when to use the different tools, the data and input needed for each tool, and the MOEs used to evaluate operations.

TDM and service volume tables are the main tools used analyze segments at a Sketch-level or macroscopic level. The outputs of a TDM are typically used if the segment to analyze is available in the model. In some instances, TDM provides a more detailed analysis than is necessary for the project stage or scope, in which case the service volume tables can be used. Service volume tables are discussed in depth below.

9.2.2 Analysis Tools

Sketch-level or macroscopic analysis of segments can be performed with either TDM outputs or service volume tables. TDM outputs are typically used for all Sketch-level or macroscopic analysis, except for instances when a basic analysis is adequate. In this case, the service volume tables can be used.

9.2.2.1 Travel Demand Model

TDM is a macroscopic analysis tool that is best for analyzing a large area with low precision. There are different types of TDMs, which include four-step/trip-based models and ABM. The traditional four-step model includes trip generation, trip distribution, mode split, and

traffic assignment for a single OD from traffic analysis zone to traffic analysis zone. Conversely, ABMs examine continuing trips from one zone to another over time.

TDMs are best used for subregional/subarea-, regional-, and state-level planning and serves as a support tool for long-range areawide transportation planning. TransCAD and Cube are common software programs used to complete this analysis (for detailed guidance on inputs and outputs for these software programs, see their respective user guides). Highway and corridor networks are coded into the software program, along with socioeconomic data for each traffic analysis zone. Facility type (e.g., major and minor arterials, collectors, and locals), number of lanes, and area type impacts both the intensity and usage of links within the model.

TDMs are typically maintained by the local MPO. TxDOT's SAM can be used in rural areas where an MPO TDM is not available. TDM outputs are typically all that is used for an analysis, however, there may be circumstances for updating and running the TDM for detailed analysis depending project scope and on project impacts to the existing network. A TDM is typically updated, calibrated, and validated for large projects or when major data is updated (i.e., census data, land-use data). When an update is necessary, the basic steps to develop/update and calibrate a TDM are:

- TDM Development and Update; and
    - Collect data (see data and input parameters section)
    - Update Traffic Analysis Zone (TAZ) structure using base year demographic and socioeconomic data
    - Use HCM-based (mesoscopic) procedures for roadway capacities and intersection delay
    - Verify coding of urban and rural area types
    - Follow NCHRP Report 716 Travel Demand Forecasting and FHWA's Model Validation and Reasonableness Checking Manual
- TDM Calibration
    - Use big data resources (StreetLight, INRIX, Replica, etc.) to develop, calibrate, validate, and refine the TDM. Reinforce big data with statewide travel survey data regarding trip purpose, occupancy, and multi-modes
    - If corridor extends beyond TDM limits, calibrate external stations with historical and collected data

TDM outputs include multimodal time-dependent OD tables, link volumes, vehicle miles traveled, turning movement percentages, and network performance. These outputs can be used in alternatives analysis, traffic projections, HCM-based, mesoscopic, microsimulation, and other forms of traffic analysis for segments.

When there are discrepancies between actual counts and TDM outputs, actual count data is typically used.

9.2.2.2 Service Volume Tables

Generalized service volume tables are used for segment analysis, as described in Table 9-1. Service volume tables from the HCM 7th Edition can be used to evaluate individual segments or whole facilities of freeways, highways, and arterials. The roadway sections within a study area that are highest traveled should be selected for analysis.

A segment analysis using service volume tables following the below steps:

- Collect necessary data for the segment type (Table 9-3);
- Use reference tables to determine service volume for the facility in question (Table 9-2) and collected data (as shown in Table 9-3); and
- An existing or anticipated volume higher than the service volume indicates the need for further analysis

If all the segments within a facility are operating within capacity (i.e., existing, or anticipated volumes are less than calculated service volume), there may not be queue buildup into other segments, indicating that a full facility analysis is not needed. These tables estimate maximum daily thresholds for a given LOS and default conditions. They are typically used as a general tool to identify specific segments that may need further evaluation. The tables are set for specific conditions and cannot be used as a final decision-making tool or as a substitute for engineering judgment. Comparing a segment's demand to the service volume thresholds can provide a quick estimation of LOS and volume-to-capacity ratios of a segment.

Table 9-2: Service Volume Reference Tables

Segment Type	Reference Table
Freeways (Basic)	Appendix J, Section 3, Table 1 (urban) or Appendix J, Section 3, Table 2 (rural)
Multi-Lane Highways (Basic)	Appendix J, Section 3, Table 3 (urban) or Appendix J, Section 3, Table 4 (rural)
Two-Lane Highways	Appendix J, Section 3, Table 5
Arterial Facilities	Appendix J, Section 3, Table 5

9.2.3 Data and Input Parameters

9.2.3.1 Travel Demand Model

If updating the TDM is necessary, collect the following data to complete the analysis:

- Socioeconomic and demographic data;
  - Latest census
  - Land use data
  - Travel surveys
- OD data, such as Streetlight, Replica, and INRIX (also outputs travel times);
- Traffic counts; and
- Geometric data

- Segment: length, number of lanes, lane assignments, area type, posted speed and/or free flow speed, highway type

For more guidance on data and input parameters for a TDM, coordinate with the TPP Division for the SAM and MPOs for their respective TDMs.

Data requirements for macroscopic analysis of segments using service volume tables are shown in Table 9-3. Existing or anticipated traffic volumes are used to compare values from the service volume tables to determine whether the facility needs further analysis.

9.2.4 Measures of Effectiveness (MOEs)

9.2.4.1 Travel Demand Model Outputs

For macroscopic analysis using TDM outputs, typical MOEs include VMT, VHT, vehicle hours of congestion delay, vehicle hours of traffic control delay, travel speed, volumes, and the v/c. LOS can be computed using the volume-to-capacity ratio. The thresholds for LOS vary by location and the agency's expectation of congestion level. Refer to Appendix R, Section 3 – Traffic Tool Outputs for a TDM output example.

9.2.4.2 Service Volume Tables

LOS can be determined using the generalized service volume tables. The LOS is based on volume and capacity thresholds.

Table 9-3: Data Requirements for Service Volume Tables

Segment Type	Data Required
Freeways (Basic)	• Urban or Rural designation • K-factor • D-factor • Number of lanes (both directions) • Terrain Type (Level or Rolling) • Existing or anticipated traffic volumes
Multi-lane Highways (Basic)	• Urban or Rural designation • K-factor • D-factor • Number of lanes (both directions) • Terrain Type (Level or Rolling) • Existing or anticipated traffic volumes
Arterial Facilities	• Posted Speed • K-factor • D-factor • Number of lanes (both directions) • Existing or anticipated traffic volumes

9.3 HCM-Based (Mesoscopic) Analysis

9.3.1 Overview and Intended Use

HCM-based (mesoscopic) analysis combines characteristics of both Sketch-level or macroscopic and Microsimulation (microscopic) analysis. Like Sketch-level or macroscopic analysis, the behavior of individual vehicles is based on the average speed on the segment and is not sensitive to changing relationships between traffic variables. Like Microsimulation (microscopic) analysis, vehicle classifications and driver behavior parameters are tied to individual vehicles. HCM-based (mesoscopic) analysis combines the properties of both microscopic and macroscopic simulation models. Queueing is considered on a segment-wide, not vehicle-specific, level. HCM-based (mesoscopic) analysis is used when the Sketch-level or macroscopic analysis does not capture enough detail, such as the impact of specific operational improvements or congestion levels.

HCM-based (mesoscopic) analysis is suitable for projects that need moderate level of detail; they need more input than Sketch-level or macroscopic tools and are useful for smaller study areas.

9.3.2 Analysis Tools

HCM based methods are used for segment analysis when a TDM is unavailable or unsuitable for the project. Several types of HCM-based (mesoscopic) software can be used to analyze segments. As with all HCM-based (mesoscopic) tools, they are deterministic and will output the same results given the same inputs. HCS is the recommended software when conducting segment analysis, but other HCM-based (mesoscopic) software can be used

if HCS is unavailable or does not include analysis of the facility type in question. Synchro is recommended for the analysis of arterial roadways and other segments whose LOS is mainly based on intersection delay. Detailed illustrations of inputs and outputs of HCS can be found in Appendix J, Section 2 – HCS Data Inputs and Outputs by Segment Type. For detailed guidance on inputs and outputs of other HCM-based (mesoscopic) tools, refer to each tool's user guide and/or software. Several available software and analysis capabilities include:

- HCS;
  - Facility capabilities
    - Basic freeways
    - Basic multi-lane highways
    - Weaving segments of freeways
    - Merge and diverge segments of freeways
    - Two-lane highways
    - Arterial facilities
- FREEVAL;
  - Facility capabilities
    - Basic freeways
    - Basic multi-lane highways
    - Weaving segments of freeways
    - Merge and diverge segments of freeways
    - Two-lane highways
  - Other capabilities
    - Work zone impact assessment
    - Managed lanes analysis
    - Travel time reliability analysis
- HCM-CALC; and
  - Facility capabilities
    - Basic freeways
    - Basic multi-lane highways
    - Weaving segments of freeways
    - Merge and diverge segments of freeways
    - Two-lane highways
- Synchro
  - Facility capabilities
    - Segments with signalized intersections
    - Segments with roundabouts
    - Segments with all-way stop-control or two-way stop-control

While some of the default values in the software listed above can be used to conduct analysis of segments, it is recommended that four characteristic inputs to these tools represent actual conditions in the field:

1. Segment length

2. Free flow speed

3. Number of lanes

4. Flow rates

Field data for other default values are collected and inputted based on engineering judgement.

9.3.2.1 Texas A&M Transportation Institute (TTI) Procedures

TTI has developed procedures for analyzing one-way and two-way frontage roads. Frontage roads operate similarly to arterials since they are corridors with signalized or unsignalized intersections. However, frontage roads also have ramp connections to and from freeways and driveways on only one side. TTI used HCM's urban and suburban arterial LOS analysis as a base model for analyzing frontage roads and made modifications to the methodology to account for ramp interactions and driveways to develop a seven-step process for evaluating frontage road operations. The steps can be repeated to analyze both sides of a two-way frontage road. It is recommended to follow the seven-step process, substituting the latest HCM methodologies where relevant. See Figure 9-2 for a flowchart that provides an overview of TTI's seven-step process for frontage road analysis. A guide with examples is included in Appendix J, Section 1 – TTI Frontage Road Analysis Steps and Examples.

9.3.3 Data and Input Parameters

9.3.3.1 HCM Method

The data and input requirements for the HCM Method are similar across software. This section focuses on the inputs necessary to conduct a segment analysis using HCS. For a detailed list of HCS input by segment type, see Appendix J, Section 2 – HCS Data Inputs and Outputs by Segment Type. Table 9-4 has a simplified list of the necessary data for each segment type.

9.3.3.2 Synchro

Synchro is typically used to analyze segments whose LOS is governed by intersection delay. Data inputs to Synchro include geometric data, lane settings, volume settings, timing settings, and phasing settings. For detailed inputs to a Synchro model, refer to the Synchro user guide.

9.3.3.3 TTI Frontage Road Analysis Procedures

Data requirements for a frontage road analysis are broken into two categories: one-way analysis inputs and two-way analysis inputs. A summary table of data inputs for each type of frontage road is shown in Table 9-5.

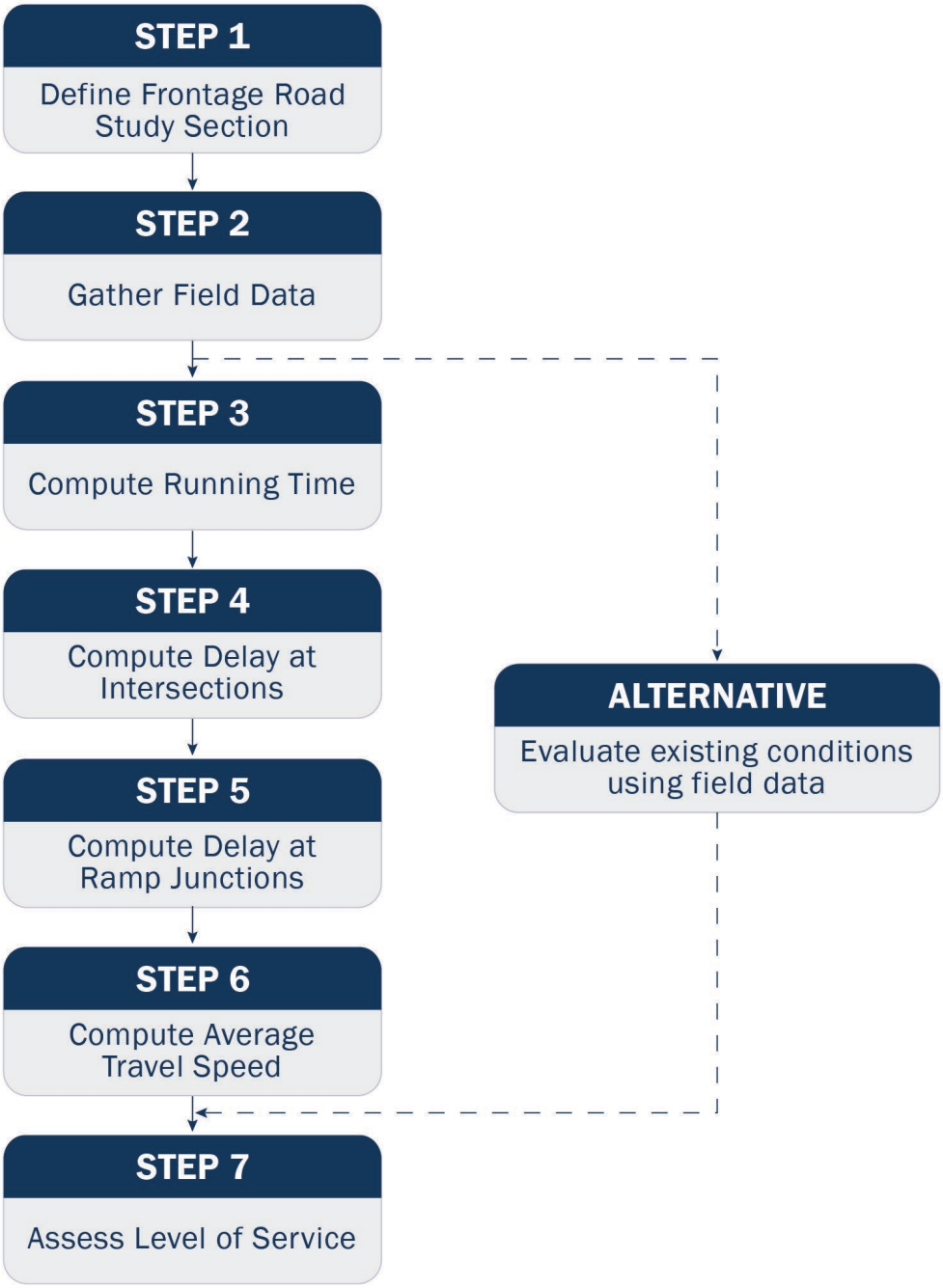


Figure 9-2: TTI Frontage Road Analysis Methodology Flowchart

Table 9-4: Basic HCS Data Inputs by Segment Type

Segment Type	Corresponding HCS7 Analysis Type	Necessary Data
Freeways (Basic)	FREEWAYS →Freeways →Basic	• Project Properties • Freeway Geometric Data • Demand Data • Adjustment Factors
Multi-lane Highways (Basic)	HIGHWAYS →Multilane	• Project Properties • Highway Geometric Data • Demand Data • Adjustment Factors
Weaving	FREEWAYS →Freeways →Weaving	• Project Properties • Freeway Geometric Data • Ramp Geometric Data • Demand Data • Freeway Adjustment Factors
Merge and Diverge	FREEWAYS →Freeways →Merge or Diverge	• Project Properties • Freeway Geometric Data • Demand Data • Adjustment Factors • Adjacent Ramps
Two-lane Highways	HIGHWAYS →Two-lane	• Project Properties • Highway Geometric Data • Demand Data • Subsegments
Arterial Facilities	STREETS →Streets	• Traffic • Phasing • Timing • Detailed Input

Table 9-5: Data Inputs for Frontage Road Analysis

Type of Data	Data Necessary	Frontage Road	
		One-Way	Two-Way
Roadway Characteristics	Segment length (km)	Necessary	Necessary
	Type of traffic control at intersections (e.g., no-control, stop-controlled, or traffic signal)	Necessary	Necessary
	Number of all exit and entrance ramps	N/A	Necessary
	Number of exit ramps without auxiliary lanes	Necessary	N/A
	Segment access density, access/km (number of driveways and unsignalized intersections per kilometer)	Necessary	Necessary
Traffic Data	Frontage road approach volume at stop-controlled and signalized intersections, vehicles per hour (vph)	Necessary	Necessary
	Ramp and frontage road volumes at all exit and entrance ramps, vph	N/A	Necessary
	Exit ramp and frontage road volumes at exit ramps without auxiliary lanes, vph	Necessary	N/A
Signal Data	Signal progression data	Necessary	Necessary
	Intersection capacity (c), vph	Necessary	Necessary
	Cycle length (C), sec	Necessary	Necessary
	Green/cycle time ratio (g/C)	Necessary	Necessary
	Volume/capacity ratio (v/c)	Necessary	Necessary

9.3.4 Measures of Effectiveness (MOEs)

9.3.4.1 HCM Method

Outputs of a segment analysis vary by facility type and by analysis tool used. For a detailed illustration of HCS outputs by segment type, see Appendix J, Section 2 – HCS Data Inputs and Outputs by Segment Type. For outputs of other HCS-based tools, refer to the tool's user guide.

9.3.4.2 Freeways

LOS for freeway facilities is based on the facility-wide average density expressed in pcpmpl. There are separate density thresholds for urban and rural locations. The LOS for an overall freeway facility is typically accompanied by the LOS for the individual segments. LOS for basic freeway segments, weaving segments, merge, and diverge segments are also based on density. The LOS thresholds apply to both urban and rural locations. The thresholds for weaving segments are higher than basic segments because drivers tolerate higher density in areas where lane-changing is expected. Supplemental information with example applications are provided in HCM 7th Edition Chapter 25 (freeway facilities), Chapter 26 (freeway and highway segments), Chapter 27 (freeway weaving), and Chapter 28 (freeway

merges and diverges). For LOS criteria of various freeway facilities see Table 9-6, Table 9-7, Table 9-8, and Table 9-9.

Table 9-6: HCM's LOS Criteria for Basic Freeway

LOS	Density (pc/mi/ln)
A	≤ 11
B	>11-18
C	>18-26
D	>26-35
E	>35-45
F	Demand exceeds capacity OR density > 45

Table 9-7: HCM's LOS Criteria for Urban and Rural Freeway Facilities

LOS	Urban Freeway Facility Density (pc/mi/ln)	Rural Freeway Facility Density (pc/mi/ln)
A	≤11	≤6
B	>11-18	>6-14
C	>18-26	>14-22
D	>26-35	>22-29
E	>35-45	>29-39
F	>45 or any component section v/c ratio > 1.0	>39 or any component section v/c ratio > 1.0

Table 9-8: HCM's LOS Criteria for Freeway Merge and Diverge Segments

LOS	Density (pc/mi/ln)
A	≤10
B	>10-20
C	>20-28
D	>28-35
E	>35
F	Demand exceeds capacity

Table 9-9: HCM's LOS for Weaving Segments

LOS	Freeway Weaving Segments	Weaving Segments on Multilane Highways or Collector-Distributor Roads
A	0-10	0-12
B	>10-20	>12-24
C	>20-28	>24-32
D	>28-35	>32-36
E	>35-43	>36-40
F	>43, or demand exceeds capacity	>40, or demand exceeds capacity

9.3.4.3 Highways

The LOS thresholds for multi-lane highway segments are the same as basic freeway segments. The thresholds for weaving segments on multi-lane highways, however, are different than the thresholds for freeway weaving segments, as presented in Table 9-10. The LOS criteria for freeway merge and diverge segments are used for merge and diverge segments on multi-lane highways. See for HCM's LOS criteria for multi-lane highways.

LOS criteria for two-lane highways are based on three performance measures: ATS, PTSF, and PFFS. ATS is the segment length divided by average travel time for the segment. See Chapter 4 for definitions of PFFS and PTSF. Additional information, with **example** applications, is available in HCM 7th Edition Chapter 26 (freeway and highway segments), Chapter 27 (freeway weaving), and Chapter 28 (freeway merges and diverges). See Table 9-11 for the LOS criteria for two-lane highways in the HCM.

9.3.4.4 Arterials (or Urban Streets)

The LOS thresholds for urban arterial segments are based on travel speed of the vehicles traveling through the segment. HCM-based (mesoscopic) analyses are applicable for arterial and collector street segments with a length of two miles or less. If a segment is longer than two miles between boundary intersections, it is recommended that it is treated as a highway and the intersections are studied individually. If the segment being studied has intersections along its length, the speed and travel times of vehicles is largely dependent on intersection delay. Supplemental information with **example** applications is found in HCM 7th Edition Chapter 29 (Urban Street Facilities: Supplemental) and Chapter 30 (Urban Street Segments: Supplemental). Table 9-12 shows the LOS criteria for urban arterial segments.

Table 9-10: HCM's LOS Criteria for Multi-lane Highway Segments

LOS	Density (pc/mi/ln)
A	≤ 11
B	>11-18
C	>18-26
D	>26-35
E	>35-45
F	Demand exceeds capacity OR density > 45

Table 9-11: HCM's Motorized Vehicle LOS for Two-Lane Highways

LOS	Follower Density (followers / mi / ln)	
	Higher-Speed Highways Posted Speed Limit ≥ 50 MPH	Lower-Speed Highways Posted Speed Limit < 50 MPH
A	≤ 2.0	≤ 2.5
B	> 2.0 – 4.0	> 2.5 – 5.0
C	> 4.0 – 8.0	> 5.0 – 10.0
D	> 8.0 – 12.0	> 10.0 – 15.0
E	> 12.0	> 15.0
F	Demand exceeds capacity	

Table 9-12: HCM's LOS Criteria: Motorized Vehicle Mode (On Urban Streets ≤ 2 miles)

LOS	Travel Speed Threshold by Base Free-Flow Speed (mi/h)							Volume-To-Capacity Ratio[a]
	55	50	45	40	35	30	25	
A	>44	>40	>36	>32	>28	>24	>20	≤1.0
B	>37	>34	>30	>27	>23	>20	>17	
C	>28	>25	>23	>20	>18	>15	>13	
D	>22	>20	>18	>16	>14	>12	>10	
E	>17	>15	>14	>12	>11	>9	>8	
F	≤17	≤15	≤14	≤12	≤11	≤9	≤8	
F	Any							>1.0

Note: [a]Volume-to-capacity ratio of through movement at downstream boundary intersection.

9.3.4.5 TTI Method

The LOS of frontage roads is based on the ATS of vehicles traveling through the segment, which is a function of segment length and total travel time. Travel time is estimated using TTI's procedures or measured directly in the field. For an analysis requiring medium amounts of detail, it is recommended that travel time be estimated using TTI's procedures or calculated using HCS or similar software. Travel time is a function of running time (the time it takes to travel a segment), intersection delay, and ramp delay. Factors that influence the operations of a frontage road include the intersections along the segment and the driveways along the segment.

9.4 Microsimulation Modeling, Microscopic Analysis

9.4.1 Overview and Intended Use

Microsimulation (microscopic) analysis is often used for conducting a traffic analysis with a high level of precision. The purpose of this section is to provide an overview of the tools available to complete a Microsimulation (microscopic) analysis and the performance measures used to evaluate operations.

Microsimulation (microscopic) analysis is the most detailed level of analysis available and needs the most time and data inputs. Individual vehicle movements are modeled using car following and lane-changing theories (FHWA Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools). Vehicles in a network are assigned a vehicle and driver behavior type and tracked through the network for short time periods. It is recommended that Microsimulation (microscopic) models be calibrated for a specific area and adjusted for different driving behaviors. Microscopic analysis is well-suited for analyzing unique transportation situations, such as unique geometry or bottlenecks with queue spillovers or interaction with public transit. Microsimulation (microscopic) analysis provides in-depth results with higher accuracy. Based on a project's complexity level, scope, and budget, conducting a Microsimulation (microscopic) analysis may not be possible, especially for screening many alternatives or analyzing a large area.

The study area or segment is determined based on the area of influence of the project. For example, in segments with bottlenecks at the ends of the study segment, it is recommended that the area of influence is expanded to include the upstream and downstream intersections/interchanges.

9.4.2 Analysis Tools

9.4.2.1 Vissim

Vissim is a common microsimulation software. Vissim is typically used for complex configurations and freeway operations but may be used for Microsimulation (microscopic) analysis of any segment. Vissim is customizable but needs significant input data. For more information on Microsimulation (microscopic) analyses, including inputs and outputs, see **Chapter 13**.

9.4.2.2 Data and Input Parameters

9.4.2.2.1 Vissim

The data requirements for Microsimulation (microscopic) analysis are more extensive than for Sketch-level or macroscopic analysis or HCM-based (mesoscopic) analysis. See Chapter 13 for guidance of data inputs and parameters for a Microsimulation (microscopic) model.

9.4.2.3 MOEs

9.4.2.3.1 Vissim

Microsimulation (Microscopic) models produce a wide range of MOEs. See Chapter 13 for guidance MOEs for Microsimulation (microscopic) analysis.

Chapter 10
Intersection Analysis

10.1 Introduction

10.1.1 Overview

Delays at intersections and along corridors are primarily caused by vehicles stopped at intersections. Additionally, over half of fatal and injury crashes occur within or near an intersection. Multiple modes crossing within the same intersection create multiple points of conflict that occur at high speeds. Due diligence on intersection planning, design, and improvement projects is the first step toward preventing many of these crashes. This has become especially important as alternative intersection types are becoming widely recognized. Documenting existing intersection operational and safety deficiencies leads to enhanced decision-making in the implementation of treatments to address these issues. Each intersection type under consideration has its own advantages and disadvantages, especially when accommodating vehicular, pedestrian, and bicyclist needs.

10.1.2 Purpose and Intended Use

The purpose of this chapter is to provide guidance on conducting operational analysis, safety analysis and cost-benefit analysis of intersections. This chapter provides information on ICE intersection types, analysis tools, data requirements, and how to interpret analysis results for projects in various stages of project development.

The analysis and tools identified herein promote evaluating alternatives based on operational and safety performance, cost-benefit performance, and other considerations.

10.1.3 Limitations

The operational analysis of intersections is limited to the HCM methodologies and software developed as of 2024. For instance, methodologies for pedestrian and bicycle LOS have not been developed for all intersection types. This limits emphasis on multimodal considerations. In addition, analysis is often limited to the type of data available. Due to individual project scope, schedule, and budget, missing data creates inaccuracies in the results of the analysis. Use engineering judgment when evaluating the outputs from any analysis.

10.2 Intersection Control Evaluation (ICE) - Context

ICE, the process and analysis tools, is necessitated by the appearance of roundabouts and alternative intersection designs (RAID). The (ICE) process is used in evaluating the intersection traffic and geometric control at new or modified intersections. This chapter covers the main intersection types, evaluation process, analysis tools, and their inputs and outputs. Intersection Control Evaluation tools can be seen under Appendix K, Sections 1, 2, and 8.

According to FHWA, ICE (see Appendix K, Section 8), (ICE) is a tool that uses data and performance metrics to analyze intersection control and geometric options. ICE provides a transparent and traceable decision process to compare alternative intersection types. ICE is performed during the planning and schematic development phase and not started until after environmental documents are finalized and/or ROW acquisition is authorized. Using quantifiable measures (such as safety, capacity, cost, and impacts) to evaluate alternatives, public agencies, engineers, and planners can make more informed decisions. Quantitative measures are considered alongside qualitative measures such as multimodal needs and community vision goals to provide a balanced perspective when selecting the preferred alternative. It is recommended that the preferred alternative is context-sensitive to its surroundings and users. See FHWA's website under Appendix K, Section 8 – External References for additional technical materials, tools, and information on the ICE framework.

TxDOT's RDM covers additional guidance for TxDOT's approach to alternative intersection design. A link to the RDM is found in Appendix K, Section 8 – External References (Reference 9).

10.2.1 ICE Workflow

The ICE process fits into project development at the earliest stages, considering all practical and feasible intersection or interchange alternatives to produce a traceable and transparent evidence-based method of proving the choice and design of an intersection/interchange. Figure 10-1 and Figure 10-2 illustrate the stages of the ICE process in the early stages of project planning.

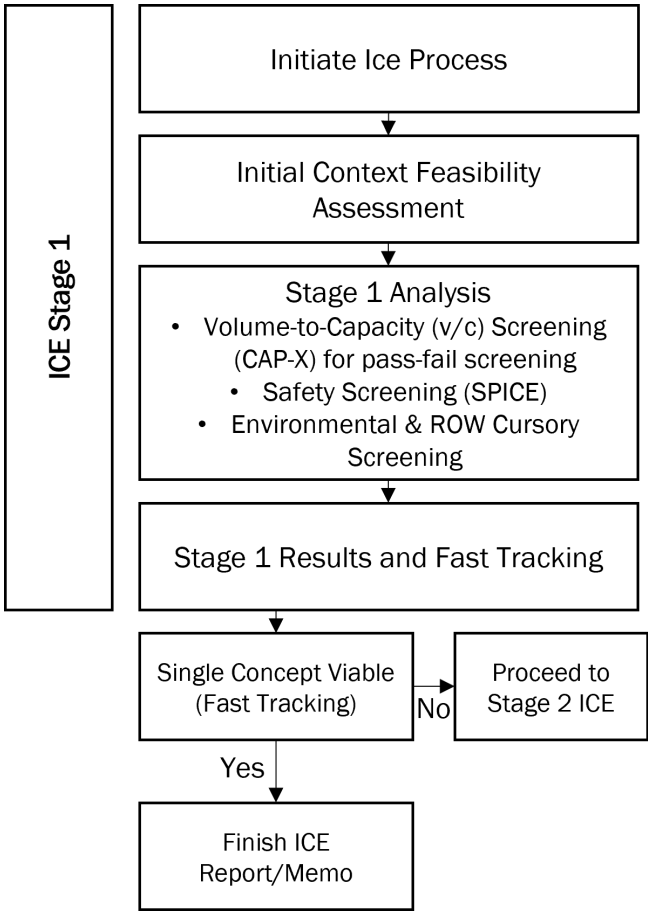


Figure 10-1: ICE Stage 1 in the Project Workflow

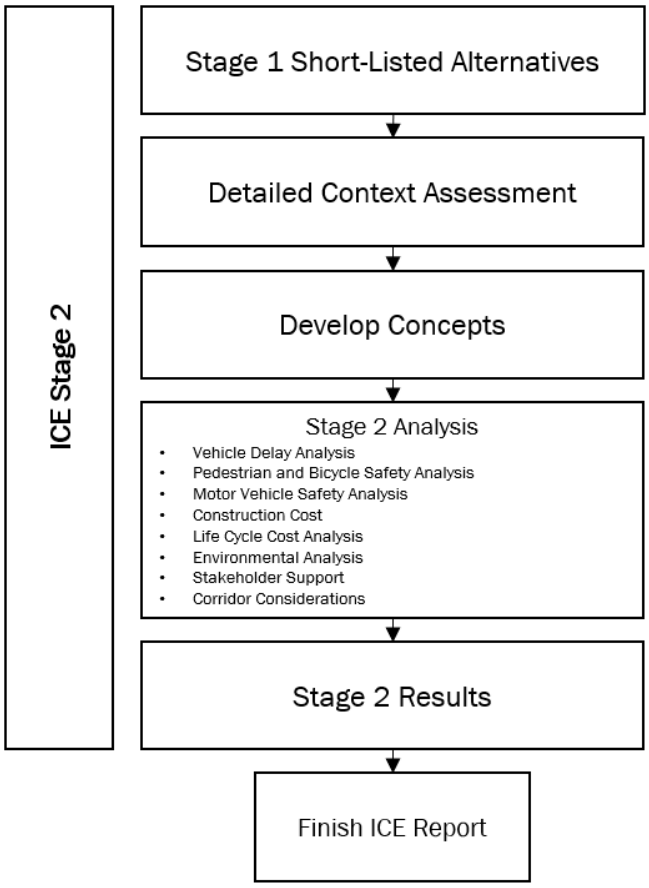


Figure 10-2: ICE Stage 2 in the Project Workflow

10.2.2 ICE Applicability

ICE does not apply to development of studies or projects that involve system optimization, which is common for post-construction fine-tuning of operations. However, ICE is completed under the following circumstances:

- The intersection includes a roadway designated as a State route or as part of the National Highway System.
- The intersection or corridor improvements present opportunity to change the type of intersection or control to improve safety and/or operations.
- The intersection will be designed or constructed using State or Federal funding.

ICE does not need to be completed (but may be considered), under the following circumstances:

- The proposed work does not increase the vehicular footprint (as through-put) of the intersection, such as:
    - sidewalk/streetscape improvements;
    - signal permit revision;
    - minor turn lane adjustments, such as converting a short section of shoulder to a turn lane or lengthening a turn lane; and
    - resurfacing
- Local road intersection where the proposed condition is a right-in and right-out.
- Where routine traffic signal timing and equipment maintenance is required, such as where the build condition is being improved with signal timing optimization.

Driveway permits: A District has the authority to make the determination as to when ICE needs to be performed for a driveway permit.

For corridor improvement projects with multiple intersections that are likely to need a change in control to maintain operations or improve safety, ICE is applied to each intersection, but with a view to the corridor as a system. For example, it is common to use combinations of roundabouts, R-CUT and medians that restrict turning movements in or out of minor intersections or driveways. With combinations of roundabouts, the U-turn movements that are

generated by an R-CUT can be accommodated more safely, especially for slow moving vehicles affected by an R-CUT.

When a corridor collection of individual ICE analyses represents a system level review, documentation is recommended in the form of a summary memo that combines results and explanation of how adjacent intersection controls are interdependent, e.g., R-CUTs combined with roundabouts for U-turns.

10.2.3 Intersection Types

The analysis methods in this chapter apply to the following intersection types (see Chapter 11 for Interchanges). Unique and alternative designs are presented in the sections that follow:

Signalized:

- Conventional Signal (Isolated, Coordinated, Clustered);
- Signalized RCUT;
- Quadrant Roadway;
- Turn lane Improvements;
- DLT; and
- CGT

Unsignalized:

- TWSC;
- All-way Stop-controlled (AWSC);
- Single Lane Roundabout;
- Multilane Roundabout;
- RCUT – Unsignalized;
- RIRO w/Downstream U-Turn;
- High-T (unsignalized Green Tee); and
- Turn Lane Improvements

Basic descriptions of intersection types (i.e., geometric configuration, operational considerations, and safety considerations) are provided below. See Table 10-1 provides general considerations for intersection type and the benefits each intersection type provides. Determining which type of intersection is being evaluated will help define which analysis tools to use. Appendix K, Section 2 – Intersection Type Additional Resources lists additional resources used to understand various intersection types. Appendix K, Section 7 – Intersection Type Graphics shows additional alternative intersections and Appendix K, Section 8 – External References (Reference 11) provides a link to an alternative intersection inventory in Texas.

Table 10-1: Intersection Control Selection Matrix

Intersection Type	When to Consider	Benefits	Disadvantages
Conventional Signalized (Isolated)	• Intersections more than one mile apart • Built-up areas of Rural communities	• Lower maintenance compared to coordinated	• Isolated may have more delay than coordinated intersections

Table 10-1: Intersection Control Selection Matrix

Intersection Type	When to Consider	Benefits	Disadvantages
Conventional Signalized (Coordinated)	• Intersections spaced less than a half mile apart	• Improved operations • Signal progression may improve congestion	• Signal timing plan updates to reflect changing traffic patterns are necessary. • 32 conflict points with moderate severity risk
Conventional Signalized (Clustered)	• At closely spaced intersections • Typically, several hundred feet or less between intersections	• Cost-efficient • Typically use a single signal controller for two intersections	• Close spacing could cause vehicle stacking/storage issues. • 32 conflict points with moderate severity risk
Two-Way Stop-Controlled (TWSC)	• At intersections with: ○ Moderate to heavy through traffic on a major street (>90%) ○ Low to moderate volume on a minor street (<10%) • Volumes that do not warrant signalization	• Cost-efficient	• Could cause significant delay for the side streets • Limited operational and safety benefits as traffic volumes become high. Left-turn and angle crossing collisions at high speeds
All-Way Stop-Controlled (AWSC)	• At intersections with: ○ Balanced volumes on major and minor streets • Volumes that do not warrant signalization	• Cost-efficient • Good safety performance at low-speed intersections	• Has the most delay of all control types • Unsuitable for rural high-speed intersections • Multilane designs are not practical • Limited operational and safety benefits as traffic volumes become high
Continuous Green-T (CGT)	• At intersections with: ○ Heavy through traffic on major street ○ Low left-turn volume on minor street ○ No driveways along a major street opposite a minor street • Low pedestrian crossings at intersection	• Increased vehicular safety • Improved operations ○ Free flow in one direction • Cost-efficient	• Could initially violate driver expectancy • Pedestrian crossing could be more difficult • Decreased access within the functional area surrounding the CGT

Table 10-1: Intersection Control Selection Matrix

Intersection Type	When to Consider	Benefits	Disadvantages

Roundabout (See **Chapter 12** for more information)	• All intersections – both rural and urban
	• Rural high-speed intersections
	• Three or more legs
	• More than four legs
		• Increased safety
		  ○ Typically, slower intersection speeds
		  ○ Fewer conflict points
		  ○ Fewer severe conflict points
		• Improved operations
		  ○ Fewer delays and shorter queues
		• Long-term cost efficiency
		• No signal maintenance
		• Safest for pedestrians
			• Initial construction cost could be higher than other intersection types
			• Could disrupt progression along an arterial with traffic signals

Median U-Turn (MUT)	• Divided roadways with wide medians
	• At intersections with:
	  ○ Heavy through traffic
	  ○ Moderate left-turn volumes
	• Three or four legs
		• Increased safety
		• Improved operations for through movements
		• Cost-efficient
		• Recovery of green time for through movements crossing at high volume intersections
			• Not intuitive to drivers
			• Greater ROW requirements
			• Visibility of the location for the U-turn

Restricted Crossing U-Turn (RCUT)	• On roadways with a median • At intersections with heavy through or left-turn volumes on major street • Three or four legs • Where traffic signals are not warranted	• Increased safety • Improved operations for the higher volume mainline • Cost-efficient • Avoids more costly and disruptive solutions, e.g. traffic signals or roundabouts	• Not intuitive to drivers • Pedestrian crossing could be more difficult • Visibility of the location for the U-turn • Acceleration merge and deceleration lane change distances (LCDs) along the mainline

Displaced Left-Turn (DLT)	• At intersections with:
	  ○ Heavy through traffic in all directions
	  ○ Heavy left-turn traffic
	  ○ Limited access near intersection approaches
		• Increased safety
		  ○ Reduced conflict points
		• Improved operations
		  ○ Four phases to two phases
		• Enhanced synchronization
		• Maximizes both through traffic and high left-turn demand
			• Not intuitive for drivers
			• Pedestrian crossing could be more difficult
			• Restricted U-turn possibilities.
			• Traffic signal timing coordination with adjacent intersections

Table 10-1: Intersection Control Selection Matrix

Intersection Type	When to Consider	Benefits	Disadvantages

Grade-Separated Intersection	• Constrained space for a larger intersection or interchange footprint
	• At intersections with:
	  ○ Heavy through traffic on a major street
	  ○ Moderate left-turn volumes
		• Increased capacity and uninterrupted flow
		• Accommodates U-turns
		• Increased safety Reduced vehicle conflicts and delay
			Could be more costly than other intersection alternatives

10.2.3.1 Signalized Intersection

Compared to unsignalized intersections, signalized intersections increase capacity, reduce right-angle crashes, and permit vehicles, pedestrians, and bicyclists from minor volume approaches to safely cross an intersection. However, they create off-peak delay to minor approaches, increase frequency of rear-end crashes, increase congestion, and have high maintenance costs. TMUTCD signal warrants are recommended to be met before an intersection is converted into a signalized intersection. Signalized intersections are comprised of the following subcategories: isolated, coordinated, and clustered.

10.2.3.2 Coordinated Signalized Intersection

Coordinated intersections include two or more intersections that promote progression between each other along a corridor. According to the National Association of City Transportation Officials' (NACTO's) Urban Street Design Guide, coordinated intersections are typically spaced one-half mile or less apart and provide more continuous traffic flow for major street users going from one coordinated intersection to the next. Coordinated intersections can be optimized to a specific target speed to meet the lower speed needs of bicyclists and pedestrians.

10.2.3.3 Cluster Intersection

According to the HCM, groups of two or more intersections that are closely spaced and work operationally together using displaced or distributed movements are clustered intersections. It is recommended that these intersection clusters be analyzed as one system. Most alternative intersections are made of clustered intersections due to left-turn or U-turn movements that occur either before or after the main intersection.

10.2.3.4 Continuous Green-T (CGT)

In a High-Tee (Unsignalized CGT) or CGT intersection, one major street movement passes through the intersection without stopping. This movement typically occurs on the opposite side of the side street (on top of the "T"). The other major street direction of travel is typically uncontrolled or controlled by a traffic signal. Vehicles turning left from the side street to the major street use a left-turn pocket and merge with the major street through traffic. CGT intersections are not suitable for high-speed roadways (> 55mph). CGT intersections can be difficult for pedestrians to cross. See Figure 10-3 for the basic features of a CGT.

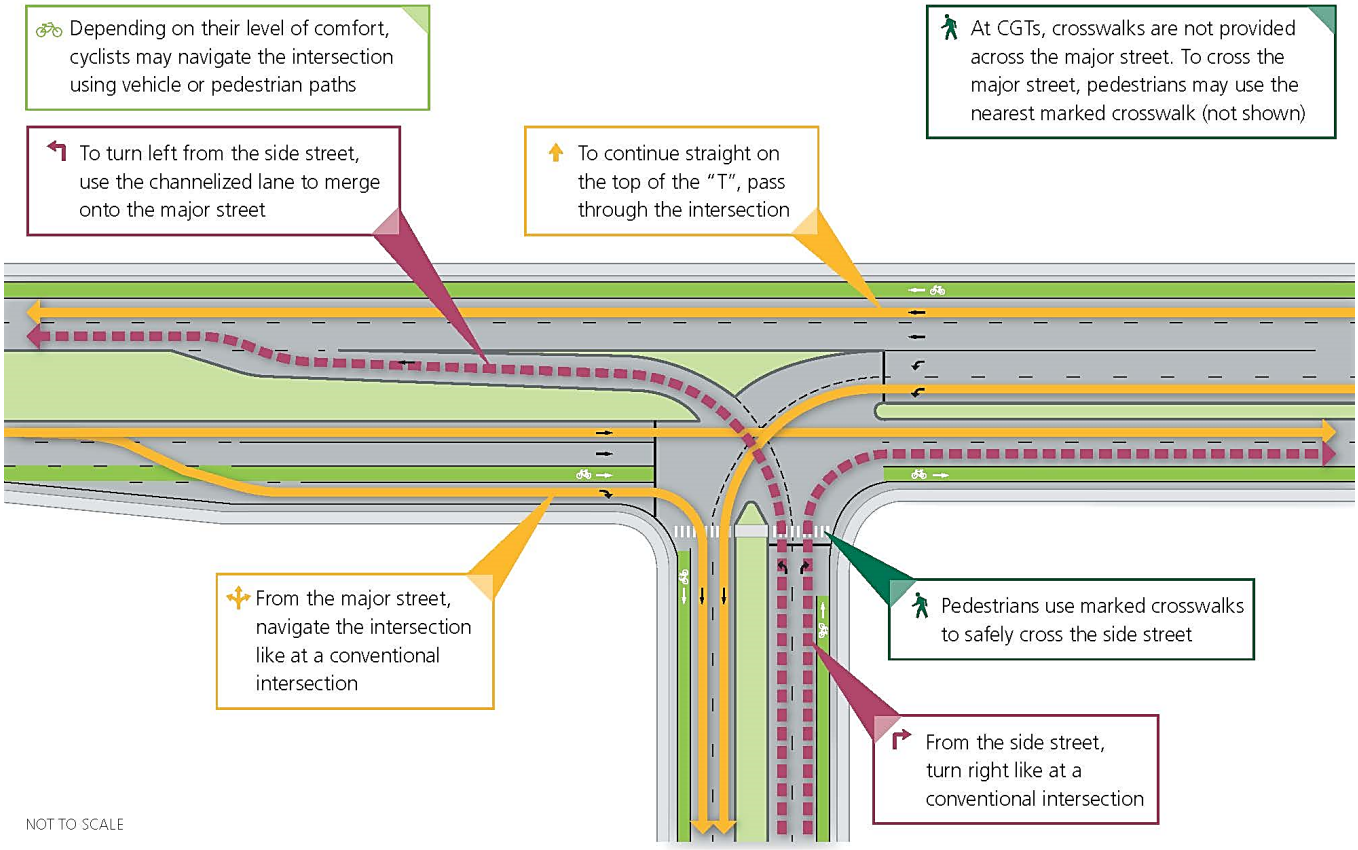


Figure 10-3: Continuous Green-T Features (1)

Source: Virginia Department of Transportation, 03/05/2024

10.2.3.5 Restricted Crossing U-Turn (RCUT)

This alternative intersection can either have traffic signals or be stop controlled. RCUTs have directional medians to force minor street through and left-turning traffic to make a right-turn and then a U-turn on the major street to complete their maneuvers. When analyzing operations or safety of an RCUT intersection, the analysis typically includes the core intersection as well as the satellite intersections. See Figure 10-4 for the basic features of an RCUT intersection.

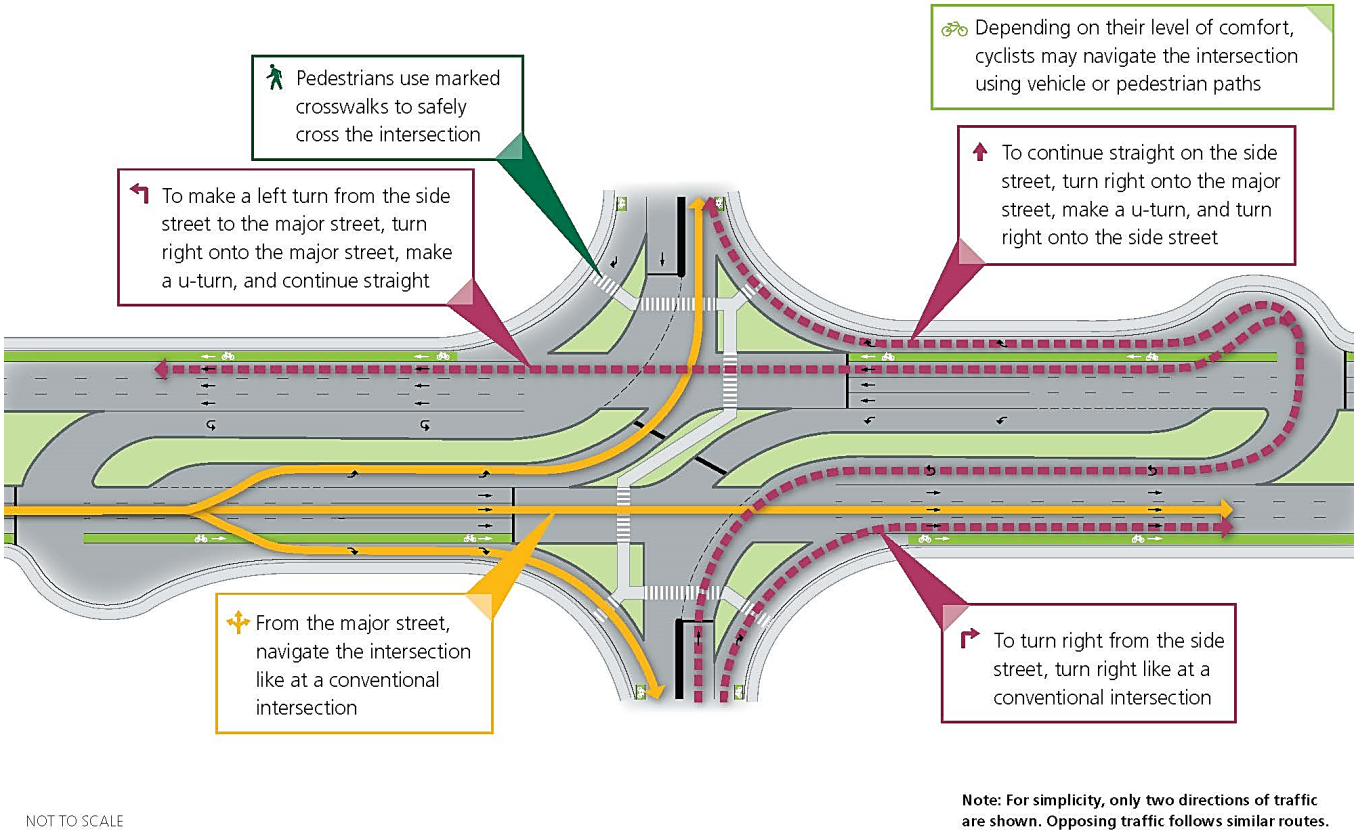


Figure 10-4: Restricted Crossing U-Turn Features

Source: Virginia Department of Transportation, 03/05/2024

10.2.3.6 Median U-Turn (MUT)

At MUT intersections, left-turning traffic on the major and minor street U-turn at wide medians to complete their maneuver. This eliminates the need for left turn phases at the intersection. When analyzing operations or safety of a MUT intersection, the analysis typically includes the core intersection as well as the travel time and delay at the satellite intersections. See Figure 10-5 for the basic features of a MUT intersection.

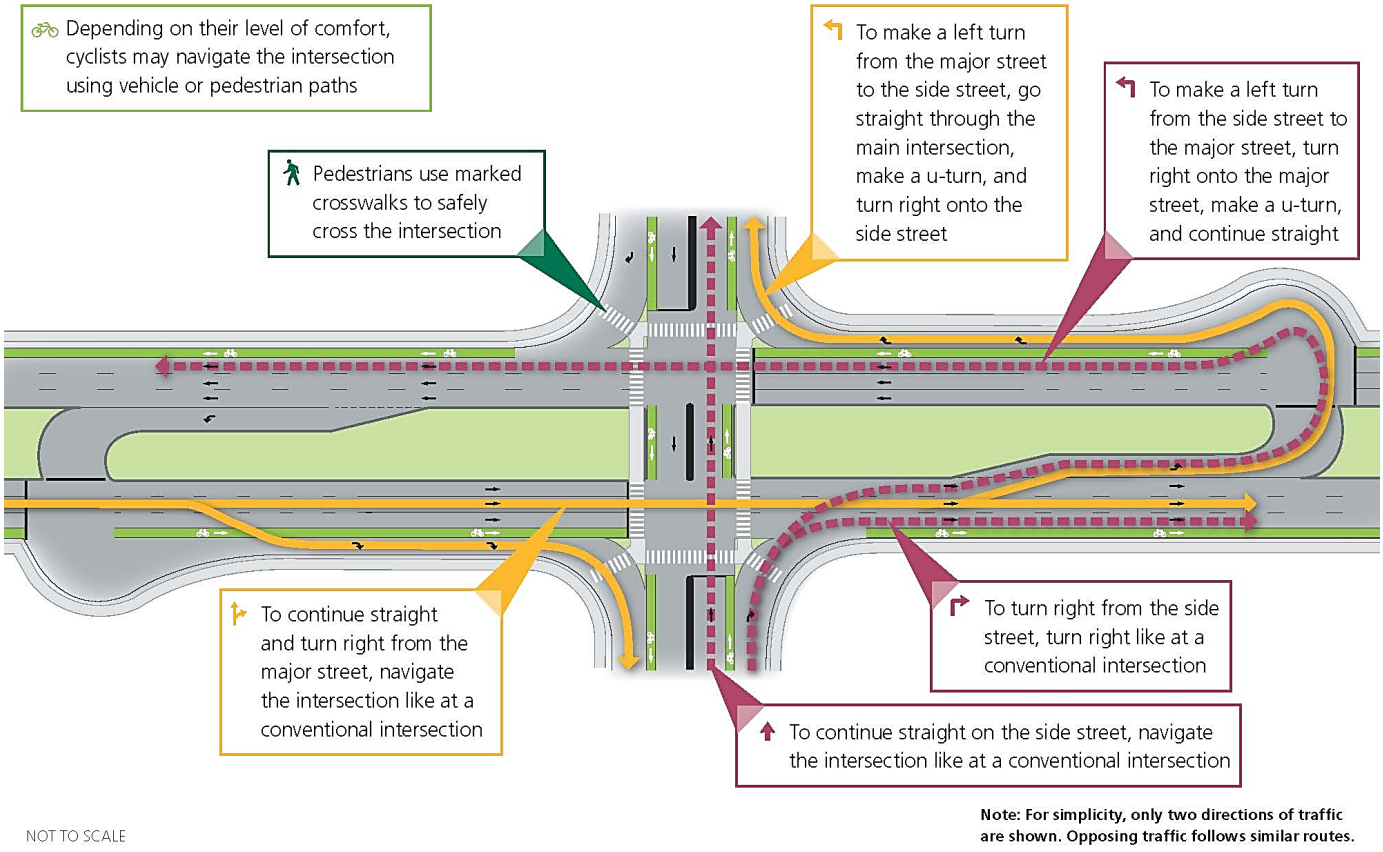


Figure 10-5: Median U-Turn Features

Source: Virginia Department of Transportation, 03/05/2024

10.2.3.7 Displaced Left-Turn (DLT)

Also known as a continuous flow interchange (CFI) or crossover displaced left-turn (XDLT), this signalized intersection type relocates one or more left-turn movements on an approach to the other side of the opposing traffic flow. Signals are placed at crossover intersections upstream of the main intersection and left-turn movements run simultaneously with the through movement, eliminating the need for a left-turn phase for that approach. When analyzing operations or safety of a DLT intersection, the analysis typically includes the core intersection as well as the satellite intersections. See Figure 10-6 for the basic features and flow patterns of a DLT. This intersection type requires restriction of access within the influence area of the layout. Right-in and right-right access may be permitted but not close to the cross-over areas.

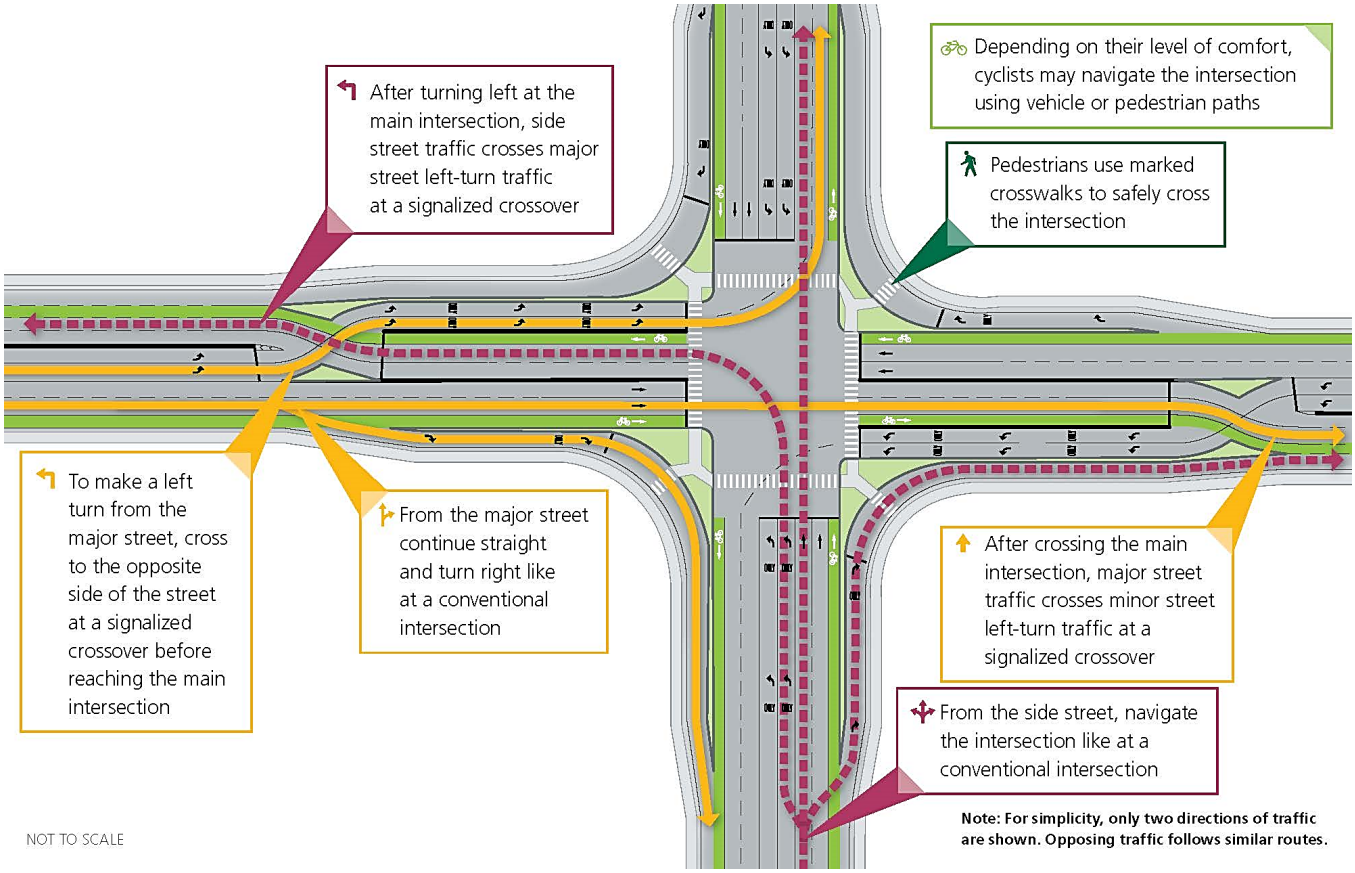


Figure 10-6: Displaced Left-Turn Features

Source: Virginia Department of Transportation, 03/05/2024

10.2.3.8 Two-way Stop-controlled (TWSC)

TWSC intersections are comprised of one uncontrolled street and one stop-controlled street (see Figure 10-7). A typical configuration of TWSC intersections is a four-leg intersection with an uncontrolled major street and a stop-controlled minor street. Another typical configuration is a three-leg intersection where the third leg (minor street) is stop-controlled, and the major street is uncontrolled. TWSC are typically applied at locations with a large majority of overall intersection traffic occurring on the major street. Safety analysis of TWSC intersections is discussed in Section 10.3 of this chapter or in Chapter 5 and Chapter 6.

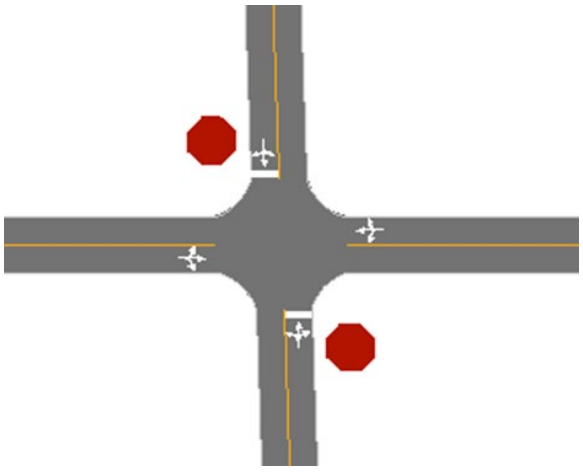


Figure 10-7: TWSC Intersection

10.2.3.9 All-way Stop-controlled (AWSC)

At AWSC intersections, all approaches have stop control (see Figure 10-8). AWSC are typically applied at locations with a balanced volume of vehicles traveling on intersecting segments. Operational analysis of AWSC intersections is dependent on traffic patterns at the intersection because delay at each approach is dependent on the arrival patterns of the other approaches. Safety analysis of Two-way Stop-controlled intersections is discussed later in this chapter and in Chapter 5 and Chapter 6.

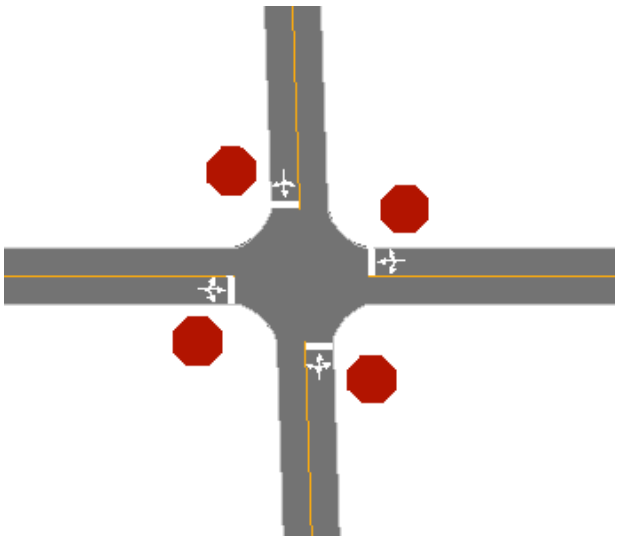


Figure 10-8: AWSC Intersection

10.2.3.10 Roundabouts

Roundabouts are circular intersections that use either signals or yield control and channelizing islands to circulate traffic in a counterclockwise motion around and through an intersection. The channelizing islands provide a refuge for pedestrians. The geometric features of a roundabout deflect and slow approaching vehicles. Roundabouts are designed to varying sizes from a single-lane mini-roundabout with a 90-foot inscribed circle diameter to a multi-lane roundabout with a 200-foot inscribed circle diameter. An example of a roundabout is shown in Figure 10-9. For more information about roundabouts (including example figures) and roundabout analysis, see Chapter 12.

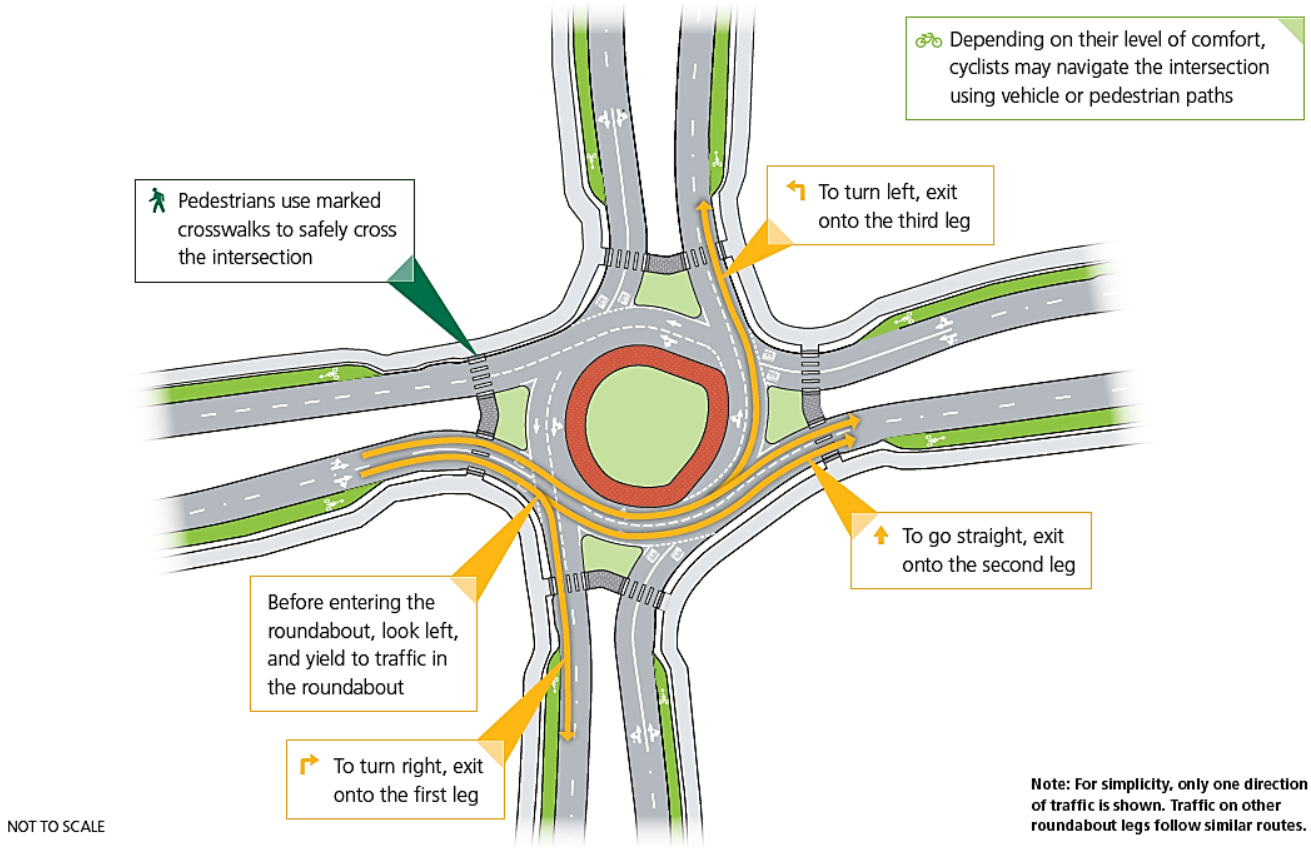


Figure 10-9: Roundabout Features

Source: Adapted from Virginia Department of Transportation, 03/05/2024

10.2.3.11 Grade-Separated

Grade separation is a method of aligning a junction of two or more roadways at different heights (grades) so that they will not disrupt the traffic flow on other routes when they cross each other. Grade separation is typically introduced for the major street through movement, while major street turning movements and all minor street movements still occur at the same grade. See Figure 10-10 for the basic features of a grade-separated intersection.

Figure 10-10: Grade Separated Features

Source: TxDOT Visual Dictionary - Grade Separation

10.3 Intersection Control Evaluation – Process and Analysis

10.3.1 ICE Process Overview and Reporting

The two-stage ICE study procedure is beneficial for intersection analysis of intersection modification, reconstruction or where new construction is planned.

In Stage 1 the intersection analysis is a streamlined combination of operations and safety components:

- Operational analysis using CAP-X and TMUTCD warrants; and
- Safety analysis using SPICE

See Appendix K, Section 3 – Intersection Analysis Checklist for an intersection analysis checklist. An expanded checklist is also provided for non-ICE type studies and system optimization considerations.

The main tools used in intersection analysis at Stage 1 are TMUTCD warrants (two-way stop controlled, AWSC, and signalized intersection), SPICE and CAP-X are considered sketch-level or macroscopic tools. Sketch-level or macroscopic analysis tools are typically used in analyzing individual intersections and large projects with interchanges or corridors, without requiring extensive resources. CAP-X is a pass-fail tool and not a ranking tool. The CAP-X LOS results are not granular enough to rank alternatives. Conversely, SPICE, in Stage 1, can be used as a ranking tool for all intersection control alternatives.

Stage 1 ICE considers all intersection control alternatives, ranks and removes the alternatives that do not meet the project's purpose and needs based on existing conditions, field observations, and analyzed data. Conceptual exhibits of some intersection designs, such as roundabouts, help to determine the footprint and space needed. See Chapter 8 for additional information on alternatives analysis. Engineering judgement and a series of questions are considered during this determination. Does the alternative:

- Meet the specified project goals and needs in a practical way?
- Meet the applicable warrants?
  - See warrants for TWSC, AWSC, and signalized intersections below.
- Address known crash history or improve future safety?
- Demand additional ROW, and if so, how feasible will it be to acquire it?
- Demand railroad coordination for ROW or encroachment?
- Meet the TxDOT standards for turn-bay length?
- Provide adequate left-turn capacity?
- Have any known environmental impacts or produce higher emissions?
- Provide a sustainable solution that is context-sensitive to any long-range plans and improvements?
- Address stakeholder and public areas of interest?
- Foster error-free driving tasks?

Stage 2 ICE applies more rigorous analysis of geometry, safety and operations, along with

other factors such as cost and impacts (utilities, ROW, environmental, etc.). The main tools used in Stage 2 operations analysis are Synchro, HCS, and Vissim. The analysis software tool selection is based on intersection type, project complexity, and object level of detail (see Table 10-2) for recommended analysis tools. The analysis tools recommended are example tools and other comparable software can be used. HCM-based (mesoscopic) tools are typically used when a more detailed analysis is necessary, but microsimulation (microscopic) analysis would be too much detail. Information related to the capabilities of the software is found in Chapter 4 and Chapter 12, Appendix M.

Appendix K, Section 1 provides an abbreviated version of an ICE report. It covers the Stage 1 requirements and generates a preferred type of intersection control without requiring more detail that Stage 2 typically generates.

When both the safety (SPICE) and operations (CAP-X) analyses generate a clear preference for intersection control during the Stage 1 study tasks, Stage 2 ICE investigation may not be necessary, and the project can proceed to schematic design and detailed cost estimation. ICE Stage 2 is necessary when a clear preference for safety improvement is not evident in Stage 1, or where more detailed operational or impacts analysis is needed, such as where intersections are closely spaced.

10.3.2 Stage 1 Operational Performance and ICE

CAP-X is a spreadsheet-based tool that compares anticipated v/c of various intersection types. This analysis determines the intersection type that will provide the most capacity given a set of simple traffic flow estimates. CAP-X analyzes multiple intersection types, but there are a few exceptions, such as TWSC and AWSC. An analysis in CAP-X can be completed for a large or small network. CAP-X does not account for varying costs of intersection implementation, nor an intersection's impact on safety. The CAP-X inputs include:

- turning movement volumes (veh/hr);
- percent heavy vehicles;
- historical growth rate;
- lane assignments for each control type; and
- pre-selection of practical alternatives to be analyzed (Step 2B)

Optional CAP-X inputs include:

- Volume adjustment factor;
- Passenger car equivalent (PCE) factor;
- Critical lane volume sum limits;
- Heavy vehicle percentages; and
- Multimodal bicycle and pedestrian accessibility needs by the number of crossings for each intersection type being evaluated

10.3.2.1 Traffic Control Warrants

It is recommended that two-way stop control warrants, all-way stop control warrants, and traffic signal warrants be checked (if applicable) per the TMUTCD (Appendix K, Section 8 – External References (Reference 7)) prior to intersection analysis. The investigation will help determine whether the intersection

control type is warranted and if further analysis is necessary.

10.3.2.2 TWSC Warrants

Two-way Stop-control warrants are typically checked per TMUTCD. According to the TMUTCD, the use of STOP signs on the minor-street approaches can be considered if engineering judgement indicates that a stop is always necessary because of one or more of the following conditions:

- The vehicular traffic volumes on the through street or highway exceed 6,000 vehicles per day;
- A restricted view exists that necessitates road users to stop to adequately observe conflicting traffic on the through street or highway; and/or
- Crash records indicate that three or more crashes that are susceptible to correction by the installation of a STOP sign have been reported within a 12-month period, or that five or more such crashes have been reported within a two-year period. Such crashes include right-angle collisions involving road users on the minor-street approach failing to yield the ROW to traffic on the through street or highway.

For more information regarding TWSC warrants, see Section 2B.06 in the TMUTCD.

10.3.2.3 AWSC Warrants

AWSC control warrants are typically checked per the TMUTCD. According to the TMUTCD, AWSC may be a useful safety measure at intersections if certain traffic conditions exist. Safety issues associated with AWSC include pedestrians, bicyclists, and all road users expecting other road users to stop. AWSC is used where the volume of traffic on the intersecting roads is approximately equal.

- The decision to install an AWSC is based on an engineering study.
- The following criteria is typically considered in the engineering study for an AWSC sign installation:
    - Where traffic signal controls are justified, the AWSC is an interim measure that can be installed quickly to control traffic while arrangements are made for the installation of the traffic control signal.
    - Five or more reported crashes in a 12-month period that are susceptible to correction by an AWSC sign installation. Such crashes include right-turn and left-turn collisions as well as right-angle collisions.
    - Minimum volumes:
        - The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 vehicles per hour for any eight hours of an average day; and
        - The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches

(total of both approaches) averages at least 200 vehicles per hour for the same eight hours, with an average delay to minor-street vehicular traffic of at least 30 seconds per vehicle during the highest hour; but

- If the 85th percentile approach speed of the major-street traffic exceeds 40 mph, the minimum vehicular volume warrants are 70 percent of the values provided in Items 1 and 2.

- Where no single criterion is satisfied, but where crash criteria and minimum volume criteria 1 and 2 are all met. Minimum volume criteria 3 is excluded from this condition.

For more information regarding AWSC warrants, refer to Section 2B.07 in the TMUTCD.

10.3.2.4 Signalized Intersection Warrants

Signal intersection warrants are checked per the TMUTCD. Typically, a signal warrant analysis comes after the determination that a signalized intersection is a viable alternative.

According to the TMUTCD, a signal warrant analysis is comprised of nine warrants, all of which are considered as part of the analysis. The warrants are:

- Warrant 1, Eight-Hour Vehicular Volume;
- Warrant 2, Four-Hour Vehicular Volume;
- Warrant 3, Peak Hour;
- Warrant 4, Pedestrian Volume;
- Warrant 5, School Crossing;
- Warrant 6, Coordinated Signal System;
- Warrant 7, Crash Experience;
- Warrant 8, Roadway Network; and
- Warrant 9, Intersection Near a Grade Crossing

For detailed information about conducting a signal warrant analysis, see Appendix K, Section 5 - TMUTCD Signal Warrant Analysis Guidelines. Additionally, a signal warrant analysis workbook is provided in Appendix K, Section 6 - TMUTCD Signal Warrant Analysis Spreadsheet.

10.3.3 Stage 1 Safety Performance and ICE

The SPICE Tool is intended to aid in the determination of a preferred alternative for a given intersection project by providing an objective, quantifiable basis to compare the safety performance of different intersection types. Appendix K, Section 8 provides a link to acquire the SPICE spreadsheet tool. The SPICE Tool uses the SPF's in Part C of the HSM (and subsequent NCHRP Reports) to select high-quality CMF's from Part D of the HSM and the FHWA/University of North Carolina CMF Clearinghouse crash database, to predict crash frequency and severity for a variety of intersection control strategies. Based on the input parameters, the tool specifies the predicted crash frequency and crash severity for each control strategy selected for evaluation. Practitioners can conduct analysis

for the opening year, Design Year, or over the lifecycle of the improvement. Inputs include pre-selection of practical control strategies, AADT information, pedestrian volume and site context information, e.g., schools within 100ft of the intersection., the number of turn lanes. The tool generates crash predictions that are used to rank the most and least safest control strategies. Those results are compared and combined with the CAP-X results to short-list intersection control alternatives to be studied in Stage 2 detailed evaluation.

10.3.4 Stage 2 Operational Performance and ICE

The main tools used in Stage 2 ICE are Synchro, HCS, and Vissim. The analysis software tool selection is based on intersection type, project complexity, and level of detail (see Table 10-2). Information related to the capabilities of the software is found in Chapter 4 and Chapter 12, Appendix M.

When performing Stage 2 operational analysis, expanding the study area to include more than the project intersection is recommended if:

- The study intersection or adjacent intersections will be impacted by queue spillback.
- The study intersection operates within a coordinated system due to signalization.
- The study intersection has geometric conditions in the vicinity, such as a nearby U-turn intersection.

See Chapter 2 for data collection resources.

Table 10-3 provides needed and optional data inputs for the various tools in the two stages of ICE. For optional data inputs, default values are often used. Changing default values of optional data inputs is not critical to the analysis output but changing default values of needed data inputs is critical for operational analysis.

10.3.4.1 Service Volumes

FHWA has created “rule-of-thumb” intersection capacities that are used to determine if left-turn lane configuration at a signalized intersection is sufficient. See Table 10-4 for thresholds based on various left-turn treatment scenarios.

Table 10-2: Operational Analysis Tools

Intersection Type	Level of Detail		
	Sketch Level or Macroscopic	HCM Based (Mesoscopic)	Microsimulation (Microscopic)
Two-Way Stop Control (TWSC)	Not applicable	Synchro, HCS	Vissim, CORSIM
All-Way Stop Control (AWSC)	Not applicable	Synchro, HCS	Vissim, CORSIM
Traffic Signal	CAP-X	Synchro, HCS	Vissim, CORSIM
Roundabout	See **Chapter 12, Appendix M**	See **Chapter 12, Appendix M**	See **Chapter 12, Appendix M**
Alternative Intersection (DLT, RCUT, MUT, CGT, grade-separated)	CAP-X[1] (Synchro for CGT or grade separated)	Synchro, HCS[2]	Vissim, CORSIM

[1]Synchro can be used for CGT and grade-separated intersections

[2]Vissim can be used for HCM-based (mesoscopic) analysis when the facility type is unavailable in HCS

Table 10-3: Operational Analysis Tool Inputs (Stage 2 ICE)

Tool	Necessary Data Inputs	Optional Data Inputs
Synchro	• geometric conditions • turning movement volumes (veh/hr) • speeds • peak hour factor • control type	• heavy vehicle percentages • number of bus blockages • number of parking maneuvers • percent of traffic from midblock sources
HCS	• geometric conditions • turning movement volumes (veh/hr) • speeds • peak hour factor • growth factor • control type	• heavy vehicle percentages • buses/hour/approach • parking per hour • arrival type • detector length • initial queue
Vissim	• geometric conditions • turning movement speeds • static vehicle routes (turning movement volumes veh/hr) • conflict rules • vehicle inputs • control type and signal timing	• driver behavior parameters • heavy vehicle percentages
CORSIM	• geometric conditions • turning movement volumes (veh/hr) • speeds • control type	• heavy vehicle percentages

Table 10-4: Signalized Intersection Capacities for Exclusive Left Turn Treatments

Case I: No Exclusive Left-Turn Lanes				
Assumed critical signal phases*		2		
Left-turn volumes		Critical major approach**: ≤ 125 veh/hr		
		Critical minor approach: ≤ 100 veh/hr		
Planning-level capacity (veh/hr), sum of critical approach volumes* **		**Number of basic lanes,**** major approach**		
		2	**3**	**4**
Number of basic lanes, minor approach	**1**	1,700	2,300	-
	2	2,400	3,000	-
	3	-	-	-
Case II: Exclusive Left-Turn Lane on Major Approaches Only				
Assumed critical signal phases		3		
Left-turn volumes		Critical major approach: 150-350 veh/hr		
		Critical minor approach: ≤ 125 veh/hr		
Planning-level capacity (veh/hr), sum of critical approach volumes		**Number of basic lanes, major approach**		
		2	**3**	**4**
Number of basic lanes, minor approach	**1**	1,600	2,100	2,300
	2	2,100	2,600	2,800
	3	2,700	3,000	3,200
Case III: Exclusive Left-Turn Lane on Both Major and Minor Approaches				
Assumed critical signal phases		4		
Left-turn volumes		Critical major approach: 150-350 veh/hr		
		Critical minor approach: 150-250 veh/hr		
Planning-level capacity (veh/hr), sum of critical approach volumes		**Number of basic lanes, major approach**		
		2	**3**	**4**
Number of basic lanes, minor approach	**1**	1,500	1,800	2,000
	2	1,900	2,100	2,400
	3	2,200	2,300	2,800

Notes:
* Critical signal phases are nonconcurrent phases
**A critical approach is the higher of two opposing approaches (assumes same number of lanes)
***Use fraction of capacity for design purposes (e.g., 85 or 90 percent)
****Basic lanes are through lanes, exclusive of turning lanes
Adapted from NCHRP 279, figure 4-11

10.3.4.2 HCM-based

Synchro and HCS are recommended to be used when a more detailed analysis is necessary. HCM-based tools call for more inputs than CAP-X and sketch-level roundabout analysis and results could account for variables not considered with ICE Stage 1. For information on conducting an intersection analysis using HCM-based tools, refer to software user guides.

10.3.4.3 Microsimulation

Microsimulation may be used for intersection analysis where complex geometry exists, other tools cannot adequately model the intersection, and projects that call for high levels of detail. See Chapter 13 for more information on conducting an analysis using microsimulation.

10.3.4.4 Results and Measure of Effectiveness (MOEs)

Intersection analysis using HCM-based tools (i.e., Synchro and HCS) are evaluated in terms of LOS based on either control delay, LOS score (a measure used to rank pedestrian and bicycle facilities based on pedestrian perception and bicycle perception), or experienced travel time (ETT). Table 10-5 shows the MOEs for each type of operational analysis tool. Enhanced operational performance equates to a low v/c ratio, low control delay, LOS A (optimal) to LOS D (acceptable), and short queue length.

The delay output by Vissim is calculated using a different method than in HCM based tools, so use caution when comparing the delays between Vissim results and HCM-based software. Relevant pairs of intersection chapters from the HCM 7th Edition are listed below:

- Signalized Intersections: Chapter 19 (methodology), Chapter 31 (applications);
- Two-way Stop-controlled Intersections: Chapter 20 (methodology), Chapter 32 (applications);
- AWSC: Chapter 21 (methodology), Chapter 32 (applications);
- Roundabouts: Chapter 22 (methodology), Chapter 33 (applications); and
- Alternative Intersections (Continuous Flow/Displaced Left-Turn, RCUT, MUT): Chapter 23 (methodology), Chapter 34 (applications)

Table 10-6 shows HCM LOS criteria for signalized intersections. Table 10-7 provides HCM LOS criteria for TWSC and AWSC intersections.

Table 10-5: Operational Analysis Tool Outputs

Tool	Outputs
CAP-X	v/c ratios of top 10 selected intersection types
Synchro	v/c ratio, control delay, LOS, 95% queue length
HCS	v/c ratio, control delay, LOS, 95% queue length,
Warrants (using Synchro, HCS, or other tools)	Warrant met or warrant not met
Vissim	Average vehicle travel times (sec), average total delay per vehicle (sec), percent of queue length, ETT
CORSIM	Control delay, queue length, travel speed, travel time, LOS

Table 10-6: LOS Criteria for Signalized Intersections: Motorized Vehicle Mode

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	v/c ≤ 1.0	*v/c* >1.0
≤ 10	A	F
> 10-20	B	F
> 20-35	C	F
> 35-55	D	F
> 55-80	E	F
>80	F	F

Note: For approach-based and intersection-wide assessments, LOS is defined solely by control delay.

Table 10-7: LOS Criteria for TWSC & AWSC Intersections: Motorized Vehicle Mode

Control Delay (s/veh)	**LOS by Volume-to-Capacity Ratio**	
	***v/c* ≤ 1.0**	***v/c* >1.0**
≤ 10	A	F
> 10-15	B	F
> 15-25	C	F
> 25-35	D	F
> 35-50	E	F
>50	F	F

Note: The LOS criteria apply to each lane on a given approach and to each approach on the minor street. LOS is not calculated for major-street approaches or for the intersection.

10.3.5 Stage 2 Safety Performance and ICE

A Stage 2 safety analysis is completed when more analysis is beneficial beyond Stage 1 and/or when detailed safety analysis is needed for cost-benefit analysis. This section covers the primary safety analysis tools (historical crash analysis, collision diagram, crash rates, HSM Safety SPFs, and CMFs, and SPICE and the SSI Tool that are typically used to evaluate different intersection control options for vehicles, pedestrians, and bicyclists. Chapter 5

and Chapter 6 cover additional information and guidance on conducting a safety analysis.

It is recommended that safety countermeasures are incorporated as part of the project, based on crash analysis. A typical safety analysis of an existing intersection includes performing a historical crash analysis, creating a collision diagram, and calculating the crash rate. An historical crash analysis is typically completed to identify the types of crashes occurring at the intersection. FHWA recommends collecting a minimum of three to five years of crash data due to the variability of crash frequencies each year. At a minimum, collect the number of crashes, crash type (rear-end, sideswipe, etc.), crash severity, and contributing factors. See Chapter 2 for data collection resources.

A typical safety analysis of a future intersection includes performing a predictive crash analysis. Table 10-8 lists the data inputs for the historical and predictive safety analysis tools.

Following development of future crash predictions for a proposed intersection conversion, the Stage 2 safety analysis determines the expected crash reduction of converting and intersection. Each eligible proposed highway safety project is subjected to a B/C analysis. For this purpose, TxDOT has developed the SII tool.

Another tool that is used for post-ICE analysis is the Intersection SST, adopted by the Texas Transportation Commission in 2019. It is applied at the end of the ICE process, when a preferred intersection type is confirmed. The SST is used to optimize the preferred type of control through an exploration of design elements that affect safety. The basic approach to safety scoring assigns design elements to categories then defines standard and optimal values for each element in categories of geometric, traffic and roadside. The score of a combination of optimal elements helps to identify an optimal design overall. Its purpose is to increase awareness of how design changes can affect safety.

Table 10-8: Safety Analysis Tool Inputs and Outputs

Tool	Inputs	Outputs
Historical Crash Analysis and Collision Diagram	Intersection crash frequency, description, severity, and type over a period of 3-5 years	Identification of patterns by class, type and spatial locations
Crash Rate	Intersection crash frequency over three to five years, turning movement volumes, or AADTs per approach	Comparison of project crash rates with the state-wide critical rates
HSM and current SPFs and CMFs	Turning movement volumes, AADT, speed limit, pedestrian volumes per day, and maximum number of lanes crossed by a pedestrian	Crash frequency of converted intersection derived from SPF's or CMF's
SPICE – Stage 1 ICE Process	AADT for major and minor road, number of turn lanes, modifications to HSM Part C CMF, and SPF calibration default values (optional)	Validation of safety benefits of various intersection types Ranking of intersection type by safety benefit
Safety Improvement Index (SII) – Stage 2 ICE Process	• Initial cost of the project • Number of preventable fatal and incapacitating injury crashes • Cost of a fatal or incapacitating injury crash • Cost of a non-incapacitating injury crash • Number of years of crash data • Design year average annual Average Daily Traffic (ADT)	• The ratio of the annual savings in preventable crash costs vs. the cost to convert the intersection Benefit/cost (B/C) ratio • Rank multiple intersection alternatives according to B/C ratio of lifecycle crash costs.
TxDOT's Intersection Safety Scoring Tool (Appendix G, Section 4 – External References (Reference 7))	AADT for major and minor road, number of through lanes, speed limit, existing sight distance, pedestrian and bicycle flow; annual crash frequencies (veh., ped and bike)	At the end of Stage 2 ICE, ranking of the preferred intersection improvement according to specific design elements included or added to each alternative intersection by safety benefit

10.3.5.1 Historical Crash Analysis

Intersection Crash Rate

Intersection crash rate is a diagnostic tool rather than a predictive tool. It is calculated from historical data to determine the safety level at an existing intersection. Crash rates calculate the number of crashes for a given period and location over a measure of exposure in terms of traffic volume. They help account for low volume intersections with a seemingly low number of crashes that are experiencing a high crash exposure. Crash rates are used to prioritize intersection improvement projects identified through network screening, when resources and funds are limited. The intersection crash rate equation is:

$$R = \frac{C\ x\ 1{,}000{,}000}{\mathrm{V\ x\ N\ x\ 365}}$$

Where:

R = Crash rate for the intersection expressed as crashed per 1 MEV

C = Total number of intersection crashes in the study period (typically three to five years of data)

V = Traffic volume entering the intersection daily (obtained from traffic management center data or AADTs) per approach

N = Number of years in the study period

10.3.5.2 Collision Diagram

Once the crash frequencies, types, and severities are identified, conduct a crash pattern analysis using a collision diagram. Collision diagrams visually display locations and types of crashes by direction of travel to facilitate identification of patterns and clusters. Recognizing over-represented or target crash patterns helps identify which control type countermeasures can help prevent those crash patterns from reoccurring. For example, installing a traffic signal could help reduce the number of right-angle crashes. See Figure 10-11 for an example of an injury collision diagram. See Appendix K, Section 9 – Crash Diagram Template for a template of a crash diagram.

10.3.5.3 Predictive Safety Analysis

AAHSTO's HSM Part C uses SPFs to predict average crash frequency of three-leg and four-leg signalized and TWSC intersections. The HSM uses CMFs in Part C to compute the change in expected average crash frequency. CMFs less than one indicate a decrease in crash rates. HSM Part D includes additional CMF at stop-controlled, signalized, and roundabout intersections but is focused on conventional four-leg and three leg intersection types. CMFs cover the following intersection applications:

- Converting a four-leg TWSC to two three-leg intersections;
- Converting a signalized intersection to a single lane or multilane roundabout;
- Converting a TWSC or AWSC intersection into a single lane or multilane roundabout;
- Converting a TWSC to AWSC (assuming TMUTCD warrants are met); and
- Converting a TWSC to signal control (assuming TMUTCD warrants are met)

The HSM also provides CMFs related to geometric design changes, such as adding left-turn lanes to approaches on TWSC, AWSC, and signalized intersections. CMFs are not provided but crash trends are provided in the HSM for multimodal design changes, such as providing bicycle lanes, raised crosswalks, raised bicycle crossings, marked crosswalks, and refuge islands. Regarding alternative intersections, the HSM covers CMFs associated with replacing direct left-turns with right-turn/U-turn maneuvers at unsignalized intersections.

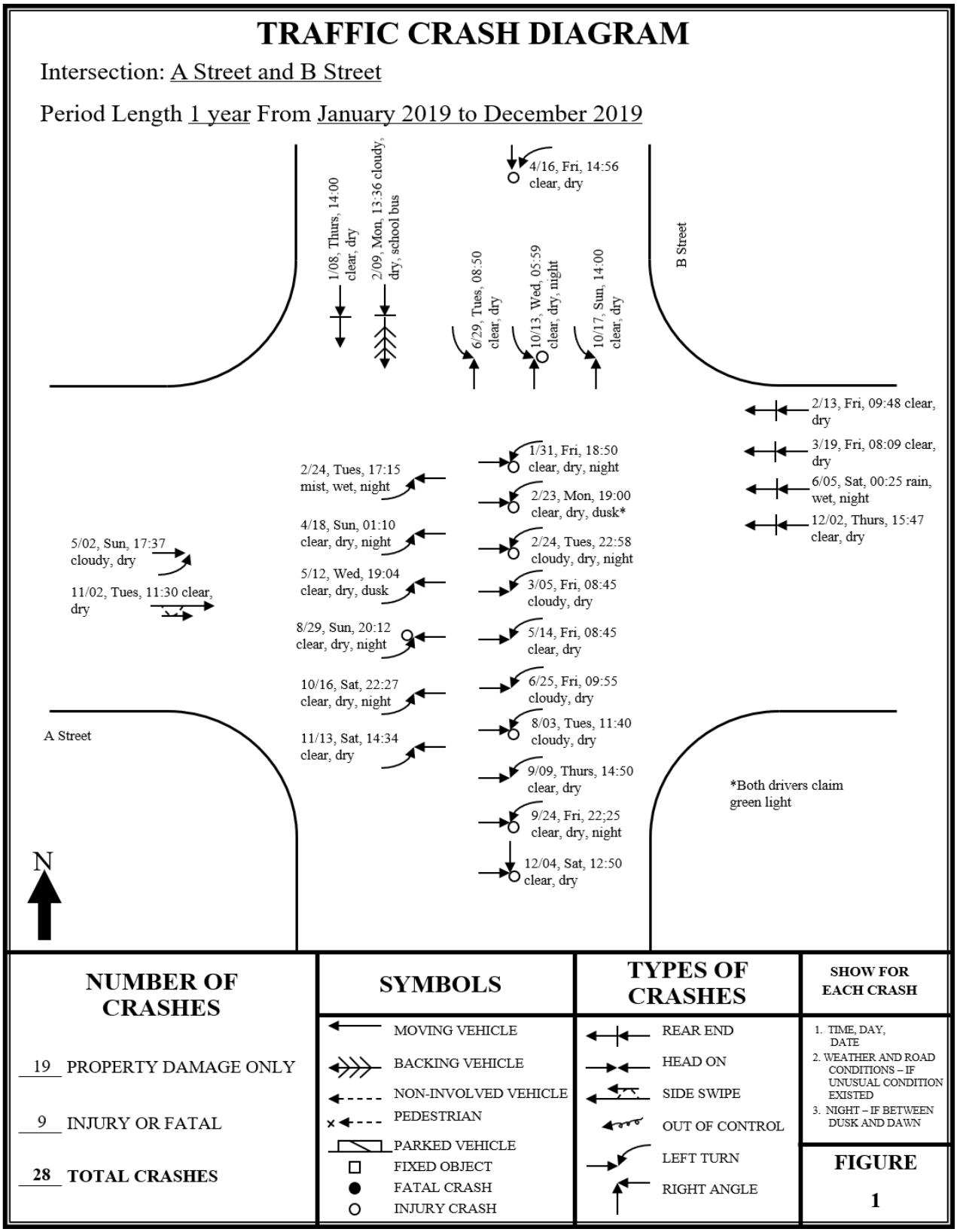


Figure 10-11: Injury Collision Diagram

10.3.5.1 Pedestrian and Bicycle Considerations

As of 2024, pedestrian and bicycle LOS for interchanges is not included in the HCM 7th Edition. Pedestrian control delay can be evaluated at individual signalized intersections, and pedestrian crossing delay can be evaluated at unsignalized intersections. The quality of service of pedestrian and bicyclists along the arterial of an interchange can be approximated using HCM's Urban Street Facilities methodologies. CAP-X evaluates the level of pedestrian and bicycle accommodations at intersection and interchange types. Inputs include number of pedestrian crossings, number of lanes, and vehicle speeds at each crossing. CPA-X also provides a similar assessment of bicycle accommodations to compare alternative intersections for bicycle friendliness. The suitability of each intersection alternative for pedestrians and bicyclists is assessed with an emphasis on convenience and accessibility.

NCHRP 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges provides additional guidance on accommodating pedestrians and bicyclists at diverging diamond interchanges (DDI). See Chapter 14 for more information on multimodal accommodations and analyses.

10.3.6 Cost-Benefit Analysis

A cost-benefit analysis should be done for each alternative to gain a complete picture of benefits and cost, particularly to achieve maximum crash reduction benefits. For this purpose, the SII spreadsheet can be used. In its most basic form, the SII is the ratio of the annual savings in preventable crash costs that have occurred at a location to the cost of constructing the proposed improvement. Costs include cost of constructing or implementing improvements and cost of maintenance. Benefits are calculated in crash reduction savings, to weigh each cost in relation to its importance to the overall project purpose when comparing alternatives. A cost-benefit analysis consists of three parts:

1. Opinion of Probable Construction Cost (OPCC)
   - Estimate overall construction cost for the improvements.
   - Review similar completed projects for an approximation.
   - Include costs for ROW acquisition, utility relocations, and environmental impacts due to construction.
2. Life Cycle Cost
   - Compares intersection control costs including construction, maintenance, and operational costs.
   - NCHRP's Life-Cycle Cost Estimation Tool:
     - For cost parameters, use TxDOT's Road User Costs and NSC's PCE average economic costs per injury severity.
3. Safety Improvement Index (SII)
   - TxDOT's SII Calculator
     - Refer to TxDOT's HSIP Guidelines for CRF, service life, and preventable crash information for countermeasures permitted in the HSIP. Internal TxDOT personnel use the MicroStrategy

SII reports, and external partners use the SII calculator worksheet.

10.3.7 Other Considerations (Impacts)

An alternative may address the intersection needs from an operational and safety perspective, but several other considerations may determine whether it is a practical option to pursue. These include the following:

- ROW, environmental impacts, and construction costs;
- Constructability timelines, staging, temporary traffic control needs, and project delivery;
- Acceptability of the alternative by the public, local jurisdictions, and other stakeholders; and
- Consistency within interregional corridors or other highways where a corridor study has been prepared.

Additionally, the multimodal assessment considers the suitability of each alternative for transit, freight, and other large vehicle operations when applicable. The Stage I scoping analysis with respect to freight and other large vehicle operation can be informed by whether an intersection is part of a designated Truck Route or Over-Size-Over-Weight Route. Transit assessments can be informed by discussions with the transit provider about different treatment options and any operating restrictions associated with different intersection and control types.

Chapter 11
Interchange Analysis

11.1 Introduction

11.1.1 Overview

Interchanges enable movement between two or more grade-separated roadways. Interchanges vary in size and complexity, from directional ramps connecting roadways to multiple intersections and grade-separated facilities. This chapter focuses on two-level interchanges, where an arterial either overpasses or underpasses a freeway or another arterial. This chapter covers the conventional diamond interchange, along with other alternative interchanges that offer safety and/or operational benefits. Analyzing existing interchanges for operational and safety deficiencies leads to improved decision-making in the implementation of treatments to address these issues. Due diligence on interchange planning and comparing multiple alternatives are the first steps toward preventing future issues. TxDOT is implementing the Interchange Configuration Evaluation (ICE) process to streamline the evaluation of interchange alternatives for objective and evidence-based analysis. ICE tools can be seen under Appendix K, Sections 2 and 7.

The purpose of this chapter is to provide information on interchange designs, the methodology behind evaluating the performance of interchanges, using the ICE process (see Chapter 10). and tools available for interchange analysis. The tools presented herein help evaluate alternatives based on operational and safety performance, multimodal needs, cost-benefit analysis, and other considerations. This chapter is intended to be used as a guide for engineers, planners, and stakeholders when planning or evaluating existing or future interchange projects.

11.2 Interchange Configuration Evaluation (ICE) - Context

Interchange and intersection are exchangeable terms in the ICE process. According to FHWA, ICE (see Chapter 10 and Appendix K, Section 7), ICE is a tool that uses data and performance metrics to analyze interchange control and geometric options. ICE provides a transparent and traceable decision process to compare alternative intersection types. Using quantifiable measures (safety, capacity and cost) to evaluate alternatives so that public agencies, engineers, and planners make enhanced and more informed decisions. Quantitative measures are considered alongside qualitative measures such as multimodal needs and community vision goals to provide a balanced perspective when selecting the preferred alternative. It is recommended that the preferred alternative is context-sensitive to its surroundings and users. See FHWA's website under Appendix K, Section 7 – External References for additional technical materials, tools, and information on the ICE framework.

TxDOT's RDM covers additional guidance for TxDOT's approach to alternative intersection design. A link to the RDM is found in Appendix K, Section 7.

Chapter 10 outlines additional ICE process criteria and applicability. Appendix K, Section 1 provides an example of an abbreviated ICE report that applies when the ICE results are clear-cut at Stage 1 with safety as an overriding criterion for intersection control selection.

11.2.1 Types of Interchanges

There are many types of interchanges. This chapter focuses on seven common interchange types (five of which are covered in the HCM): conventional diamond, contraflow left, DLT—diverging diamond, single-point urban, roundabout, Michigan Urban Diamond, and partial cloverleaf. For descriptions on other interchange types, refer to the RDM and FHWA's Alternative Intersections/Interchanges: Informational Report (AIIR) (see Appendix K, Section 7).

A diamond interchange is the most common type of interchange in Texas. At a diamond interchange, both directions of a major road intersect with the same cross street at separate locations, creating two closely spaced intersections. A diamond interchange demands less land area than other interchange types. The distance between intersections in urban and suburban settings is typically a minimum of 300 feet. There are several types of diamond interchanges: conventional, reverse, and spread.

At a conventional diamond, either freeway ramps or frontage roads intersect at grade with the cross street. The intersection of freeway ramps or frontage roads with the cross street can either be controlled by All-Way Stop-Control, Two-Way Stop-Control, Signalization, or Roundabouts. The exit ramp before the intersection is followed by an entrance ramp after the intersection. Figure 11-1 shows a conventional diamond interchange. Figure 11-2 shows a diamond interchange with frontage roads.

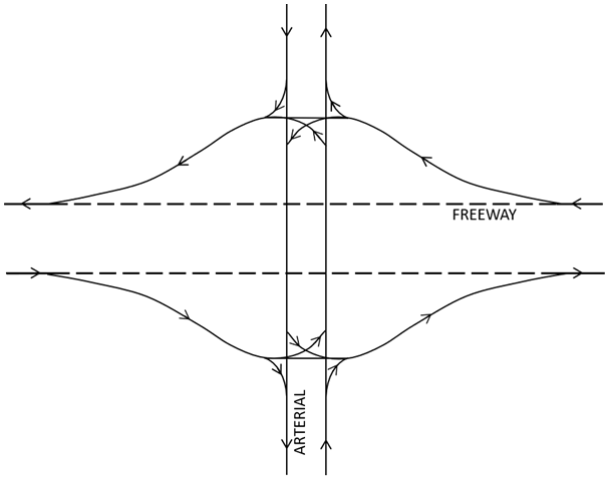


Figure 11-1: Conventional Diamond Interchange

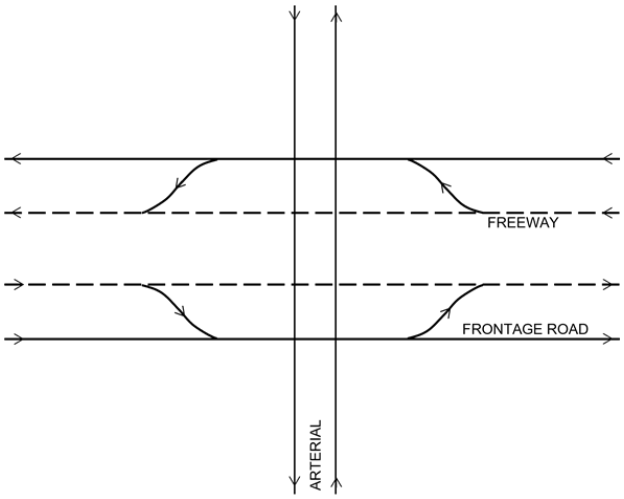


Figure 11-2: Diamond Interchange with Frontage Roads

At a reverse diamond or X ramp arrangement, the exit and entrance ramp locations are flipped so that exiting and entering freeway traffic does not have to pass through the controlled intersections at the cross street or surface level, which reduces queues and delay at intersections. Figure 11-3 shows a reverse diamond interchange. At a spread diamond, the intersections are placed farther apart to improve sight distance and operations.

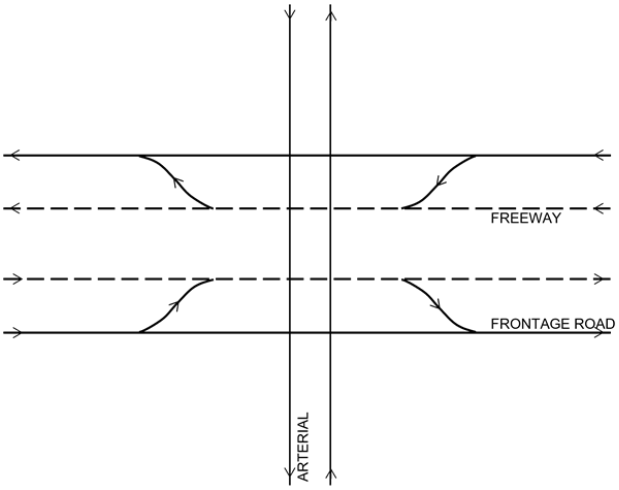


Figure 11-3: Reverse Diamond Interchange

A contraflow left interchange is similar to a conventional diamond interchange. However, the left-turn lane on the arterial crosses the opposing left-turn lane via channelized lanes. Figure 11-4 shows a line diagram with the movements of a contraflow interchange configuration. Contraflow interchanges are useful in areas where there are heavy left-turns from the arterial onto the frontage road and there is not enough space to add dual left-turn lanes. This type of interchange helps overall traffic operations by providing additional queuing space for left-turn lanes and increases efficiency of the signal operations. As with most alternative interchanges, there can be issues with driver expectancy. Drivers turning left from the frontage road may be inclined to turn into the nearest lane, which would be the opposing left-turn lane. Adequate signage and striping is provided for this design to avoid instances where drivers choose the wrong lane

A Displaced Left Turn (DLT) interchange previously called a CFI is similar to a contraflow left interchange, but instead of the left-turn lanes crossing each other, the left-turn lanes cross the opposing through lanes in advance of the intersection. Figure 11-4 shows a line diagram of the movements for a DLT. This configuration allows left turns and opposing through movements to run concurrently, which increases overall efficiency and reduces delay. A DLT also improves safety by spreading out the number of conflicts rather than concentrating them at one location. Drivers may find navigating through a DLT challenging at first, as alternative interchanges are not commonly encountered by most drivers. There are several variations of the CFI, one of which is called the parallel flow interchange, which moves the bypass road adjacent to the cross street instead of adjacent to the approach road. This type of interchange is recommended to be examined when there are heavy left-turn volumes onto the freeway ramps.

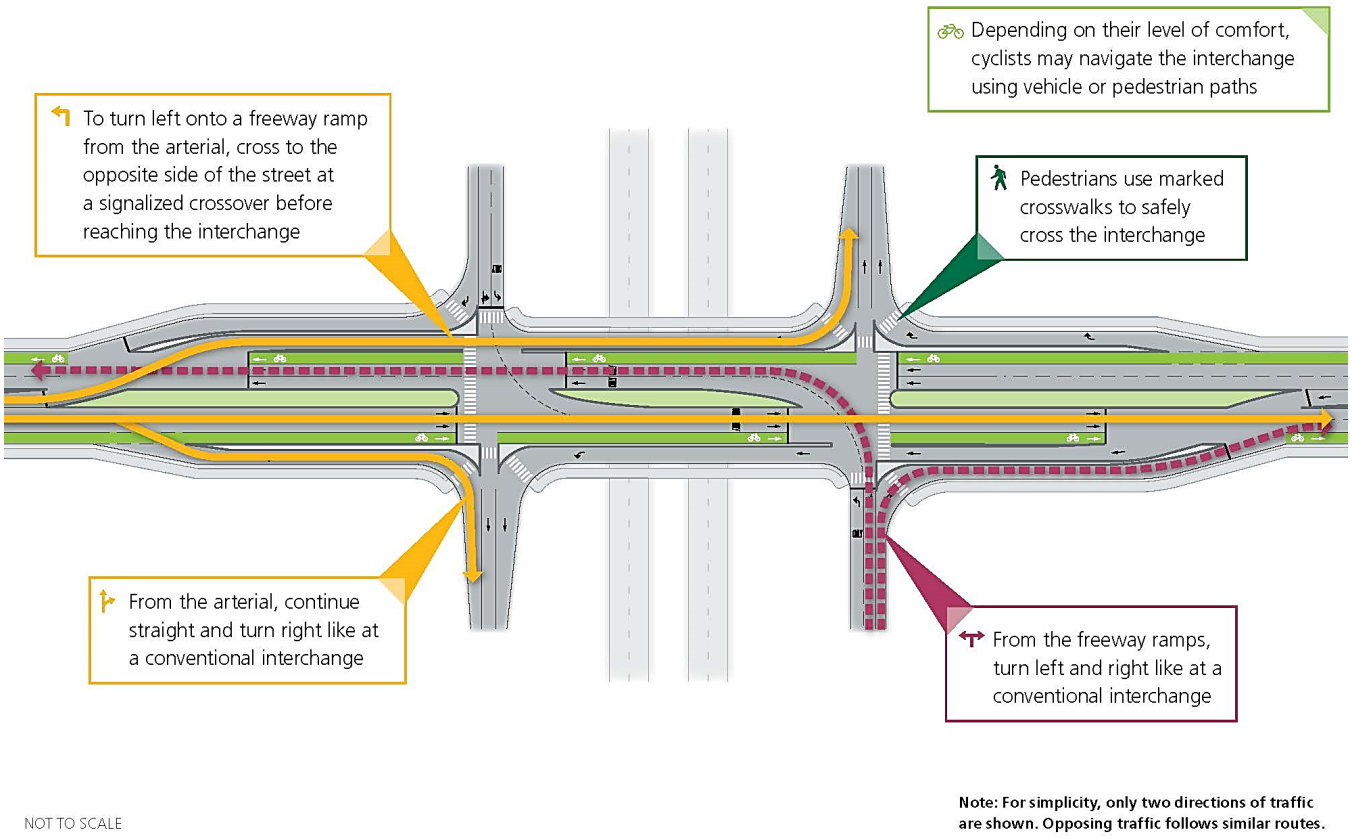


Figure 11-4: Displaced Left Turn (DLT) Interchange

Source: Virginia Department of Transportation, 03/05/2024

At a Diverging Diamond Interchange (DDI), sometimes referred to as the double crossover diamond (DCD) interchange, ramps or frontage roads along both sides of a freeway intersect

with the same cross street at separate locations, creating two closely-spaced intersections like a diamond interchange, as shown in Figure 11-5. The major difference is that, at a DDI, traffic on the cross street externally crosses over to the other side of the street at one intersection and crosses back at the next intersection. This reduces the number of left-turn conflicts by allowing easier access to and from the freeway. Left-turning vehicles from the cross street do not conflict with approaching vehicles from the ramps. Capacity may be adjusted with two-phase signal operations coordinated between crossover intersections. Refer to NCHRP *959 Diverging Diamond Interchange Informational Guide* and TxDOT's *Diverging Diamond Interchange Fact Sheet* (provided in Appendix L, Section 2 – DDI Factsheet) for more information. TxDOT's RDM (see Appendix E) covers additional guidance for TxDOT's approach to DDI design.

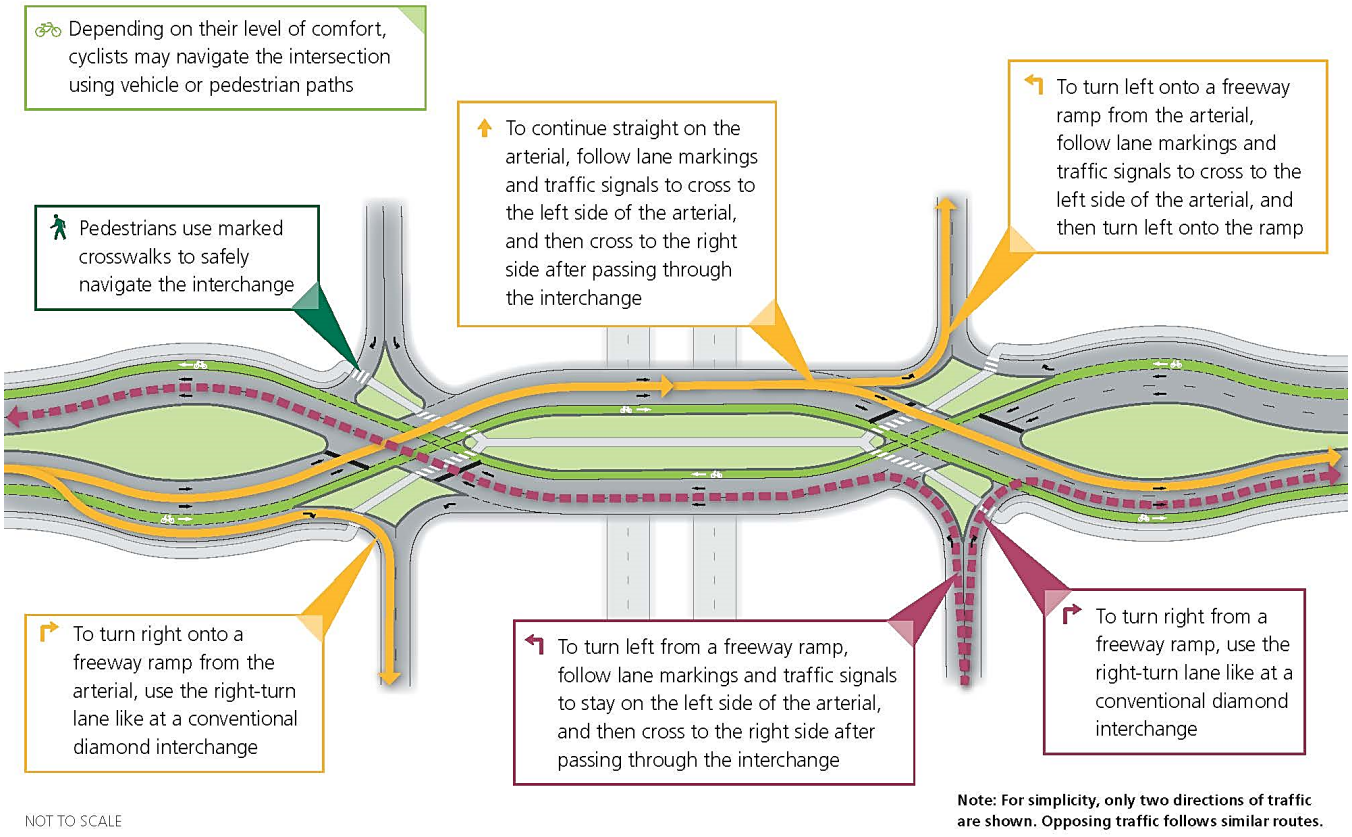


Figure 11-5: Diverging Diamond Interchange (DDI)
Source: Virginia Department of Transportation, 03/05/2024

At a single-point urban interchange (SPUI), one major intersection is created with the freeway ramp left-turn movements and the cross street through and left-turn movements, shown in Figure 11-6. All the right turns are channelized. Freeway mainlanes are grade separated from the intersection. Because a SPUI only has one main intersection, it typically uses less space and simpler traffic signal phasing than the conventional diamond. Phasing has three movements: through movements on the cross street, left turns in one direction, and left turns in the other direction. A SPUI may also accommodate the through movement on frontage roads and/or freeway ramps. However, these movements are separated from the intersection and could be costly. The length of the bridge span for a SPUI is typically 160 to 280 feet. Refer to *TxDOT's Single-Point Urban Interchange Fact Sheet* (provided in Appendix L, Section 3 – SPUI Factsheet) for more information.

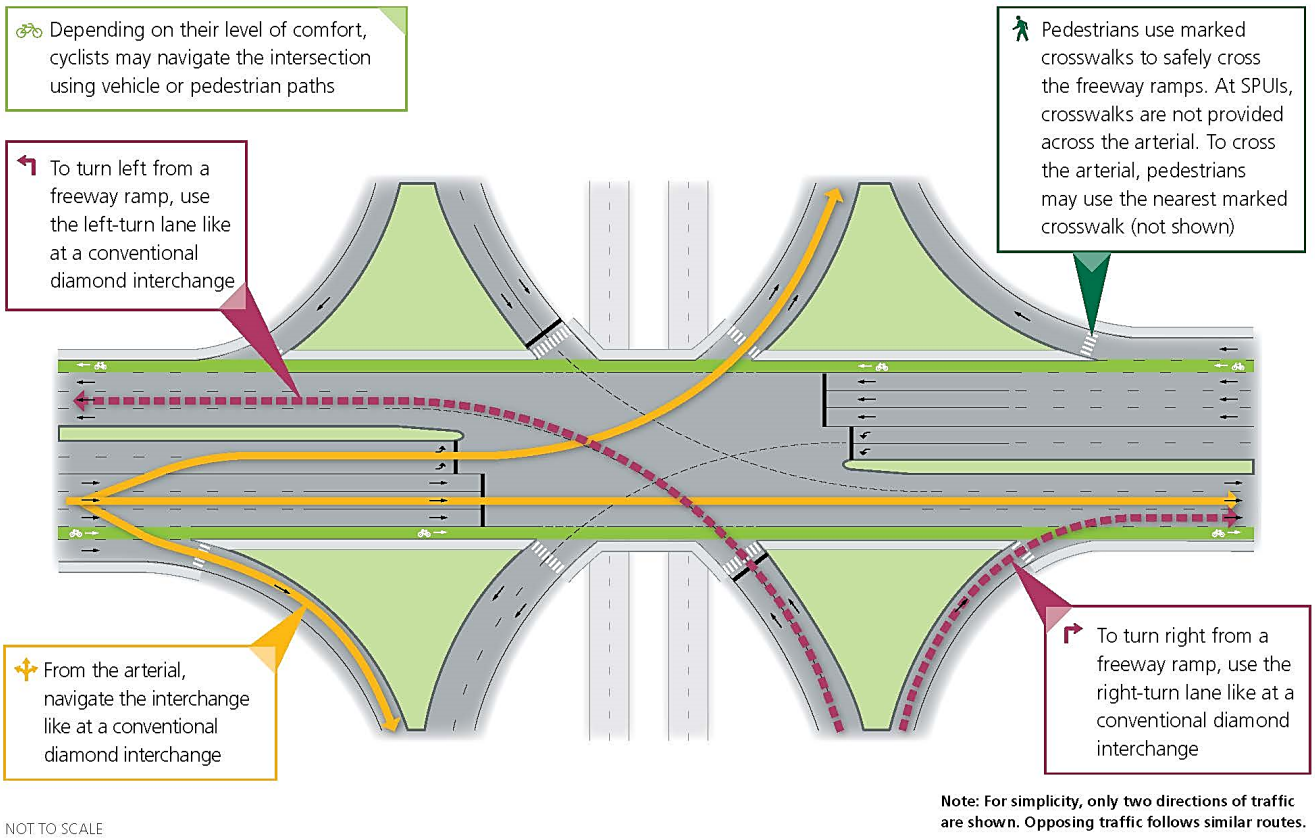


Figure 11-6: Single Point Urban Interchange

Source: Virginia Department of Transportation, 03/05/2024

At roundabout interchanges, there are three main design types: a conventional double roundabout, a raindrop-shaped double roundabout, and a single-point roundabout. The main difference between the conventional and raindrop-shaped roundabout is the conventional roundabout permits U-turns on the cross street at the nodes and accommodates an additional approach. The rain-drop configuration is less desirable because it prevents U-turns and mixes yield control with free-flow regulation of priority. Figure 11-7 shows the double roundabout interchange. See Chapter 12 or NCHRP Report 1043, Section 10.10 for additional information on roundabout interchange analysis.

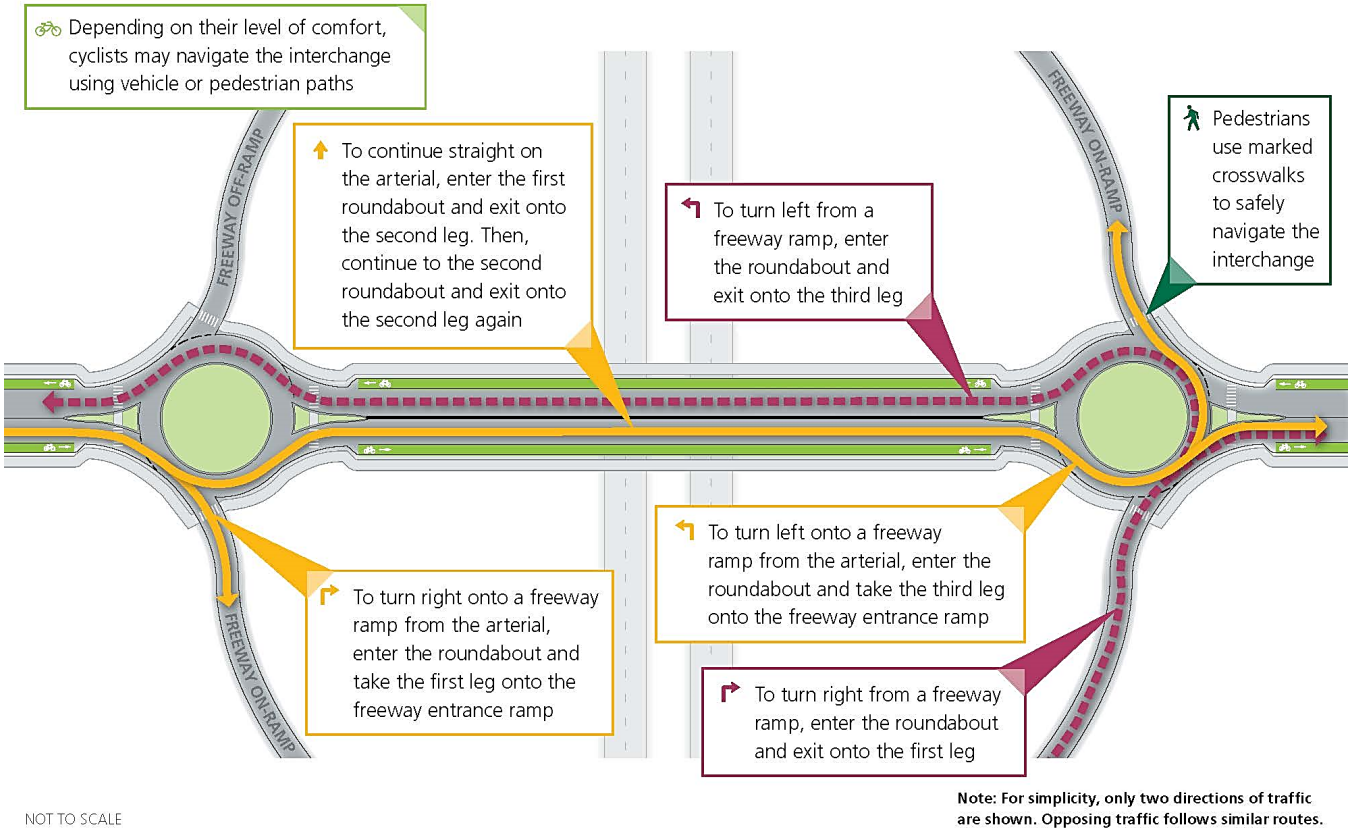


Figure 11-7: Double Roundabout Interchange

Source: Virginia Department of Transportation, 03/05/2024

The single-point roundabout interchange is preferred in areas with ROW constraints and moderate volumes. Single-point roundabout interchanges typically demand larger and multiple bridge spans to accommodate the circle size and sight distance requirements for circulating vehicles. Figure 11-8 shows the single-point roundabout interchange. Roundabout interchanges have been proven as a safety improvement compared to signal control and stop control ramp intersections. This type of interchange could also reduce delay when operating within appropriate range of design volumes, particularly during off-peak hours. They demand fewer lanes (narrower bridge cross-sections) and no signal coordination between the closely spaced ramp intersections. As with all interchange configurations, it is recommended that operational analysis consider potential queue spillback.

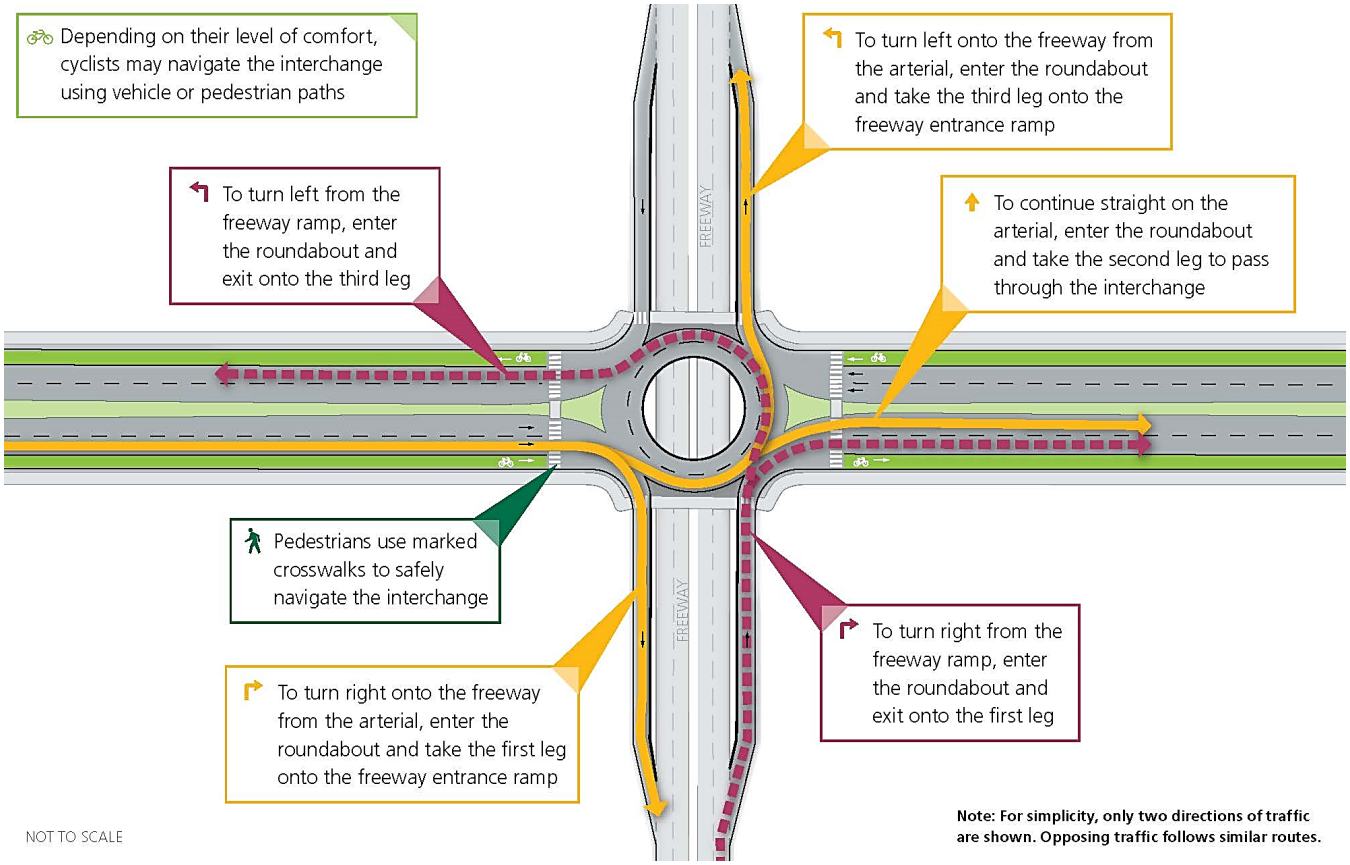


Figure 11-8: Single-Point Roundabout Interchange

Source: Virginia Department of Transportation, 03/05/2024

The Michigan Urban Diamond Interchange facilitates traffic flow and safety by redirecting traditional left-turn movements: drivers intending to turn left onto and off the freeway make a right turn followed by a U-turn at a designated crossover. Right turns are executed in a standard manner, both onto and from the freeway. Through traffic on the arterial road proceeds as it would at a conventional diamond interchange. Pedestrian movement is safeguarded through marked crosswalks, while cyclists have the option to navigate using either the vehicular or pedestrian paths, based on their comfort level. The interchange design aims to streamline vehicular movements, reduce conflict points, and enhance overall traffic efficiency within a compact urban layout. Figure 11-9 shows a Michigan Urban Diamond Interchange.

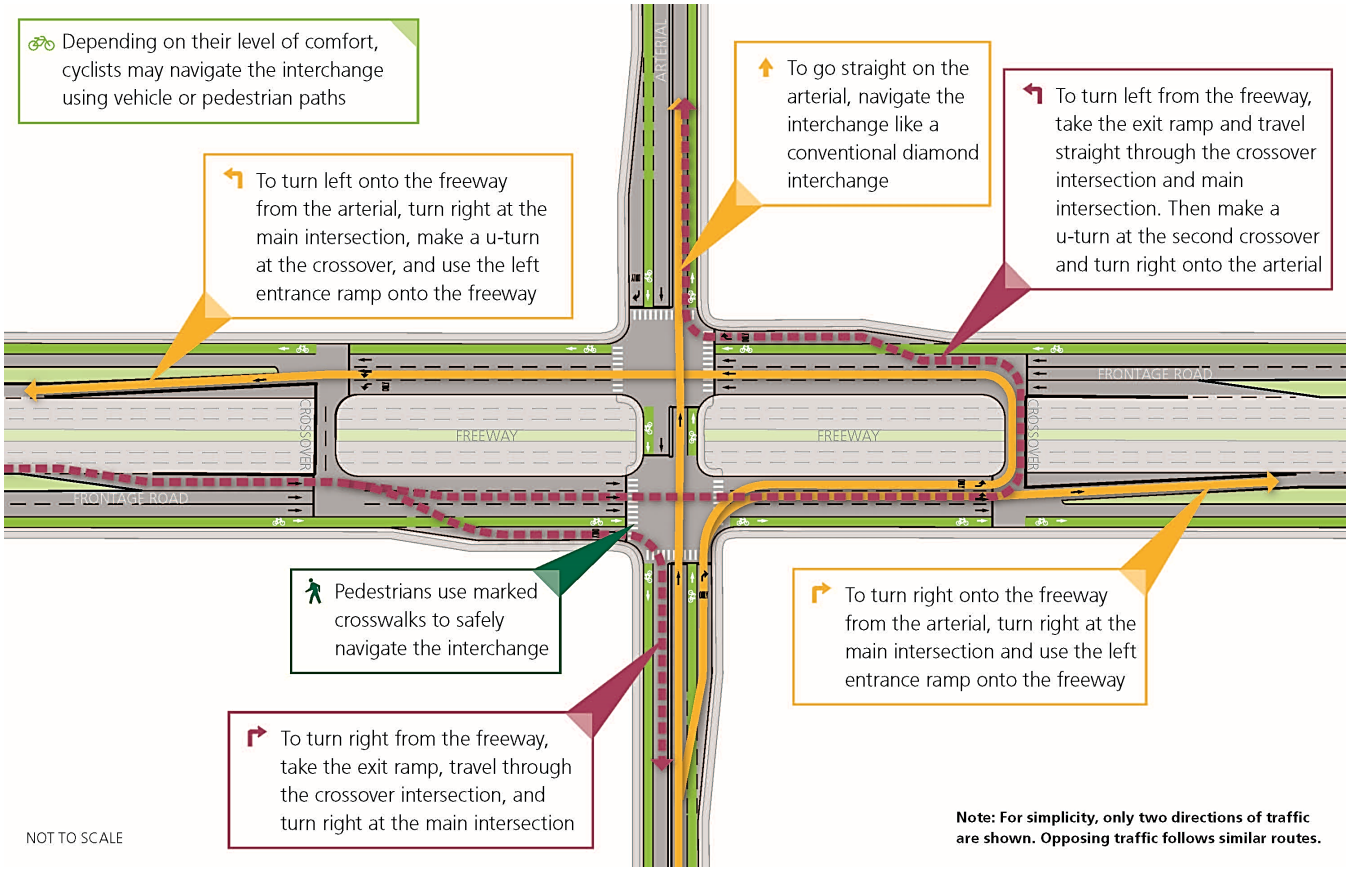


Figure 11-9: Michigan Urban Diamond Interchange
Source: Virginia Department of Transportation, 03/05/2024

At a **cloverleaf interchange**, traffic uses right-turn loop ramps and directional ramps to move between both directions of the cross street and freeway mainlanes, shown in Figure 11-10 and Figure 11-11. A full cloverleaf interchange eliminates all left-turn conflicts (conflict points are a measure of the potential threats of two intersecting roadway configurations). Please note, the full cloverleaf design is not included in HCM 7th Edition due to its freeway-to-freeway interaction.

A partial cloverleaf has loops in one to three quadrants:

- In partial cloverleaf A interchanges, major street loop ramps are in advance of the minor street.
- In cloverleaf AB interchanges, major street loop ramps are located on the same side as the minor street. This type of cloverleaf is shown in Figure 11-12.
- In cloverleaf B interchanges, major street loop ramps occur beyond the minor street. This type of cloverleaf is shown in Figure 11-13.

Cloverleafs are categorized between four and two quadrant partial interchanges. These four quadrant interchanges are addressed as parclo A4 and B4. Parclo A4 contains six ramps and two slip lanes that aid in releasing traffic congestion entering the highway from the arterial. Similarly, B4 mirrors A4, however favors traffic exiting the highway. The two quadrant partial interchanges, A2 and A4 contain four ramps and intend to aid traffic congestion on the highway onto the arterial.

Cloverleaf interchanges are not preferred in locations with high interchange volumes or left-turn volumes exceeding 1,200 passenger cars per hour because loop ramps are usually one lane and have much lower speeds, especially for trucks. Ideally, cloverleaf interchanges can be installed when frontage roads are present for more satisfactory operations. HCM methodology, or other similar methods, may be applied to partial cloverleaf interchanges with either signal or roundabout control.

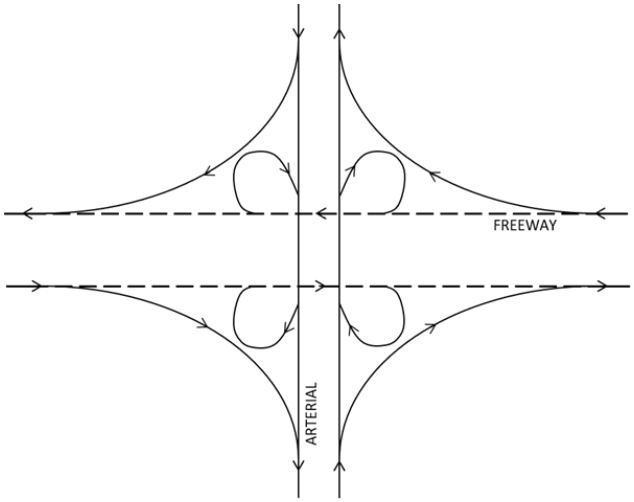


Figure 11-10: Full Cloverleaf Interchange

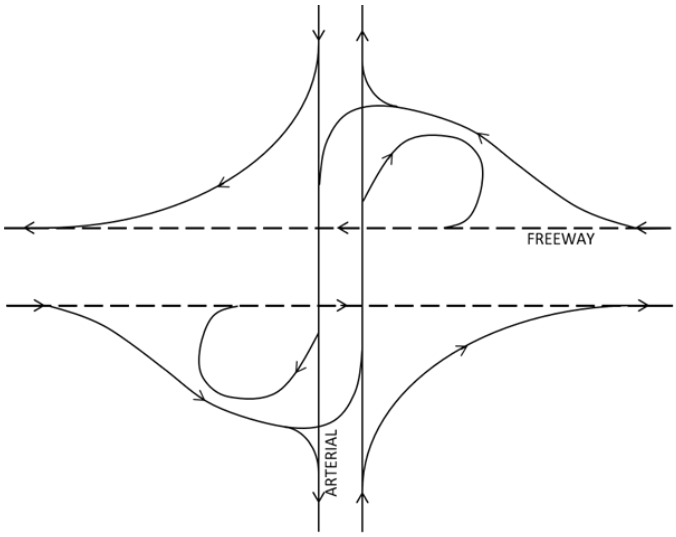


Figure 11-11: Partial Cloverleaf A (4 quadrant) Interchange

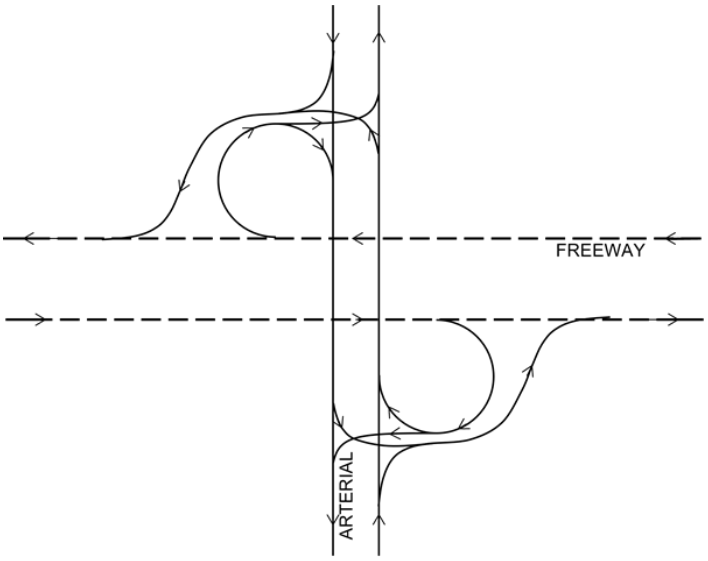


Figure 11-13: Partial B (2 quadrant) Cloverleaf Interchange

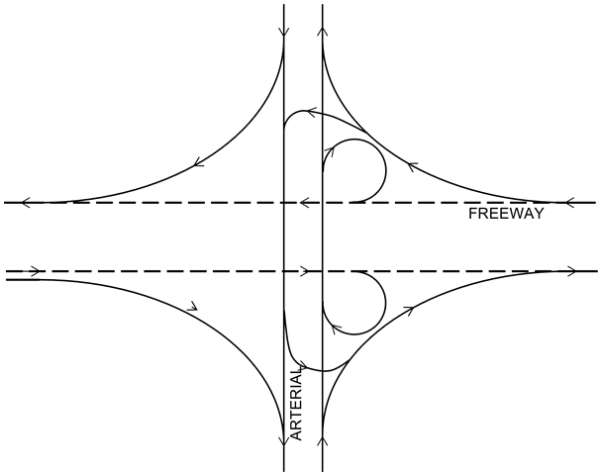


Figure 11-12: Partial AB (4 quadrant) Cloverleaf Interchange

An interchange is often selected based on operational results from tools like CAP-X, HCS, or safety results from HSM-based tools. Initial screening can be done by referencing Table 11-1, which provides information on the benefits of each interchange type and considerations for selecting one. For more information on interchanges, see Appendix L, Section 4 – External References

Table 11-1: Interchange Selection Matrix

Interchange Type	When to Consider	Benefits
Diamond or "X"	• Based on adjacent property access points • Low to moderate traffic • Low-cost solution	• Well-suited for both urban and rural use • Driver expectancy • Flexibility "X" for property access
Contraflow Left	• Heavy left-turning traffic from arterial to frontage/freeway • Enough space available between the interchange to accommodate three-phase signal operations	• Reduced backup and rear-end crashes • Increased efficiency due to three-phase signal operations • Additional queuing space
Displaced Left Turn (DLT)	• Heavy through traffic volumes on the arterial in both directions • Moderate to heavy left-turn traffic from arterial to freeway/frontage, with low to moderate left-turn traffic from freeway/frontage on to arterial	• Spreads out conflict locations • Enables concurrent left-turn and opposing through movements to occur • Improved signal progression on a corridor
Diverging Diamond	• Heavy left-turn traffic from arterial to frontage/freeway • No nearby adjacent signals or driveways	• Two-phase signal operations • Reduces number of conflict points • Reduces delay for left turns to/from freeway/frontage
Single Point Urban Interchange (SPUI)	• Heavy left-turn traffic on arterial and frontage/freeway • Enough space to accommodate wider intersection and structure widths • Limited through demand on ramps/ non-continuous frontage roads	• Vehicles cross path only at one location • Allows for higher capacity of left turns • Improved coordination for arterial
Single Roundabout	• Where ROW is limited • Urban areas with moderate traffic • Heavily used off-ramps • At locations where there are no frontage roads	• Eliminates potential of right-angle and head-on crashes • Decreases delay for traffic exiting the freeway
Double Roundabout	• Heavy left-turn traffic onto frontage/freeway • Limited room between ramps • Heavily used off-ramps	• Eliminates potential of right-angle and head-on crashes • Allows for narrower bridges because it does not demand turning lanes
Partial Cloverleaf	• In areas with abundant ROW • Low to moderate ramp volumes • Low to moderate weaving volumes	• Increases the number of left-turn vehicles that can be processed

11.3 Interchange Configuration Evaluation (ICE)

11.3.1 Process Overview and Reporting

The two-stage ICE study procedure is beneficial for interchange modification, reconstruction or where new construction n is planned.

In Stage 1 the intersection analysis is comprised of operations and safety components:

- Operational analysis using CAP-X and traffic signal warrants per the TMUTCD warrants.
- SPICE

See Chapter 10 for process and data requirements. Appendix L, Section 1 – Interchange Analysis Checklist provides two sample checklists of data required and information to be reported for ICE type studies. Other interchange studies may require a more detailed gathering of information, per Appendix L, Section 1 -Interchange Analysis Checklist – Other Studies. CAP-X is a pass-fail tool and not a ranking tool. The CAP-X LOS results are not granular enough to rank alternatives. SPICE, in Stage 1, can be used as a ranking tool.

Stage 2 ICE includes more advanced safety and operations analysis as needed, along with other factors such as cost and impacts (utilities, ROW, environmental, etc.), as needed. The main tools used in Stage 2 operations analysis are Synchro, HCS, and Vissim. The analysis software tool selection is based on intersection type, project complexity, and object level of detail. See Figure 11-15 for recommended analysis tools. The capability of the software is found in Chapter 4.

Stage 2 Safety analysis and detailed comparison of alternatives uses the FHWA Interchange Safety Comparison Tool (see Appendix L, Section 4).

When both the safety (SPICE) and operations (CAP-X) analyses generate a clear preference for intersection control, Stage 2 ICE investigation may not be necessary and the project can proceed to schematic design and detailed cost estimation. ICE Stage 2 is necessary when a clear preference for safety improvement is not evident in Stage 1, or where more detailed operational or impacts analysis is needed.

11.3.2 Stage 1 Operational Performance and ICE

CAP-X is a Stage 1 ICE spreadsheet-based tool that compares anticipated v/c ratios of various interchange and ramp terminus types. CAP-X analysis determines the interchange type that will provide the most capacity given a set of inputs. CAP-X analyzes multiple intersection types. CAP-X covers initial screening of the following types of interchanges:

- Diamond;
- Partial cloverleaf A and B;
- Displaced left-turn;
- Contraflow left;
- DDI;
- SPUI; and
- Single-point roundabout

CAP-X screens most types of interchanges except for the double roundabout interchange. CAP-X is typically used for initial screening of interchanges, but not for ranking alternatives – just a pass/fail indication. Any additional analysis on interchanges is done in HCM-based (mesoscopic), deterministic, or microsimulation (microscopic) tools. An example output of CAP-X is shown in Appendix K, Section 4 – Sample Output.

11.3.3 Stage 1 Safety Performance and ICE

The Stage 1 SPICE Tool aids in determining a preferred alternative for a given ramp terminal intersection type by providing an objective, quantifiable basis to compare the safety performance of different ramp terminal intersection types. Appendix L, Section 4 provides a link to acquire the SPICE spreadsheet tool. Where ramp terminal intersections are being compared, the tool provides for both ramp terminal intersections to be analyzed and the results combined for the entire interchange.

The tool automates the SPF and CMF selection process. The types of ramp terminal intersection control strategies that can be analyzed include a conventional traffic signal, a crossover traffic signal of a DDI, or stop control on the ramps. As of 2024, SPFs or CMFs are not available for roundabout ramp-terminal intersections. Use the stand-alone roundabout intersection and run it for each ramp terminal, as a suitable substitute until SPICE is updated.

11.3.4 Stage 2 Operational Performance and ICE

At this stage, safety and operations for the short list of alternative interchange configurations are analyzed in more detail. The main tools used in intersection operational analysis are Synchro, HCS, and Vissim. ETT and the effects of varying origin and destination patterns can be accounted for using the methods described in the next sections. The analysis software tool selection is based on ramp intersection type, project complexity, and object level of detail (see Figure 11-15). Information related to the capabilities of the software is found in Chapter 4.

11.3.4.1 Operational Analysis Using Experienced Travel Time (ETT)

LOS for interchanges is based on a combination of guidelines provided in the HCM 7th Edition for isolated intersections and urban segments. Because most interchanges are made up of clustered intersections, each user experiences both control delay at each signalized or unsignalized intersection and extra travel time due to the longer distances between intersections. ETT is a way to measure delay at interchanges, introduced in the HCM. ETT measures both control delay and travel time delay. Appendix L, Section 4 provides ETT computational aids for several alternative intersections and interchanges through the FHWA Techbrief: Publication No.: FHWA-HRT-16-069.The LOS for interchanges is measured in terms of ETT. Computing ETTs makes it possible to compare operations between standard and alternative interchanges that depend on diverted movements and multiple

decision points. ETT is the sum of control delay at every junction and the extra distance travel time (EDTT) through the interchange, as shown below:

$$ETT = \sum d_i + \sum EDTT$$

ETT = Experienced Travel Time (sec)

d_i = control delay (sec) at every junction i encountered by the driver from origin to destination.

EDTT (sec) due to the extra distance necessary to travel between the individual intersections of the interchange.

An ETT calculation example of capturing ETT for one movement going from point A to point D at a conventional diamond interchange is shown in Figure 11-14. The ETT is equal to the control delay of the eastbound left movement at intersection 1 and the control delay of the northbound through movement at intersection 2, plus any EDTT. The EDTT for this movement would be equal to the difference in travel time between the indirect left-turn maneuver and a direct 90-degree left-turn movement from the eastbound approach to the northbound approach.

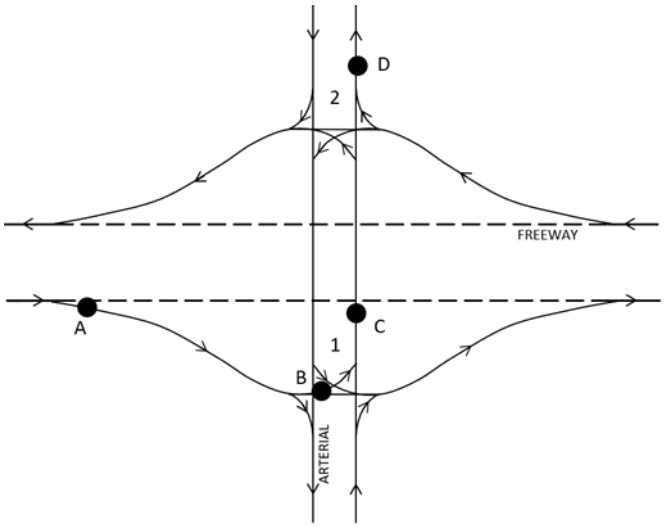


Figure 11-14: Experienced Travel Time at Diamond Interchange

The following equation is applied to calculate the ETT for the movement between points A and D:

$$ETT_{AD} = d_{EBL1} + d_{NBT2} + EDTT_{AD} = d_{EBL1} + d_{NBT2} + (TT_{ABC} - TT_{AC})$$

Where:

ETT_{AD} = Experienced Travel Time from A to D

d_{EBL1} = Eastbound left control delay at first point

d_{NBT2} = Northbound through control delay at second point

$EDTT_{AD}$ = Extra distance travel time between A and D

TT_{ABC} = Travel time along path A-B-C

TT_{AC} = Travel time along (hypothetical) path A-C

11.3.4.2 O-D and Turning Movements

Each turning movement (left, through, right, U-turn) of each approach of an interchange has an origin point at the approach leg and a destination point at the departure leg. Each OD pair experiences delay as it travels through the interchange. The sum of these delays makes up the ETT. The LOS for each OD pair is based on the average ETT of the users completing that movement. Table 11-2 from HCM 7th Edition, Chapter 34, presents a worksheet for converting turning movement volumes to/from OD movement volumes at a diamond (including DDI) interchange. HCM also includes similar worksheets for a partial cloverleaf interchange, a double roundabout interchange, and a SPUI (one input intersection). Once OD volumes are obtained, the performance of various interchange types can be compared. The worksheets accommodate up to the following number of OD movements:

- 16 OD movements for roundabout interchanges (turning left, through, right, or U-turn per approach on four approaches);
- 14 OD movements for diamond (including DDI) interchanges (turning left, though, or right per approach on four approaches and making a U-turn on the major road approaches);
- 12 OD movements for SPUIs (turning left, though, or right per approach on four approaches); and
- 12 OD movements for partial cloverleaf interchanges (turning left, right, or U-turn on major road approaches and turning left, though, or right on minor road approaches)

Table 11-2: HCM Based Worksheet (adapted) for Obtaining OD Movements from Turning Movements for Diamond Interchanges

Input					Output	
	Intersection I		Intersection II			
Approach	Turning Movement	Volume (veh/h)	Turning Movement	Volume (veh/h)	OD Movement Calculation	Volume (veh/h)
Eastbound (EB)	LT		INT-LT		A = (NB LT) – (NB UT)	
	EXT-RT		RT		B = NB RT	
	EXT-TH		INT-TH		C = SB RT	
Westbound (WB)	INT-LT		LT		D = (SB LT) – (SB UT)	
	RT		EXT-RT		E = (EB INT-LT) – (SB UT)	
	INT-TH		EXT-TH		F = EB EXT-RT	
Northbound (NB)	LT		LT		G = WB EXT-RT	
	RT		RT		H = (WB INT-LT) – (NB UT)	
	TH		TH		I = (EB INT-TH) – (SB LT) + (SB UT)	
	UT		UT		J = (WB INT-TH) – (NB LT) + (NB UT)	
Southbound (SB)	LT		LT		K = NB TH	
	RT		RT		L = SB TH	
	TH		TH		M = NB UT	
	UT		UT		N = SB UT	

Note: LT=left turn, RT=right turn, UT=U-turn, TH=through, INT=internal, EXT=external. The flows of the two U-turn movements from the freeway (NB UT and SB UT) are user-specified. Shading indicates movements that do not occur in this interchange form.

11.3.4.3 LOS Guidelines

Roundabout interchanges and signalized interchanges have separate LOS thresholds. LOS is typically found for each OD movement through the interchange rather than individual turning movements occurring at the different intersections. Table 11-3 shows the delay-based LOS criteria for signalized interchanges for each OD pair. LOS is defined as F for any OD pair or lane group that exceeds a volume-to-capacity (v/c) ratio or queue-to-storage ratio of 1.0.

Table 11-3: HCM LOS Criteria for Each OD Pair for Signalized Interchanges

ETT (s/veh)	LOS
≤15	A
>15-30	B
>30-55	C
>55-85	D
>85-120	E
>120	F (v/c > 1)

Table 11-4 shows the delay-based LOS criteria for roundabout interchanges for each OD pair. The LOS criterion is the same regardless of whether the interchange is a single or double roundabout.

Table 11-4: HCM LOS Criteria for Each OD Pair for Roundabout Interchanges

ETT (s/veh)	LOS
≤15	A
>15-25	B
>25-35	C
>35-50	D
>50-75	E
>75	F (v/c > 1)

When evaluating interchanges using deterministic traffic analysis software, the software does not provide ETT as an output. In those instances, manual (spreadsheet) calculation of ETT can be performed based on the outputs provided by the software. If manual calculation is not possible, it is acceptable to report intersection LOS for each intersection of the interchange. However, ETT results are recommended to be reported when analyzing interchanges in Microsimulation (microscopic) analysis software or HCS. Microsimulation (microscopic) analysis is often used for complex geometry, atypical conditions, and oversaturated conditions.

Additional information on LOS methodology for diamond, cloverleaf, diverging diamond, single-point urban, and roundabout interchanges is covered in Chapter 23 (methodology) of the HCM 7th Edition. Chapter 34 (applications) of HCM 7th Edition provides guidance on selecting an interchange type based on operational performance. The LOS methodology does not cover interchanges with two-way stop-controlled intersections, interchanges consisting of both roundabout and signalized intersections, or freeway-to-freeway interchanges. Chapter 38 of the HCM presents methodologies for corridors involving freeways and surface streets, including queue spillback.

Microsimulation (microscopic) analysis is typically used to analyze the impact of queuing.

When calculating LOS for signalized diamond interchanges, it is recommended that coordination with adjacent arterial signalized intersections be considered, along with optimized timing and the appropriate diamond timing sequence for traffic patterns present or projected.

11.3.5 Data Input and Parameters

The general inputs needed to perform traffic operational and safety analysis for interchanges are below.

- Peak hour TMC for all the approaches;
- Distance between intersections of an interchange;
- Number of lanes and lane assignment;
- Heavy vehicle percentages;
- Turning movement speeds and speed limits;
- Pedestrian/bicyclist volumes;
- Number of lanes crossed by a pedestrian/bicyclist;
- Crash records for the preceding three to five years; and
- OD information to discount U-turn movements or properly account for the depending on configuration

11.3.6 Additional Operational Analysis

Many tools are available to perform traffic operational analysis. Depending on the type of analysis and level of detail necessary, different tools are needed. Figure 11-15 below summarizes the overall tool selection process based on interchange type and analysis level of detail. Appendix L, Section 1 – Interchange Analysis Checklist can also be used to guide the operational analysis.

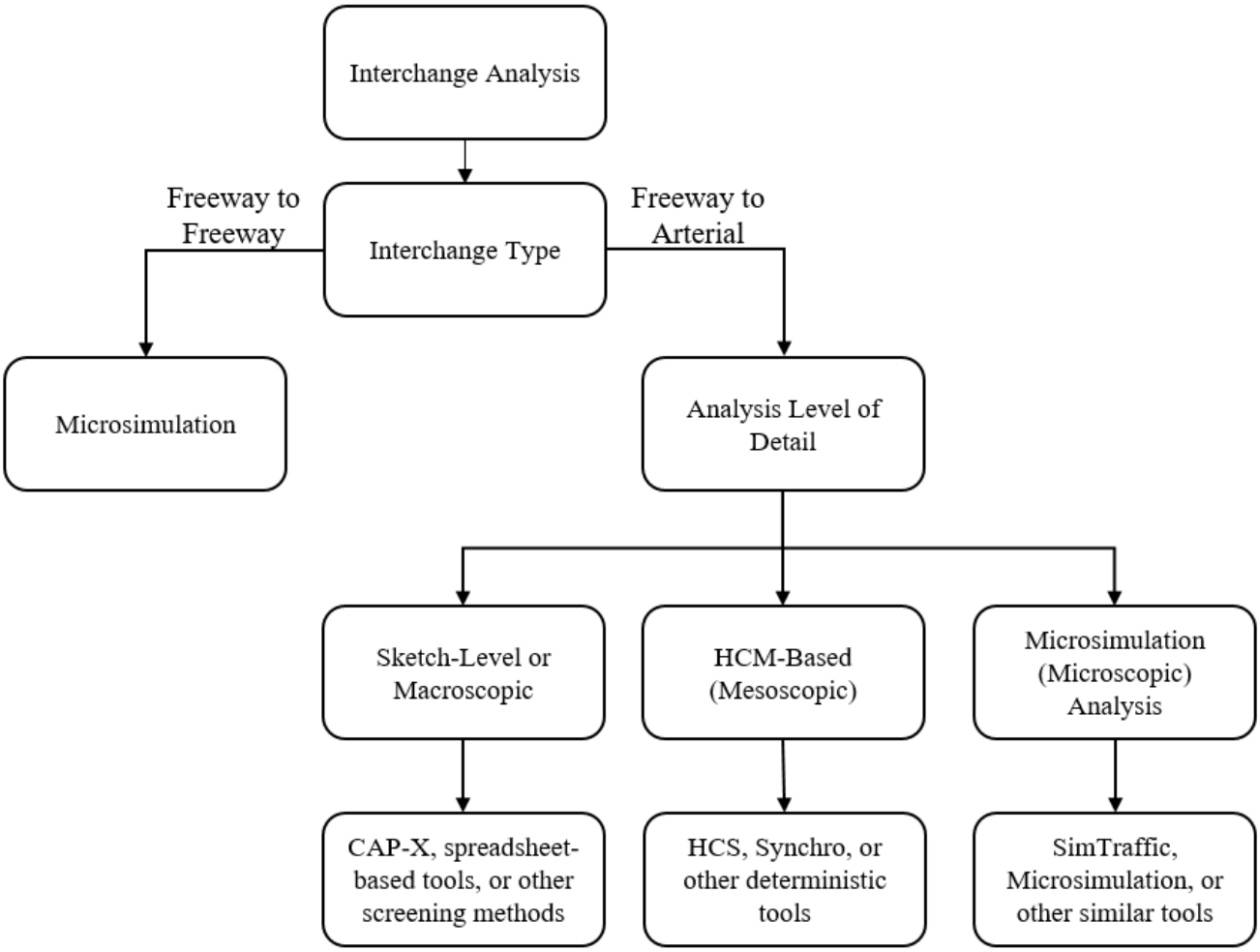


Figure 11-15: Traffic Operational Analysis Tool Selection Flow Chart for Interchanges

The most common tools used for traffic operational analysis for interchanges are HCS, Synchro, and Vissim. A summary of the capabilities of the tools, how the tools can be used, and their limitations is below.

11.3.6.1 HCS

HCS is an HCM-based (mesoscopic) tool that allows for evaluation of several types of interchanges. HCS covers the following interchange types:

- Diamond (stop control, signals, or roundabouts);
- Partial cloverleaf A and B;
- DDI; and
- SPUI (Signals or roundabout)

HCS outputs include traffic operations MOEs (e.g., LOS, delay, queue lengths) and ETT. HCS is one of the only tools that directly reports ETT.

It is important to note that **HCS cannot be used to evaluate oversaturated conditions**, particularly when there is queue spillback

affecting upstream and downstream operations. Other limitations of HCS include analyzing impacts of interchange operations on the arterial street, providing travel time for upstream and downstream links, and interchanges with two-way stop control junctions or combination of signalized and unsignalized junctions. It is recommended to use microsimulation (microscopic) tools in these scenarios.

11.3.6.2 Synchro

Synchro is a deterministic tool that has capabilities for performing HCM-based (mesoscopic) analysis. Synchro evaluates all interchange types mentioned in Section 11.2.1. Synchro analyzes signalized and unsignalized intersection delay for HCM-based (mesoscopic) interchange types (see HCS discussion above). However, Synchro is limited in evaluating and properly reporting results for interchanges with complicated geometry. Results from single roundabout, double roundabout, displaced left turn, and contraflow left turn interchanges may need to be scrutinized further or validated by another tool to confirm the results are reasonable. Similar to HCS, Synchro is limited in evaluating oversaturated interchanges with queue spillbacks that might affect upstream and downstream operations. Unlike HCS, Synchro does not directly report ETT.

11.3.6.3 Vissim

Vissim is a Microsimulation (microscopic) tool and can be used based on the project scope and complexity. Vissim evaluates all interchange types mentioned in Section 11.2.1. Because it is a Microsimulation (microscopic) software, Vissim evaluates oversaturated conditions well when compared to deterministic or HCM-based (mesoscopic) tools. However, Vissim analyses are typically data-intensive and demand more effort. Vissim does not capture real-world rerouting due to extreme congestion. Similar to other analysis tools, Vissim does not directly output ETT, but travel time routes can be set up in the network to account for ETT.

11.3.7 Stage 2 Safety Performance and ICE

Stage 2 safety analysis and detailed comparison of alternatives uses the FHWA Interchange Safety Comparison Tool (see Appendix L, Section 4). This spreadsheet tool, developed through the FHWA's Safety Comparison Between Interchange Types, combines the safety implications of pairs of ramp terminal intersections or overall interchange configuration. This spreadsheet implements the crash prediction models for diamond, tight diamond, roundabout diamond, diverging diamond, single-point diamond, tight diamond, and partial cloverleaf (parclo) interchanges.

11.3.7.1 Conflict Points

Conflict points are a high-level, simple measure of the potential collision or crossing between two intersecting roadway configurations. Conflicts are created at points where users cross, diverge, or merge with another user. Crossing conflict points, which are points that show the crash potential of two opposing traffic streams, often result in higher severity collisions than merging and diverging conflict points, where vehicles are traveling in the same

directions. Table 11-5 presents the number of conflict points based on type of interchange, assuming a single lane in each direction. The number of conflict points vary depending on the number and configuration of lanes. A greater number of conflict points does not automatically result in more alarming operations. For example, although the DDI has more conflict points than a partial cloverleaf interchange, the conflict points are more spread out and so the overall relative exposure is comparable. A conflict points diagram for a single roundabout is shown as an example in Figure 11-16.

Table 11-5 Interchange Conflict Points

Interchange	Diverging	Merging	Crossing	Total
Conventional Diamond	8	8	10	26
Single-Point Urban	8	8	8	24
Single Roundabout	6	6	0	12
Conventional Double Roundabout	8	8	0	16
Cloverleaf	8	8	0	16
Diverging Diamond	6	6	2	14
Partial Cloverleaf (Parclo)	6 (Parclo A4) / 4 (Parclo B4)	4 (Parclo A4) / 6 (Parclo B4)	2	12

Sources: FHWA Signalized Intersections: Informational Guide, FHWA AIIR

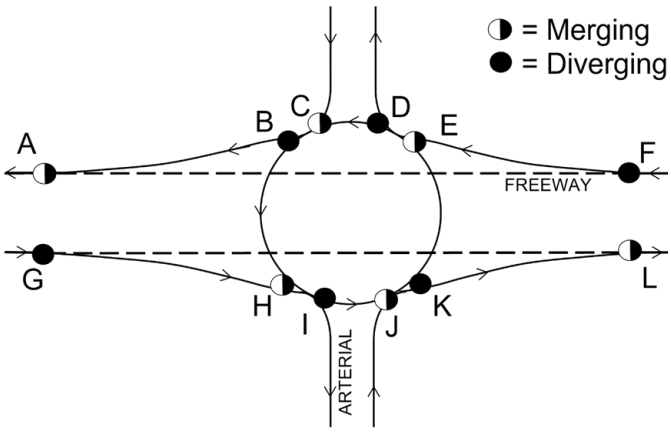


Figure 11-16: Single Roundabout Conflict Points

11.3.7.2 Historical Crash Analysis

A historical crash analysis is completed to identify the types of crashes occurring at an interchange. A crash analysis is typically completed for each separate intersection of an interchange. See Chapter 6 in this manual and Chapter 9 in the HSM for information on the data needed to complete a historical crash analysis, how to calculate an intersection crash rate, and how to create a collision diagram. The HSM tools described in more detail below can also be used to estimate the safety performance of an existing interchange.

The ISATe is useful for safety assessment of ramp terminals. It provides information about

the relationship between roadway geometric design features and safety. This analysis uses design data, traffic control data, cross section data, and up to five years of crash data. The ISATe tool outputs include expected number of crashes for the study period and CMFs related to different geometric design features. It does not account for safety prediction of a frontage road ramp terminal and for roundabouts, nor SPUI's. Appendix L, Section 4 provides a reference to access this safety prediction tool.

The IHSDM can also be used to predict crash frequencies at ramp terminal intersections and compare safety effects of different geometric design features. Roundabouts at freeway ramp terminals can also be evaluated. The tool outputs predicted average crash frequencies for total and fatal/injury crashes. Appendix L, Section 4 provides a reference to access this safety prediction tool.

Additional information related the HSM predictive method, SPFs, CMFs, SPICE, and IHSDM are provided in greater detail in Chapter 5 and Chapter 6 of this manual and additional references are listed in Appendix L, Section 4.

11.3.7.1 Pedestrian and Bicycle Considerations

As of 2024, pedestrian and bicycle LOS for interchanges is not included in the HCM 7th Edition. Pedestrian control delay can be evaluated at individual signalized intersections, and pedestrian crossing delay can be evaluated at unsignalized intersections. The quality of service of pedestrian and bicyclists along the arterial of an interchange can be approximated using HCM's Urban Street Facilities methodologies. CAP-X evaluates the level of pedestrian and bicycle accommodations at a few interchange types. Inputs include number of pedestrian crossings, number of lanes, and vehicle speeds at each crossing.

NCHRP 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges provides additional guidance on accommodating pedestrians and bicyclists at DDI. Refer to Chapter 14 for more information on multimodal accommodations and analysis.

11.3.8 Cost-Benefit Analysis

Another method of alternative analysis for interchanges is a cost-benefit analysis. This is typically done for all interchange analysis that demand analyzing multiple interchanges to select the preferred alternative. All costs associated with an interchange are accounted for and compared when performing a cost-benefit analysis:

- OPCC Perform rough order of magnitude costs;
- Review similar completed projects for an approximation;
- Include costs for ROW acquisition, utility relocations, and environmental impacts due to construction;
- Life Cycle Cost;
- Compares interchange control costs, including construction, maintenance, and operational costs;
- NCHRP's Life-Cycle Cost Estimation Tool (see Appendix L, Section 4);

- For cost parameters, use TxDOT's Road User Costs and the NSC's average economic costs per injury severity; and
- For crash prediction estimates use FHWA's Interchange Comparison Safety Tool, User Guide, 2023. This tool implements the crash prediction models for diamond, compressed diamond, roundabout diamond, diverging diamond, single-point diamond, tight diamond, and partial cloverleaf (parclo) interchanges (see Appendix L, Section 4).

Weigh each cost in relation to its importance to the overall project purpose when comparing alternatives. Collect additional data if needed.

11.3.9 Other Considerations (Impacts)

An alternative may address the intersection needs from an operational and safety perspective, but several other considerations may determine whether it is a practical option to pursue. These include the following:

- ROW, environmental impacts, and construction costs;
- Constructability timelines, staging, temporary traffic control needs, and project delivery;
- Acceptability of the alternative by the public, local jurisdictions, and other important stakeholders; and
- Consistency within interregional corridors or other highways where a corridor study has been prepared.

The suitability of each interchange alternative for pedestrians and bicyclists should be assessed with an emphasis on convenience and accessibility and consideration of pedestrian and bicyclist network information from local and community plans. Potential items to consider include number of lanes to cross, protected versus permitted turning movements, and motorist approach speeds. Additionally, the multimodal assessment should consider the suitability of each alternative for transit, freight, and other large vehicle operations when applicable. The Stage I scoping analysis with respect to freight and other large vehicle operation can be informed by whether an intersection is part of a designated Truck Route or Over-Size-Over-Weight Route. Transit assessments can be informed by discussions with the transit provider about different treatment options and any operating restrictions associated with different intersection and control types.

Chapter 12 Roundabout Analysis

12.1 Introduction

12.1.1 Purpose and Intended Use

The purpose of this chapter is to provide guidance to the user on how to perform a roundabout capacity analysis. This chapter discusses analyzing motorized vehicles as well as guidance on analyzing pedestrians and bicycles within the roundabout context. This chapter highlights typical MOEs and tools used for roundabouts, but it is not exhaustive in presenting available analysis alternatives. This chapter is best used during Planning and Preliminary Schematics.

12.1.2 Limitations

The methods of analyzing roundabouts described in the chapter are primarily based on the HCM 7th Edition. As such, this chapter highlights motorized vehicle analysis while multimodal considerations are limited to level of traffic stress and LOS. Furthermore, this chapter only briefly reviews safety analysis of roundabouts. For more information on safety analysis of roundabouts, see Chapter 5 and Chapter 6. This chapter provides roundabout-specific guidance on Microsimulation (Microscopic) analysis, which can be used to verify results of the empirical method found in the HCM 7th Edition. For general guidance on microsimulation (microscopic) analysis, see Chapter 13.

12.1.3 Intersection Control Evaluation

The Intersection Control Evaluation (ICE) process as described in Chapter 10 and Chapter 11, provides a framework of quantifiable and qualitative measures to evaluate intersection control alternatives so that public agencies, engineers, and planners can make evidence-based decisions. TxDOT employs ICE to determine intersection control type including roundabout feasibility. Roundabout analysis is a part of the ICE process. Roundabout attributes are described in the following sections.

12.1.4 Safety

The reduction in vehicle speeds, conflict angles, and conflict points in a roundabout enhances vehicular and pedestrian safety. Roundabouts provide additional safety for bicyclists due to the slower vehicular speeds, which result in a smaller speed differential between bicyclists and motor vehicles. See Chapter 5, Chapter 6, Chapter 10, and Chapter 11 for more information on roundabout safety analysis.

12.1.5 Roundabout Categories

Roundabouts are an increasingly common form of intersection control that are typically circular, use yield control, and have geometric features that promote desirable vehicular speeds and provide accessibility to all roadway users. Common geometric features of a roundabout

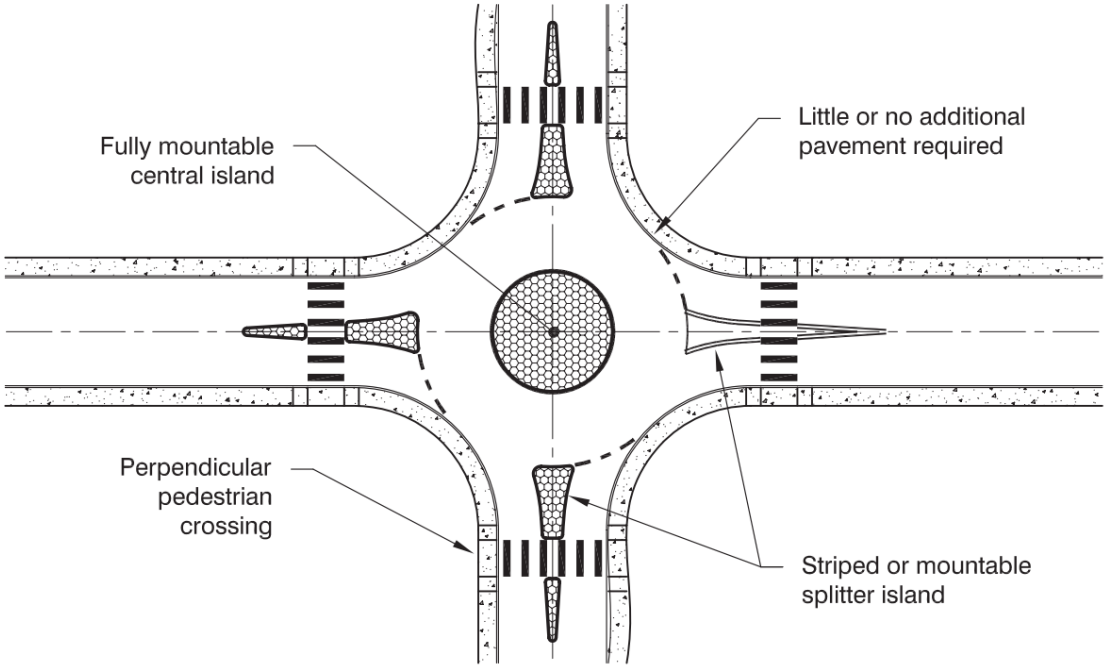
include a central island, traversable apron, splitter islands (channelizing islands), a circulatory roadway, entrance lines, pedestrian crossings, and landscape strips. There are three types of modern roundabouts:

1. Mini-roundabouts;
2. Single-lane roundabouts; and
3. Multilane roundabouts

Roundabouts vary in size, with mini-roundabouts and compact roundabouts ranging from 70 feet to 110 feet in inscribed circle diameter (ICD). Single lane and multilane roundabouts range from 110-feet to 200-feet ICD (refer to RDM Chapter 14). Geometric elements of roundabouts, e.g., are only partially addressed in part with the available operational analysis models. Number of entry lanes is dominant key predictive variable of roundabout capacity.

Roundabouts can handle a wide range of vehicular volumes and provide operational and safety benefits in many circumstances.

Figure 12-1 shows the typical mini-roundabout features, Figure 12-2 shows the typical single-lane roundabout features, and Figure 12-3 shows the typical multilane roundabout features. For information regarding other roundabout design principles, refer to RDM Chapter 14 and NCHRP 1043, Chapter 2. For information regarding roundabout interchanges, see Chapter 11 in this manual.



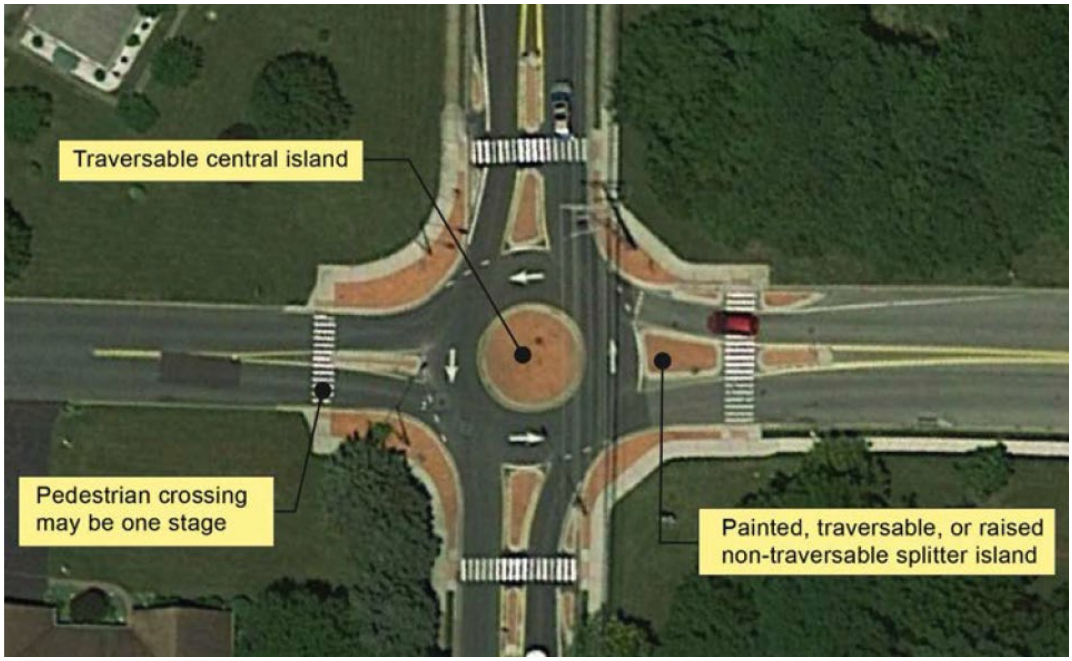


Figure 12-1: Features of a Typical Mini-Roundabout

Source: NCHRP 672 Exhibit 1-10 and NCHRP 1043 Exhibit 2.10

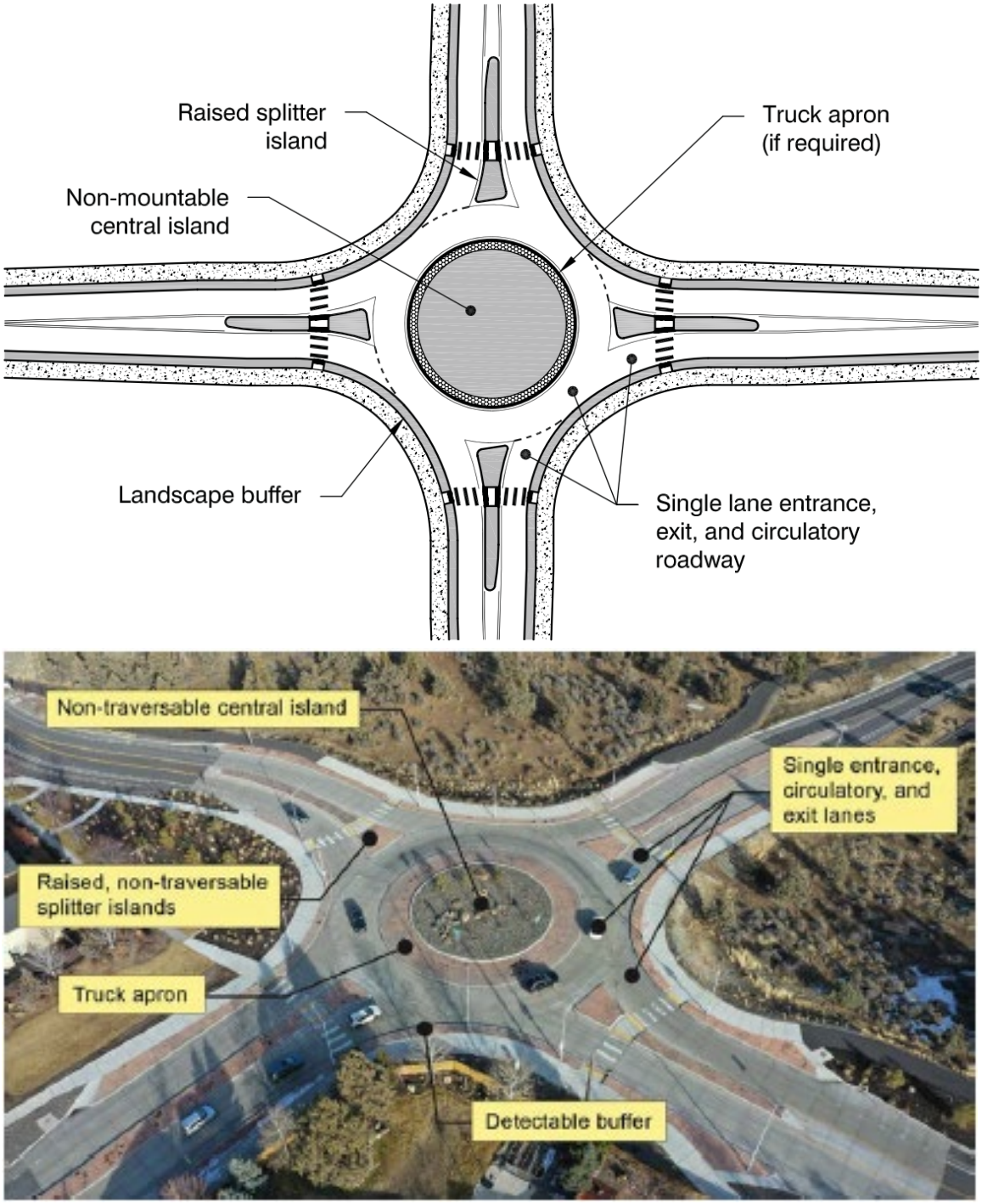


Figure 12-2: Features of a Typical Single-lane Roundabout

Source: NCHRP 672 Exhibit 1-12 and NCHRP 1043 Exhibit 2.15

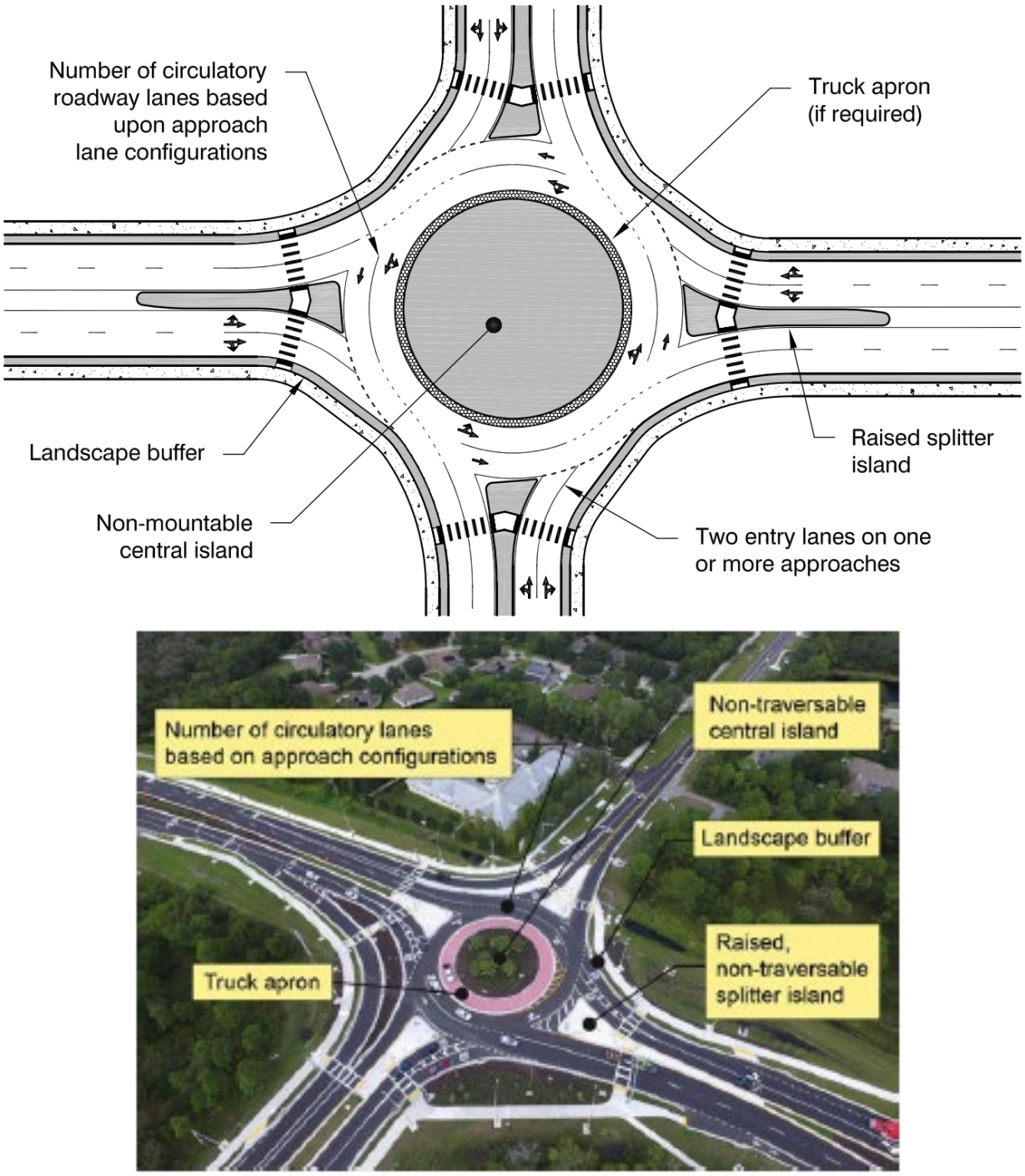


Figure 12-3: Features of a Typical Multilane Roundabout

Source: NCHRP 672 Exhibit 1-14 and NCHRP 1043 Exhibit 2.18

12.1.6 Overview

Roundabout analysis begins with determining whether a roundabout is an appropriate intersection control method for a particular location. See Chapter 10 for guidance on undertaking the ICE process. The prescribed methods in this chapter focuses on roundabout analysis for motorized vehicles, pedestrians, and bicycles. Various methods of analysis are available for the two stages of project development and are discussed in this chapter. See Table 12-1 for the selection of an appropriate analysis tool according to the project planning and schematic development phases of the project development process.

Table 12-1: Project Development and Analysis Methodology

Stage of Project Development Process	Application	Input Data Needed	Potential Operational Analysis Tool
Intersection Control Evaluation (ICE) Stage 1	Sizing of roundabouts – single lane versus multilane	Peak hour traffic volumes	CAP-X, Appendix M
Intersection Control Evaluation (ICE) Stage 2 and Subsequent Geometric Design Refinement	Conceptual design of roundabouts with configurations within the scope of the HCM	Peak hour traffic volumes, lane configuration (multilane) from Appendix M	HCM 6 Capacity Methodology (HCS, Synchro) and other deterministic software models, e.g., Junctions , Sidra
	Conceptual analysis of bicyclist and pedestrian quality of service	Vehicular traffic, bicycle and pedestrian volumes, crosswalk design and traffic control	Techniques in NCHRP 1043 Chapter 9.8
	System analysis with two or more closely spaced intersections	Traffic volumes, lane configuration, intersection spacing and geometry	Simulation (Synchro SimTraffic, Vissim, etc.)

12.2 Motorized Vehicle Capacity Methodology

12.2.1 Overview and Intended Use

This section provides guidance on conducting a daily service volume capacity evaluation, a peak hour service volume capacity evaluation, and basic parameters of using software tools for roundabout analysis (e.g., data input and parameters and reporting MOEs). Section 12.2.2 is intended for use in the ICE Stage 1 analysis of alternatives while Sections 12.2.3, 12.2.4, and 12.2.5 are applied to Stage 2 of project development and again in latter stages of project development.

12.2.2 Computational Steps – Stage 1 ICE

The computational steps make use of the peak hour service volume and capacity evaluation in the FHWA CAP-X model and the NCHRP 1043, Exhibit 8.6, Planning-level sizing guide. For a step-by-step guide on conducting a peak hour volume capacity evaluation, see Appendix M, Section 1 – Planning Level Roundabout Sizing Guide.

12.2.3 Computational Steps ICE Stage 2 and Subsequent Analyses

This section discusses software used for roundabout analysis in Stage 2 ICE and for subsequent purposes related to design

refinement. It includes a basic overview of different software packages, basic input parameters, typical output parameters, and additional external guidance that can be used during analysis. The tools mentioned in this section represent common software used in roundabout analysis, but do not represent all software options that can be used in roundabout analysis. Several different software can be used for roundabout analysis. See Appendix M, Section 2 for a more detailed description of each analysis software package. The selection of software depends on the project type and needs. In addition, when results from one analysis software are on the boundary of indicating a need for additional lanes, use of more than one analysis software is recommended. A summary of commonly used roundabout analysis tools is shown in Table 12-2.

Table 12-2: Roundabout Analysis Tools

Tool	Type	When to use	Notes	Outputs
Highway Capacity Software (HCM 7th Edition)	Deterministic	After CAP-X and planning-level analysis of number of lanes. Use peak hour volumes	Apply software default values for headway and capacity parameters If V/C results > 0.85 use Junctions	V/C, Control delay and LOS, 95% queue lengths by approach
SIDRA Intersection	Deterministic	After CAP-X and planning-level analysis of number of lanes. Use peak hour volumes	Use US HCM model and default HCM headway parameters	V/C ratio, control delay, LOS, 95% queue length
Synchro	Deterministic	After CAP-X and planning-level analysis of number of lanes. Use peak hour volumes	Use software default HCM gap parameters	V/C ratio, control delay, LOS, 95% queue length
Junctions (Assessment of Roundabout Capacity and Delay (ARCADY))	Deterministic	After computational steps are complete and more detail is necessary. For analyzing more than two lanes.	Analyze both the US HCM model and the ARCADY model to create a range of results. Calibrate the Y-Intercept by -10% for build-year conditions analysis and -5% for design year analysis.	V/C ratio, control delay, LOS, 95% queue length
Vissim	Microsimulation	For oversaturated conditions; closely spaced signals and/or roundabouts; complex roadway geometry; or when a visual representation is necessary	Can be accompanied by a deterministic tool (SIDRA, Synchro, or Junctions). Use default headway values	Delay and average network travel time
Synchro/ SimTraffic	Microsimulation	For oversaturated conditions; closely spaced signals and/or roundabouts; complex roadway geometry; or when a visual representation is necessary	Can be accompanied by a deterministic tool (HCM, SIDRA, Synchro, or Junctions). Use default headway values	Delay and average network travel time

12.2.4 Reporting MOEs

Capacity, delay, queue length, and LOS are typical MOEs used in roundabout analysis. Other MOEs may be used if deemed appropriate. Improved operational performance equates to a low volume-to-capacity (V/C) ratio, low control delay, LOS A (best) to LOS D (acceptable), and short queue lengths. Table 12-3 shows tools used for roundabout analysis and their corresponding MOE outputs.

Table 12-3: Analysis Tool Outputs

Tool	Outputs
SIDRA Intersection	V/C ratio, control delay (sec), LOS, 95% queue length (feet)
Synchro	V/C ratio, control delay (sec), LOS, 95% queue length (feet)
Vissim	Average vehicle travel times (sec) and average total delay per vehicle (sec)
Junctions	V/C ratio, control delay (sec), LOS, 95% queue length (feet), crash exposure

12.2.4.1 Entry Capacity

Within the context of this chapter, capacity is the maximum number of vehicles that can pass through a roundabout entry during an interval of time. The computational steps in Section 12.2.2 explain how to determine approximate daily service volumes and peak hour service volumes for a roundabout. Software such as SIDRA, Synchro, or Junctions may also be used for a more detailed determination of capacity. Vissim and SimTraffic do not have a direct entry capacity output and cannot be used to determine exact capacity values for a roundabout.

The volume-to-capacity (V/C) ratio describes the number of vehicles entering from one approach to the roundabout (volume) divided by the maximum number of vehicles that can pass through that same entry during an interval of time, usually one hour. The V/C ratio is typically used as an indicator of the level of saturation of a roundabout entry. If V/C ratio exceeds 0.85, consider delay and queue length more carefully and conduct sensitivity testing using alternate models, geometry and/or unanticipated traffic flows).

12.2.4.2 Delay

Delay is the sum of the deceleration delay, stopped delay, and acceleration delay caused by a roundabout. Geometric delay is not accounted for in the models identified in this section. Delay is calculated using formulas found in the HCM to compute:

- The average control delay for each approach; and
- The overall roundabout control delay

Delay is reported in seconds per vehicle. Values may be rounded to the nearest tenth of a second.

12.2.4.3 Queue Length

Queue length is the number of vehicles waiting to proceed through the roundabout due to congestion. Queue length is typically reported as the 95th percentile queue length and is reported in feet. Queue length is calculated with formulas found in the HCM and is dependent on V/C ratio, capacity, and analysis time period. Queue may be used:

- When calibrating simulation models;

- To determine adequate vehicular storage length based on queue length;
- To determine driveway or through lane blockages; and
- As an MOE

12.2.4.4 Level of Service

LOS is the letter grade assignment (A-F) of roundabout. It is based on control delay caused by a roundabout entry and is assumed to be LOS F if V/C is greater than 1.0. While the LOS A is the most favorable, scores A through D are typically acceptable ranges for LOS. Refer to HCM 7th Edition Chapter 22 for a step-by-step guide on performing manual calculations of LOS for motorized vehicles at roundabouts. SIDRA, Junctions and Synchro determine LOS automatically, while Vissim and SimTraffic can calculate LOS using control delay. The unsignalized LOS thresholds, referred to in HCM 7th Edition Chapter 22, as shown in Table 12-4, apply to roundabout yield control.

Table 12-4: Level of Service Criteria

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio*	
	v/c≤1.0	v/c>1.0
0-10	A	F
> 10-15	B	F
> 15-25	C	F
> 25-35	D	F
> 35-50	E	F
> 50	F	F

Note: *For approaches and intersection wide assessment, LOS is defined solely by control delay

12.2.4.5 Sensitivity Testing

The anticipated operational performance for future conditions considers a sensitivity testing-approach that varies the design year peak period traffic volumes by more or less an assigned percentage (i.e., +/- 30 percent).

This accounts for the uncertainty of future traffic conditions, especially at intersections where a roundabout is installed with adjacent land use that is undeveloped or anticipated to re-develop before the design year. Sensitivity testing may reveal that the chosen entry or a specific lane would experience excessive queuing. Varying the mode to be used for analysis and varying the geometry or lane configuration are also useful sensitivity testing considerations. Often the most probable result is not the exact result produced by any given model, but with a range of results produced by more than one type of model or for more than one geometry.

12.3 Other Modes

While roundabout analysis is mostly limited to the vehicular methodology, there are some considerations available for roundabout analysis of pedestrians and bicycles. These methodologies are generally described in this section and are described in detail in the HCM, NCHRP 616, NCHRP 834, and Mineta Transportation Institute Report 11-19. For more information on multimodal analysis, see Chapter 14.

12.3.1 Pedestrian

High volumes of pedestrians at a roundabout may warrant the need for a LOS analysis, which may be conducted using the guidance found in HCM 7th Edition, Chapter 22, or NCHRP 616, Chapter 8. The methodology in NCHRP 834, Chapter 7 may also be used as an alternative

method of analyzing pedestrian crossing needs, (e.g., need for PHBs at a roundabout). Even in situations where high volumes of pedestrians are not consistent at a roundabout, it is common for a few pedestrians or groups of pedestrians to sporadically interrupt vehicular traffic. Junctions (ARCADY: Assessment of Roundabout Capacity and Delay) or Microsimulation (microscopic) analysis may be used to model the interactions in this scenario. Microsimulation can provide valuable visual and numerical insights on how pedestrians interact with and impact the operations of a roundabout.

An alternative method of multimodal analysis is based on bicycle level of traffic stress (BLTS) and may be applied to pedestrian analysis at a roundabout. The pedestrian level of traffic stress (PLTS) methodology classifies the roundabout into one of four walkability categories. Each of these categories is based on perceived safety issues near the roundabout rather than pedestrian LOS. Characteristics that affect level of traffic stress are sidewalk existence, condition and widths, buffer between the sidewalk and the road, and roadway speed. A level of traffic stress score of 1 indicates that the roundabout is suitable for most pedestrians; a level of traffic stress score of 4 indicates that only able-bodied pedestrians may attempt to cross the roundabout. This methodology is based on the Mineta Transportation Institute, Report 11-19. See Chapter 14 of this manual for more information. Additional analysis methods can be found in NCHRP Research Report 992: Guide to Pedestrian Analysis. It presents a state-of-the-art guide to conducting pedestrian traffic analysis on the basis of volume, safety, operations, and quality of service.

12.3.2 Bicycle

Bicyclists can either use the vehicular travel lanes or the pedestrian sidewalk to traverse the roundabout. In instances where large volumes of bicycles are anticipated to use the sidewalk to traverse the roundabout, slip ramps can be integrated into the roundabout to accommodate the transition from road to sidewalk. When bicycles traverse the roundabout on the road, they are analyzed for capacity similarly to other vehicular traffic. Conversely, when they traverse the roundabout on the sidewalk, they are analyzed as pedestrians. The volume of bicycles that enter the roundabout on the road are included in the vehicular volumes when analyzing roundabouts with the motorized vehicle methodology.

For bicycle LOS analysis, refer to HCM 7th Edition, Chapter 22, or NCHRP 616, Chapter 7.

Chapter 13 Microsimulation Analysis

13.1 Introduction

13.1.1 Overview

Microsimulation is the modeling and analysis of transportation networks and is used to assess the performance of highway and street systems, transit, and multi-modal facilities. These models analyze existing and future conditions and are useful in developing transportation solutions. To create a realistic and dependable model with reliable results, modelers are recommended to properly scope the project, choose the appropriate analysis tool, replicate existing conditions as accurately as possible, complete the analysis, and effectively summarize and document the results.

Microsimulation models are typically complex and demand experience and careful attention to detail to confirm accurate outputs. Because models are largely built on modeler-defined inputs and assumptions, it is recommended that modelers carefully analyze and report results. In addition to requiring strong modeling judgement, model development, debugging, and calibration are also resource-intensive processes. These processes are potentially more resource-intensive than other forms of analysis and it is recommended that care be given when deciding whether microsimulation is the correct method to analyze the project.

13.1.2 Purpose and Intended Use

The purpose of this chapter is to provide guidance on how to perform traffic analysis using microsimulation tools. This chapter discusses traffic analysis on freeways and arterials. Additionally, this chapter explains debugging and calibration methodology, alternative development, and reporting of results. This chapter can be used as guidance on any project that involves microsimulation.

13.1.3 Limitations

Content in this chapter is limited to an overview of how to apply microsimulation to a traffic analysis, including: guidance for scoping microsimulation projects, collecting data, developing the base model, calibrating the model, analyzing alternatives, and reporting results. The guidance provided in this chapter is generalized for all microsimulation software. Further guidance on coding model features not discussed in this chapter can be found in the respective tools' user manuals. See Chapter 2 and Chapter 12 of this manual for information on data collection and roundabouts in microsimulation, respectively.

13.2 Project Scope

13.2.1 Overview

As stated in Chapter 1 of this manual, a project scoping form is typically developed to serve as the project guidance document that includes all elements discussed in the analysis methodology. This chapter outlines scoping guidance specific to microsimulation.

13.2.2 Study Limits

The study limits for a project are determined during the scoping process. The study limits incorporate the project limits plus the area of influence, which have an impact on the operations in the study area. Wherever applicable, it is recommended that the model extends a minimum of one intersection or interchange both upstream and downstream of the farthest intersection or interchange within the study area. Figure 13-1 below shows an example from the FHWA Interstate System Access Informational Guide of potential study limits on an interstate project.

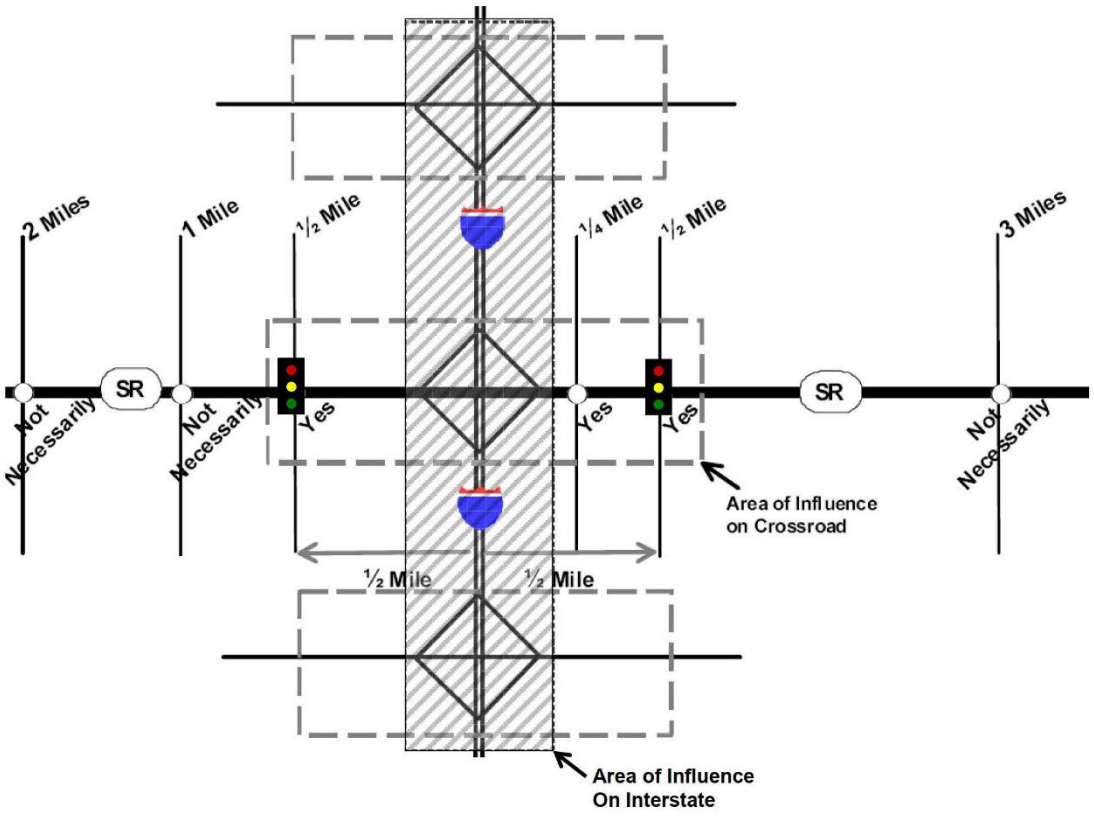


Figure 13-1: Area of Influence

Source: FHWA's Interstate System Access Informational Guide

See Section 13.6 of this chapter for more information about incorporating unmet demand into a microsimulation model. Preferably, travel speeds at the study limits remain near free-flow

speeds throughout the analysis period. This allows the modeler to fully capture the formation and dissipation of congestion within the study area limits.

13.2.2.1 Freeways

It is recommended that models extend at least one interchange (including ramp terminals) beyond the study limit in both the upstream and downstream directions. This additional area is included during the calibration and debugging process, but results are not always reported. All intersections with significant influence on the arrival patterns of vehicles entering the network are typically included in the model. If extending the study limit is not practical, additional information on capturing unmet demand is provided in Section 13.6.

13.2.2.2 Arterials

Arterial model networks typically capture both one signalized intersection upstream and one signalized intersection downstream of the study intersections. If signalized intersections are not present, such as in rural areas, it is recommended that the network capture approximately half a mile of the arterial in both the upstream and downstream directions. Visual inspection of field data is used to determine if more of the roadway network will be included in the analysis. Like freeways, all intersections with significant influence on the arrival patterns of vehicles entering the network are included in the model. Additionally, it is recommended that all resulting congestion during the peak period be captured within the study limits. If congestion is identified on a network boundary, extend the study limits to capture the entirety of the queue. If extending the study limits is no longer practical, additional information on capturing unmet demand is provided in Section 13.6.

13.2.3 Study Time Period

Study time periods are selected such that they include the time prior to the buildup of congestion and end after the dissipation of congestion. A simulation model is developed for a period of time that is necessary to replicate the full extent of congested traffic operations within the study area peak period or peak hour. For models that are oversaturated, the study period is typically expanded to include the buildup and dissipation of congestion. Otherwise, a peak hour analysis and seeding period (the initial time it takes for the model to represent real-world conditions) may be sufficient. The seeding period is typically at least twice the minimum amount of time that it takes one vehicle to traverse the longest extent of the network. The peak hour is defined as four consecutive 15-minute intervals of turning movement traffic count data that represents the highest traffic volume in an hour. A peak period consists of two or more hours, including the time segment when traffic demands are highest and traffic operations are typically sub-standard. Land use adjacent to the project is considered as it may impact not only the time when data is collected, but also which study time period to use.

13.2.4 MOE Selection

As stated in Chapter 4 of this manual, MOE provide information to decision makers on the

performance of the microsimulation model and help determine similarities and differences between alternatives. These MOEs are project- and tool-specific but generally aim to quantify mobility, reliability, and accessibility. Modelers typically measure some or all of the following network MOEs while conducting a microsimulation analysis:

- Control Delay (sec/veh);
    - LOS (A-F) can be derived from control delay by converting all vehicles to passenger car equivalents per the HCM methodology. Otherwise, analysts can note that the LOS used is not equivalent to the HCM methodology.
    - Results from the seeding period are typically excluded when reporting control delay.
- Queue Length (ft);
- Speed (mph);
    - Includes average link speed and average route speed
- Travel Time (sec);
- Total Network Delay; and
- Density (passenger cars per hour per lane or pcphpl)

In addition to network MOEs, link MOEs are used if the results of specific roadway segments are of particular interest. MOEs for links include volume, density, speed, emissions, and relative delay. Add a caveat when reporting density directly from a microsimulation model since microsimulation tools have their own way of interpreting density while the HCM density is based on converting all vehicles to a passenger car equivalent. Network MOEs are also an output from some microsimulation models. These MOEs include environmental MOEs (total emissions released), total number of vehicles, average speed, total stops, average stops, fuel consumption, latent demand, total travel time, and total delay. These MOE types describe the results of the entire network rather than specific intersections or links. See Chapter 4 for additional guidance on MOE selection.

13.2.5 Analysis Tool Selection

Due to the complex and resource-intensive nature of microsimulation tools, carefully consider the tool based on project scope, project schedule, project type, needs, complexity, MOEs, and budget. There is often more than one suitable traffic analysis tool for a given project. Only use microsimulation when necessary.

Microsimulation is often used to analyze locations with the following characteristics:

- oversaturated conditions (traffic volumes over capacity);
- corridors with multiple hours of congestion;
- multilane or two-lane rural roads where traffic signals or stop signs considerably impact capacity and/or operations;
- freeway widening projects;
- access management studies;
- climbing lanes for trucks;

- short through-lane is added or dropped at a signal;
- roundabouts of more than a single lane;
- tight diamond interchanges;
- multimodal operations (transit, pedestrian, bike, freight); and
- atypical conditions

13.3 Data Collection

13.3.1 Overview

Several types of data are necessary to develop a microsimulation model. Necessary data varies on the project scope, complexity, and MOEs. The quality of data collected directly impacts the quality of the analysis, so it is crucial the data collected is reliable. As noted in Chapter 2 of this manual, it is crucial that all data be collected within the same time frame to confirm accuracy and reliability. For guidance on the types of data, their collection methods, and resources, please see Section 2.2.

Chapter 2 of the FHWA *Traffic Analysis Toolbox, Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software 2019* (FHWA 2019 Guidelines) also discusses key steps in the data collection and analysis. The steps it outlines are as follows:

- Identify data sources;
- Assemble contemporaneous data;
- Verify data quality; and
- Identify travel conditions using cluster analysis

These steps are recommended to be followed for all projects that use FHWA approval and can be used for any project. For detailed guidance, refer to Chapter 2 in the *Traffic Analysis Toolbox, Volume III*.

13.3.2 Data Requirements Determination

It is of key importance that sufficient data be collected to calibrate and validate a microsimulation model. Loop counts, video counts, probe-based data, travel time runs, intersection TMCs, and in-person observations are typically performed when field data is collected for microsimulation models. However, with the FHWA 2019 Guidelines, the following data collection sources are recommended to be able to perform cluster analysis and determine travel conditions:

- Demand;
  - Permanent count locations from STARS II within and/or adjacent to the project.
  - Lonestar has data available for urban/metro Districts.
  - OD data from Big Data sources or OD trip tables from TDMs to determine travel patterns.
- Weather;
  - The National Weather Service (NWS) or similar sources for data on precipitation, wind speed, snow, visibility, etc.
- Incident;
  - Local area traffic management centers.
  - TxDOT's CRIS data to identify crashes that occurred on the facility by time of day.

- Transit;
    - Local transit authority for data related to ridership, routes, transit stops, etc. within the study area.
- Freight;
    - Classification counts or permanent counters
    - TxDOT's Statewide Planning Map
- Bottleneck Throughput; and
    - Stationary bottleneck location data within the study area.
    - Bottleneck throughput data via traffic counts upstream and downstream of the bottleneck (within 0.5 miles of the bottleneck and upstream of any major interchanges or intersections.)
- Travel Time
    - Big data sources such as INRIX or others can be used.

FHWA recommends collecting a year's worth of data to perform cluster analysis. Collect at least 100 days of traffic data from permanent counters on STARS II website, Traffic Management Centers, Travel Times from INRIX or other Big Data sources. For projects that require FHWA review or approval, coordinate with FHWA regarding an acceptable data collection methodology if FHWA's data collection recommendations cannot be met.

13.3.3 Standard Analysis Data

Per the FHWA 2019 Guidelines, to mirror real-world conditions, models are typically calibrated to data collected on a single day, rather than an average of multiple days. When multiple days of data are collected, the most representative day is typically selected and replicated in the model. As stated in Chapter 2, for microsimulation projects that require FHWA approval, such as an IAJR, FHWA recommends collecting at least a 100 days of traffic data. The TxDOT permanent count stations may be used to collect the 100 days of data. While this may not be feasible for all microsimulation analysis studies, a minimum of seven-to-14 consecutive days of ADT data is to be collected for key locations along a study corridor. Additional data collection requirements are noted in Chapter 2.

13.3.3.1 Cluster Analysis and Travel Condition

Cluster analysis groups similar objects into respective categories using a statistical method. Cluster analysis determines patterns of association by grouping objects together. Cluster analysis in microsimulation develops multiple clusters that outline different types of travel conditions a road user might experience throughout the year. Examples of travel conditions include the following:

- Medium demand with high precipitation and low travel times.
- High demand, clear weather, and high travel times.
- High demand, clear weather, major incidents, and high travel times.

For cluster analysis, data from multiple sources is used to establish relationships between the different data types and determine different

travel conditions. Therefore, FHWA recommends collecting up to a year's worth of data for the different data types mentioned above. The FHWA 2019 Guidelines include a step-by-step process on how to perform cluster analysis. Perform a representative day analysis for one cluster (travel condition) and meet the calibration criteria for that. See Figure 13-2 for a graphical representation of a cluster analysis. There may be multiple clusters derived from a dataset. Work with the TxDOT project manager to determine how many of the clusters to analyze.

See Appendix N, Section 3 – Calibration Criteria Calculations Example for a table on representative day selection. See Appendix N, Section 5 – Lonestar Data in Cluster Analysis Case Study for an example of how to use TxDOTs Lonestar data for cluster analysis.

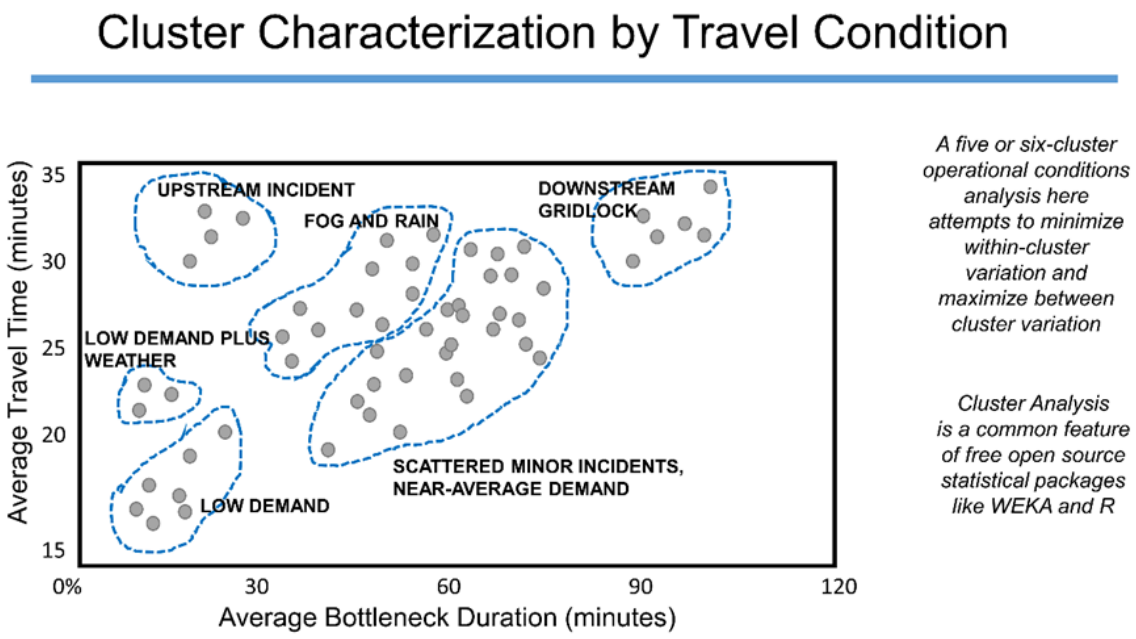


Figure 13-2: Cluster Characterization by Travel Condition

Source: FHWA Cluster Analysis Workshop

13.3.3.2 Selecting a Representative Day

To build a reliable and accurate microsimulation model, it is important to calibrate to a single observed-representative day, rather than the average of multiple days of data. An average of multiple days could create unrealistic performance measures. Additionally, averaging creates the impression of weak bottlenecks with inconsistent time-dependent flow rates.

To select a representative day from the travel conditions, key performance measures used in the cluster analysis are averaged at 15-minute time intervals across all days the data was collected. Then the percentage difference between the average and the observed is calculated. Based on this calculation, the representative day is selected, which is the day with the lowest percentage difference. The process of selecting a representative day is

typically completed by using a cluster analysis, which helps account for variations in data caused by weather, incidents, and construction. For additional guidance on how to complete a cluster analysis, refer to Chapter 2 of the FHWA *Traffic Analysis Toolbox, Volume III*.

An example of selecting the representative day from a single cluster is provided in Appendix N, Section 3 – Calibration Criteria Calculations Example.

13.3.3.3 Base Model Development

The following data is necessary for base model development:

- Road geometry (lengths, number of lanes, lane assignments, curvature);
- Traffic controls (signal timings, stop and yield sign locations, right turn on red (RTOR) designations, speed limits);
- Demand (entry volumes, turning volumes, OD tables);
- Pedestrian (volumes); and
- Transit (type, frequency, location of stops)

In addition to geometric and control data, microsimulation models also demand vehicle characteristics. These typically include:

- Vehicle Mix (% heavy vehicles, % passenger vehicles, vehicle types);
- Vehicle Dimensions; and
- Performance Characteristics

Additional information, such as driver characteristics, may be necessary:

- Driver Aggressiveness;
- Reaction Times;
- Desired Speeds; and
- Acceptable Critical Gaps

13.4 Base Model Development

13.4.1 Overview

A microsimulation analysis typically begins with developing the base model, which includes coding the geometry, conflicts, speed areas, data collection locations, etc. This section outlines the base model development methodology specific to Vissim. However, most of the base model development concepts described apply to other microscopic traffic simulators such as CORSIM, SUMO, AIMSUN, TransModeler and SimTraffic.

13.4.2 Introduction

The steps in base model development are generally as follows:

1. General preparation

   a) Switch units from metric to US Standard

   b) Switch from European fleet to American fleet

   c) Add an ortho rectified aerial background photo

2. Code basic geometry

   a) Roadway links, traffic control, turning movement speeds, link level speeds, etc.

3. Network loading

   a) Network loading in Vissim entails adding different vehicle composition/mixes from counts to the network, adding in the different types of vehicles and classes, and adding vehicle inputs. More detail is provided for network loading later in this section.

4. Set up simulation and run the model

5. Debug

When starting a new model, take note of the current Vissim software version. Once a file is saved to a new version, it cannot be converted back to the old version. It is best practice to keep the Vissim software version consistent between different models used in the same analysis. There is a potential for considerable differences between Vissim build versions based on the car following algorithm and other underlying principles. Vissim build version is recommended to be kept consistent throughout the course of the project to avoid affecting calibration and overall results. Additional information on Vissim can be found in the Planung Transport Verkehr (PTV) Vissim Help Manual. A link to the PTV Vissim Help Manual is provided in Appendix N, Section 4 – External References (Reference 1).

13.4.3 Basic Terminology

13.4.3.1 Links

A link represents a roadway segment. Links carry through movements and follow the general curvature of the roadway. All vehicles, bicycles, and pedestrians follow the path defined by links.

13.4.3.2 Connectors

Connectors are a type of link used to join two separate links. It is best practice to minimize the length of connectors whenever feasible (length through an intersection is the only exception). Connectors are intended to join links, not to serve as analysis segments where vehicles traverse long distances. Connectors are recommended to be used only where needed.

13.4.3.3 Nodes

Nodes are intersections of links and are used to determine intersection performance. It is recommended to establish a node-numbering scheme to facilitate error-checking and the aggregation of performance statistics for groups of links related to a specific facility or facility type. Nodes are drawn to capture all movements at the intersection by including all relevant links.

13.4.3.4 Conflict Areas

Conflict areas dictate how vehicles interact with each other between two links. Conflict areas affect vehicle movements on overlapping links or connectors by defining locations where vehicle movements conflict and determining which vehicle has priority. A conflict area can be used to code a do not block intersection area or a densely spaced urban area with considerable pedestrian interaction.

13.4.3.5 Priority Rules

Like conflict areas, priority rules dictate how vehicles interact with each other between two

links. It is recommended that priority rules only be used when conflict areas cannot reasonably replicate the desired interaction. They are also helpful in coding congested urban environments where it is important to have vehicles not block the intersections or approaches.

13.4.3.6 Desired Speed Decision (DSD)

A desired speed decision (DSD) is a location on a link that, when crossed, will modify the desired speed of a vehicle. A vehicle does not accelerate or decelerate prior to encountering a DSD in anticipation of changing its desired speed. Rather, the DSD permanently updates the desired speed of a vehicle until the vehicle leaves the network or crosses a different DSD. Vissim provides a set of default desired speed distributions. New speed distributions can be created using field data. DSDs can be set for specific vehicle classes.

13.4.3.7 Reduced Speed Areas (RSA)

RSA are zones with a reduced speed. These can be used to temporarily slow the speed of vehicles traversing sharp turns on ramps or turning movements. A vehicle approaching a RSA decelerates in anticipation of it to reach its temporarily reduced desired speed. The RSA assigns a temporary desired speed to the vehicle, after which the desired speed of the vehicle reverts to the original desired speed set by the last DSD or the global network speed. A RSA only affects vehicles with a desired speed greater than the temporary speed assigned by it. If the desired speed is less than the RSA speed, the vehicle ignores it and continues to operate at the desired speed. RSA can be set for specific vehicle classes.

13.4.3.8 Ring Barrier Controllers

Ring barrier controllers (RBC) are used to create signal groups. The *.RBC file contains all the standard parameters of a signal controller with some advanced options. It is best practice to import an *.RBC signal file directly from Synchro as a baseline. It is recommended to check the signal timing in the Vissim RBC file against Synchro as values are sometimes not imported correctly. Save the *.RBC file in the same folder as the Vissim *.INPX file for Vissim to read it during model development and simulation.

13.4.3.9 Signal Heads

Signal heads are typically placed at the same location as stop bars in the field. Modelers then assign signal heads to an *.RBC file. Assign all signal head a signal controller and phase. Signal heads at the same intersection can have the same signal controller number. Signal heads for the same movement can have the same phase number.

13.4.3.10 Detectors

Detectors are used to detect vehicles and activate actuated traffic signals. The detectors are typically the same length and location as the detector in the field. Presence detection zone lengths are typically coded as 30 – 90 ft from the stop bar or from the signal head in Vissim. Advance detection zones should be placed 400 to 600 ft from the stop bar and should not be more than 50 ft in length. The detector is assigned to the same signal controller as the signal with the same port

number as the phase that it activates. For detectors that control pedestrian signals, it is best practice to overlap the detectors with the pedestrian signal heads to make sure that relatively small pedestrians activate the detector.

13.4.3.11 Stop Signs

Stop signs are placed at the same location as stop bars in the field. Dwell time distributions may be assigned to dictate how long a vehicle waits at a stop sign. Stop signs can be accompanied by priority rules and/or conflict areas to control multi-stop movements. RTOR movements are coded by placing stop signs on the right-turn connector and assigning the stop sign to the intersection's signal group.

13.4.4 Basic Geometry – Freeway Coding

13.4.4.1 Merge

Freeway entrance ramp merge areas are coded using connector lane change distance (LCD) in combination with a vehicle route. The effective merging area typically includes the entire auxiliary lane (or lane drop) to the farthest extent of the auxiliary lane taper and capture the full effective length used by vehicles. Vehicles in Vissim use the extra link length, when necessary, which more accurately models the use of the taper area. The merging or weaving section is typically one link with the number of lanes equal to the number of lanes on the main freeway plus the number of lanes merging onto the freeway. There can only be one connector downstream of the merge link or at the end of a lane drop section. There can be two connectors upstream of the merge link, one for the ramp link and one for the main freeway link. Figure 13-3 below shows an illustration of a merge segment.

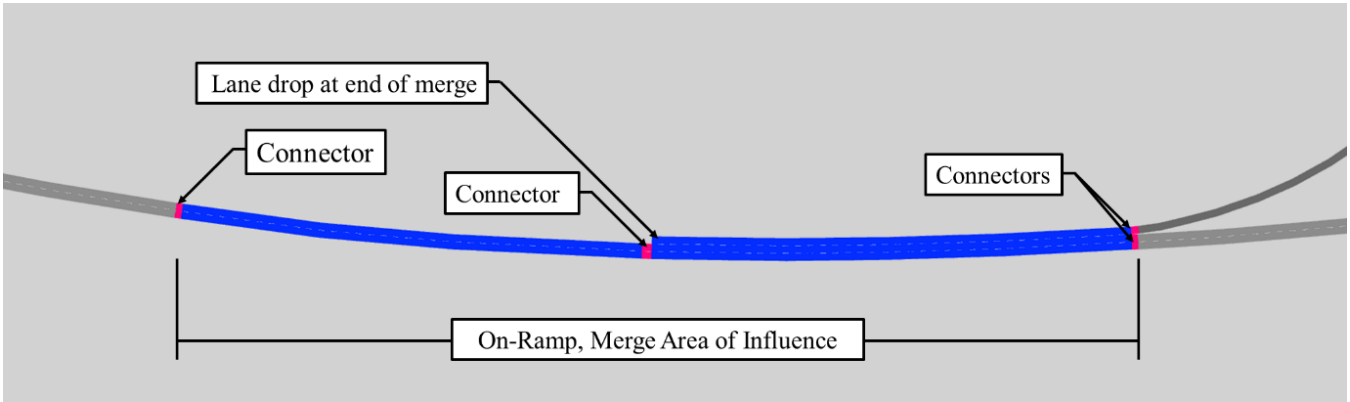


Figure 13-3: Freeway Merge Coding

The modeler typically uses the LCD of the connectors to accurately code the merge/weave area. One of the following two options can be implemented to avoid unrealistic lane changes on the freeway mainline into the acceleration lane:

- In the Connector dialog box, confirm the "Lane Change" distance for the

connector downstream of the merge link is longer than the length of the merge area.

OR

- Indicate “No Lane Change” for the appropriate lane, using the Link dialog box.

13.4.4.2 Diverge

Freeway exit ramp diverge areas (parallel) are coded similar to the entrance ramp merge areas. The effective diverging area includes the entire auxiliary lane (or drop lane) starting at the taper and continuing to the painted gore point. The diverge section is typically one link with the number of lanes equal to the number of lanes on the freeway plus the number of lanes diverging from the freeway. There can only be one connector upstream of the diverge link. There can be two connectors downstream of the merge link, one for the ramp link and one for the main freeway link. The LCD can be coded similar to that of the merge/weave area of entrance ramps such that the distance exceeds that of the diverge area.

Freeway exit ramp diverge areas (taper) are coded using one connector placed at the painted gore point connecting the main freeway link to the ramp link. The main freeway link may not be broken with a connector. An appropriate LCD is recommended to be assigned to the connector to give vehicles enough time to merge to the correct lane to reach the exit ramp. A LCd is assigned such that it reflects the driver expectation and typically matches the location of the first guide or overhead sign indicating the approaching off-ramp. Figure 13-4 below illustrates a diverge segment.

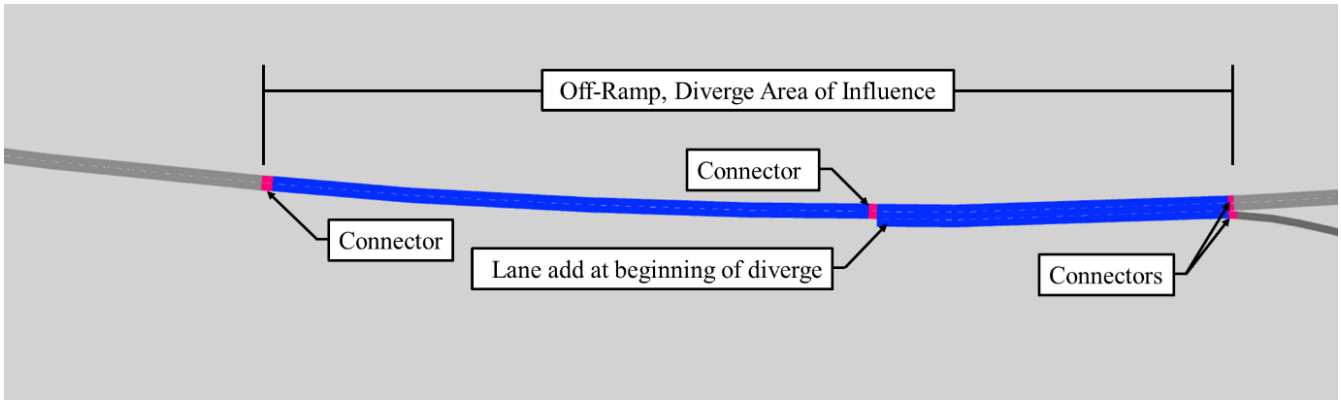


Figure 13-4: Freeway Diverge Coding

13.4.4.3 Weaving

Weave segments follow the same rules as merge and diverge areas. Appropriate LCD is assigned to connectors, so vehicles follow realistic weaving behavior. This can be based on guide sign placements or other driver behavior characteristics of the local area.

13.4.4.4 Managed Lanes

HOV managed lanes are coded by restricting certain vehicle classes from a lane in the link. It is best practice to code a separate HOV managed link display type to show which lane is coded as an HOV managed lane. These lanes can also be coded as an independent link if physically separated from the general-purpose lanes.

13.4.5 Basic Geometry – Arterial Coding

Intersections are coded using different links for each approach that end at the intersection. Links typically should not continue through the intersection and all movements for an intersection should be coded using connectors. For the introduction of additional lanes at intersection approaches, a separate link with the total number of intersection approach lanes is used downstream of the network link, using a single connector to smoothly make the transition. The link with the intersection approach lanes is typically the entire storage length of these lanes plus half the length of the taper for the developing lanes.

Once all approach links have been coded, connectors are used to code all possible movements at the intersection. The modeler typically follows the standard number of splines for each movement (if the standard number of splines does not accurately reflect the movement curvature, a different number of splines can be used):

- 12-point spline for left-turns;
- 8-point spline for right-turns;
- 15-spline for right-turn channelization; and
- 2-point spline for through movements

The modeler connects all connectors to the appropriate lane on the downstream link. For instance, connectors for right-turns connect to the right-most lane of the downstream link and connectors for left-turns to the left-most lane.

An RSA is coded on all turning movement connectors, so that vehicles slow their speed when making a turn. For right turns, 10 mph is typically used as the desired distribution for RSA. For left turns, 15 mph is typically used as the desired distribution for RSA.

13.4.5.1 Traffic Control Devices

Traffic control devices are an important part of network coding. There are numerous ways to code the different traffic control devices such as signalized intersections, AWSC intersections, two-way stop control (TWSC) intersections, roundabouts, etc. in Vissim. Table 13-1 below provides a summary of the main network objects that are used to code the different types of traffic controls and their applications.

Table 13-1: Traffic Control Devices

Traffic Control	Description	Application
Signal Heads	Signal heads are used to code signalized intersections and are assigned to the signal controller created for that intersection. Signal controllers are typically created using an *.RBC file that is imported from Synchro or created based on signal timing plans.	• Used for coding signalized intersections • Can be imported from Synchro or developed natively in file • Is typically placed on top of links and confirm that connectors do not cross the signal head • Is assigned to the corresponding signal group, which includes the signal controller and the signal phase associated with the timing plans
Detectors	A detector is used to model traffic sensors in the field that help detect vehicles for actuated signal operations.	• Is placed directly behind the signal heads and are typically coded to a length of 30 - 90 ft to match the detection area in field. • Is assigned a port number (signal phase) and a signal controller number associated with the signal head and signal timing plan.
Stop Signs	Stop signs are used to model unsignalized intersections.	• Is placed at the location of the stop bar. • Used to model right-turn on red operations. • Used to model AWSC and TWSC intersections.
Conflict Rules	Conflict rules occur where two links or connectors overlap each other. They are initially set to a passive stage. If an actual conflict exists, the rules need to be adjusted to give one movement priority over the other based on the actual ROW for the conflict vehicles.	• Used to model yield conditions. • Is used for all basic types of conflicts such as right-turns, stop control intersections, permissive left-turns at signalized intersections, etc. • Use them were necessary and restrain from exorbitant use of conflict rules as they could lead to gridlock, especially in congested networks.
Priority Rules	Priority rules are similar to conflict rules. They are used to model yield conditions, however, they allow for more customization and are recommended for use in complex situations.	• Used to model yield conditions. • Minimum gaps and headways are typically modified by vehicle type. • Can be tied to specific phases of signal. • Are used for more complicated conflicts that are not easily coded with a conflict rule such as multi-lane roundabout entries, keep clear of intersection, etc.
Roundabout	Roundabouts are typically coded using a combination of links, connectors, and priority rules/conflict areas. There are example demos within Vissim that can be used to understand the principles of coding a roundabout.	• Use priority rules to code multi-lane roundabouts. • Use the HCM critical gap values for starting off points for minimum gaps for roundabouts. Adjust as needed per visual audits and other factors. • Links typically have their attributes modified to not allow lane changes within the circulating lanes. • RSA are typically used to model approach speeds and circulating speeds of a roundabout based on the fastest path/design speed or speed measured in field.

13.4.5.2 Pedestrians

A pedestrian crosswalk is typically coded at an intersection using links that match the width and location of the crosswalk in the field that cross over the leg of the intersection. It is best practice to use a different display type for pedestrian crosswalk links to show that these are separate from the vehicle network links. Signal heads and detectors are used on the pedestrian crosswalk links for pedestrian movements controlled by a pedestrian signal. Conflict areas are coded between vehicle and pedestrian links. It is best practice to give priority to pedestrians by coding the green conflict area for pedestrian links and red for the overlapping vehicle links. However, conflict areas can lead to gridlock in certain situations, such as urban areas and areas with congestion. For those areas, it is recommended to use priority rules to avoid the network from gridlocking.

13.4.5.3 Transit

A transit route is coded to show where a transit vehicle moves within the model. These routes originate from the start of a link and are coded with a departure time, which determines the exact time the transit vehicle enters the network. Transit stops are coded along the network to provide locations where the transit vehicle stops. The duration of the stop is controlled using either a predetermined dwell time or passenger boarding. Dwell time distributions are used to code the predetermined dwell time.

Passenger boarding is coded by adding passengers in the network that board the transit vehicle at the stop. The modeler can toggle the transit stops as active/inactive for specific transit vehicles.

13.4.6 Network Loading

The next step in coding a Vissim model is adding vehicles, bicycles, and pedestrians to the network. For the purposes of this section, the word “vehicles” includes vehicles, bicycles, and pedestrians.

Vissim uses the European fleet as a default when beginning a new network. Change this setting to the American fleet to reflect longer vehicle lengths in America.

2D/3D models are the basis for the vehicle mix in the Vissim model. Each 2D/3D model is assigned a *.v3d model with a length of the vehicle that is simulated in the network. The distribution of the 2D/3D models is assigned using the 2D/3D model distributions, which establish the mix of 2D/3D models that appear in the network. The 2D/3D model distribution is assigned to the Vehicle Types. This provides a variety of vehicle lengths for each Vehicle Type used. For example, there can be several 2D/3D models that represent different models of cars. The 2D/3D distribution determines the ratio of each model of car expected to be seen in the network. The Vehicle Types for cars is assigned to this 2D/3D distribution so that the cars in the network show the correct ratio of each car model.

Vehicle Types are made of 2D/3D models. These aid in setting the variety of vehicles in the network. Vehicle Types are assigned to a

specific Vehicle Composition that is used in a Vehicle Input to appear in the network.

Vehicle Compositions describe the type of vehicles simulated and are made of Vehicle Types. The Vehicle Composition is assigned to each individual vehicle input and determines the flow of different vehicle types. Vehicle Compositions typically have one or more Vehicle Type assigned to it. The Relative Flow determines what portion of the vehicle input volume is simulated as each Vehicle Type in the Vehicle Composition. For example, if a Vehicle Composition has three Vehicle Types with a total Relative Flow of 1 and a Relative Flow for Vehicle Type A of 0.25, then 25 percent of the vehicle input volume associated with that Vehicle Composition is simulated as Vehicle Type A.

Vehicle Classes are used to group Vehicle Types. Vehicle Classes typically contain any number of Vehicle Types, with the option to contain all Vehicle Types. Vehicle Classes provide the basis for speed data, evaluations, path selection behavior, and other network objects. For example, it is possible to restrict a Vehicle Class from entering a specific lane in a network link. The Vehicle Class does not determine the mix of vehicles in the network; this is determined by the Vehicle Composition.

Vehicle Inputs determine the volume of vehicles entering the network. These are assigned to specific links in units of vehicles per hour. Vehicle Inputs can either be stochastic (varies according to random functions based on the seed number for a given run) or exact (exact number of vehicles simulated as indicated by the flow rate). Microsimulation projects typically involve stochastic modeling of vehicle inputs. Figure 13-5 shows the relationship between the different network loading characteristics. Vehicle characteristics are shown in Table 13-2.

Table 13-2: Vehicle Characteristics

Characteristic	Summary
Vehicle Type	Made of 2D/3D vehicle model distribution.
Vehicle Composition	Made up of Vehicle Types. Vehicle composition is used to assign the percentage makeup of the traffic entering the network via Vehicle Inputs.
Vehicle Class	Used to group Vehicle Types; can contain any number (or all) Vehicle Types.
Vehicle Input	Volume of vehicles entering the network; assigned to links in units of vehicles per hour.
Vehicle Route	Determines where vehicles travel in a network. Most common route types are Static and Partial.

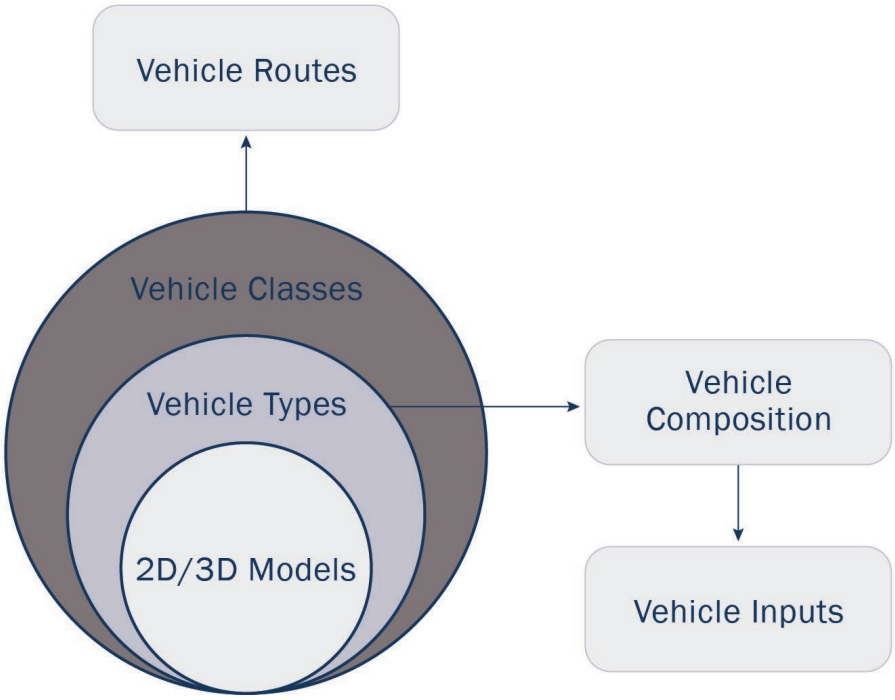


Figure 13-5: Relationship between the different network loading characteristics

Vehicle Routes are coded using Vehicle Routing Decisions and determine where the vehicles travel within the network. Relative Flows determine how many vehicles are assigned to each route based on the total number of vehicles that arrive at the Routing Decision during the time interval. There are many different types of Vehicle Routes, but the two most common are Static and Partial.

- Static Routes are used for base routing of network volumes. Static Routes are chosen to create relay routes that provide a new Routing Decision at each decision point. Static Routes can also be chosen to create end-to-end routes that account for travel patterns in the Vissim network and are often based on trip tables. Vehicle Routes default to the path of least resistance, but routes can be manually adjusted by the analyst. Static routes are typically used when no parallel routes exist in the model.
- Partial Routes are used for a secondary routing system of network volumes. Partial Routes can be used to control the Relative Flow of vehicles that are able to use multiple paths.

It is important to establish a consistent numbering scheme when coding Vehicle Inputs and Vehicle Routes. These numbering schemes are used when assigning inputs and routes at intersections.

DTA can be used in circumstances where parallel routes exist (i.e., multiple paths to and from an OD pair). Setting up a model with dynamic traffic assignment demand

determining an OD matrix, coding nodes at the network corners, inserting nodes at diverging internal paths, and coding zones that are used as the origins and destinations. Using DTA can be a difficult and time-consuming process. It is recommended that DTA only be used if it is critical and cannot be substituted by static or partial routing.

13.4.7 Set up the Simulation and Run the Model

Before running a simulation, set up the desired Simulation Period, Random Seed Increment, and Number of Runs.

- The Simulation Period describes the total simulation time for each model run in simulation seconds.
- The Simulation Period is made up of the Seeding Period (time necessary for the network to become filled with vehicles) and Analysis Period (time that the network is evaluated for performance metrics).
- The Random Seed initializes a random number generator used to vary network conditions assigned using stochastic functions. This creates variations of behavior in the Vissim network that accounts for variations in real-world traffic conditions. The Random Seed Increment defines the difference between different Random Seeds of multiple simulation runs. It is best practice to keep the Random Seed Increment consistent between different models that are compared to one another in the same analysis.
- The Number of Runs determines the number of Random Seeds for the model to may run if the Random Seed Increment is greater than 0. Multiple model runs help account for variations in network operational performance. The variations between model runs result from variations in driver behavior in different Random Seeds. The Number of Runs are calculated based on the number of initial model runs, the mean and standard deviation of the initial run, t-statistic for the desired confidence level, and the tolerance error. More information is provided in Section 13.7.2.

Vissim begins each simulation without any vehicles in the model network, so some period of time is necessary to seed the network prior to collecting operational data. It is recommended that this Seeding Period (warm-up period) be as long as necessary for the model to reach equilibrium. Equilibrium is reached when the number of vehicles entering the network is approximately equal to vehicles exiting the network. The number of vehicles entering and exiting the network are tracked during simulations to determine an appropriate initialization period. As discussed previously, the model simulation includes the build-up of congestion and the dissipation of congestion. Including this warmup and cool down period helps create a more accurate model.

13.4.8 Debugging

An important step after running a model is debugging. This is the process in which coding

errors are identified and addressed. Coding within the network is typically checked so that it conforms to best practices and results in simulated conditions that are consistent with observed field conditions.

The debugging process is recommended to focus on checking the quality of big picture items such as the number of lanes, the RBCs used, and the location and type of DSD. The recommended method for debugging is to complete an initial review of the network prior to running the simulation, observe the model during the simulation, and/or review the error log file that may appear in a pop-up window. It is best practice to document the items checked while debugging.

Common coding errors are typically found in the following model objects:

- Signal timing/Signal Head assignments;
- Conflict Areas;
- DSD;
- Unusual vehicle behaviors due to errors in coding on network; and
- Types of Vehicle Inputs on Links

A checklist for debugging models is provided in Appendix N, Section 1 – Model Debugging Checklist.

13.5 Calibration

13.5.1 Overview

To validate a model's accuracy, the model is recommended to report results that are not only representative of the model but that also match results to real-world conditions. Previous model debugging indicates that reported results are representative of what is occurring in the network which instills confidence in model results. Before a model is deemed reliable, calibrate it to certify that the results match the real-world conditions it was based on. The goal of calibration is to find the set of parameter values that best mimics observed measures. The following section provides guidance on calibration thresholds and methodology. The majority of the discussion in this section is based on the FHWA 2019 Guidelines.

Calibration is the adjustment of various model parameters to improve the accuracy of the model's results. Parameters are modified to create congestion patterns that are accurate to observed data, such as how congestion forms and dissipates over time under specific conditions. Default parameters are not considered calibrated.

Per the FHWA 2019 Guidelines, calibration is applied using data from a single representative day. Model results are analyzed with a single Random Seed run. Note that this is different from the *FHWA Traffic Analysis Toolbox, Volume III* (2004) Guidelines, where model results for calibrated models were analyzed from an average of multiple Random Seed runs. It is still recommended that a model be ran with multiple Random Seeds to check for any errors in coding and errors that might cause gridlock conditions. A few common reasons for gridlock include vehicles, pedestrians, bicycles stuck in an unsolvable conflict, or a missing detector at an actuated,

signalized intersection. The model is typically debugged further before continuing the calibration process.

FHWA 2004 Guidelines may be followed for traffic analysis for TxDOT projects that do not involve FHWA approval. Average day traffic analysis may be performed for these projects. Follow FHWA 2019 Guidelines for projects that involve IAJRs or FHWA approval. The 2019 guidelines require considerably more data than the 2004 guidelines. If sufficient data is not available or practical to collect, then the use of the 2004 guidelines may be requested as an exception for projects that require FHWA approval.

During calibration, solving one issue often highlights new issues elsewhere. It is crucial to strategize calibration by splitting up the process into logical, sequential steps. A good strategy is to:

- Divide model parameters into two categories; and
    - Parameters adjusted during calibration
    - Parameters that are to not be adjusted
- Divide the adjustable parameters into global and local parameters
    - Global parameters are those that affect the entire network (e.g., specific attributes of the representative day covering the entire network)
    - Local parameters are those that affect the parts of the network (e.g., parameter that affects a particular link, movement, speed decision, etc.)

Calibrating a model using DTA is similar to calibration of microscopic traffic simulation models. The basic steps in calibrating a DTA model (as defined in the FHWA *Traffic Analysis Toolbox XIV: Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling*) is as follows:

- Establish calibration objectives and review the project objective to confirm that the calibration task directly supports the project objective.
- Identify the performance measures and critical locations against which the models will be calibrated.
- Determine the statistical methodology to be used to compare modeled results to the field data.
- Determine the strategy for model calibration and identify parameters within the DTA models that are the focus of adjustments.
- Assemble field data previously collected for comparison to model outputs.
- Conduct model calibration runs following the strategy and conduct statistical checks. When statistical analysis falls within the acceptable ranges, the model is calibrated.
- Validation: Test or compare the calibrated model with a data set not used for calibration. If the model replicates the different data set, the calibration parameters and model are validated.

13.5.2 Acceptability Criteria

Effective calibration demands several performance measures for calibration. This section summarizes the *FHWA Traffic Analysis Toolbox, Volume III (2004)* and *FHWA Traffic Analysis Toolbox, Volume III (2019)* Guidelines for calibration. For all FHWA related projects, it is necessary to use the FHWA 2019 Guidelines. For non-FHWA projects, calibration criteria is typically determined during project scoping and based on discussions with the TxDOT project manager. If a non-FHWA project is in an urban area and the data is available, it is recommended to use the FHWA 2019 Guidelines.

13.5.2.1 FHWA Traffic Analysis Toolbox, Volume III (2004) Requirements

The previous FHWA 2004 Guidelines provided guidance on calibrating travel times and throughputs. To consider a model calibrated, at least two metrics are calibrated. The calibration criteria only apply to the peak hour.

13.5.2.2 Travel Time

Travel time calibration criteria are separated into two types of roadway facilities: uninterrupted flow and interrupted flow. To calibrate a model, the allowable travel time variation is measured using the equations shown in Table 13-3.

Table 13-3: Travel Time Calibration Criteria

Facility Type	Equation
Free-Flowing	$\Delta = \frac{1}{\frac{1}{t} - \frac{4.4}{L}} - t$
Interrupted Flow	$\Delta = \frac{1}{\frac{1}{t} - \frac{.1 \times 5280S}{3600L}} - t$

Δ = Allowable Travel Time Variation (+/- seconds)

t = Real-World Travel Time (seconds)

L = Length (ft)

S = Free Flow Speed (FFS) in mph; Posted Speed can be used for FFS if unknown

13.5.2.3 Throughput

To measure and compare field data and simulation throughputs, this guidance uses the Geoffrey E. Havers (GEH) formula. The GEH statistic is typically calculated for mainline segments and ramps. It is recommended that calibration of the model using the GEH formula is calculated to a value of 3 or lower:

$$GEH = \sqrt{\frac{2(m-c)^2}{m+c}}$$

where,

m = output traffic throughput volumes from the simulation model (veh/h/ln)

c = traffic throughput volumes based on field data (veh/h/ln)

Additional criteria for GEH statistics are shown in Table 13-4 and Table 13-5.

Table 13-4: GEH Statistic Guidelines

GEH Statistics	Guidance
< 3.0	Acceptable Fit
3.0 to 5.0	Acceptable for Local Roadway Facilities
> 5.0	Unacceptable

Table 13-5: Throughput Traffic Volume (veh/h/ln) Calibration Criteria

Criteria	Acceptable Targets
GEH < 3.0	All State facility segments within the calibration area
GEH < 3.0	All points of entry and exit locations within the calibration area
GEH < 3.0	All entrance and exit ramps within the calibration area
GEH < 5.0	At least 85% of applicable local roadway segments
Sum of all segment flows within the calibration area	Within 5%

13.5.2.4 FHWA Traffic Analysis Toolbox, Volume III (2019) Requirements

The FHWA 2019 Guidelines has four separate acceptability criteria. These calibration criteria are recommended for projects that involve FHWA review and approval. Each calibration criterion can be applied to all performance metrics that are being used for calibration purposes such as travel time routes, throughputs, etc.

The first two are related to sigma bands and the last two are related to accuracy. Sigma bands contain the number of outliers and inliers in the simulated results. Using graphical representation, the simulated data typically fits between the upper and lower limits of the sigma band criterion.

- Criterion I is Control for Time-Variant "Outliers". The purpose of this criterion is to control for maximum number of outliers associated with the simulation results. To fulfill this criterion, the 2-sigma band criterion, 95 percent of all simulated data points are contained within the 2-sigma band thresholds. Note that if fewer than 20 time-intervals are used for the analysis, then a maximum of one value may fall outside of the time-variant envelope.
- Criterion II is Control for Time-Variant "Inliers". The purpose of this criterion is to constrain the simulated results to fall

closely in line with the representative day. To satisfy this criterion, the 1-sigma band criterion, 66 percent of all simulated data points are contained within the 1-sigma thresholds, and simulated results for 2 non-adjacent critical time intervals are within the time-variant envelope. Figure 13-6 below shows the time-variant envelopes for the representative day travel times for Criterion I (2 sigma band) and Criterion II (1 sigma band).

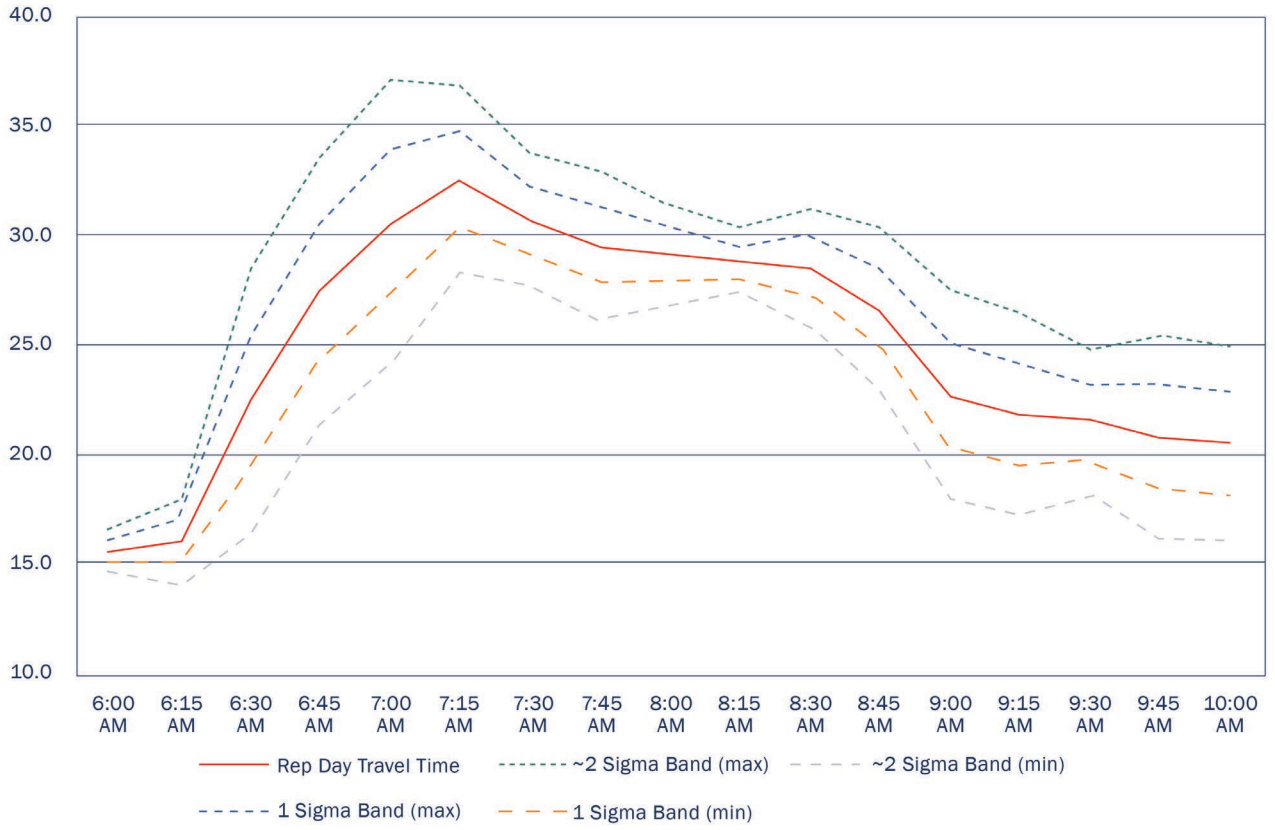


Figure 13-6: Sample Chart Plot of Variation Envelope for Travel Times from FHWA

- Calibration Criterion III is the Bounded Dynamic Absolute Error (BDAE) and verifies that the data accurately captures the data from the representative day. The BDAE is calculated before comparing the simulated results against it. The following equations are used to calibrate for Criteria III and Criteria IV:

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

where,

$c_r(t)$ = Observed value of representative day (r) during time interval *t*

$c_i(t)$ = Observed value of non-representative day (i) within the cluster during time interval *t*

$c_{si}(t)$ = Simulated performance measure during time interval *t*

N_T = Number of time intervals

$N_{cluster}$ = Number of days in the cluster representing this travel condition

Criterion III checks the simulated data with the field data to determine whether it is an overestimate or underestimate for the calibration metrics. The following equation is used to calibrate for Criterion III:

$$\left|\frac{\sum_t c_r(t) - c_{si}(t)}{N_T}\right| \leq BDAE\ Threshold$$

- Calibration Criterion IV, Bounded Dynamic Systematic Error, checks for the simulated data against the field data to determine whether it is an overestimate or underestimate for the calibration metrics. The following equation is used to calibrate for Criteria IV:

$$\left|\frac{\sum_t c_r(t) - c_{si}(t)}{N_T}\right| \leq \frac{1}{3} \times BDAE\ Threshold$$

A detailed **example** of the calibration criteria calculations is provided in Appendix N, Section 3 – Calibration Criteria Calculations Example.

Comparison Summary between FHWA 2004 and 2019 Guidelines:

There are several differences between the FHWA 2004 and 2019 calibration guidelines. Although, calibration is still performed on similar performance measures such as travel time, throughput, queues, etc., the approach is very different when comparing the two guidance documents. Instead of each performance measure having different sets of calibration acceptance targets, all performance measures are analyzed using the same four criteria in the FHWA 2019 Guidelines. The FHWA 2019 Guidelines also has a heavy emphasis on collecting a larger amount of data for calibration. Table 13-6 shows a comparison between the two guidance documents.

Table 13-6: FHWA Calibration Criteria Comparison Between 2004 and 2019 Guidelines

Calibration Parameter	2004	2019
Calibration for an average day	X	
Calibration for a single representative day		X
Hourly flows (individual links and sum of all links)	X	
Travel times (within 15%, or 1 min, if higher)	X	
GEH statistics (individual link flows and sum of all link flows)	X	
Visual audits (queues/bottle necks)	X	X
Bottleneck throughputs	X	X
Calibration for saturation flow rate	X	X
Criterion I – Control for time-variant outliers		X
Criterion II – Control for time-variant "inliers"		X
Criterion III – Bounded Dynamic Absolute Error (BDAE)		X
Criterion IV – Bounded Dynamic Systematic Error		X

13.5.3 Calibration Parameters and Best Practices

Calibration demands several iterations of adjustments to calibrate to real-world conditions. There are several model parameters that are typically attuned to the collected field data. The calibration of a model relies on the data collected. Table 13-7 presents various calibration measures and potential data sources

Table 13-7: Various Calibration Measures and Potential Data Sources

Calibration Measure	Facility	Potential Data Sources	Potential Output Files
Volume/Throughput	Freeway/Ramps	Tube or video counts	Link evaluation, Data collection points
	Arterials/Intersections	Tube, video, or manual counts	Link/node evaluation, Data collection points
Travel Times	Freeways/Arterials	Field Travel Time Runs or Probe Data	Travel time segments
Speed/Congestion	Freeways/Arterials	Spot-Speed Data Collection or Probe Data	Data collection points, Travel time segments
Bottleneck Locations	Freeways/Arterials	Field photographs/videos/notes or recent peak period aerial imagery (if available)	Visual inspection of model

Microsimulation calibration best practices are summarized below:

- Select key performance measures for each project. Calibrate selectively for those performance measures.
- Use reliable observed data for the performance measures used for calibration.
- Calibrate based on study area dynamics (bottleneck throughput or duration) and time-variant (travel time, speed) performance measures.

- Use a representative day for calibration rather than an average day that combines multiple days.

The following sections outline possible parameters for calibrating Vissim, CORSIM, and Trafficware's SimTraffic models.

13.5.3.1 Vissim Calibration

Several parameters can be adjusted in Vissim to fully calibrate a model. The most impactful and common parameters are outlined below:

13.5.3.1.1 Lane Change Parameters

Two common parameters related to lane change behavior are the LCD and the Emergency Stop Distance (ESD). LCD is the point at which a vehicle attempts to change lanes prior to a decision point (e.g., a turning movement). The default LCD setting of 656.2 feet may cause vehicles to switch lanes too late. ESD is defined as the location where vehicles decide to stop and wait for a lane change. These two parameters have great effects on upstream traffic, so their calibration greatly improves a model's accuracy. Additionally, the following parameters are calibrated in Vissim; reference the Vissim user guide for more guidance:

- Advanced Merge;
- Safety Distance Reduction Factor;
- Cooperative Lane Change; and
- Maximum Deceleration of Own Vehicle (MDOV)

13.5.3.1.2 Speed Distributions

The speed distribution curve in Vissim is set to represent the speed distributions from the collected field data. The posted speed limits are defined as 85 percent of the desired speed distribution in Vissim. Maximum speed distributions is recommended to be set no greater than 10 mph above the speed limit and no less than 5 mph below the speed limit. When calibrating speed distributions, it is possible to increase the percentage of vehicles traveling at the speed or the maximum speed limit cap based on field data.

13.5.3.1.3 Driving Behavior

The interaction between vehicles is modeled using the Wiedemann 1974 and 1999 car-following models. Such models are assigned for different driving behavior containers. The Wiedemann 1974 is used for 'Urban (motorized)' link types that represent urban arterial roads and streets. The Wiedemann 1999 is primarily used for 'Freeway (free lane selection)' link types to model freeway operations. With updated parameters, Wiedemann 1999 is often used for 'Cycle-Track (free overtaking)' links to model bicycle lanes. The link type 'Footpath (no interaction)' does not monitor the interaction between users of this link type. As such, it can be used for pedestrian movements and walkways and crosswalks. Table 13-8 shows all the car-following parameters in a Vissim model that can be changed. However, it is recommended to only modify CC0, CC1, and CC2 when adjusting the car-following parameters. Car following and lane changing parameters are shown in Table 13-8.

Table 13-8: Car-Following and Lane Changing Parameters

Parameter	Description
CC0	Standstill distance. The distance between two vehicles when they are not moving.
CC1	Following distance. A time distribution of the speed-dependent portion of safety distance.
CC2	Longitudinal oscillation. Defines the distance in which a driver will intentionally move closer to the car it is following.
CC3	Perception threshold for following. Defines when the beginning of the deceleration process occurs.
CC4	Negative speed difference. Low values result in more sensitive reactions when following vehicles.
CC5	Positive speed difference. Low values result in more sensitive reactions when following vehicles.
CC6	Influence speed on oscillation. Defines how car-following distance impacts the acceleration of vehicles.
CC7	Oscillation acceleration value. Minimum value used when a driver is following another vehicle.
CC8	Acceleration value when starting from a standstill.
CC9	Acceleration value at 80 km/h.
Diffusion Time	This is the maximum amount of time that a vehicle can wait at an ESD before the vehicle is removed from the network
Min. Clearance	The minimum distance between two vehicles after a lane change occurs.
Safety distance reduction factor	The safety distance of a following vehicle after a lane change, the safety distance of the vehicle making the lane change, and the distance to the preceding, slower lane change.
Maximum deceleration for cooperative braking	Defines how much a trailing vehicle will brake to allow an adjacent vehicle to change into its lane.
Use implicit stochastics	When this option is checked, safety distance, desire acceleration, desired deceleration, minimum lateral distance is stochastic to reflect variations in human perception. When this option is not checked, the characteristics listed above are non-variable.

13.5.4 CORSIM Calibrating Capacity at Bottlenecks

Calibrating a CORSIM model begins with a calibration of the capacity at key bottlenecks. Replicate the location and severity of bottlenecks, if present. This can be accomplished by evaluating a few key locations in the model and adjusting model parameters in a repeatable process that adjusts throughput volume downstream of the bottleneck until throughputs and queues are similar to local conditions.

When calibrating capacity on a freeway, there are several model parameters that can be adjusted. The parameters and their definitions are listed here:

- Car-following sensitivity factor – A global parameter that represents the primary factor used to calculate headway between a lead-follow pair. The higher the value the more space between vehicles and therefore a lower freeway capacity.
- Car-following sensitivity multiplier – This parameter is adjusted for individual segments. A higher value represents more space between vehicles and therefore a lower freeway capacity.
- Lag acceleration and deceleration time – A global parameter that represents the reaction time necessary for drivers to accelerate or decelerate. A higher value represents a slower reaction time and therefore a lower freeway capacity.
- Pitt car-following constant – A global parameter that represents the minimum amount of space between the rear of the lead vehicle and the front of the follow vehicle. A higher value represents more space between the vehicles and therefore a lower freeway capacity.

When calibrating capacity on surface streets there are several model parameters that can be adjusted. The parameters and their definitions are listed here:

- Mean discharge headway – This parameter is adjusted for individual segments and represents the mean headway between the rear of the lead vehicle and the front of the follow vehicle in a standing queue. A higher value represents a longer headway and therefore a lower capacity.
- Mean startup delay – This parameter is adjusted for individual segments and represents the mean startup lost time for the first vehicle in a standing queue. A higher value represents a greater startup delay and therefore a lower capacity.
- Acceptable gap in oncoming traffic (left turns and right turns) – These are global parameters that represents the minimum acceptable gap in seconds for left turns and right turns. A higher value represents a higher minimum acceptable gap and therefore lower capacity.

- Cross-street acceptable gap distribution (near-side and far-side) – These are global parameters that represent the minimum acceptable gap in seconds at stop signs. A higher value represents a higher minimum acceptable gap and therefore lower capacity.

13.5.5 Calibrating Traffic Volumes

Calibrating the traffic volumes in the model is the second step in calibration and is typically included for all microsimulation models.

This step is completed by comparing the turning movement volumes and link volumes in the model to local conditions. Traffic volumes typically fall within established calibration targets. Traffic volumes are typically calibrated at all locations within the model. If this is not possible for some large networks, calibration of several key locations is acceptable.

When calibrating traffic volumes on a surface street with parallel streets or a network of streets, analysts can use conditional turn movements to define turn percentages. Additionally, a full OD table can be manually coded to minimize differences in modeled volumes.

The FHWA microsimulation guidelines do not demand traffic volume calibration.

13.5.6 Calibrating System Performance

The third calibration step is to calibrate traffic performance in the model to local conditions. Speed, density, travel time, and queue lengths are often used in comparison. It is recommended that system performance is modeled to meet established calibration targets. Methods for calibrating system performance on a freeway are shown here:

Criteria:

- Car-following sensitivity factor, car-following sensitivity multiplier, lag acceleration and deceleration time, and Pitt car following constant – these factors are described in detail under the "Calibrating Capacity at Bottlenecks" section and are adjusted to calibrate system performance.
- Time to complete lane change –A global parameter that represents the time a vehicle takes to change lanes. A higher value means the lane change takes longer, but this generally leads to a smoother system performance.

Methods for calibrating system performance on arterials are shown here:

- Mean discharge headway, mean startup delay, acceptable gap in oncoming traffic (left turns and right turns), and cross-street acceptable gap distribution (near-side and far-side) – these factors are described in detail under the "Calibrating Capacity at Bottlenecks" section and are adjusted to calibrate system performance.
- Spillback probabilities – A global parameter that impacts the probability that a vehicle enters an intersection with downstream queues, blocking the intersection.

- Time to react to sudden deceleration of lead vehicle – A global parameter that represents the time it takes for vehicle to begin decelerating after the lead vehicle suddenly decelerates. A higher value represents declined system performance.

Additional information on CORSIM calibration is provided in FHWA Traffic Analysis Toolbox, Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software, available here: Appendix N, Section 4 – External References (Reference 2).

13.5.7 SimTraffic

Calibration is completed to match field measurements via adhering to established calibration criteria. Calibration in a SimTraffic model includes calibrating travel times, travel volumes, lane alignment, positioning, and crucial distances.

13.6 Unmet Demand

13.6.1 Overview

Unmet demand refers to the number of vehicles that were destined to travel through a network at a specific time period (e.g., signal phase, signal cycle, peak hour, etc.) but were unable due to capacity constraints. A visual representation of unmet demand is shown in Figure 13-7.

The need to include unmet demand in an analysis is determined prior to model development, typically in the project scoping stage and data collection stage. The main components with unmet demand are:

- Determining locations that may have unmet demand;
- Estimating unmet demand; and
- Integrating unmet demand into a microsimulation model

Each of these steps is discussed below.

Figure 13-7: Graphical Depiction of Unmet Demand

Source: UDOT Traffic Analysis Guidelines

13.6.2 Unmet Demand Locations

Unmet demand is common during oversaturated conditions on network facilities. Intersections and freeway merge, diverge, and weaving segments sometimes experience unmet demand. During field visits, attention is given to locations that experience long queues,

heavy congestion, and/or trip diversion, as these situations often indicate unmet demand exists. Unmet demand is estimated for facilities that experience the situations described above.

13.6.3 Estimating Unmet Demand

Unmet demand is measured in vehicles and is typically estimated by dividing the queue length by the average vehicle occupancy length. The unmet demand queue length is equal to the total queue length minus the served queue length. Average vehicle occupancy lengths typically range from 25 to 50 feet and vary based on local conditions.

Field measurement is a common method to estimate queue length. Real-time online congestion maps (e.g., Google maps, Bing maps, INRIX, etc.) may be used to understand average queue lengths. For intersections, queue length is collected at the start of red and averaged over the entire analysis period. For freeway facilities, queue length is collected and averaged over the entire analysis period. Unmet demand data may also be collected from Traffic Management Centers (TMCs). In circumstances where vehicles are diverting from their normal route due to congestion, a diversion analysis using a TDM or other methods may be used to estimate the number of diverting vehicles.

After unmet demand is estimated, the additional volumes are added to the microsimulation model. Appropriate measures are taken to confirm that all vehicles are allowed entry into the model (e.g., review error logs to see how many vehicles were denied entry). It is important to confirm all vehicles enter the model, because vehicles that are denied entry to the model are not tracked which may lead to inaccurate model results.

13.6.4 Integrating Unmet Demand into a Microsimulation Model

The following steps are recommended to be taken after unmet vehicle volumes have been added to the model. These steps may help troubleshoot denial of entry to the network.

- View error logs to see where vehicles are being denied entry.
- Verify denial of entry is not due to coding errors (e.g., incorrect lane assignments, signal timing errors).
- Extend geographic limits (spatial) of the network to accommodate the maximum queue lengths.
- Extend time limits (temporal) to accommodate the traffic demand. Typically, the analysis begins before the onset of congestion and ends after congestion dissipates.
- If the previous steps do not resolve denial of entry, the model results are typically adjusted to account for unmet demand in the analysis outputs. Unmet demand delay is typically reported as a separate category to served demand delay.

The unmet demand may not be included in volume served calibration thresholds. For more information on calibration thresholds, see Section 13.5.

13.7 Alternatives Analysis

13.7.1 Overview

This section provides guidance on developing alternatives analyses in microsimulation models. When comparing potential solutions, a modeler is recommended to develop a model for the existing conditions, future conditions without improvements (no-build), and the proposed improvements (build alternatives). Comparing the MOEs selected across all models will help in the selection of the locally preferred alternative. Chapter 8 of this manual provides more information on analyzing alternatives and additional criteria to consider.

13.7.2 Number of Simulation Runs

Simulation models use numerous Random Seeds to demonstrate natural variations in driving behaviors and vehicle entry into the network. To confirm validity of a model, it is recommended that the number of simulation runs is large enough where an atypical run has minimal effect on the sample average. Simulation runs are typically determined for every model being tested. Per FHWA guidance, the following formula is used to calculate the necessary minimum number of simulation runs with a 95% confidence level. A 95th-percent confidence interval is typically used, but may not be the best value for every analysis:

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

where:

N: Minimum number of simulation runs

$\bar{x}$: Mean of observations

s: Standard deviation of observations

n: Number of observations

$tn-1,95\%$: t statistic for n-1 degrees of freedom and 95% confidence level

e: tolerance error percentage

To use this equation, first select a preliminary number of model runs for which the initial mean and standard deviation are derived. These initial values are then used in the equation to determine the minimum number of simulation runs. If the calculated number of simulation runs is unreasonably high, first confirm there are no significant deviations in any of the simulation runs that would skew the calculation. After that, if the calculated number of simulation runs is still high, the cap is 25 runs per project. Generally, the minimum number of simulation runs is 10.

13.7.3 No-Build and Build Model Development

After developing, debugging, and calibrating an existing conditions model, no-build and build (alternative) models are created. These models are created from the existing model. No-build and build conditions can include optimizing existing signal timing plans; however, adding or modifying signal timing phases is considered an operational improvement alternative. There can be minimal changes to calibrated parameters in the model when developing future year models. However, use engineering judgement to confirm that new geometries and conditions in the future build years are represented realistically in the microsimulation

model. Some elements maintained between models are driving behaviors, terminal conditions, and lane change distances. See Figure 13-8 for a flowchart of the different aspects of both no-build and build model development.

13.7.4 Future Year Models

13.7.4.1 Geometry

In developing a future year model, other planned projects are considered as they may impact traffic in the study area. If there are geometric changes to the study area determined from planned projects in TxDOT's Project Tracker or the Unified Transportation Plan (UTP), implement those changes by following the development guidance used to develop the existing model. Planned multi-modal improvements are also included unless otherwise agreed upon.

13.7.4.2 Forecasted Demand

Future traffic demand is used to analyze planned projects in the future year models. Further guidance on the process of traffic forecasting is provided in Section 3.3 of this manual. Traffic volumes are projected and balanced for the new conditions under the future year models to reflect the changes. Traffic volumes, classification data, vehicle characteristics, and traffic patterns are examples of inputs that are modified based on forecasted demand.

13.7.4.3 Debugging

Future year models are recommended to follow the same debugging process as outlined in Section 13.4.8. Use engineering judgement when debugging.

13.7.4.4 Validation

Validation demands data, which does not exist for future year analyses. Nevertheless, parameters are updated when necessary. Signal timing and phasing are changed to accommodate demand and new geometry improvements. Driving behavior can only be adjusted in future conditions when roadway geometry or traffic control changes drastically. The HCM 7th Edition provides guidance on adjusting capacities to accommodate CAVs. Guidance on CAVs in the HCM 7th Edition can be found in various chapters. For information on modeling autonomous vehicles, refer to the respective microsimulation software user guide.

13.7.5 Future No-Build Models

No-build models represent future traffic conditions without the implementation of considered improvements or alternatives. They are the baseline for future model comparisons. These models are created from a calibrated existing model and include any committed projects. These models sometimes include other planned projects that impact traffic in the proposed project study area.

13.7.6 Build (Alternative Design) Models

Build (alternative design) models are developed to represent one or more design alternatives for evaluation. These build models include exclusive improvements or a combination of

improvements. These are created from the no-build model for the same future year.

Figure 13-8 illustrates the process for creating the No-Build and Build (alternative) Models.

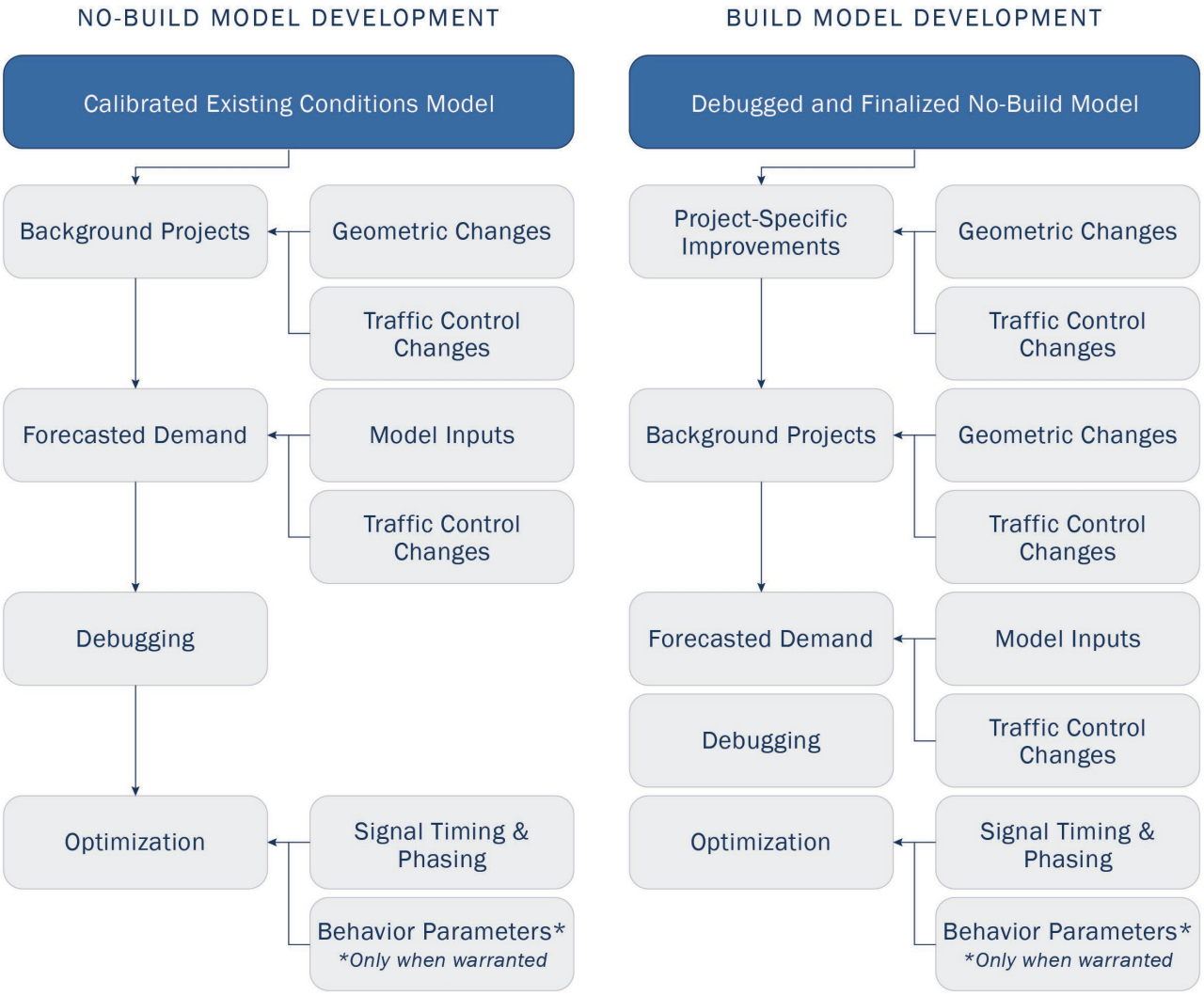


Figure 13-8: No-Build and Build Model Development

13.8 Reporting Results and MOEs

13.8.1 Overview

There are multiple methods for coding, reviewing, and evaluating MOEs) or performance measures in a microsimulation model. The guidance outlined in this section is based on best practices and covers the most common performance measures for reporting existing and future conditions. For detailed explanations on the use of MOEs, see Chapter 4 of this manual. While there could be general principles that apply to reporting results and MOEs for microsimulation, this section outlines the reporting results specific to Vissim. For examples of reporting MOEs, see Chapter 17 of this manual.

One of the main purposes for conducting an alternatives analysis is to test future build conditions that cannot be tested in the field. For this reason, it is important to extract speeds, throughputs, travel times, and other data outputs from various models, including Vissim, in the same way they are collected in the field. Animations of Vissim model runs are often used to supplement tabular presentation of results. For information on recording animations (including visualization, camera positions, and 3D elements), refer to the Vissim user guide.

When reporting results and MOE's, it is important to distinguish between segment wide results and network level results. Networkwide MOEs such as network delay are used to determine the impacts of a model change to the overall network, while segment wide MOEs such as travel time are used to determine the impacts of a model change to a segment.

13.8.2 Coding of Evaluation Parameters

This subsection emphasizes coding evaluation parameters specific to Vissim. For the coding of evaluation parameters in other software, see respective user guides. The primary Vissim elements used for data collection are as follows:

13.8.2.1 Data Collection Points

DCP most closely replicate loop and video detectors that capture volume, occupancy, and speed. Similarly, these points also represent stationary radar guns that capture speeds on freeways or arterials. DCP can be placed on any link or connector such that the object is in a location that matches the collected field data. DCP0 record information for a single lane. To collect information for all lanes, DCP can be combined into data collection measurements (DCM). DCMs are then used to report results. Data collection points are appropriate to use when spot speed data using radar guns or other sources has been collected.

13.8.2.2 Travel Time Segments

Travel time segments represent travel time runs, where the travel time between two points is measured. They are also used to capture probe vehicle data or average SMS and travel time. These segments capture all lanes of traffic on the link or connector on which they are coded. Travel times are measured between the start and end locations. To capture travel time throughout an entire network, travel time segments are coded similarly to relay routing

that obtains travel time data for each segment. Segmental travel times are added to determine an overall travel time for the entire network. Travel time segments are appropriate to use when SMS data has been collected.

13.8.2.3 Nodes

Nodes capture intersection throughput, queuing, and delay. Nodes can be drawn around an intersection that encloses all movements such that all approaches are bisected by one side of the polygon. Additionally, when creating nodes, the start of delay segment encompasses the entirety of the expected queue. It is important to note that to use node evaluation results, the "use for evaluation" attribute is selected in the Node Object Table.

Please note this is true for a link-based software like Vissim but does not apply to a node-based software.

13.8.2.4 Queue Counters

Queue counters are typically used to measure queue counts at freeway ramps and other movements of interest like intersections or along roadway segments. Various types of detectors or field observations are used to capture queue lengths in the field. Queue counters can be placed on any link or connector in the model. The coded marker represents the furthest downstream position for which the queue can be measured. As with DCP, it is recommended that queue counters be placed in the same location that field data was collected.

13.8.3 Report and Results Formatting

Creating a clear and concise summary of analytical findings is critical in developing a successful microsimulation analysis. The purpose of the report is to inform decision-makers so that they can make a rational and thoughtful decision. Section 17.3 of this manual demonstrates general principles that can be used when reporting results. Appendix N, Section 2 – Model Development Report can be used as an outline for documenting model development.

Chapter 14
Multimodal Analysis

14.1 Introduction

14.1.1 Purpose and Intended Use

The operation and safety of transportation facilities is relevant to all users. In addition to passenger vehicles, users include pedestrians, bicyclists, freight, and transit. The purpose of this chapter is to provide guidance on multimodal analysis by providing flowcharts for analysis methodology selection, templates for requisite data collection, step-by-step guides on various analysis methods, and references to additional resources. The chapter's intent is to provide a baseline for analysis and supplementary sources that could aid in a more detailed analysis.

14.2 Multimodal Analysis

Several approaches to multimodal analysis presented in this chapter are derived from perceptions of safety, convenience, and comfort. This chapter introduces these methodologies and best practices to support a holistic approach to multimodal analysis. Each method has different data input requirements, limited supported facility types, and various performance measures. Although method selection flowcharts are provided for guidance, the context of each project plays a large role in determining which methodology is ultimately selected.

The methodologies used in this chapter as the basis for multimodal analysis are:

- HCM;
- The Mineta Transportation Institute (MTI) Report 11-19, May 2012;
    - This manual uses adaptations of the original methodology found in the report
- The Shared-Use Path Level of Service (SUPLOS) calculator created by the FHWA;
- The Freight Analysis Framework (FAF) tool created by the FHWA;
- The Transearch tool developed by the company IHS Markit for freight analysis;
- Transit Capacity and Quality of Service Manual, Third Edition (2013);
- NCHRP Report 616, Multimodal Level of Service Analysis for Urban Streets;
- Microsimulation; and
    - Applicability to multimodal analysis
    - Multimodal-specific guidance on microsimulation
- TDM outputs
    - Statewide area model
    - MPO models

14.2.1 Pedestrian

Selecting the correct methodology or tool for pedestrian analysis depends on several factors, including pedestrian facility type, anticipated delay caused by pedestrian facilities to other modes, perceived safety, comfort, and

convenience of the pedestrian facilities, and expected volume of pedestrians on facilities. A pedestrian analysis methodology selection flowchart is provided in Figure 14-1 to guide the selection of pedestrian analysis methodologies. Refer to TxDOT's RDM Chapter 7, Section 3 for information on pedestrian facility design. See Appendix O, Section 5 – External References (Reference 3) for the Texas Bicycle and Pedestrian Count Exchange which includes bicycle and pedestrian data counts.

The pedestrian analysis subsection includes methodologies from the following resources/tools. Key notes are provided under each resource.

- HCM and the HCS;
  - Provides information for various pedestrian analysis methodologies
  - Methodologies emphasize pedestrian density and pedestrian-to-vehicle or pedestrian-to-bicycle interactions
  - Application of HCM methodologies as seen in the HCS (i.e., signalized intersections and urban street segments) are emphasized in this chapter.
- PLTS;
  - Adaptation of the Mineta Transportation Institute's Bicycle Level of Traffic Stress (BLTS) Report
  - Comparable to an assessment in which various pedestrian facilities are classified based on connectivity, perceived comfort, and perceived safety criteria
- Microsimulation; and
  - Guidelines on when to use microsimulation for pedestrian analysis
  - Microsimulation may be used to create animations and analyze the interaction between pedestrians and vehicles, but it does not analyze the perceived safety and comfort of pedestrian facilities
- Various Safety Guidelines
  - External resources, such as the ones provided in Appendix O, Section 2 – Pedestrian and Bicycle Safety Resources, can be used for pedestrian facility improvements via countermeasure selection and scenario-specific enhancements

See Table 14-1 for various pedestrian facilities and their descriptions.

Table 14-1: Pedestrian Facility Types and Descriptions (per HCM 7th Edition)

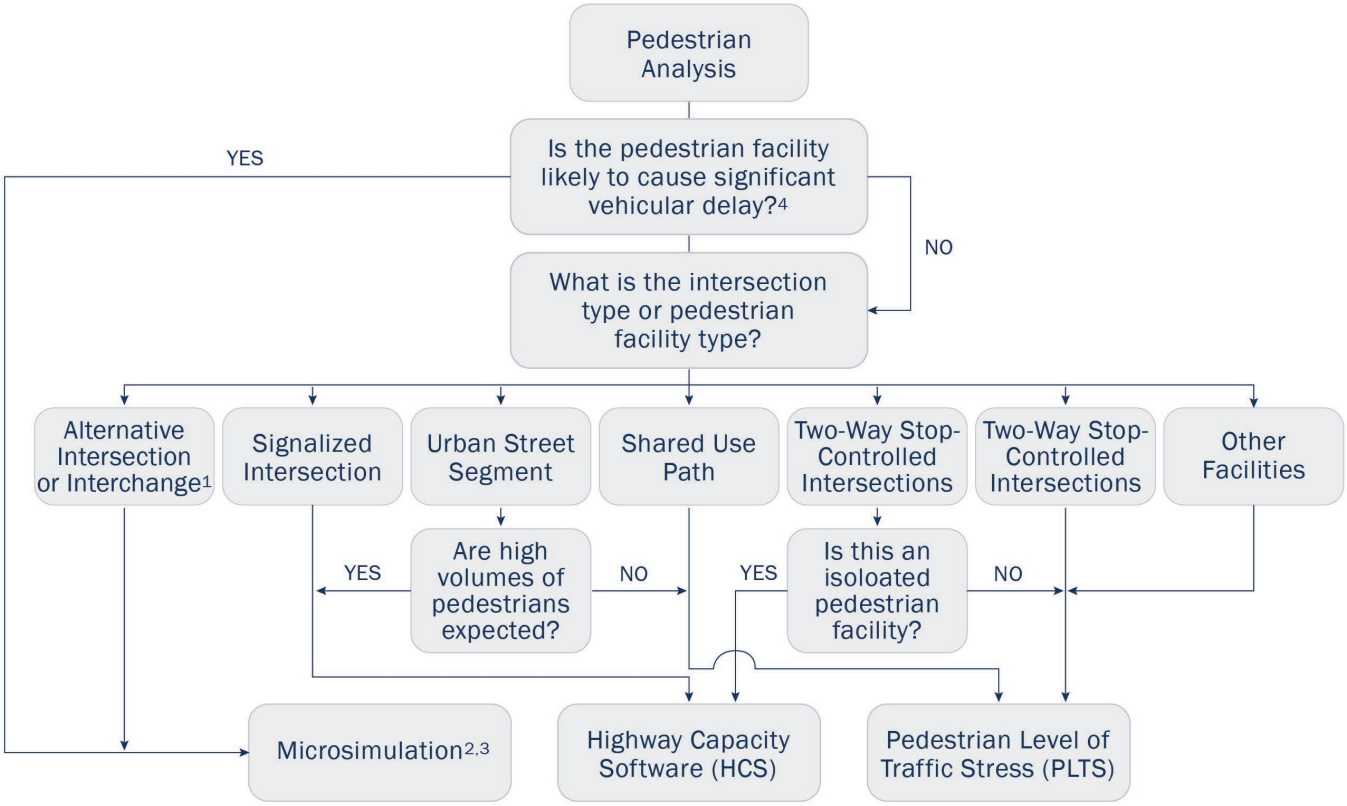
Facility Type	Definitions/Description
Sidewalk	Sidewalks are located parallel and in proximity to roadways
Walkways	Walkways are "similar to sidewalks in construction… but they are located well away from the influence of automobile traffic.
Pedestrian Zones	Pedestrian zones are "streets that are dedicated to pedestrian-only use on a full- or part-time basis
Queuing Areas	Queuing areas are places where pedestrians stand temporarily while waiting to be served, such as at the corner of a signalized intersection. In dense standing crowds, there is little room to move, and circulation opportunities are limited as the average space per pedestrian decreases.
Crosswalk	Pedestrian crosswalks, whether marked or unmarked, provide connections between pedestrian facilities across sections of roadway used by motorized vehicles, bicycles, and transit vehicles.
Underpass and Overpass	Overpasses and underpasses provide a grade-separated route for pedestrians to cross wide or high-speed roadways, railroad tracks, busways, and topographic features.
Stairway	Stairways are sometimes used to help provide pedestrian connectivity in areas with steep hills, employing the public ROW that would otherwise contain a roadway.
Shared Pedestrian-Bicycle Path	Shared pedestrian paths typically are open to use by nonmotorized modes such as bicycles, skateboards, and inline skaters. Shared-use paths often are constructed to serve areas without city streets and to provide recreational opportunities for the public.

14.2.1.1 HCM and Related Software

The HCM-based software HCS is used for pedestrian analysis scenarios as described in Figure 14-1.

The HCM contains methodologies (including formulas for calculating LOS) for several pedestrian facility types (see Table 14-2), but the HCS only analyzes urban street segments, Two-Way Stop-Controlled (TWSC) intersections, and signalized intersections. For street segment analysis, the HCM uses pedestrian density to determine LOS. As such, it is recommended that the HCM methodology for street segment analysis only be considered for pedestrian facilities with high pedestrian volumes (e.g., suburban residential, greenbelts, parks/plazas, low-density commercial, central business districts, mixed-use developments, tourist destinations, outdoor shopping centers). HCS (or similar software tool) is recommended for analysis of pedestrian facilities at signalized intersections. LOS D is recommended as a minimum target for signalized crossings and street segments.

While pedestrian analysis can be conducted by hand for most pedestrian facilities covered in the HCM, PLTS analysis is recommended for most facilities, as described in Figure 14-1.



[1] Alternative Intersections include roundabouts within the context of pedestrian analysis
[2] If a visual rendering of the pedestrian facility is required; microsimulation should be used
[3] When microsimulation is used, a PLTS analysis should also be conducted (where possible), to complement the microsimulation analysis.
[4] Significant vehicular delay is defined as failing level of service. Applicable to locations that have acceptable LOS without pedestrian facility.

Figure 14-1: Pedestrian analysis methodology/tool selection flowchart

Table 14-2: HCM 7th Edition Pedestrian Analysis by Facility Type

Facility Type	HCM Chapter and Section Number
Urban street facilities	16.4
Urban street segments	18.4
Signalized intersections	19.5
Two-way stop-controlled intersections	20.5
All-way stop-controlled intersections	21.5
Roundabouts	22.5
Ramp terminals and alternative intersections	23.B.4
Off-street facilities	24.3, 24.4

To conduct a pedestrian analysis of signalized intersections, the inputs below are collected and entered into the corresponding fields on the HCS. Definitions of multimodal inputs are found in the HCS User Guide. Traffic inputs for the intersection will impact LOS calculations for the analysis and are entered.

- Permitted left-turn flow, veh/h;
- Mid-segment 85th % speed, mi/h;
- Number of right-turn islands;
- Walkway width, ft;
- Crosswalk width, ft;
- Corner radius, ft;
- Outgoing pedestrian volume, ped/h;
- Incoming pedestrian volume, ped/h;
- Circulating ped volume, ped/h;
- Rest-in-walk enabled;
- Pedestrian signal head; and
- Crosswalk closed

HCM defines pedestrian LOS at signalized intersections using a LOS Score. LOS thresholds for pedestrians are presented in Table 14-3.

Table 14-3: HCM LOS Criteria for Pedestrians at Signalzed Intersections

LOS	LOS Score
A	≤1.50
B	>1.50-2.50
C	>2.50-3.50
D	>3.50-4.50
E	>4.50-5.50
F	>5.50

To conduct a pedestrian analysis of urban street segments, the inputs shown below are collected and entered into the corresponding fields on the HCS. Definitions of multimodal inputs are found in the HCS *User Guide*. To view results, print the "segments report" located in the HCS.

- Two-way pedestrian volumes, ped/h;
- Pedestrian waiting delay, s/ped;
- Pedestrian free-flow speed, ft/s;
- Downstream intersection width, ft;
- Sidewalk presence;
- Inside object effective width, ft;
- Outside object effective width, ft;
- Buffer width, ft;
- Nearest signal distance, ft;
- Sidewalk length adjacent to window, proportion;
- Sidewalk length adjacent to building, proportion; and
- Sidewalk length adjacent to fence, proportion

Table 14-4 shows the HCM LOS criteria for pedestrians for urban street segments (linked-based). The overall segment pedestrian LOS uses the higher or worse of the LOS letter scores resulting from the average pedestrian space on the sidewalk and the segment pedestrian LOS score.

Table 14-4: HCM LOS Criteria: Pedestrian Mode Along Segments or Links

Segment-Based Pedestrian LOS Score	Segment-Based LOS by Average Pedestrian Space (ft²/p)						Link-Based Pedestrian LOS	
	>60	>40-60	>24-40	>15-24	>8-15	≤8.0[1]	Link-Based LOS Score	LOS
≤2.00	A	B	C	D	E	F	≤1.50	A
>2.00-2.75	B	B	C	D	E	F	>1.50-2.50	B
>2.75-3.50	C	C	C	D	E	F	>2.50-3.50	C
>3.50-4.25	D	D	D	D	E	F	>3.50-4.50	D
>4.25-5.00	E	E	E	E	E	F	>4.50-5.50	E
>5.00	F	F	F	F	F	F	>5.50	F

[1]In cross-flow situations, the LOS E/F threshold is 13ft²/p

14.2.1.2 Pedestrian Level of Traffic Stress (PLTS)

PLTS is used for pedestrian analysis scenarios as described in Figure 14-1.

A PLTS analysis is conducted by taking inventory of existing/proposed pedestrian facilities. The inventory is used to gather relevant information about each pedestrian facility (e.g., sidewalk width, adjacent roadway speed, buffer width between pedestrian facility and vehicular roadway, etc.). Inventory data is collected, compared to predefined PLTS classifications for each roadway characteristic, and used to assign each facility an overall PLTS classification that describes safety, comfort, and convenience (see Table 14-5). The steps for a PLTS analysis are shown in Figure 14-2. For detailed steps on conducting a PLTS analysis, see Section 14.2.1.2.1.

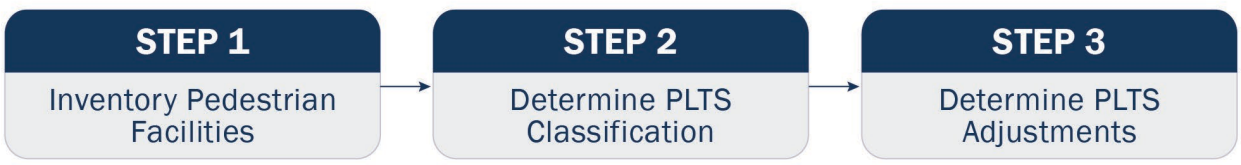


Figure 14-2: Steps in a PLTS analysis

The intent of a PLTS analysis is to determine individual pedestrian facility deficiencies and connectivity gaps in a network to prioritize pedestrian facility improvements. A PLTS analysis is used at all levels of project development.

The four PLTS classifications that are typically assigned are PLTS 1 (the best rating), PLTS 2 (the minimum standard for most pedestrian facilities), PLTS 3 (the first failing rating), and PLTS 4 (the worst rating). The four classifications and their definitions are shown in Table 14-5.

Table 14-5: PLTS Classification Information

Classification	Characteristics
PLTS 1	Pedestrian facilities with this classification have little to no traffic stress. These facilities are perceived as safe, open, and comfortable. Sidewalks are in good condition and are either far from vehicles or are near lower vehicle speeds and volumes. These facilities are suitable for users of all ages and abilities. **This is the best classification.**
PLTS 2	Pedestrian facilities with this classification have a low level of traffic stress caused by sidewalks in fair condition or proximity to higher speeds or higher volumes of vehicles. These facilities are suitable for most ages and abilities. This is the minimum standard for most pedestrian facilities.
PLTS 3	Pedestrian facilities with this classification represent facilities with a medium level of traffic stress caused by small buffers between sidewalks and the road, fair to low quality sidewalk conditions, and higher vehicle speeds or volumes. These facilities are suitable for some able-bodied adults. This is the first failing classification.
PLTS 4	Pedestrian facilities with this classification represent facilities with the highest levels of traffic stress. They often have very low quality or non-existent sidewalks, high vehicle speeds and volumes, and no buffer. These facilities are only suitable for highly confident able-bodied adults. **This is the worst classification.**

14.2.1.2.1 Step One: Template Selection and Data Collection for Pedestrian Facility

The PLTS Inventory and Classification template provided in Appendix O, Section 1 – Pedestrian Level of Traffic Stress Inventory and Classification) has two tables, one for signalized midblock crossings and segment facilities and one for unsignalized intersection crossings or unsignalized midblock crossings. This fillable template will serve as the basis for the analysis and contains information on data needs and reference tables used in the analysis.

Once the correct template is selected based on facility type, collect data for the pedestrian facility in question. Use the PLTS Inventory and Classification template discussed previously.

Characteristics to inventory depend on the facility type and are shown here:

- If the facility is a signalized midblock crossing or segment facility, inventory the following characteristics:
  - Sidewalk width
  - Sidewalk condition
    - See Table 14-7 footnotes for definitions.
  - Buffer type
    - See Table 14-8 footnotes for definitions.

- Buffer width
  - See Table 14-9 footnotes for definition.
- Posted speed on adjacent vehicular roadway
- Number of adjacent roadway lanes
  - See Table 14-10 footnotes for definition.
- Adjacent land use
  - See Table 14-11

- If the facility is an unsignalized intersection crossing or unsignalized midblock crossing, inventory the following characteristics:
  - Posted speed on adjacent vehicular roadway
  - Number of adjacent roadway lanes
    - For roadways *without* a median refuge, see Table 14-12 footnotes for definition.
    - For roadways *with* a median refuge:
      - For roadways with one to two lanes, see Table 14-13 footnotes for definition.
      - For roadways with three or more lanes, see Table 14-14 footnotes for definition.
  - ADT of adjacent vehicular roadway
  - Crossing treatments
    - See Table 14-15 for definitions

14.2.1.2.2 Step Two: Determine Preliminary PLTS Classification

Use the data gathered from the facility inventory and the relevant PLTS classification tables shown on the PLTS Inventory and Classification Template (see Appendix O, Section 1 – Pedestrian Level of Traffic Stress Inventory and Classification) to determine a PLTS classification. Determining the overall PLTS classification of the facility occurs in Section 14.2.1.2.3, this step is a preliminary determination of PLTS classification. The PLTS classification tables used are also shown in Table 14-16.

A pedestrian walking route can be comprised of several individual pedestrian facilities (e.g., a sidewalk, an unsignalized midblock crossing, and a shared use path). If this is the case, data is collected for each facility and a PLTS classification assigned to each facility separately in preparation for the overall facility PLTS classification.

Table 14-6: PLTS Analysis Tables by Facility Type

Facility Type	Tables Used to Determine PLTS
Segment facility or signalized midblock crossing • The overall facility PLTS is determined using five individual facility characteristics and their respective PLTS classifications.	• Sidewalk Walkability, Table 14-7 • Buffer Type, Table 14-8 • Buffer Width, Table 14-9 • Road Usage, Table 14-10 • Land Use, Table 14-11
Unsignalized intersection crossing or unsignalized midblock crossing • The overall facility PLTS is determined by using a single table shown in the adjacent cell.	• Unsignalized intersection crossing or unsignalized midblock crossing (no median refuge), Table 14-12 • Unsignalized intersection crossing or unsignalized midblock crossing of one to two lanes (median refuge), Table 14-13 • Unsignalized intersection crossing or unsignalized midblock crossing of three or more lanes (median refuge), Table 14-14

Table 14-7: PLTS Classification of Sidewalk

Sidewalk Width (ft)	Sidewalk Condition			
	Good[1]	Fair[2]	Low[3]	No Sidewalk[4]
≥6	PLTS 1	PLTS 1	PLTS 2	PLTS 4
≥5 to <6	PLTS 2	PLTS 2	PLTS 3	PLTS 4
≥4 to <5	PLTS 3	PLTS 3	PLTS 3	PLTS 4
<4	PLTS 4	PLTS 4	PLTS 4	PLTS 4

[1]No cracking, patching, raveling, or faulting

[2]Minor cracking, patching, raveling, faulting is not greater than ½"

[3]Major cracking, patching, raveling, faulting is greater than ½"

[4]Travel lane, paved soil, and loose aggregate are not considered sidewalks

Table 14-8: PLTS Classification of Buffer Type

Type	Posted Speed (mph)			
	≤25	30	35-40	≥45
Wall[1]	PLTS 1	PLTS 1	PLTS 1	PLTS 2
Landscaped – Thick[2]				
Landscaped – Medium[3]	PLTS 1	PLTS 1	PLTS 2	PLTS 3
Landscaped – Thin[4]	PLTS 1	PLTS 2	PLTS 3	PLTS 4
Solid Surface – With Buffering Elements[5]	PLTS 1	PLTS 1	PLTS 2	PLTS 3
No Buffer[6]	PLTS 2	PLTS 3	PLTS 4	PLTS 4

[1]A vertical buffer separating the pedestrian facility from the roadway (i.e., retaining wall, concrete barrier).

[2]Area between the edge of sidewalk closest to the road and back of curb is landscaped with items that will prevent vehicles from crossing buffer (e.g., large mature trees, large rocks, large ditch).

[3]Area between edge of sidewalk and back of curb is landscaped with items that will prevent most vehicles from crossing buffer (e.g., small/young trees, medium-sized bushes, medium-sized rocks, medium-sized ditch).

[4]Area between edge of sidewalk and back of curb is landscaped with items that will prevent some vehicles from crossing buffer (e.g., small bushes, small rocks, small ditch).

[5]Area between edge of sidewalk and back of curb is a solid surface that has buffer elements along the facility (e.g., illumination poles, electric poles, benches, bicycle racks).

[6]Sidewalk is less than 8 feet wide and edge of sidewalk and back of curb are touching. On-street parking and bicycle lanes are not considered buffer types but do contribute to the buffer width.

Table 14-9: PLTS Classification of Buffer Width

Buffer Width[1]	Posted Speed (mph)			
	≤25	30	35-40	≥45
≥25	PLTS 1	PLTS 1	PLTS 1	PLTS 1
≥15 to <25	PLTS 1	PLTS 1	PLTS 1	PLTS 2
≥10 to <15	PLTS 1	PLTS 1	PLTS 2	PLTS 3
≥5 to <10	PLTS 1	PLTS 2	PLTS 3	PLTS 4
<5	PLTS 2	PLTS 3	PLTS 4	PLTS 4

[1]Buffer width is the summation of on-street width (i.e., on-street parking width, bicycle facility width, and roadway shoulder width), and off-street buffer width (i.e., distance between the edge of sidewalk closest to the road and back of curb).

Table 14-10: PLTS Classification of Number of Lanes

Adjacent Roadway Lanes[1]	Posted Speed (mph)			
	≤25	30	35-40	≥45
2	PLTS 1	PLTS 1	PLTS 2	PLTS 3
3	PLTS 1	PLTS 2	PLTS 2	PLTS 3
4	PLTS 2	PLTS 2	PLTS 3	PLTS 3
5	PLTS 2	PLTS 3	PLTS 3	PLTS 4
6	PLTS 3	PLTS 3	PLTS 4	PLTS 4

[1]For signalized intersection crossings or midblock crossings, this is the total number of lanes on the segment (e.g., a roadway with two lanes in each direction and a two-way left turn lane would have an adjacent roadway lanes value of 5).

Table 14-11: PLTS Classification of Land Use

Adjacent Land Use	PLTS Classification
Suburban residential, greenbelts, parks/plazas, low-density commercial	PLTS 1
Urban residential, medium density commercial, mixed land use, schools, hospitals, government buildings	PLTS 2
Light industrial, auto-driven commercial, central business district (CBD)	PLTS 3
Heavy industrial, adjacent to freeway interchanges or freeway facilities	PLTS 4

Table 14-12: PLTS Classification of Unsignalized Intersection Crossing or Unsignalized Midblock Crossings (no raised median)

Posted Speed	Adjacent Roadway Lanes[1]					
	2 Lanes			3+ Lanes		
	<5,000 vpd	5,000 – 9,000 vpd	>9,000 vpd	<8,000 vpd	8,000 – 12,000 vpd[2]	>12,000 vpd
≤25	PLTS 1	PLTS 3	PLTS 3	PLTS 3	PLTS 3	PLTS 4
30	PLTS 1	PLTS 3	PLTS 4	PLTS 3	PLTS 4	PLTS 4
35-40	PLTS 3	PLTS 4	PLTS 4	PLTS 4	PLTS 4	PLTS 4
≥45	PLTS 1	PLTS 2	PLTS 3	PLTS 3	PLTS 3	PLTS 4

[1]For unsignalized intersection crossings or midblock crossings without a median refuge, this is the total number of lanes on the segment (e.g., a roadway with two lanes in each direction and a two-way left turn lane would have an adjacent roadway lane value of 5).
[2]Use this column when ADT is unavailable.

Table 14-13: PLTS Classification of Unsignalized Intersection Crossing or Unsignalized Midblock Crossings (1 to 2 lanes – raised median)

Posted Speed	Adjacent Roadway Lanes[1]			
	1 Lane	2 Lane		
	Any	<5,000 vpd	5,000 – 9,000 vpd[2]	>9,000 vpd
≤25	PLTS 1	PLTS 1	PLTS 2	PLTS 2
30	PLTS 2	PLTS 2	PLTS 2	PLTS 2
35-40	PLTS 2	PLTS 2	PLTS 2	PLTS 3
≥45	PLTS 3	PLTS 3	PLTS 3	PLTS 4

[1]For unsignalized intersection crossings or midblock crossings with a median refuge, this is the maximum number of lanes crossed in one direction (e.g., a roadway with two lanes in both directions would have an adjacent roadway lane value of 2).
[2]Use this column when ADT is unavailable.

Table 14-14: PLTS Classification of Unsignalized Intersection Crossing or Unsignalized Midblock Crossings (3 or more lanes – raised median)

Posted Speed	Adjacent Roadway Lanes[1]			
	3 Lanes			4+ Lanes
	<8,000 vpd	8,000 – 12,000 vpd[2]	>12,000 vpd	Any
≤25	PLTS 1	PLTS 2	PLTS 3	PLTS 4
30	PLTS 2	PLTS 2	PLTS 3	PLTS 4
35-40	PLTS 3	PLTS 3	PLTS 4	PLTS 4
≥45	PLTS 4	PLTS 4	PLTS 4	PLTS 4

[1]For unsignalized intersection crossings or midblock crossings with a median refuge, this is the maximum number of lanes crossed in one direction (e.g., a roadway with two lanes one direction and three lanes in the other direction would have an adjacent roadway lane value of 3).
[2]Use this column when ADT is unavailable.

14.2.1.2.3 Step Three: Determine PLTS Adjustments

If the facility is a signalized midblock crossing or segment facility, the overall PLTS classification is the lowest of the individual classifications, or highest traffic stress classification, determined in step two (e.g., a facility with a PLTS 4 as the lowest classification in any of the characteristics would have an overall PLTS classification of 4).

If the facility is an unsignalized intersection crossing or unsignalized midblock crossing, the overall PLTS classification is the classification determined in step two, adjusted for any crosswalk enhancements. The crosswalk enhancement adjustments are shown in Table 14-15.

A pedestrian walking route comprised of several individual pedestrian facilities (e.g., a sidewalk, an unsignalized midblock crossing, and a shared use path) usually has a PLTS classification given to each facility and the worst rating governs the whole route. A pedestrian route with a sidewalk (PLTS 3), midblock crossing (PLTS 2), and shared-use-path (PLTS 1) would have an overall PLTS 3 classification.

Table 14-15: PLTS Classification Adjustments for Unsignalized Intersection Crossings and Midblock Crossings

Treatment[1]	Adjustment
High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs	-0.5
Raised crosswalk	-1.0
Advance Yield Here To (Stop Here For) pedestrian sign and yield (stop) line	-0.5
In-street pedestrian crossing sign	-0.5
Curb extension	-0.5
Pedestrian refuge island	-1.0
RRFB	-1.0
PHB	-1.0

[1]The maximum reduction is two classification levels, or PLTS 2, whichever comes first.

A PLTS 2 classification is recommended as a minimum target for most pedestrian facilities. For pedestrian facilities near hospitals, schools, or other locations with vulnerable or young populations, a PLTS 1 classification is recommended.

For examples of an inventory and PLTS classification for a pedestrian facility on a segment and for a pedestrian facility at a midblock crossing, see Table 14-16 and Table 14-17, respectively. These two examples occur on independent pedestrian facilities and the assigned PLTS classifications are also independent.

In the first example shown in Table 14-16, the pedestrian accommodation was a segment facility (i.e., sidewalk adjacent to an arterial). The first step was to determine which inventory and classification template table to use (see Appendix O, Section 1 – Pedestrian Level of Traffic Stress Inventory and Classification). The upper table in the PLTS Inventory and Classification Template was used based on the footnote at the bottom of the table that states, "Applicable to signalized midblock crossings and segment facilities." Next, an inventory was conducted for the facility in question, the collected data was based on the PLTS Inventory and Classification Template chosen, and for this example, included the following data:

- Sidewalk condition and width;
    - Determined to be six-foot wide and in fair condition for this example
- Buffer type and width;
    - Determined there was "No Buffer" type as defined in Table 14-8, but an overall buffer width of one foot
- Adjacent roadway speed and number of lanes; and
    - Determined the speed of the adjacent road to be 40mph and the number of adjacent lanes to be six
- Adjacent land use type
    - Determined to be suburban residential

This collected data was written in the appropriate cells on the PLTS Inventory and Classification Template. Next, the collected data was used to determine the PLTS classification of the facility based on individual characteristics of the facility (i.e., PLTS classification based on sidewalk conditions, buffer type, buffer width, adjacent roadway characteristics, and adjacent land use type). The PLTS classification for the sidewalk characteristic was determined using Table 14-7. A sidewalk with a six-foot width in fair condition is given a PLTS 1 classification. This classification is written in the appropriate box on the template and the next characteristic is classified, until all the characteristics have been classified.

The last step is to determine the overall facility PLTS classification. This is done by selecting the worst rating given for any of the individual PLTS classifications. In this example, the buffer type and buffer width both have PLTS classifications of 4, which means the overall PLTS classification of this facility is PLTS 4.

Table 14-16: Example 1 – Segment Facility Inventory and PLTS Classification

Facility[1]: Segment along a principal arterial				
Characteristics		Value	PLTS Reference Table	PLTS Classification
Sidewalk	Condition	Fair	Table 14-7	PLTS 1
	Width (ft)	6		
Buffer	Type	No Buffer	Table 14-8	PLTS 4
	Off-Street Width (ft)	0	Table 14-9	PLTS 4
	On-Street Width	1		
	Total Width	1		
Adjacent Roadway	Speed (mph)	40	Used in various tables	PLTS 3
	Number of Lanes	6	Table 14-10	
Adjacent Land Use	Type	Suburban Residential	Table 14-11	PLTS 1
Overall PLTS Classification				PLTS 4

[1]Applicable to signalized intersection crossings and segment facilities

In the second example shown in Table 14-17, the pedestrian accommodation was an unsignalized midblock crossing. The first step was to determine which inventory and classification template to use (see Appendix O, Section 1 – Pedestrian Level of Traffic Stress Inventory and Classification). The bottom table in the PLTS Inventory and Classification Template was used based on the footnote at the bottom of the table that states, "Applicable to unsignalized intersection crossings or midblock crossings (includes midblock crossings with PHB or RRFB)". Next, an inventory was conducted for the facility in question, the collected data was based on the PLTS Inventory and Classification Template chosen, and for this example included the following data:

- Adjacent roadway
  - Speed;
    - Determined to be 35 mph
  - Number of lanes;
    - Determined to be four
  - ADT (vpd); and
    - Determined to be 14,972
  - Crossing treatments
    - Determined that there is an RRFB and crosswalk markings

This collected data was written in the appropriate cells on the PLTS Inventory and Classification Template. Next, the collected data was used to determine the PLTS classification of the facility based on a single reference table. Although there are three reference tables on the PLTS Inventory and Classification template, only one is used, based on number of lanes, and presence of a center raised median. For this example, Table 14-12 was used because there is no raised median. Based on Table 14-12, an unsignalized midblock crossing with four lanes, a speed of

35mph, and an ADT of 14,972, is given a PLTS 4 classification.

The last step in this example was to consider the positive effects that crossing treatments can have on this crossing. It was determined that this unsignalized crossing has an RRFB and crosswalk markings. Using Table 14-15, a 1.5 reduction in PLTS classification is used due to the RRFB and crossing sign present at this crossing. Rounding up to the nearest whole number results in a PLTS 3 classification for this facility.

Table 14-17: Example 2 – Unsignalized Midblock Crossing Inventory and PLTS Classification

Facility[2]: School crossing near high school				
Characteristic		Value	PLTS Reference Table	PLTS Classification
Adjacent Roadway	Speed (mph)	35	Table 14-12, Table 14-13, or Table 14-14	PLTS 4
	Number of Lanes	4		
	ADT (vpd)	14,972		
	Raised Median	No		
Crossing Treatments(s)		RRFB, crossing sign	Table 14-15	-1.5
Overall PLTS Classification				PLTS 3

[2]Applicable to unsignalized intersection crossings or unsignalized midblock crossings (includes midblock crossings with PHB or RRFB)

14.2.1.3 Microsimulation

Microsimulation is used for pedestrian analysis scenarios as described in Figure 14-1.

Microsimulation is often used if the pedestrian facility interacts with motor vehicles (e.g., a midblock crossing across an arterial) and the interaction is expected to cause considerable pedestrian or vehicular delay. Microsimulation does not analyze safety or perceived comfort of a pedestrian facility; therefore, a microsimulation (microscopic) analysis is typically paired with a PLTS analysis.

A pedestrian crosswalk can be coded at an intersection using links that match the width and location of the crosswalk in the field that cross over the leg of the intersection. It is a best practice to use a different display type for pedestrian crosswalk links to show that these are separate from the vehicle network links. Signal heads and detectors are used on the pedestrian crosswalk links for pedestrian movements controlled by a pedestrian signal. Conflict areas are coded between vehicle and pedestrian links. Pedestrians are given priority by coding the conflict area for pedestrian links green and coding the overlapping vehicle links red.

Animations of pedestrian facilities can be created with microsimulation (microscopic) tools, and these animations are a valuable resource in a pedestrian analysis. Animations

are not necessary for any pedestrian facility analysis but could be recommended based on project complexity and level of detail. Animations are not acceptable as a standalone form of analysis and are to be used only as a complement to a PLTS, HCS, or traditional microsimulation (microscopic) analysis.

For information on coding detectors, conflict areas, and links for pedestrian analysis, see Chapter 13.

If using Vissim to conduct a pedestrian analysis, refer to the Vissim user manual for information on specific best practices and guidance.

14.2.1.4 Safety

In addition to the safety emphasis found in the PLTS analysis, additional resources on pedestrian facility safety are provided in Appendix O, Section 2 – Pedestrian and Bicycle Safety Resources, which contains information about countermeasure selection tools and crash analysis tools. The document also lists external reports that focus on pedestrian safety at various facilities. TxDOT has created the Pedestrian Safety Action Plan (PSAP) to address the rising number of pedestrian related crashes. A link to the PSAP is provided in Appendix O, Section 5 – External References (Reference 4). A link to the PSAP screening tool is provided in Appendix O, Section 5 – External References (Reference 5).

While predictive safety analysis for pedestrian facilities is limited as of 2024, the NCHRP Report 1784 is developing crash prediction model SPFs for use in the Second Edition of the HSM. For further information on the application of the HSM and other safety considerations, see Chapter 5 and Chapter 6.

14.2.2 Bicycle

Selecting the correct methodology or tool for bicycle analysis depends on several factors such as bicycle facility type, anticipated vehicular delay caused by bicycle facilities, and desired performance measures. A bicycle analysis methodology selection flowchart is provided in Figure 14-3 to guide in the selection of bicycle analysis methodologies. Refer to TxDOT's RDM Chapter 6, Section 4 for information on bicycle facility design.

The bicycle analysis subsection methodology is based on the following resources/tools (key notes are provided under each resource):

The bicycle analysis subsection methodology is based on the following resources/tools (key notes are provided under each resource):

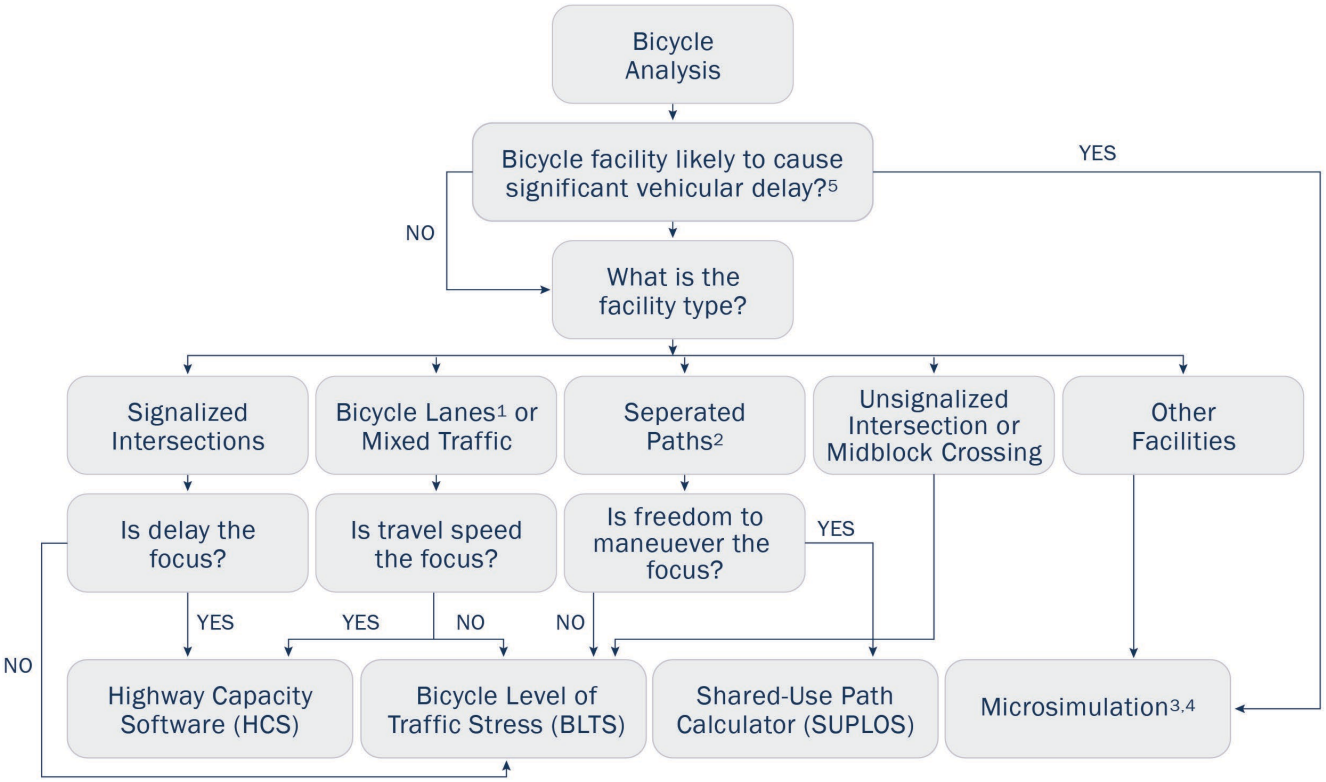
- HCM and the HCS;
  - Provides limited information for bicycle analysis methodologies
  - Methodologies emphasize bicycle crossings at signalized intersections and bicycle travel speed
  - This chapter emphasizes using the application of the HCM methodologies as seen in the HCS (i.e., signalized intersections and urban street segments)
- BLTS;
  - This methodology is from the Mineta Transportation Institute's

BLTS Report 11-19, May 2012 and is comparable to an assessment in which various bicycle accommodations are classified based on safety, comfort, and connectivity criteria

- Microsimulation; and
  - Guidelines on when to use microsimulation for bicycle analysis
  - This methodology is used to provide animations and analyze the interaction between bicycles and vehicles, but it does not analyze the perceived safety and comfort of bicycle accommodations
- Various Safety Guidelines
  - External resources that are used for bicycle facility improvements via countermeasure selection and scenario-specific enhancements
  - The future of predictive safety analysis for bicycle accommodations
- See Table 14-18 for various bicycle facilities and their descriptions.

Table 14-18: Bicycle accommodation types and descriptions

Type	Definitions/Descriptions
Shared Lane (Mixed Traffic)	Bicycles and vehicular traffic operate in the same space.
Bicycle Lane (may or may not have a buffer)	A bicycle lane is an on-street bicycle accommodation that gives bicycles defined ROW within certain areas. This includes paved shoulders.
Sidepath	Sidepaths are off-street bicycle accommodations.



[1] A bicycle lane is a standard bicycle lane (on-street bicycle lanes adjacent to vehicular traffic with no vertical buffer)
[2] Seperated paths are either bicycle facilities separated by vertical buffers or bicycle facilities that are not close to vehicular traffic
[3] If a visual rendering of the bicycle facility is required, microsimulation should be used
[4] When microsimulation is used, a BLTS analysis should also be conducted (where possible), to complement the microsimulation analysis.
[5] Significant vehicular delay is defined as failing level of service

Figure 14-3: Bicycle analysis tool/methodology selection flowchart

14.2.2.1 The HCM

The HCM-based software, HCS is best for bicycle analysis scenarios, as depicted in Figure 14-3.

The HCM contains methodologies for several bicycle facility types (see Table 14-19), but the HCS only analyzes urban street segments and signalized intersections. For street segment analysis, the HCM uses bicycle travel speed as a major factor to determine LOS. As such, it is recommended that the HCM methodology for street segment analysis only be considered for bicycle accommodations with high volumes of bicyclists (e.g., central business districts, mixed-use developments, tourist destinations, outdoor shopping centers). It is recommended to use HCS (or another similar software tool) for analysis of bicycle accommodations at signalized intersections. LOS D is recommended as a minimum target for signalized crossings and street segments.

Table 14-19: HCM 7th Edition Bicycle Analysis by Facility Type

Facility Type	HCM Chapter and Section Number
Urban street facilities	16.5
Urban street segments	18.5
Signalized intersections	19.6
Two-way stop-controlled intersections	20.6
All-way stop-controlled intersections	21.6
Roundabouts	22.6
Ramp terminals and alternative intersections	23.B.4
Off-street facilities	24.3

While bicycle analysis can be conducted by hand for other accommodations covered in the HCM (i.e., accommodations besides urban street segments and signalized intersections), it is recommended to use BLTS analysis for these other accommodations.

To conduct a bicycle analysis of signalized intersections, the inputs shown below are collected and entered into the corresponding fields on the "Bicycle Mode - Signals" section of the Multimodal Input Data on HCS. Definitions of multimodal inputs are provided in the HCS User Guide. Traffic inputs for the intersection will impact LOS calculations for the analysis and are also entered.

- On-street parking occupied, proportion;
- Curb-to-curb street width, ft;
- Outside through lane width, ft;
- Bicycle lane width, ft;
- Paved shoulder width, ft; and
- Presence of curb

To conduct a bicycle analysis of urban street segments, the inputs shown below are collected and entered on the "Bicycle Mode - Streets" section of the Multimodal Input Data on HCS. Definitions of multimodal inputs are provided in the HCS User Guide. To view results, print the "segments report" found in the HCS.

- Bicycle running speed, mi/h;
- Percent heavy vehicles;
- Total number of access points; and
- Pavement condition rating

14.2.2.2 Bicycle Level of Traffic Stress (BLTS)

BLTS is used for bicycle analysis scenarios as described in Figure 14-3.

A BLTS analysis is conducted by taking inventory of existing/proposed bicycle accommodations. The inventory gathers relevant information about each bicycle facility (e.g., bike lane width, on-street parking width, through lanes per direction, etc.). Inventory data is then compared to predefined BLTS classifications for each roadway characteristic and used to assign each facility an overall BLTS classification. A BLTS classification is a ranking that describes safety, comfort, and convenience (see Table 14-20). The steps for a BLTS analysis are shown in Figure 14-4. Detailed steps on conducting a BLTS analysis are provided on the next page.

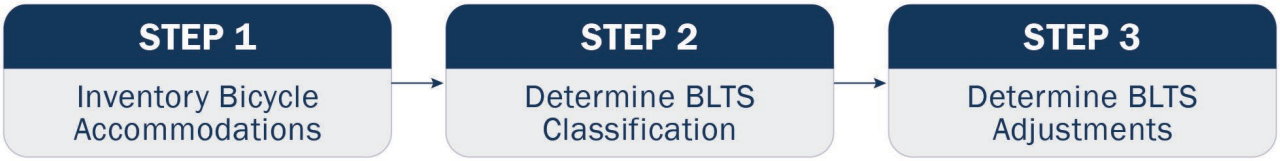


Figure 14-4: Steps in a BLTS analysis

The intent of a BLTS analysis is to determine individual bicycle facility deficiencies or connectivity gaps in a network to prioritize bicycle facility improvements. It can be used at any stage in the project development. At the planning level, it can be used to determine priority locations for improving bicycle accommodations. At the design level, it can be used to determine specific facility needs such as wider bicycle lanes, bicycle lanes separated by a buffer, or vertical feature, etc.

A BLTS analysis does not analyze capacity, travel times, or delay, but does analyze safety, comfort, and connectivity based on facility design.

The four BLTS classifications are BLTS 1 (the best rating), BLTS 2 (the minimum standard for most bicycle accommodations), BLTS 3 (the first failing rating), and BLTS 4 (the worst rating). The four classifications and their definitions are shown in Table 14-20.

Table 14-20: BLTS Classification Information

Classification	Characteristics
BLTS 1	Bicycle accommodations with this classification have little to no traffic stress. They are perceived as safe, open, and comfortable. Accommodations are often separated from motor vehicles by a buffer or vertical feature or are adjacent to roads with low speeds and low volumes. These accommodations are suitable for all abilities and ages. **This is the best classification.**
BLTS 2	Bicycle accommodations with this classification have a small level of traffic stress. They can be adjacent to motor vehicles and speeds higher than BLTS 1. These accommodations are suitable for most ages and abilities. This is the minimum standard for most pedestrian facilities.
BLTS 3	Bicycle accommodations with this classification represent accommodations with a medium level of traffic stress. These accommodations are often adjacent to motor vehicles and can be mixed bicycle traffic flow. Vehicle speeds and volumes are higher. These accommodations are suitable for some able-bodied adults. This is the first failing classification.
BLTS 4	Bicycle accommodations with this classification represent accommodations with the highest levels of traffic stress. They are often exclusively mixed traffic accommodations with high vehicle speeds and volumes. These accommodations are only suitable for highly confident able-bodied adults. **This is the worst classification.**

14.2.2.2.1 Step One: Template Selection and Data Collection for Bicycle Accommodations

The BLTS Inventory and Classification template (provided in Appendix O, Section 3 – BLTS Inventory and Classification) has four tables based on facility type:

- One for bicycle accommodations that are adjacent to vehicular traffic (with or without buffers);
- One for mixed traffic bicycle accommodations;
- One for bicycle accommodations at intersection approaches; and
- One for unsignalized intersection crossings or midblock crossings

This fillable template will serve as the basis for analysis and contains information on data needs, reference tables used in the analysis, and fillable boxes to input information.

Once the correct table on the BLTS Inventory and Classification template is selected, collect data for the bicycle facility in question. Use the BLTS Inventory and Classification template discussed previously to list all collected data. Characteristics to inventory depend on the facility type and are shown here:

- Separated bicycle lanes
    - Separated by proximity (e.g., bicycle lane is completely disconnected from vehicular traffic) or separated by a large vertical barrier (e.g., a large vertical feature between bicycle lane and vehicles)
    - BLTS 1 classification is recommended with no further analysis
- Bicycle lanes adjacent to vehicular traffic (does not include bicycle lanes separated by a large vertical barrier)
    - Posted speed
    - Through lanes per direction
    - Bicycle lane width
    - On-street parking width (if applicable)
        - See Table 14-22 or Table 14-23 for applicability criteria
- Mixed traffic bicycle accommodations (bicycles and vehicular traffic share the road)
    - Posted speed
    - Through lanes per direction
- Bicycle accommodations at intersection approaches
    - Generally, if more than 80 percent of bicyclists use signalized intersection crosswalks instead of crossing via bicycle lanes or vehicular lanes, a BLTS 1 classification can be given, and no further data collection or analysis is recommended
    - Posted speed
    - Right-turn length (if applicable)
        - A measure of how many vehicles use the right-turn lane (i.e., the longer the right-turn lane, the more people that use it)
        - Right-turn length is a substitute for TMCs at an intersection
        - Table 14-25 or Table 14-26 for applicability criteria
    - Lanes crossed to reach left-turn lane (if applicable)

        - See Table 14-27 for applicability criteria
- Unsignalized intersection crossing or midblock crossings
    - Posted speed on adjacent vehicular roadway
    - Number of adjacent roadway lanes
        - For roadways without a median refuge
            - Table 14-28 footnote 1 for adjacent roadway lanes definition
        - For roadways with a median refuge
            - See Table 14-29 or Table 14-30 footnote 1

14.2.2.2.2 Step Two: Determine BLTS Classification

Use the data gathered from the facility inventory and the relevant BLTS classification tables shown on the BLTS Inventory and Classification Template (see Appendix O, Section 3 – BLTS Inventory and Classification) to determine a BLTS classification. The BLTS classification reference tables are also shown in Table 14-21. The preliminary BLTS classification is written down on the BLTS Inventory and Classification template. Determining the overall BLTS classification of the facility occurs in Step 3, this step is a preliminary determination of BLTS classification.

Table 14-21: BLTS Analysis Tables by Facility Type

Facility Type	Tables Used to Determine PLTS
Bicycle lanes that are adjacent to vehicular traffic (does not include bicycle lanes that are adjacent to vehicular traffic but are separated by a large vertical barrier)	• Use Table 14-22 if the facility is adjacent to on-street parking • Use Table 14-23 if the facility is not adjacent to on-street parking
Mixed traffic bicycle accommodations	• Use Table 14-24
Bicycle accommodations at intersection approaches	• Use Table 14-25 if the facility is a pocket bike lane (a bike lane positioned between a right-turn lane and a through lane at an intersection) • Use Table 14-26 for mixed traffic bicycle accommodations at intersection right-turns • Use Table 14-27 for mixed traffic bicycle accommodations at intersection left turns
Bicycle accommodations at unsignalized intersection crossings or midblock crossings	• Use Table 14-28 if the facility is an unsignalized intersection crossing or midblock crossing with no raised median. • Use Table 14-29 if the facility is an unsignalized crossing or midblock crossing with a raised median (one to two lanes). • Use Table 14-30 if the facility is an unsignalized intersection crossing or midblock crossing with a raised median (three or more lanes).

A bicycle route can be comprised of several individual bicycle accommodations (e.g., a segment of bike lane not disconnected from vehicular traffic, a segment of mixed traffic bicycle accommodations, and a bicycle facility at an intersection approach). If this is the case, data is collected for each facility and a BLTS classification assigned to each facility separately in preparation for the overall facility BLTS classification.

Table 14-22: BLTS Criteria for Bicycle Lanes Alongside a Parking Lane

Posted Speed	1 Lane Per Direction			≥2 Lanes Per Direction
	≥15-ft bicycle lane + parking width	14-14.5-ft bicycle lane + parking width	≤13.5-ft bicycle lane + parking width[2]	
≤25	BLTS 1	BLTS 2	BLTS 3	BLTS 3
30	BLTS 2	BLTS 2	BLTS 3	BLTS 3
35	BLTS 3	BLTS 3	BLTS 3	BLTS 3
≥40	BLTS 4	BLTS 4	BLTS 4	BLTS 4

[1]Applicable to bicycle accommodations that are adjacent to on-street parking
[2]Use this column if bicycle lane blockage is common

Table 14-23: BLTS Criteria for Bicycle Accommodations Not Alongside a Parking Lane

Posted Speed	1 Lane Per Direction		2 Lanes Per Direction with Raised Median	≥2 Lanes Per Direction or No Raised Median
	≥6-ft bicycle lane width	≤5.5-ft bicycle lane width		
≤30	BLTS 1	BLTS 2	BLTS 2	BLTS 3
35	BLTS 3	BLTS 3	BLTS 3	BLTS 3
≥40	BLTS 4	BLTS 4	BLTS 4	BLTS 4

[1]Applicable to bicycle accommodations that are not adjacent to on-street parking

Table 14-24: BLTS Criteria for Mixed Traffic Bicycle Lanes

Posted Speed	Unmarked Centerline	1 Through Lane Per Direction	2 Through Lanes Per Direction	≥3 Through Lanes Per direction
≤20	BLTS 1	BLTS 1	BLTS 3	BLTS 3
25	BLTS 1	BLTS 1	BLTS 3	BLTS 3
30	BLTS 2	BLTS 2	BLTS 3	BLTS 4
35	BLTS 2	BLTS 2	BLTS 3	BLTS 4
40	BLTS 4	BLTS 4	BLTS 4	BLTS 4
≥45	BLTS 4	BLTS 4	BLTS 4	BLTS 4

Table 14-25: BLTS Criteria for Pocket Bicycle Lanes at Intersection Approaches[1,2]

Posted Speed	≤150-ft Right-Turn Lane Length	>150-ft Right-Turn Lane Length	Other[3]
≤25	BLTS 1	BLTS 2	BLTS 4
30	BLTS 2	BLTS 3	BLTS 4
35	BLTS 3	BLTS 3	BLTS 4
≥40	BLTS 3	BLTS 4	BLTS 4

[1]Only applicable when bicycle accommodations interact with right-turn lanes at an intersection approach
[2]Pocket bicycle lanes are bicycle lanes positioned between a right-turn lane and a through lane at an intersection
[3]Scenarios in this category include dual right-turn lanes, or a right turn and shared through-right combination

Table 14-26: BLTS Criteria for Mixed Traffic Bicycle Accommodations at Intersection Approaches (Right-Turn Lanes)[1]

Posted Speed	≤75-ft Right-Turn Lane Length	75 – 150-ft Right-Turn Lane Length	>150-ft Right-Turn Lane Length
≤25	BLTS 1	BLTS 1	BLTS 2
30	BLTS 1	BLTS 2	BLTS 3
35	BLTS 2	BLTS 3	BLTS 4
≥40	BLTS 3	BLTS 4	BLTS 4

[1]Only applicable when bicycle accommodations interact with right-turn lanes at an intersection approach

Table 14-27: BLTS Criteria for Mixed Traffic Bicycle Accommodations at Intersection Approaches (Left-Turn Lanes)[1]

Posted Speed	No Lane Crossed	1 Lane Crossed	≥2 Lanes Crossed	Other
≤25	BLTS 2	BLTS 3	BLTS 4	BLTS 4
30	BLTS 3	BLTS 4	BLTS 4	BLTS 4
≥35	BLTS 4	BLTS 4	BLTS 4	BLTS 4

[1]Only applicable when bicycle route can turn left and uses left-turn lane instead of two stage crossing at signalized crosswalks

Table 14-28: BLTS Classification of Unsignalized Intersection Crossing or Midblock Crossings (No Raised Median)

Posted Speed	Adjacent Roadway Lanes[1]					
	2 Lanes			3+ Lanes		
	<5,000 vpd	5,000 – 9,000 vpd	>9,000 vpd	<8,000 vpd	8,000 – 12,000 vpd[2]	>12,000 vpd
≤25	BLTS 1	BLTS 1	BLTS 2	BLTS 3	BLTS 3	BLTS 4
30	BLTS 1	BLTS 2	BLTS 3	BLTS 3	BLTS 3	BLTS 4
35-40	BLTS 2	BLTS 3	BLTS 4	BLTS 3	BLTS 4	BLTS 4
≥45	BLTS 3	BLTS 4	BLTS 4	BLTS 4	BLTS 4	BLTS 4

[1]For bicycle accommodations that are unsignalized intersection crossings or midblock crossings without a median refuge, this is the total number of lanes on the segment (e.g., a roadway with two lanes in each direction and a two-way left turn lane would have an adjacent lane value of 5)

[2]Use this column when ADT is unavailable

Table 14-29: BLTS Classification of Unsignalized Intersection Crossing or Midblock Crossings (1 to 2 Lanes – Raised Median)

Posted Speed	Adjacent Roadway Lanes[1]			
	1 Lane	2 Lane		
	Any	<5,000 vpd	5,000 – 9,000 vpd[2]	>9,000 vpd
≤25	BLTS 1	BLTS 1	BLTS 2	BLTS 2
30	BLTS 2	BLTS 2	BLTS 2	BLTS 2
35-40	BLTS 2	BLTS 2	BLTS 2	BLTS 3
≥45	BLTS 3	BLTS 3	BLTS 3	BLTS 4

[1]For bicycle accommodations that are unsignalized intersection crossings or midblock crossings with a median refuge, this is the maximum number of lanes crossed in one direction (e.g., a roadway with two lanes in each direction would have an adjacent roadway lane value of 2)

[2]Use this column when ADT is unavailable

Table 14-30: BLTS Classification of Unsignalized Intersection Crossing or Midblock Crossings (3 or More Lanes – Raised Median)

Posted Speed	Adjacent Roadway Lanes[1]			
	3 Lanes			4+ Lanes
	<8,000 vpd	8,000 – 12,000 vpd[2]	>12,000 vpd	Any
≤25	BLTS 1	BLTS 2	BLTS 3	BLTS 4
30	BLTS 2	BLTS 2	BLTS 3	BLTS 4
35-40	BLTS 3	BLTS 3	BLTS 4	BLTS 4
≥45	BLTS 4	BLTS 4	BLTS 4	BLTS 4

[1]For bicycle accommodations that are unsignalized intersection crossings or midblock crossings with a median refuge, this is the maximum number of lanes crossed in one direction (e.g., a roadway with two lanes one direction and three lanes in the other direction would have an adjacent roadway lane value of 3)

[2]Use this column when ADT is unavailable

14.2.2.2.3 Step Three: Determine BLTS Adjustments

As stated previously, separated bicycle lanes and bicyclists using pedestrian crossings at signalized intersection crosswalks are classified as BLTS 1.

For bicycle accommodations that are not separated, accommodations that are mixed traffic bicycle accommodations, and accommodations at intersection approaches, use the BLTS classification designated in step two.

For bicycle accommodations that are unsignalized intersection crossings or midblock crossings, use the overall BLTS classification determined in step two, adjusted for any crosswalk enhancements. The crosswalk enhancement adjustments are shown in Table 14-31.

Table 14-31: BLTS Classification Adjustments for Unsignalized Intersection Crossings and Midblock Crossings

Treatment[1]	Adjustment
High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs	-0.5
Raised crosswalk	-1.0
Advance Yield Here To (Stop Here For) bicycle sign and yield (stop) line	-0.5
In-street bicycle crossing sign	-0.5
Curb extension	-0.5
Bicycle refuge island	-1.0
RRFB	-1.0
PHB	-1.0

[1]The maximum reduction is 2 classification levels or BLTS 2, whichever comes first

If a bicycle route is comprised of multiple accommodations, the BLTS classification with the highest level of traffic stress governs the entire route (e.g., a route comprised of a BLTS 2 bicycle lane, a BLTS 3 intersection approach, and a BLTS 4 midblock crossing would receive a BLTS 4 classification).

Examples of a completed inventory and BLTS classification for an on-system bicycle facility are shown in Table 14-32 and Table 14-33.

In the first example shown in Table 14-32, the bicycle facility was a bicycle lane between intersections. The first step was to determine which inventory and classification template table to use (see Appendix O, Section 3 – BLTS Inventory and Classification). The upper table in the BLTS Inventory and Classification Template was used based on the footnote at the bottom of the table that states, “Applicable to bike accommodations that are adjacent to vehicular traffic”. Next, an inventory was conducted for the facility in question, the collected data was based on the BLTS Inventory and Classification Template chosen, and for this example included the following data:

- Bike lane width;

    - Determined to be five feet
- On-street parking width;
    - Determined that it is not applicable for this facility
- Through lanes per direction; and
    - Determined to be one
- Posted speed
    - Determined to be 35 mph

The collected data was used to determine the BLTS classification of the facility based on a single reference table. It is important to select the correct table. Although there are two reference tables on the BLTS Inventory and Classification template table, only one is selected, based on if the facility is adjacent to on-street parking. In this example, there is no on-street parking, so Table 14-23 was used to determine the BLTS classification. Based on Table 14-23, a bicycle accommodation adjacent to vehicular traffic with a five-foot bicycle lane width, a 35-mph speed limit, and one through lane of vehicular traffic per direction is given a BLTS 3 classification. This type of facility is not eligible for treatment reductions, therefore the final classification of this facility is BLTS 3. In part 2 of this example (see Table 14-33), the next portion of this bicycle route will be inventoried. Although a BLTS 3 classification was given to this facility, if other portions of the route are classified inferior, they will govern the entire route.

Table 14-32: Example 1 (Part 1) – Bicycle Lane Inventory and BLTS Classification

Facility: Bicycle Lane between intersections			
Characteristic	**Value**	**BLTS Reference Table**	**BLTS Classification**
Bike lane width (ft)	5	Table 14-23	BLTS 3
On-street parking width (ft)	Not applicable		
Through lanes per direction	1		
Posted speed (mph)	35		

In the second example shown in Table 14-33, the bicycle facility was a bicycle lane at an intersection approach. The first step was to determine which inventory and classification template table to use (see Appendix O, Section 3 – BLTS Inventory and Classification). The third table from the top in the BLTS Inventory and Classification Template was used based on the footnote at the bottom of the table that states, “Applicable to bicycle facilities at intersection approaches.” It was determined that most bicyclists cross the intersection on the bike lane and do not use the pedestrian crosswalk. Next, an inventory was conducted for the facility in question, the collected data was based on the BLTS Inventory and Classification Template chosen, and for this example included the following data:

- Right-turn length;
    - Determined to be 200 feet
- Number of lanes crossed; and

    - Determined to be four
- Posted Speed
    - Determined to be 35 mph

The collected data was used to determine the BLTS classification of the facility based on a single reference table. Although there are three reference tables on the BLTS Inventory and Classification template, only one is selected, based on if the facility is for a through-right movement or left turn and if the facility is mixed with traffic or if there is a bike lane. In this example, this is a through-right movement and is in mixed traffic, so Table 14-26 was used to determine the BLTS classification. Based on Table 14-26, a bicycle accommodation that approaches an intersection with a 200-foot right turn lane, crosses four lanes through the intersection, and has a posted speed of 35 mph is given a BLTS 4 classification. This type of facility is not eligible for treatment reductions, therefore the final classification of this facility is BLTS 4. Example 1 (Part 1) resulted in a BLTS 3 classification for the facility and example 1 (part 2) resulted in a BLTS 4 classification for the facility. Since the two facilities are on the same route, the overall route classification is BLTS 4 (i.e., the worse of the classifications).

Table 14-33: Example 1 (Part 2) - Bicycle Lane at Intersection Approach Inventory and BLTS Classification

Facility: Bicycle Lane at intersection approach			
Characteristic	**Value**	**BLTS Reference Table**	**BLTS Classification**
Right-turn length (ft)	200	Table 14-26	BLTS 4
Lanes crossed	4		
Posted speed (mph)	35		

The Shared-Used Path Level of Service (SUPLOS) calculator is used for bicycle analysis scenarios as described in Figure 14-3.

This tool is mainly used to evaluate bicycle mobility. Though the results of using this calculator will likely improve conditions for all modes on the path, it was designed from the bicyclist's point of view. It was created with the following usage criteria:

- The tool is for shared paths with paved hard surfaces (e.g., asphalt or concrete).
- The tool uses the following modes as inputs:
    - Adult bicyclists
    - Pedestrians
    - Runners
    - In-line skaters
    - Child bicyclists
- The tool is not applicable to trails with stop signs, signal controls, or road crossings with spacing less than 0.25 miles apart.
- The tool is best suited for two-way shared-use path facilities. It does not apply to on-street bicycle facilities.

Links to the SUPLOS calculator and user guide are provided in Appendix O, Section 4 – Shared-Use Path Level of Service Calculator Guidance.

14.2.2.3 Microsimulation

Microsimulation is used for bicycle analysis scenarios as described in Figure 14-3.

Animations of bicycle accommodations can be created with microsimulation (microscopic) tools and are a valuable resource in bicycle analysis. Animations are not necessary for any bicycle facility analysis but could be recommended based on project complexity and level of detail. Animations are not acceptable as a standalone form of analysis and are recommended to be used only as a complement to a BLTS, HCS, or traditional microsimulation (microscopic) analysis.

Microsimulation can be used if the bicycle facility interacts with motor vehicles and if there are significant delays. Microsimulation does not analyze safety or perceived comfort of a bicycle facility, so a microsimulation (microscopic) analysis is paired with a BLTS analysis wherever possible (i.e., for all facility types except signalized intersections, alternative intersections or interchanges, and high-volume urban street segments).

For general guidance on conducting a microsimulation (microscopic) analysis, see Chapter 13.

If using Vissim to conduct a bicycle analysis, refer to the Vissim user manual for information on specific best practices and guidance.

14.2.2.4 Safety

In addition to the safety emphasis found in the BLTS analysis, additional resources on bicycle facility safety are provided in Appendix O, Section 2 – Pedestrian and Bicycle Safety Resources. It contains information about countermeasure selection tools and crash analysis tools for bicycle accommodations. The document also lists many external reports that focus on bicycle safety at various accommodations and scenarios.

While predictive safety analysis for bicycle accommodations is limited as of 2024, NCHRP Report 1784 is developing crash prediction model SPFs for use in the Second Edition of the HSM. For further information on the application of the HSM and other safety topics, see Chapter 5 and Chapter 6. Additionally, TxDOT Research and Technology Implementation is sponsoring a research project to address bicycle safety through the development of CMF for bicycle accommodations.

14.2.3 Freight

This section focuses on truck freight and does not discuss rail, pipeline, air, and maritime freight.

Though typically a component of various facility analyses, truck freight does not typically receive a standalone analysis. If a standalone freight analysis is necessary (e.g., analysis of a truck freight-only facility), microsimulation is used.

Freight impacts operational analysis of many facilities because trucks have different characteristics than passenger cars (e.g., acceleration and deceleration rates, size, weight-to-power ratio, etc.). Some characteristics of freight that are considered

when conducting an operational analysis are as follows:

- Passenger car equivalency;
    - Certain analysis methods found in the HCM use a passenger car equivalency factor that converts truck traffic to passenger traffic for analysis
    - Microsimulation does not use a passenger car equivalency factor. It uses truck traffic counts or percentages
- Truck traffic percentage;
    - This includes historical truck traffic percentages and projected truck traffic percentages
    - Adjusting truck percentage in a microsimulation (microscopic) model will account for truck characteristic variation
- Origins and destinations of truck traffic; and
- Interactions between truck freight and passenger cars
    - Truck freight characteristics are to be embedded in microsimulation, but default values may need to be changed

PCE values are found in the Basic Freeway and Multilane Highway Segments Chapter of the HCM 7th Edition. For level terrain, HCM 7th Edition defines the truck PCE as 2.0; for rolling terrain, the truck PCE is 3.0. In addition to the basic PCE values, HCM 7th Edition Exhibits 12-26, 12-27, and 12-28 have PCE values for grade and truck composition (i.e., single-unit trucks and tractor-trailers) variations.

There are several resources that can be used to determine truck traffic percentage and other truck-related statistics:

- Classification counts to determine truck traffic percentage can be obtained from permanent count stations or temporary counts stations on the TxDOT's Traffic Count Database System (TCDS) application.
- Weigh-in-Motion (WIM) stations are an important source of truck classification and weight data.
- Transearch is a database tool that aggregates historical truck traffic and projects freight flows up to 30 years into the future. Freight information can be filtered by origin, destination, commodity, and transportation mode. It has county-level freight-movement data. Transearch is produced by IHS Markit. The data is classified by:
    - Inbound, outbound, intrastate, and through traffic;
    - Tonnage and value;
    - Commodity type; and
    - TxDOT TPP has a contract with the company that oversees the software (IHS Markit). Coordinate with the TxDOT Project Manager regarding the User License Agreement to access Transearch data
- Some MPOs may have an OD dashboard that can be used for freight analysis.

- MPO TDM outputs.
- **SAM Freight Assignment Module:** The SAM freight model includes a zonal structure that is specific to the freight components of the SAM. It defines freight zones based upon aggregated counts outside of Texas and counties within Texas. Freight tonnage is forecasted on an annual basis (annual tonnage) based on Transearch data. After the mode choice step, freight truck annual tonnage at the county level is converted to daily truck trips to be assigned to the roadway network. This tool can be used to obtain freight tonnage by origin and destination, the routing of tonnage carried by the mode, the commodity type of tonnage moving in the state, and the truck volumes on modeled roadways. MPOs also have TDMs that can be used to analyze freight
- The FHWA and Bureau of Transportation Statistics (BTS) have created the FAF tool that outlines general freight movement between major metropolitan areas within Texas, from Texas to other states, and from Texas to Mexico and Canada. Freight information can be filtered by flow type, year, origin, destination, commodity, and distance. This tool has an emphasis on historical truck data and can be used for projects that involve historical traffic data.

Origin and destination data is used to determine the routes used by truck freight. This helps prioritize facility improvements and can also be used in microsimulation. Origin and destination data is often collected by using third-party probe data such as INRIX, Replica, Wejo, or StreetLight.

For more information on data collection that relates to freight analysis, see Chapter 2 in this manual.

- TxDOT is developing the Truck Congestion Analysis Tool (TCAT) that is used as a Planning tool for analyzing and monitoring truck mobility. The tool provides mobility performance measures for major roads in Texas from 2017 to the present. The key features of this tool are found in Table 14-34.

Table 14-34: Truck Congestion Analysis Tool Key Features

Feature	Overview
Traditional mobility performance measures	Traditional mobility performance measures such as annual delay, delay per mile, congestion cost, travel time index, planning time index, and others are included in this tool.
Analysis levels	The TCAT includes information on the top 100 congested roadways and primarily focuses on the top 100 most congested roadways for trucks. TCAT also provides users the more comprehensive Roadway-Highway Inventory Network (RHiNo) which gives a more detailed picture at individual roadway segments, custom corridors, or regional summaries.
Performance summaries	The TCAT performance summaries presents results at various levels, including individual roadway segments, custom generated corridors defined by start and end points, regional areas, or pre-defined corridors.
Projects	The TCAT provides visualization layers for near-term and long-term transportation projects from the UTP and provide more information regarding the projects through the TxDOT Data Portal.
Annual Truck Congestion Report Cards	The TCAT provides a link to the Annual Truck Congestion Report Cards for each of the top 100 Truck Congested Roadways, as well as each of the pre-defined regions/geographies. The report cards help quickly examine performance trends.

14.2.4 Transit

Transit can be analyzed using TDM outputs. Typical outputs for transit using TDM include ridership by line or by company among other typical vehicular outputs. There are two types of TDM models that can be used to analyze transit:

- The Statewide Area Model includes a procedure to automatically generate a transit route system based on a scenario network. The Statewide Area Model short-distance mode share model applies different mode splitting factors to TAZs with different transit accessibility. The Statewide Area Model transit assignment procedure produces standard TransCAD outputs to help review transit ridership.
- MPOs may have TDMs, whose outputs can also be used to analyze transit.

Transit can also be analyzed using microsimulation. Microsimulation excels at measuring transit's impacts on other modes of transportation (and vice versa) and gives the flexibility to analyze various transit scenarios (e.g., transit stops in mixed traffic versus transit stops in an exclusive lane; transit stops downstream of intersection versus transit stops upstream of intersection; impacts of queue jumper or transit signal priority; complex transit facilities; etc.).

While a TDM or microsimulation can be used for analysis of most transit projects, the HCM 7th Edition has two chapters dedicated to transit analysis (see Table 14-35). This methodology is limited to public transit vehicles, primarily buses and lightrail, operating in mixed or exclusive transit lanes that make stops along urban streets. The HCM method emphasizes LOS as a function of transit vehicle travel speed and transit riders' perception.

The HCM methodology can be used if using microsimulation is not feasible due to resource constraints.

Table 14-35: Transit Analysis by Facility Type

Facility Type	HCM 7th Edition Chapter and Section Number
Urban street facilities	16.6
Urban street segments	18.6

The HCM transit analysis methodology for urban street segments has been integrated into HCS, which can be used to analyze transit if a microsimulation (microscopic) analysis is not feasible due to resource constraints. To conduct a transit analysis of urban street segments, the inputs shown below are collected and entered into the corresponding fields on the "Transit Mode - Streets" section of the Multimodal Input Data on HCS. Definitions of multimodal inputs are provided in the HCS User Guide. All other inputs (traffic, pedestrian, bicycle, etc.) for the intersection will impact LOS calculations for the analysis and are included. To view results, print the "segments report" found in the HCS.

- Number of transit stops;
- Dwell time, s;
- Excess wait time, minutes;
- Average passenger trip length, miles;
- Transit frequency;
- Passenger load factor;
- Transit stops near side;
- Transit top on-line;
- Stops with shelters, proportion;
- Stops with benches, proportion;
- Re-entry delay, seconds; and
- Base travel time rate, minutes/mile

There may be circumstances where microsimulation analysis is not feasible and the HCM methodology is not applicable. In such cases, the following methodologies can be used to analyze transit:

- The transit analysis methodology found in NCHRP 616 "*Multimodal Level of Service Analysis for Urban Streets*" Chapter 6 is based on how accessibility, wait time, and travel time impact the probability of users riding transit. This type of analysis is done manually and guidance on conducting this analysis is provided in the NCHRP report.
- The Transit Capacity and Quality of Service Manual (TCRP Report 165) provides in-depth guidance for the largest variety of transit scenarios. Using this methodology, users can analyze buses, demand responsive transit, vanpool, rail transit, and ferry transit. Furthermore, this methodology includes transit in mixed, semi-exclusive, or exclusive traffic as well as transit on grade-separated facilities.

14.2.5 Railroad

There are several safety and operational considerations when analyzing railroads. Typical considerations include railroad grade crossing treatments and spacing, signal pre-emption, and noise impacts of railroads. Each of these considerations are discussed below.

Crossing Treatments – The Highway-Rail Crossing Handbook can be used to determine appropriate treatments for rail grade crossings. Example of treatments include gates, sidewalks at the crossing, audible warnings, etc. Any traffic signal improvements or other treatments (e.g., RRFB, PHB) within 200 feet of the railroad crossing that could potentially stop vehicular traffic need to be coordinated with the railroad operator.

Spacing – It is desirable to have adequate spacing between railroad crossings and nearby intersections or driveways to avoid queues spilling back on the railroad tracks or upstream intersections. It is recommended that turn lanes accommodate queues when a train is crossing at or near an intersection.

Signal Preemption – In order to clear vehicles potentially stopped on the tracks when a train arrives, interconnection is necessary for traffic signals located within 200 feet of the railroad crossing and are considered for signals located further away depending on factors including traffic volumes, highway vehicle mix, highway vehicle and train approach speeds, frequency of trains, and queue lengths. For more information, refer to the (TMUTCD). TxDOT Form 2304, Guide for Determining Time Requirements for Traffic Signal Pre-emption at Highway Rail Grade Crossings can be used to determine necessary signal preemption times to sufficiently clear vehicles that may be blocking the railway tracks.

Quiet Zones (Horn-Free) – These are areas where the use of train horn is prohibited except for emergency situations. Some railroad companies may want to use a train horn whenever possible but are required to implement a quiet zone if a local jurisdiction follows Federal Railroad Administration's train rule requirements.

For more information about railroad analysis, see Appendix O, Section 5 – External References (Reference 1) and Appendix O, Section 5 – External References (Reference 2).

Microsimulation can be used to analyze railroads and is particularly useful in the analysis of interactions between rail and vehicles. Details on how to code railroad crossings and pre-emption is not provide in this guide, but each microsimulations user guide provides guidance on these topics.

Chapter 15
Transportation System Management and Operations (TSMO) and Transportation Demand Management (TDM) Analysis

15.1 Introduction

This chapter focuses on TSMO and TDM. TSMO is a set of strategies that improve the performance of travel facilities by enhancing the operational capabilities of these facilities with limited resources while TDM is a set of strategies that manage or reduce capacity demand on the roadway by increasing traveler choices and by adjusting operations in real-time.

15.1.1 Purpose and Intended Use

The purpose of this chapter is to provide an overview of TSMO and TDM definitions, benefits, goals and objectives, and various strategies. The strategies listed in this chapter, which include corridor management strategies, systems management strategies, and others, are meant to assist in developing innovative solutions to various issues faced by transportation systems today and in the future. The intended use is to understand the different actions that may be taken to use or develop said strategies and analyze the impacts they would have on travel facility operations.

15.2 Concepts

15.2.1 Definitions

The FHWA defines TSMO as a "set of strategies that focus on operational improvements that may maintain and even restore the performance of the existing transportation system before extra capacity is necessary." TSMO is not limited to the deployment of a single strategy, and it ultimately represents the optimization of safety, reliability, and mobility for the existing system with limited resources.

15.2.2 TSMO Project Scopes and Strategies

There are various TSMO project types and strategies. Each strategy involves varying levels of resources to implement and has varying levels of impact on traffic operations and safety. Table 15-1 shows example projects categorized by strategy and project scope.

Table 15-1: Example TSMO Projects Categorized by Strategy and Scope

Strategy	Project Scope		
	Systems-level	Operational	Physical Infrastructure
Work Zone Management	• Coordinating road projects • Lane closure policies • TxDOT's Design Guidelines for Deployment of Work Zone ITS and Go/No-Go Decision Tool • After-action reviews	• Temporary speed monitoring system • Queue detection and warning system • Service patrol	• Travel time dynamic message signs (DMS) units • Speed or queue detection sensors • CCTV cameras • Temporary pull-off areas
Traffic Signal Coordination	• Traffic management center (TMC) • Preemptive method for re-timing signals	• Automated traffic signal performance measures (ATSPM)	• Cellular modems or radios • Traffic signal surveillance cameras • Battery backup units
Traffic Incident Management (TIM)	• Emergency operations center (EOC) • Video-sharing agreements • Data collection • Multidisciplinary training • After-action reviews to complete TxDOT's After-Action Report form	• Pre-planned detour routes • Emergency vehicle preemption • Tow company rotation list • Tow and Go program • Service patrol	• CCTV cameras • Equipment staging areas • Preemption sensors • Crash investigation sites
Traveler Information	• DriveTexas.org • Third-party navigation applications (Google, Waze)	• Traveler information dissemination along key corridors	• Traveler information DMS units • In-vehicle devices that display static and dynamic information
Service Patrols	• TxDOT's Highway Emergency Response Operator (HERO) Roadside Assistance Program	• HERO trucks designated to patrol specific key corridors	• Wide shoulders • Service patrol calling signage
Ramp Management	• Ramp closure and metering standard operating procedures	• Ramp metering along a corridor • Exclusive HOV bypass lane or ramps • Automatic ramp closure	• Automated ramp closure gates • Ramp metering signals • Pavement markings • Ramp widening
Special Event Management	• Special event traffic control plan guidelines and standards • Special events calendar	• Traffic management plan • Pre-planned detour routes • Alternate traffic signal timings	• Destination signage • Permanent DMS units near large and frequently used event venues

Strategy	Project Scope		
	Systems-level	Operational	Physical Infrastructure
Managed Lanes	• Automated toll billing via mail or electronically	• Bypass lanes designated for trucks, HOV, transit, or tolls • Dynamic lane reversal	• Dynamic price DMS units • Pavement markings • Additional lanes designated for trucks, HOV, transit, or tolls • Reversible lane signage • Toll infrastructure
Road Weather Management	• Weather-related maintenance protocol and standard operating procedures • AVL equipment tracking	• Ice prevention pretreatment • Flood and ice detection and warning system	• Automated closure gates • Flood and ice detection sensors • Flashing warning beacons • CCTV cameras
Active Traffic Management	• Traffic management center (TMC) • Performance measure goals and tracking	• Adaptive traffic signal control • Dynamic lane reversal • Adaptive ramp metering	• Vehicle detectors • Communications equipment • CCTV cameras • DMS units • Reversible lane signage • Ramp metering signals
Transit Management	• Transit vehicle tracking	• Transit signal priority	• Preemption sensors • Additional lanes designated for transit vehicles
Integrated Corridor Management	• Traffic management center (TMC) • Signal timing improvements	• Pre-planned detour routes • Adaptive ramp metering • Tow and Go program	• CCTV cameras • Traveler information DMS units
Freight Management	• Designated truck routes	• Oversize/over-height detection and warning system • Truck parking availability information dissemination	• Parking availability DMS units • Oversize/over-height sensor • Flashing warning beacons • Truck route and parking signage
Rural Emergency Response	• Lane closure policies	• Emergency vehicle preemption	• Wide shoulders • CCTV cameras

15.2.3 Benefits

TSMO strategy selection is based on objectives and benefits. Successful implementation of TSMO strategies may include the following benefits:

- Safety improvement;
- Congestion alleviation;
- Improved travel time reliability;
- Improved air quality;
- More efficient resource consumption; and
- Informed traveler decision-making

15.2.4 Planning and Programming

The overarching TSMO vision, mission, goals, and objectives are defined by TxDOT and presented below. See Appendix P, Section 2 – External References (Reference 1) for TxDOT's Statewide TSMO Strategic Plan and Appendix P, Section 2 – External References (Reference 2) for a list of links that lead to each individual TxDOT District's TSMO Program Plan. These TxDOT plans can be integrated into plans of MPO regional areas, District areas, and local areas. Specific TSMO and TDM strategies are customized for the area in which they are implemented, but all TSMO strategies are recommended to align with the Statewide TSMO vision.

15.2.5 Statewide TSMO Vision, Mission, Goals and Objectives

Statewide TSMO Vision: Improve safety and mobility for all modes of transportation by integrating planning, design, operations, and maintenance activities and acknowledging all opportunities for innovation.

Statewide TSMO Mission: Through innovation, collaboration, and performance-based decision making, the existing transportation facilities are developed, constructed, maintained, and operated cost-effectively, with the end user in mind.

Statewide TSMO Goals and Objectives:

- Safety – Reduce crashes and fatalities through continuous improvement of traffic management systems and procedures.
- Reliability – Optimize travel times on transportation systems in critical corridors to evaluate that travelers are reaching their destinations in the amount of time they expected for the journey.
- Efficiency – Implement projects that optimize existing transportation system capacity and alleviate congestion.
- Customer Service – Provide timely and accurate travel information to customers so they can make informed mobility decisions.
- Collaboration – Proactively manage and operate an integrated transportation system through multijurisdictional coordination, and cooperation between various transportation disciplines and partner agencies.
- Integration – Prioritize TSMO as a core objective in the agency's planning, design, construction, operations, and maintenance activities.

15.2.6 Data

In the context of TSMO and TDM, data is used to determine effective strategies, make real-time changes to the transportation network (e.g., modify traveler information or signal changes), communicate project impacts to the public, and monitor performance.

For general information about data (types, collection framework, etc.) see Chapter 2 of this manual. For information on performance measurement, see Section 15.4.

15.3 Analysis

15.3.1 Overview

The FHWA Office of Operations developed the *Operations B/C Analysis Desk Reference ("the Desk Reference")* to provide guidance on how to conduct B/C analysis for a wide spectrum of TSMO strategies. A B/C analysis is defined in the *Desk Reference* as a systematic process for calculating and comparing benefits and costs of a project for two purposes:

- To determine if it is a sound investment; and
- To see how it compares with alternate projects

A B/C analysis estimates the cost-effectiveness of a project by dividing the monetized benefits associated to the project by the costs of implementing and maintaining that project. The resulting cost-effectiveness value is expressed as a ratio or a resultant value. A project with a resultant value greater than one is identified as efficient because the benefits associated with the project are greater than the expected project costs. Projects with a resultant value less than one are deemed inefficient due to the costs outweighing the benefits.

For analyzing TSMO projects, the benefits used in B/C analyses refer to **the monetized estimates of the changes in the identified MOEs** for the project that are directly attributable to the project investment. MOEs typically analyze the impacts of TSMO strategies on aspects of traffic operations, such as:

- Roadway volumes and speeds;
- Number of crashes and crash severity;
- Duration of incidents;
- Traveler route and mode choice; and
- Agency procedures

The costs used in the denominator of the B/C analysis calculations represent the life-cycle costs of implementing, operating, and maintaining the project being analyzed. These life-cycle costs include:

- Capital costs;
- Operations and maintenance costs;
- Replacement costs; and
- Annualized costs

A B/C analysis can be used at multiple stages of a project. An analysis can be conducted during the planning phase as an evaluation tool to determine which TSMO strategies are the most cost-effective and beneficial. It can also be used as an assessment tool to evaluate the success of a project once it has been implemented. The results of a B/C analysis

conducted for planning purposes may be less accurate because more assumptions and estimations are involved. A comparison of MOEs before and after a project is implemented leads to a more accurate B/C analysis because the measured impacts of project implementation are known.

15.3.2 Typical Measures of Effectiveness (MOE)

The monetized benefits in a B/C analysis are calculated by applying an established unit value for each MOE and then applying that value to an estimated change in the identified MOEs for the project being analyzed. The MOEs described below are factors often influenced by TSMO and TDM projects and commonly used as a basis for assessing a particular project's positive or negative impacts.

15.3.2.1 User Travel Time Savings

User travel time is the most used MOE for more traditional capacity-related transportation improvements as well as TSMO projects. User travel time savings refers to the change in the sum of all person hours of travel (PHT) resulting from the implementation of a TSMO project. However, this MOE is a measure of the average, recurring travel time. Many TSMO projects target reducing travel times impacted by nonrecurring factors, such as incidents or construction activity. Because of this, using only this measurement may result in underestimating the benefits of a TSMO project.

Travel time can include time spent inside and/or outside of a vehicle, depending on the mode choice the analysis considers, such as a transit or active transportation alternative. Different monetary values of travel time can also be assigned, depending upon the nature of travel in question. For example, on-the-clock freight vehicle travel time can be assigned a higher monetary value than passenger car leisure travel time.

15.3.2.2 User Vehicle Operating Costs

User vehicle operating cost is also a commonly used MOE for assessing both traditional capacity-related transportation improvements and TSMO projects. User vehicle operating costs can be split up by fuel use or nonfuel use costs. Nonfuel costs include maintenance, insurance, and vehicle depreciation costs. The fuel use MOE is typically estimated by applying a rate of average fuel use to the net change in vehicle miles of travel (VMT).

15.3.2.3 Crashes

Many TSMO projects have been shown to significantly reduce the number of crashes, as well as the severity of vehicular crashes when they do occur. TSMO projects may reduce the chance of crash exposure by smoothing the flow of traffic and alerting drivers of potential interferences. TSMO projects may also reduce the severity of crashes by improving the emergency response to incidents through shorter response times and improved preparedness. The costs associated with crashes include the actual costs, such as medical treatment and property damage, and the cost to avoid, which is an estimate of the value that individuals would be expected to pay to avoid being involved in a crash.

15.3.2.4 Emissions

A more complex MOE used for both traditional capacity-related transportation improvements and TSMO projects is emission levels. The emissions categories typically include hydrocarbons (HC)/reactive organic gases (ROG), nitrogen oxide (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM_{10}) or fine particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2). Most emissions estimates are based on the application of an emissions rate per VMT. However, emissions rates are sensitive to a variety of variables, such as vehicle speeds and type of vehicle.

15.3.2.5 Emerging MOEs

New MOEs have recently been introduced to B/C analysis to evaluate the effectiveness of emerging TSMO strategies: travel time reliability, incident-related delay, and consumer surplus. These emerging MOEs often provide more justification for TSMO projects, as these MOEs are the focus of many operations deployments.

- Travel time reliability is the variability in travel times caused by both nonrecurring and recurring congestion sources.
- Incident-related delay includes factors that relate to a facility's capacity.
- Consumer surplus refers to the difference between the amount users are willing to pay in terms of travel costs, including time and money, and how much they pay. Consumer surplus is usually used in the assessment of travel time savings.

15.3.3 Tools for Conducting B/C Analysis

15.3.3.1 Tools for Operations B/C Analysis (TOPS-BC)

The TOPS-BC is an FHWA-developed sketch-level or macroscopic planning and operations B/C decision support tool in the form of an Excel spreadsheet. This tool can be found in Appendix P, Section 2 – External References (Reference 3). The guidance provided in the *Desk Reference* includes the fundamental background information for B/C analysis, while the TOPS-BC user's manual focuses on the setup and operation of the TOPS-BC spreadsheet. According to the TOPS-BC user's manual, the TOPS-BC benefit estimation methodology was developed to incorporate the assessment of new MOEs, such as travel time reliability, that are more capable of capturing and analyzing the unique impacts of TSMO strategies.

TOPS-BC can be used to evaluate the cost-effectiveness and potential return on investment of candidate TSMO projects during the early stages of project development. The tool has two key capabilities:

- Estimate Life-cycle Costs of TSMO Strategies – provides a framework and default cost data to estimate the life-cycle costs (including capital, replacement, and continuing operations and maintenance costs) of various TSMO projects.
- Conduct Simple Spreadsheet-Based B/C Analysis for Selected TSMO Strategies – Provides a framework and suggested

impact values to conduct B/C analysis for selected strategies.

The Life-cycle cost estimation capability of TOPS-BC provides the capability to estimate the costs of various TSMO strategies. The tool is developed to provide scalable costs dependent on the scope of the user's anticipated deployments. The life-cycle cost estimates include both up front capital costs as well as on-going operations and maintenance (O&M) costs. The tool is also capable of displaying average annual costs and the expected stream of costs over time. Compared to more traditional transportation capacity improvements, TSMO projects typically have a greater proportion of continuous O&M costs, as opposed to upfront capital costs.

The B/C analysis capability enables the user to estimate the potential benefits of various TSMO strategies. TOPS-BC is designed to provide sketch planning estimates of TSMO strategy benefits primarily targeted at fulfilling the needs of practitioners wanting to conduct preliminary screening and initial prioritization of TSMO strategies. These benefits may then be compared with the estimated strategy life-cycle costs to produce the net benefit measures and B/C ratio.

15.3.3.2 Traffic Incident Management B/C (TIM-BC) Tool

The TIM-BC tool enables users to evaluate and compare the monetary value of a wide range of TIM strategies. The guidance provided in the *Desk Reference* includes the fundamental background information for B/C analysis, while the user's manual for the TIM-BC tool focuses on the evaluation of operations impacts attributed to the following eight TIM-specific TSMO project types:

- Safety Service Patrol;
- Driver Removal Laws;
- Authority Removal Laws;
- Shared Quick Clearance Goals;
- Pre-Established Towing Service Agreements;
- Dispatch Collocation;
- TIM Task Forces; and
- SHRP2 TIM Training

To conduct a B/C analysis using the TIM-BC tool, users are recommended to first input basic project-level information, including the project name, State in which the program operates, number of segments the project operates on, duration of the study period, number of annual incidents within the project's boundaries, and annual total project cost.

The next step of the TIM-BC tool involves segment information for each of the segments identified in the initial project-level input step. This step includes the input of details about the roadway geometry (segment length, number of lanes, general terrain, etc.), program information (operation time and average incident duration savings), traffic information (posted speed limit, traffic volumes, truck percentage), and weather information.

The project output screen displays the tool's calculated savings for a variety of factors, such as hours of delay, gallons of fuel, number of secondary accidents, and different emissions.

The user selects which of these factors the TIM-BC tool are used to determine the B/C ratio.

15.3.4 TxDOT Framework for TSMO Project Delivery

The TxDOT TRF Division has developed a TSMO Evaluation Tool, accessible via Appendix P, Section 2 – External References (Reference 4) The TSMO Evaluation Tool identifies items for consideration that encourage the use of relevant TSMO projects and technologies as part of overall project development. The tool includes checklists for each phase of project delivery. These checklists can be used at each applicable stage of the project delivery process to evaluate opportunities to incorporate TSMO into projects.

Planning phase checklists include lists specifically developed for stakeholder coordination, safety, operations, and technology. Design phase checklists include those specifically developed for the preliminary design concept conference, data collection efforts, and PS&E. Construction phase checklists include lists specifically developed for coordination efforts, technology, and operations. A checklist is also provided for activities to be conducted at project closeout.

Additional guidance documents on TSMO and TDM strategies are presented in Appendix P, Section 1 – TSMO and TDM Strategies, Additional Guidance Documents.

15.4 Performance Measurement

15.4.1 Overview

For discussion of MOEs see Section 15.3.2.

Chapter 11 of the HCM 7th Edition builds on the basic freeway analysis presented in the HCM and provides a methodology for evaluating a freeway's travel time reliability over a multiday or multi-month reliability reporting period (RRP) and under a variety of conditions, such as lane closures, traffic incidents, or periods of inclement weather.

Freeway reliability refers to the distribution or variability of travel times of trips through an entire freeway facility over a period of time, typically one year. Travel time variation may be caused by recurring variations in demand by hour of day, day of week, and month of year, which are generally predictable in distribution. Travel time variation may also be caused by less predictable non-recurring variations in demand or available roadway capacity.

The methodology estimates the impacts of recurring and nonrecurring congestion on travel time variability and can also estimate the impacts that TSMO and TDM strategies have on travel time and travel time variability. Many TSMO and TDM strategies target reducing congestion and delays associated with the nonrecurring factors described below and, as a result, reducing travel time variation. Nonrecurring factors that impact travel time include:

- Severe weather that reduces speeds and capacity and influences demand;
- Incidents that reduce capacity;
- Work zones that reduce capacity and influence demand; and

- Special events that produce temporary spikes in traffic demands, which may be recurring or nonrecurring

HCM freeway reliability analysis methods may be used to assess the influence of TSMO and Active Transportation and Demand Management (ATDM) projects on a freeway and the impacts of recurring and nonrecurring events that occur on the facility. The reliability analysis allows individual TSMO and ATDM projects, as well as any combination of projects, to be analyzed under a variety of freeway conditions. The analysis determines the full range of capacity under any condition, combination of conditions, and implemented transportation improvements.

For additional information and case studies on TSMO, ATDM, and performance measurement see Appendix P, Section 2 – External References (References 5,6, and 7).

15.4.2 Methodology

The freeway reliability analysis relies on the freeway facilities core methodology presented in Chapter 10 of the HCM 7th Edition, which is described in Chapter 9 of this manual. A base dataset is used to develop a base scenario, which is then adjusted to create a variety of different scenarios that represent the range of actual freeway capacity and facility demand as conditions on the facility change. The travel time distribution produced from the results of each scenario's travel time calculations may be used to determine reliability performance measures of the analyzed freeway segment. Adjustments associated with TSMO and ATDM projects can then be applied to appropriate scenarios to assess the impacts of the projects.

Figure 15-1 shows the freeway reliability analysis methodology framework as shown in the HCM.

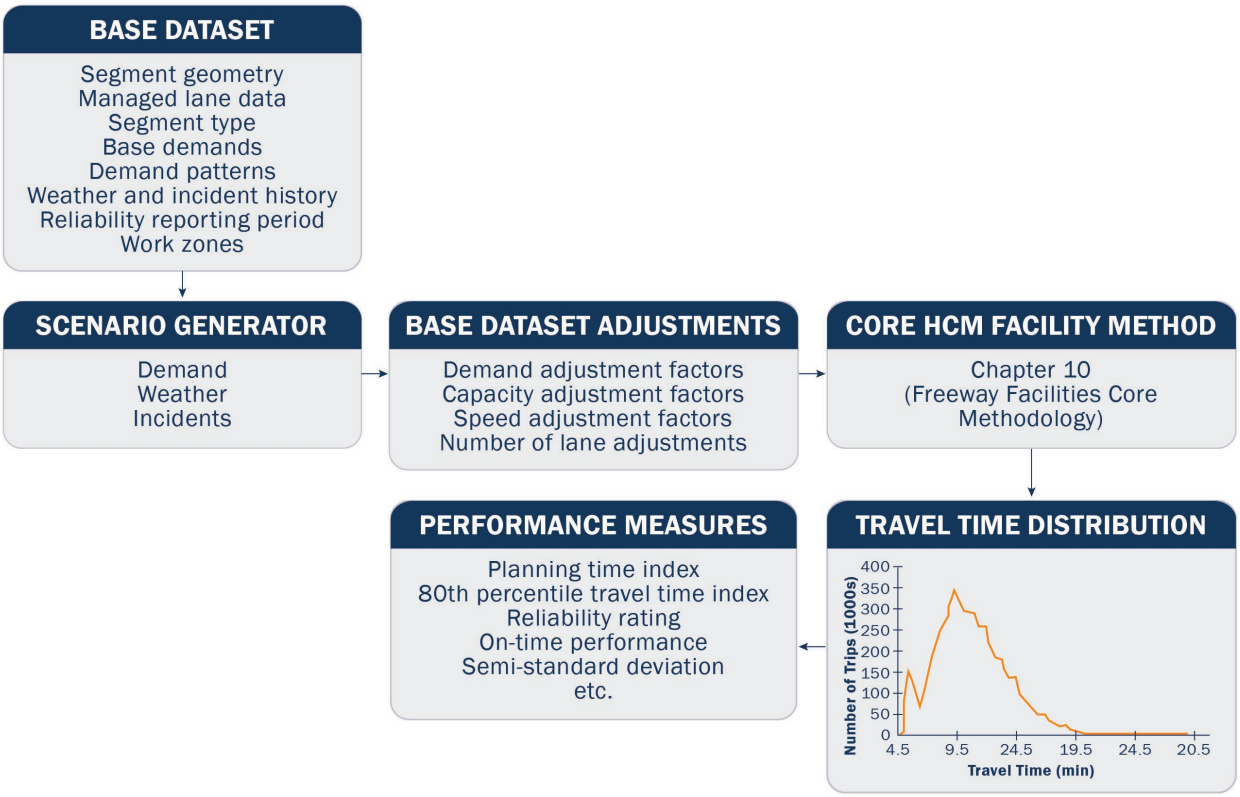


Figure 15-1: Freeway Reliability Methodology Framework

15.4.3 Scenario Generation

The freeway capacity analysis analyzes 15-minute periods of extended lengths of freeway comprised of continuous connected basic freeway, weaving, merge, and diverge segments. A base dataset provides all the necessary input data for the freeway facilities core methodology, including the facility's geometry, free-flow speeds, lane patterns, segment types, and base demand volumes. This initial freeway capacity analysis produces a base scenario model for the freeway reliability analysis.

A freeway's performance is typically analyzed under different conditions to get a more accurate picture of the facility's operations throughout the study period. Therefore, after a base scenario model is developed, a set of scenarios is created by modifying the base dataset inputs and applying adjustments, including CAFs, speed adjustment factors (SAFs), and demand adjustment factors (DAFs), associated with various factors that impact freeway capacity, such as weather events, traffic incidents, and work zones. These scenarios are generated to reflect conditions that a freeway facility experience during the RRP. Each scenario represents a single study period with adjusted demand and capacity variations specific to that scenario.

The default number of scenarios generated in a typical freeway reliability analysis, without

considering weekends, is 240. This value was obtained by creating four replications of each weekday-month demand combination. Analyzing multiple replications of each weekday-month combination confirms the presence of a large sample of weather and incident events. The number of scenarios can be fewer or greater, depending on the scope of the analysis, range of factors, and the target performance measures.

15.4.4 Factors Affecting Travel Time Reliability

The factors that affect travel time reliability tend to adjust either the demand placed upon a facility, the effective available capacity of the facility, or the base travel speed that vehicles travel at while using the facility. Each factor is described in greater detail below.

15.4.4.1 Traffic Demand

Traffic demand fluctuates both across days within the week and across months of the year. Daily and weekly fluctuations can be caused by work schedules, typical working business hours, and other factors. Monthly fluctuations can be caused by seasonal activities, such as sporting events, recreational activities, and school session schedules. Traffic demand also fluctuates across the year due to holidays, religious festivals, fairs, concerts, and other special events.

The base freeway analysis scenario accounts for traffic demand variation for different hours of a given day. To account for day-to-day traffic demand variability in the generation of multiple scenarios, the traffic demands for the analysis period are calibrated by applying a demand multiplier based on the day of week and month combination. The demand multiplier is a ratio of the day-month combination daily facility demand to the daily facility demand for a reference period. These factors are first used to adjust demand data used in the base scenario to what may be expected in terms of demand for the reference period. A second adjustment changes the demand of the reference day-and-month combination to the expected demand for any other day-month combination analyzed as part of the RRP. Table 15-2 and Table 15-3 provide default demand ratios for urban and rural freeways, respectively, with ratios shown relative to traffic demand on a Monday in January. These values can be supplemented by locally collected demand factors if they are available.

15.4.4.2 Weather Events

The base scenario assumes ideal driving weather conditions; clear, no precipitation, and high visibility. However, different weather conditions have a wide range of impacts on the capacity of a freeway and the free flow travel speed, depending on the severity of the weather event. Inclement weather, such as snow, rain, or fog, can degrade driving conditions by creating slick roads, flooding, or limiting visibility. These conditions may result in reduced roadway capacity and reduced free flow speeds.

CAFs and SAFs for weather events are applied to scenarios across a RRP based on the probability of a weather event's occurrence during a given month in the freeway location. For example, if historical weather trends

indicate for a given month that heavy rain events occur across ten percent of days, then the relevant AFs for that weather event can be applied at random to ten percent of the scenarios analyzed for that month. This methodology can be repeated for all types of weather. The 11 weather categories consist of one non-severe weather category that includes all weather conditions that generate no capacity, demand, or speed adjustments, and ten categories of severe weather events that have been shown to reduce capacity by at least four percent. CAFs are shown in Table 15-4 and SAFs are shown in Table 15-5.

Table 15-2: Default Urban Freeway Demand Ratios (ADT/Mondays in January)

Month	Day of Week						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	1.00	1.00	1.02	1.05	1.17	1.01	0.89
February	1.03	1.03	1.05	1.08	1.21	1.04	0.92
March	1.12	1.12	1.14	1.18	1.31	1.13	0.99
April	1.19	1.19	1.21	1.25	1.39	1.20	1.05
May	1.18	1.18	1.21	1.24	1.39	1.20	1.05
June	1.24	1.24	1.27	1.31	1.46	1.26	1.10
July	1.38	1.38	1.41	1.45	1.62	1.39	1.22
August	1.26	1.26	1.28	1.32	1.47	1.27	1.12
September	1.29	1.29	1.32	1.36	1.52	1.31	1.15
October	1.21	1.21	1.24	1.27	1.42	1.22	1.07
November	1.21	1.21	1.24	1.27	1.42	1.22	1.07
December	1.19	1.19	1.21	1.25	1.40	1.20	1.06

Note: Ratios represent demand relative to a Monday in January

Source: HCM 7th Edition

Table 15-3: Default Rural Freeway Demand Ratios (ADT/Mondays in January)

Month	Day of Week						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	1.00	0.96	0.98	1.03	1.22	1.11	1.06
February	1.11	1.06	1.09	1.14	1.35	1.23	1.18
March	1.24	1.19	1.21	1.28	1.51	1.37	1.32
April	1.33	1.27	1.30	1.37	1.62	1.47	1.41
May	1.46	1.39	1.42	1.50	1.78	1.61	1.55
June	1.48	1.42	1.45	1.53	1.81	1.63	1.57
July	1.66	1.59	1.63	1.72	2.03	1.84	1.77
August	1.52	1.46	1.49	1.57	1.86	1.68	1.62
September	1.46	1.39	1.42	1.50	1.78	1.61	1.55
October	1.33	1.28	1.31	1.38	1.63	1.47	1.42
November	1.30	1.25	1.28	1.35	1.59	1.44	1.39
December	1.17	1.12	1.14	1.20	1.43	1.29	1.24

Note: Ratios represent demand relative to a Monday in January

Source: HCM 7th Edition

Table 15-4: Default CAFs by Weather Condition

Weather Type	Weather Event Definition	Capacity Adjustment Factors				
		55 mi/h	60 mi/h	65 mi/h	70 mi/h	75 mi/h
Medium rain	>0.10-0.25 in./h	0.94	0.93	0.92	0.91	0.90
Heavy rain	>0.25 in./h	0.89	0.88	0.86	0.84	0.82
Light snow	>0.00-0.05 in./h	0.97	0.96	0.96	0.95	0.95
Light-medium snow	>0.05-0.10 in./h	0.95	0.94	0.92	0.90	0.88
Medium-heavy snow	>0.10-0.50 in./h	0.93	0.91	0.90	0.88	0.87
Heavy snow	>0.50 in./h	0.80	0.78	0.76	0.74	0.72
Severe cold	<-4°F	0.93	0.92	0.92	0.91	0.90
Low visibility	0.50-0.99 mi	0.90	0.90	0.90	0.90	0.90
Very low visibility	0.25-0.49 mi	0.88	0.88	0.88	0.88	0.88
Minimal visibility	<0.25 mi	0.90	0.90	0.90	0.90	0.90
Non-severe weather	All conditions not listed above	1.00	1.00	1.00	1.00	1.00

Note: Speeds given in column heads are free-flow speeds.

Source: HCM 7th Edition

Table 15-5: Default SAFs by Weather Condition

Weather Type	Weather Event Definition	Speed Adjustment Factors				
		55 mi/h	60 mi/h	65 mi/h	70 mi/h	75 mi/h
Medium rain	>0.10-0.25 in./h	0.96	0.95	0.94	0.93	0.93
Heavy rain	>0.25 in./h	0.94	0.93	0.93	0.92	0.91
Light snow	>0.00-0.05 in./h	0.94	0.92	0.89	0.87	0.84
Light-medium snow	>0.05-0.10 in./h	0.92	0.90	0.88	0.86	0.83
Medium-heavy snow	>0.10-0.50 in./h	0.90	0.88	0.86	0.84	0.82
Heavy snow	>0.50 in./h	0.88	0.86	0.85	0.83	0.81
Severe cold	<-4°F	0.95	0.95	0.94	0.93	0.92
Low visibility	0.50-0.99 mi	0.96	0.95	0.94	0.94	0.93
Very low visibility	0.25-0.49 mi	0.95	0.94	0.93	0.92	0.91
Minimal visibility	<0.25 mi	0.95	0.94	0.93	0.92	0.91
Non-severe weather	All conditions not listed above	1.00	1.00	1.00	1.00	1.00

Note: Speeds given in column heads are free-flow speeds.

Source: HCM 7th Edition

15.4.4.3 Traffic Incidents

The base scenario assumes the freeway is operating at full capacity with no traffic incidents or closures. However, the impacts of a traffic incident on freeway operations can vary depending on the severity of the incident and the extent of the resulting closure. Incidents typically cause shoulder or lane closures, as disabled vehicles block the roadway, and vehicles passing incidents tend to drive slower, reducing the capacity of the freeway segment.

Traffic incidents are generated for this analysis based on their expected frequency of occurrence on the facility within the analysis hours of a day in a given month. The incident frequency is the average number of incidents experienced on the facility and varies each month.

For scenarios with an incident, the incident details (including number of lanes impacted and incident duration) are modeled using a normal probability distribution. Table 15-6 provides parameters for normal distributions of the impacts an incident may have, depending on the severity of the resulting closure. These parameters are used to randomly generate and assign the characteristics of an incident to use for an analysis scenario. Table 15-7 displays the CAFs associated with each incident severity type, and these factors are applied based on the incident with characteristics generated from the parameters shown in Table 15-6. For example, if an analysis segment has a 50 percent chance of experiencing an incident, then for half of the scenarios generated for a month, each scenario is modeled with a unique incident.

The incident severity and duration parameters are randomly generated from the normal distribution referenced in Table 15-6. Additionally, Table 15-7 shows that a three-lane closure incident on a four-lane directional facility results in a loss of three full-lane capacities and maintaining only 52 percent of the capacity in the remaining lane. The CAFs in Table 15-7 are applied to each scenario for that scenario's randomly generated incident duration and according to that scenario's randomly generated incident severity. The CAFs are applied to the capacity results to determine the impacts of incidents on roadway capacity based on the scenario being analyzed.

Table 15-6: Default Freeway Incident Severity Distribution and Duration Parameters (min)

Parameter	Incident Severity Type				
	Shoulder Closed	1 Lane Closed	2 Lanes Closed	3 Lanes Closed	4+ Lanes Closed
Distribution (%)	75.4	19.6	3.1	1.9	0
Duration (mean)	34	34.6	53.6	67.9	67.9
Duration (standard deviation)	15.1	13.8	13.9	21.9	21.9
Duration (minimum)	8.7	16	30.5	36	36
Duration (maximum)	58	58.2	66.9	93.3	93.3

Source: HCM 7th Edition

Table 15-7: CAFs by Incident Type and Number of Directional Lanes on the Facility

Directional Lanes	No Incident	Shoulder Closed	1 Lane Closed	2 Lanes Closed	3 Lanes Closed	4 Lanes Closed
2	1.00	0.81	0.70	N/A	N/A	N/A
3	1.00	0.83	0.74	0.51	N/A	N/A
4	1.00	0.85	0.77	0.50	0.52	N/A
5	1.00	0.87	0.81	0.67	0.50	0.50
6	1.00	0.89	0.85	0.75	0.52	0.52
7	1.00	0.91	0.88	0.80	0.63	0.63
8	1.00	0.93	0.89	0.84	0.66	0.66

Notes: N/A = not applicable – the number of lanes closed equals or exceeds the number of directional lanes. The methodology does not permit all directional lanes of a facility to be closed.

Source: HCM 7th Edition

15.4.5 Work Zones

The work zones considered in this analysis refer to **scheduled, significant work zone events**, including any scheduled closures of one or more travel lanes or shoulders. These work zones typically last multiple days or weeks and may involve multiple stages, with a combination of shoulder and lane closure parameters. Minor maintenance activities, such as pavement patching or guardrail repair, is treated as an incident event due to the short-term impacts. A major construction project that occurs throughout the entire analysis period is a global factor and applied to every scenario; therefore, it is recommended that long-term work zone impacts be considered during the freeway capacity analysis and development of the base scenario, described in Chapter 9 of this manual.

When accounting for work zones across a RRP, the base freeway capacity is adjusted for the representative portion of the analysis scenarios. For example, if a work zone that closes one lane is planned for three months of a 12-month RRP, the scenarios generated for those three months are analyzed with one fewer lane than the other scenarios analyzed as part of the RRP. For a step-by-step guide of conducting a work zone analysis, refer to Chapter 10 Section 4 of the HCM.

15.4.6 Freeway Reliability Analysis Process

The freeway reliability analysis process is time-intensive and involves extensive and repetitive calculations. Use an existing tool or software (e.g., HCS, FREEVAL, etc.) to streamline the analysis and minimize calculation errors. The following steps include the necessary analysis inputs and a description of when a calculation conducted by a tool or software can be automatically performed.

1. Define RRP and Exclude Delays – Define the duration of the RRP (typically one calendar year to incorporate all day-to-day and month-to-month variability in the various factors that impact travel time reliability). Identify which days of the week to include or exclude in the analysis, such as weekdays, weekends, and holidays.
2. Gather Reliability Inputs – Collect the inputs necessary for conducting a reliability analysis, including demand variability, weather data, incident records, work zone data, and special event information.
3. Define or Refine Global Inputs – Two global calibration parameters that may require revision are facility-wide jam density and queue discharge capacity drop. These global parameters apply to the entire facility, as opposed to other parameters that exist at specific locations or segments along the freeway.
4. Define Number of Replications for Reliability Analysis – Define the number of replications used to generate scenarios (typically four for a RRP of one year) to obtain a sufficient, randomly generated sample size of data.
5. Define Demand Variability by Day and Month and Assign to Scenarios – Define

the demand multipliers by day of the week and by month of the year based on facility-specific data.

6. **Define Weather Probabilities and Impacts and Assign to Scenarios** – Define the probabilities of occurrence of each of the weather categories and the corresponding capacity, demand, and SAFs.
7. **Define Incident Frequencies and Impacts and Assign to Scenarios** – Define the incident frequencies for each of the incident severity types, the corresponding capacity, demand, and SAFs, and number of lanes lost due to the incident.
8. **Define Short-Term Work Zone Events and Adjustments** – Define the dates of any short-term work zone events, the corresponding capacity, demand, and SAFs, and number of lanes lost due to the work zone. "Short-term work zones" refers to scheduled or planned work zones that are not operating for the entire RRP. Long-term work zones are often evaluated as a stand-alone reliability analysis, with a base scenario modified with the work-zone characteristics.
9. **Generate Full Scenario List and Scenario Probabilities** – Use a computational program or software (FREEVAL-ATDM, Active Demand Management Capability Maturity Framework Tool, etc.) to automatically generate a list of all scenarios for the reliability analysis. Each scenario has a complete set of attributes defining the demand, capacity, and travel speed characteristics of that scenario relative to the base scenario.
10. **Perform Analysis for Each Scenario** – Use a computational program or software to automatically apply the adjustment matrices from the previous step to the base scenario. Each resulting scenario is evaluated with the HCM freeway capacity analysis core methodology. The computation program calculates and catalogs performance measures for each scenario.
11. **Compute Reliability Performance Measures** – Generate a travel time distribution from the average facility travel times by analysis period and scenario. The computational program or software can automatically compute a variety of reliability performance measures from the results of all scenarios.
12. **Validate Against Field Data** – Compare the reliability results to the field data from another model to determine whether the model matches the field data in an acceptable way or whether the analysis involves calibration adjustments.
13. **Report Performance Measures** – Report the facility's reliability performance measures. An ATDM evaluation may be performed to continue the analysis.

15.5 Transportation Demand Management (TDM)

According to the FHWA, TDM is a group of strategies designed to maximize traveler choices. These strategies are aimed at improving travel reliability. They affect an entire system and analysis periods, when there is an overall change in demand, most commonly when there is a reduction in demand. Although TDM is a set of strategies, it is most helpful to focus on individual strategies within the set that can be integrated into existing activities within the State or regional planning process.

The traffic analysis for the effectiveness of TDM improvements is typically based on objectives and rely on performance measures. Example performance measures that may be used for TDM analysis are shown below:

- Percentage of commute trips taken by a non-single-occupancy vehicle (SOV) mode;
- Number of vanpool/carpool participants;
- Percentage of residents within proximity of a park and ride facility;
- Percentage of residents within proximity of a transit stop;
- Number of centerline miles for active transportation facilities;
- Availability of real-time traveler information;
- Availability of last mile connections;
- Availability of micro-mobility rides; and
- Travel time data-sharing

Below are general TDM strategies that can be implemented or analyzed:

- Multimodal – Using different modes of transportation (walk, bicycle, transit, personal vehicle) to complete a trip without increasing the number of vehicles.
- Ridesharing – Reducing the number of SOV trips to reduce the number of vehicles on the road.
- Flexible Work Schedule – Teleworking or working flexible hours to take an alternate route or alternate departure time.
- Land Use – Providing compact land uses that reduce the distances between origins and destinations for live, work, and play. Supporting more travel choices and making transit, walking, and cycling more practical.

15.5.1 Active Transportation and Demand Management (ATDM) Strategies

FHWA defines ATDM as the dynamic movement, control, and influence of travel demand, traffic demand, and traffic flow on transportation facilities. ATDM is part of the broader concept of TSMO, with a deeper focus on the active management principle of TSMO and combining ATDM strategies. The ATDM analysis methodology in the 7th Edition of the HCM distinguishes between five principal categories of strategies that may affect facility operations:

- Demand Management Strategies – These strategies alter the entire system of segments and analyses when they are used in the event of an increase or decrease in demand.
- Weather Management Strategies – These strategies only impact performance during analysis periods when a severe weather event affects the facility and apply equally to all segments. For example, weather-related driver information, snow removal, flood closures, etc.
- Incident Management Strategies – These strategies only impact the performance of segments and analysis periods when an incident occurs. For example, freeway service patrol, driver information, dynamic lane assignment, etc.
- Work Zone Management Strategies – These strategies only impact the performance of segments and analysis periods when a work zone is present. For example, end-of-queue warning system, dynamic merge control, etc.
- Special Segment-Specific Strategies – These are the strategies not covered in the previous categories. These strategies impact the performance of specific target segments. For example, ramp metering, hard shoulder running, etc.

15.5.2 ATDM Analysis Process

The ATDM methodology builds on the reliability analysis described previously, which builds on a calibrated core freeway facility analysis described in Chapter 10 of the HCM 7th edition. Like the freeway reliability analysis process, the ATDM analysis process is time-intensive and includes extensive and repetitive calculations. Use an existing tool or software (FREEVAL-ATDM, Active Demand Management Capability Maturity Framework Tool, etc.) to streamline the analysis and minimize calculation errors. The following steps include the necessary analysis inputs and a description of when a calculation conducted by a tool or software can be automatically performed. Refer to FHWA-HOP-18-072 Strengthening Linkages between Transportation Demand Management and Traffic Management for real-world examples of ATDM solutions.

1. Limit Scenario List – ATDM strategies are often applied to a subset of scenarios to target a specific operational condition. If that is the case, the scenario list may be reduced to only include the appropriate scenarios that the ATDM strategy is expected to impact. For example, a freeway safety service patrol program may only be activated for scenarios in which a traffic incident has occurred, so only these scenarios can be analyzed with the ATDM strategy in place.
2. Select Pool of ATDM Strategies – Select which ATDM strategies or plans to include in the evaluation and determine which strategies or plans can be applied to which scenarios.
3. Convert ATDM Information to Operational Inputs – Convert the ATDM strategy into operational inputs,

including the applicable AFs, incident duration adjustments, and number-of-lane adjustments. The HCM 7th Edition, as of 2024, does not include default values for ATDM strategies, so the inputs are based on judgement or local data. For example, a freeway safety service patrol program might be shown locally to reduce incident duration for minor incidents by 30 percent, so all operational inputs that involve capacity adjustments over the duration of an incident are modified accordingly when evaluating scenarios with the strategy in place.

4. **Design ATDM Plans for the Facility and Assign to Scenarios** – Identify which scenarios the ATDM strategies being analyzed apply to and determine the set of inputs. If multiple strategies are combined for a single scenario, multiply their respective AFs to produce a single factor for application to the scenario.
5. **Process ATDM Scenarios** – Use a computational program or software (FREEVAL-ATDM, Active Demand Management Capability Maturity Framework Tool, etc.) to automatically evaluate each scenario by applying the HCM freeway capacity analysis core methodology.
6. **Compute Performance Measures** – Use a computational program or software to calculate performance measures for the facility, with the ATDM strategies applied for each scenario.
7. **Process Before-and-After Comparison** – Conduct a before-and-after comparison of ATDM strategy effectiveness by comparing the results of the reliability analysis with the results of the ATDM analysis. The focus of this comparison is on the travel time distribution before and after the implementation of the ATDM strategies.
8. **Validate Results** – Compare ATDM analysis results with field data, results from other models, or expert judgement.
9. **Report Performance Measures** – Report the facility's reliability performance measures with the ATDM strategy or plan applied. Comparing these performance measures to those without an ATDM strategy in place could also allow for a B/C analysis based upon these performance measures, as described in Section 4 of this chapter.

Chapter 16
Traffic Impact Analysis

16.1 Introduction

16.1.1 Purpose and Intended Use

The purpose of conducting a TIA is to determine the ability of the surrounding transportation system to handle the change in demand of traffic introduced by a project. Improvements are recommended if the existing infrastructure does not sufficiently support the increased traffic demand. This chapter provides guidance on how to complete a TIA and discusses the pertinent information that is recommended to be included in all submittals.

It is recommended that a TIA:

- Summarizes the report in an executive summary;
- Documents the project area;
- Details the proposed development;
- Analyzes existing roadway conditions and traffic operations near the site;
- Generates proposed site traffic using accepted trip generation rates in the *ITE Trip Generation Manual;*
- Generates vehicle, pedestrian, freight, transit etc. site traffic data depending on project scope;
- Formulates trip distribution and assignment for site-generated vehicular traffic;
- Analyzes traffic operations and LOS at future key study years for the site;
- Compares traffic operations between background scenarios and build scenarios;
- Addresses access management;
- Provides recommendations if mitigation is necessary; and
- Summarizes findings

16.1.2 Limitations

This chapter does not provide final guidance as to whether a TIA is recommended. TxDOT and applicable agencies may request a traffic study for various scenarios that are not accounted for in this chapter. TxDOT's Access Management Manual contains guidance in Chapter 3 on different engineering studies, including when TIAs are typically requested. A link to the TxDOT Access Management Manual can be found in Appendix Q, Section 4 – External References (Reference 4). The TxDOT project manager has the final say for the methodology used on the project.

16.2 Process

During the preliminary stages of permitting for a proposed development, TxDOT may recommend submission of a TIA. Typically, a TIA is performed when a proposed development is anticipated to generate 100 or more vehicle trips in a given peak hour with access to a TxDOT facility. It is recommended to use Appendix Q, Section 1 – TIA Quality Control

Checklist during the TIA process to maintain consistency.

16.2.1 TIA Categories

Confirm TIA categories with the local TxDOT District. If the District does not have guidelines for TIA categories, it is recommended to use Texas Transportation Institute's (TTI's) *Recommended Access Management Guidelines for Texas* (Report No. FHWA/TX-05/0-4141-2). A TIA is classified into one of three typical categories based on the number of trips generated by the development as shown in Table 16-1. Developments that generate less than 100 trips and prompt minor engineering studies for access management purposes are also recommended to confirm that proposed driveways comply with TxDOT's *Access Management Manual*. An example of determining peak hour trip generation is provided in Appendix Q, Section 3 – TIA Example Problems.

Table 16-1: TIA Categories

Categories	Peak Hour Trip Generation Range (veh/hr)	Additional Requirement	Analysis to Include
1	100-499	The TxDOT District can request a TIA if under 100 trips result from localized safety or capacity deficiencies.	• Buildout year of development • Ramps, roads, and intersections that are significantly impacted by development • Site access drives and intersections adjacent to site
2	500-1,000	NA	• Buildout year of development • Year of completion of each phase • Five years after full buildout • Ramps, roads, and intersections that are significantly impacted by development • Site access drives and intersections within 1 mile of the development
3	>1,000	NA	• Year of completion of each phase • Year of completion • Five years after full buildout • Ten years after full buildout • Ramps, roads, and intersections that are significantly impacted by development • Site access drives and intersections within 1 mile of the development

Note: Service drives, emergency drives, and other drives with minimal traffic are typically omitted. This table is adapted from TTI's Guidelines.

16.2.2 Preliminary Scoping

It is recommended that the specific project scope be confirmed with the local TxDOT District before the start of a TIA. Whether with an in-person meeting or alternate correspondence, discussing the scope with TxDOT will tailor a TIA to each specific project. TIAs can vary significantly from one to another, and consulting TxDOT is important to check that nothing is overlooked in a project.

This correspondence can help confirm:

- Number of access points to TxDOT roadways;
- Acceptable LOS thresholds;
- Selected study years;
- Anticipated influence area;
- Intersections and roadways to be analyzed;
- Scenarios to analyze;
- Data collection method;
- Project schedule and buildout year;
- Data source;
- Use of TDM outputs, growth factors, etc.; and
- Other major projects in area

Once scope is confirmed with TxDOT, the TIA can be performed.

16.2.3 Authorship

It is suggested that the TIA be prepared and completed under the supervision of a professional engineer (P.E.) licensed in the State of Texas and that the P.E. have competence and experience in traffic engineering. It is also recommended that all aspects of the deliverable be completed in a professional and ethical manner and that the final submittal be signed, sealed, and dated.

16.2.4 TIA Report

It is recommended that a technical memorandum or report be compiled detailing the analysis completed and stating all findings and recommendations. Recommended TIA report deliverables are found in Appendix Q, Section 2 – TIA Report Outline. Coordinate with the TxDOT project manager for final report deliverables.

16.2.5 Review and Approval

Once a TIA is completed, it is recommended that the document be signed, sealed, and submitted to TxDOT for review and approval. Coordinate with the local TxDOT District for specific submittal practices and deadlines. Comments received from TxDOT are typically addressed in a revised TIA.

16.3 Scope of Analysis

16.3.1 Analysis Study Area (Intersections and Segments)

The study area includes the roads and intersections within the project and the area impacted by the proposed trips generated by the development. Roadways to be included in the analysis are confirmed with TxDOT during the preliminary scoping process outlined in Section 2 of this chapter.

16.3.2 Analysis Scenarios

Analysis scenarios include:

- **Existing Scenario:** This is the analysis of existing traffic on the current roadway network. Field observations are made, and traffic counts collected if necessary. Lane configuration and geometries reflect existing field conditions. Existing traffic signal timings can be obtained from TxDOT or the City and used in the analysis.
- **Future Scenarios:** This is the analysis of the existing traffic, as well as background growth and all new trips generated by the proposed development. Typically, future analysis years involve the opening year of the development and five years out from the opening year (future horizon study year). For larger developments, interim study years can also be analyzed. These study years often correspond to the estimated completion of phases of the development.
- Lane configuration and geometries can be altered to accommodate the increase in traffic. Signal timings can be optimized to accommodate the extra traffic generated. These changes are documented as mitigations.
- **Example** problems of future scenario analysis and possible mitigations can be found in Appendix Q, Section 3 – TIA Example Problems.

16.3.3 Analysis Assumptions

Analysis assumptions include:

- Background (planned) traffic volume growth
    - When analyzing future vehicular traffic, it is necessary to account for the background growth that naturally occurs along major roadway segments. The growth rates are based on a combination of the historical AADT and current field count data collected along the segment analyzed. TxDOT's Traffic Count Database System, linked in Appendix Q, Section 4 – External References (Reference 1), may be used to obtain historical traffic counts. An **example** of calculating background growth rate is provided in Appendix Q, Section 3 – TIA Example Problems.
    - Trips are typically generated for other approved developments near the site. Coordination with TxDOT and governing municipalities takes place to confirm other developments near the site are accounted for in the background vehicular traffic volume growth. Trips for these approved developments are typically generated in the same manner as outlined in the trip generation section below.
- Background (planned) roadway improvements
    - Any future planned roadway improvements near the project site are considered when developing the future scenario

analysis. (Ex. Resurfacing, widening, ITS, traffic signals, etc.) The following resources can be checked for future TxDOT planned projects:
TxDOT's Project Tracker, found in Appendix H, Section 1 – External References (Reference 6)
TxDOT's UTP, found in Appendix Q, Section 4 – External References (Reference 3)

- **Trip generation and trip generation reductions (internal capture, pass-by, modal split)**
    - The most common source for trip generation is the Institute of Transportation Engineer's (ITE's) latest publication of the *Trip Generation Manual.* Trips are generated using either the fitted curve equation or average rates provided. It is recommended that the fitted curve equation be used when a fitted curve equation is provided, and the data plot has at least 20 data points or when a fitted curve equation is provided, and the data plot has an R2 value of at least 0.75. Consult the *ITE Trip Generation Handbook* Chapter 4, "Trip Generation Manual Data," when deciding between the fitted curve equation or average rates. Daily, AM, and PM peak hour trips are typically included in the analysis. It is recommended that TxDOT be consulted when alternate forms of trip generation are used.
    - Trip generation for the peak hour of the adjacent street is used for the majority of land uses. For uses with a known non-standard peak, such as a school, trip generation may be done for the peak hour of the generator. Use engineering judgement and consult the local TxDOT District in these cases.
    - If reductions are to be taken for internal capture, reference the ITE *Trip Generation Handbook*. This is especially common for mixed-use developments. Internal capture accounts for any trips between land uses within the same development that do not touch the off-site street system. Example calculations of trip generation and internal capture can be found in Appendix Q, Section 3 – TIA Example Problems.
    - Pass-by trips consist of trips that are already traveling on the adjacent roadway network but enter the proposed development on their way to another destination. This is typically a percentage of the total gross external trips generated. Commercial developments are eligible for pass-by trips. This percentage is based on historical pass-by data collected and is

found in the ITE *Trip Generation Handbook.*

- Multimodal reduction is typically used on trip generation in areas where alternate forms of transit are readily available. Use engineering judgement in these situations, and data backing the decision (e.g., ridership numbers) is recommended.

- Trip distribution and assignment
  - Traffic assignment for future developments are created along the surrounding network. Use engineering judgement and ITE guidance to distribute project vehicular traffic at and around the project site. If using DTA, project traffic assignment will not be needed as it is inherently provided by the model. Distribution results are typically reviewed and approved by TxDOT or the applicable city/county. Historical trends observed along the major roadway segments are considered when distributing the project traffic. Example problems involving trip distribution and traffic assignment can be found in Appendix Q, Section 3 – TIA Example Problems
- Anticipated off-site improvements
  - Roadway improvements are dependent on the project and anticipated trips. If the existing roadway network at and around the project site accommodates all future traffic, roadway improvements may not be necessary. If it is determined that future traffic results in unacceptable operations, propose roadway improvements to mitigate for the deficiencies. Typical off-site improvements are listed under Mitigation Requirements in Section 16.4.

16.4 Analysis Methodology

16.4.1 Existing Conditions

The existing field conditions within the study area are analyzed as a baseline to compare future conditions. By analyzing existing conditions, the impact a development has on the roadway system from a traffic operations standpoint can be measured. The existing conditions analysis also serves as a calibration step for the performance assumptions within the analysis procedure (e.g., saturation flow rate, gap acceptance) that can vary by geographical area and user demographics. The results of the existing conditions analysis are compared to the field observations so that the preparing engineer and reviewers can be confident that the model is valid for use in projecting future conditions.

- Peak Hour Counts
  - If the appropriate data is called for, counts at major intersections near the proposed project driveways are conducted to obtain AM and PM peak hour traffic volumes. These volumes

are typically shown in an Existing Traffic Volumes exhibit.
    - Typical analysis hours are the AM and PM peak hours. Other analysis hours can be evaluated as needed (e.g., midday peak, Saturday peak, or school peak), depending on the project site and adjacent land use. These alternate analysis hours are typically developed during the preliminary scoping stage.
    - If there are multiple intersections being counted, the hour with the highest cumulative total volumes across all intersections typically serves as the analysis hour.
    - Counts can be collected in a variety of ways with the most common forms being field TMCs, counts from ITS devices, and count data for other transportation modes including bicycles, pedestrians, transit, etc. It is recommended that raw count data be provided in the appendix of the report.
- Field Observations
    - A field visit helps explain the physical and operational conditions of the study area. Common observations include existing geometry, traffic control, queuing, delays, and pedestrian/bike activity.
    - It is recommended that a field visit take place as part of a TIA and observations be documented in the report.
    - For safety considerations in a TIA, it is recommended that intersection sight distance is analyzed and TxDOT's right-turn warrant thresholds are evaluated.
- Traffic Signal Timings
    - Timings are typically requested for any signalized intersections to be studied within the study area from TxDOT. These timings are used to model the existing conditions.
- Traffic Analysis Output
    - Existing traffic counts are used for volume inputs, heavy vehicle data, non-motorist activity, and other related characteristics of the surrounding roadway network.
    - The existing LOS for any significantly impacted intersections is typically displayed using the latest HCM analysis methodology. For signalized intersections, each approach and the overall intersection are analyzed. For stop-controlled intersections, each stop-controlled approach is analyzed by the approach. Left-turning movements of non-stop controlled approaches are analyzed by movement.
    - Multimodal (pedestrian/bicycle) activity within the project vicinity

is typically addressed. Multimodal improvements such as sidewalks and crosswalks are also typically evaluated for the project.

16.4.2 Future Conditions

After the addition of background growth and the proposed development, the surrounding roadway area needs to be reanalyzed. These conditions estimate how the roadway system will operate after the presence of the development. Acceptable future conditions may indicate the development can be incorporated successfully into the roadway system.

- Trip Generation
    - Trip generation is usually based on ITE's latest publication of the *Trip Generation Manual* or other acceptable sources. ITE's *Trip Generation Manual* includes equations for daily and study peak hour trip rates based on a specified independent variable. In many cases, this can be the square footage of the specific land use, or the number of units contained within a residential development. Example trip generation calculations can be found in Appendix Q, Section 3 – TIA Example Problems.
    - Volumes are usually generated with average rates or a fitted curve equation. Consult the ITE *Trip Generation Handbook* Chapter 4 "Trip Generation Manual Data" to decide whether rates or equations are used.
- Internal Capture
    - Vehicle trip reduction may be applicable depending on the project location and type of land uses in a proposed development. If used, it is recommended this reduction follows the methodology found in the ITE *Trip Generation Manual.*
- Pass-By Trips
    - If reducing vehicle pass-by trips, the percentage reduced typically equates to the total vehicle trips generated minus the internal capture used for each land use. Pass-by percentage has an upper limit percentage of the existing vehicular traffic to be set while scoping with TxDOT.
- Distribution
    - Project distribution of the proposed trips is assigned using engineering judgment. If only one project driveway is proposed, all trips enter and exit through this driveway. This process is used to create a trip distribution and traffic assignment exhibit.
- Background Analysis
    - When analyzing the future roadway network, background growth and future project traffic is added to the existing traffic counts. Background growth data may be available from the city or MPO. Historical AADT

information can be averaged for at least the last five years of data, when available, to obtain an average annual growth rate to grow the background volumes. Using this annual growth rate, existing traffic is grown to the future study years specified in the scope.

- If there are other approved developments to be included in the study within close vicinity to the proposed project, traffic can be projected for each development through the process of trip generation and added to the roadway network through trip distribution and traffic assignment.
- The combination of grown traffic and traffic from other approved developments are typically combined into a background traffic scenario and provided in an exhibit. This is typically completed for each future study year.

- **Background Plus Site Analysis**
  - New traffic created from the proposed site is added to the background traffic scenarios, resulting in a background plus site traffic scenario for each study year. Peak hour volumes for these scenarios are usually provided in separate exhibits for each scenario.
- **Traffic Analysis Output**
  - The future traffic analysis includes all geometric characteristics of the existing analysis with the addition of proposed driveways. Background traffic and background plus site traffic scenarios are typically analyzed.
  - Future levels of service are obtained for all study intersections, along with any new project driveways used to access the project development. The latest HCM analysis methodology is typically used. For signalized intersections, each approach and the overall intersection are analyzed. For stop-controlled intersections, each stop-controlled approach is analyzed by the approach. Left-turning movements of non-stop controlled approaches are typically analyzed by movement.
  - Traffic signal timings are typically adjusted and optimized in future scenarios in order to improve LOS. This can also be part of the proposed improvements. TxDOT area offices can request that analysis be run with existing timings in order to preserve existing signal coordination. If an intersection is operating over capacity, the mitigation requirements in Section 4 can be reviewed and used to help with capacity issues.

- An example Traffic Analysis can be found in Appendix Q, Section 3 – TIA Example Problems.

16.4.3 Mitigation Requirements

Thresholds for acceptable operations of various MOEs (LOS, queue lengths, travel times, etc.) are agreed upon with TxDOT during the preliminary scoping process. Any operational deficiencies found in the future analysis are considered for mitigation. All mitigation is typically confirmed with the local TxDOT District. The developer is responsible for implementing the mitigation measures.

Conditions often include:

- Access management guidelines for driveway spacing and turn lanes
  - *TxDOT's Access Management Manual and RDM* (Appendix Q, Section 4 – External References 'Reference 4') is used for driveway spacing and turn lane configuration.
  - Chapter 8 "Freeways" of *the RMD* has information on developments near freeways that can impact a TIA.
- Mobility
  - If the future scenario analysis shows high or unacceptable delays, appropriate mitigation measures are taken to correct or alleviate the issues on the roadway network. If a signalized intersection is experiencing unacceptable vehicular delays, phasing and timing settings are optimized to mitigate the delay levels. If signal optimization is not enough to alleviate the vehicular delay levels, improvements to intersection geometry or type are considered. If an unsignalized intersection experiences notable delay, redistribution of trips to other routes is considered.
- Safety
  - Review the location of access points on site in relation to existing nearby access points and intersections for safety considerations. It is recommended that the site plan be examined to confirm the design of external access points account for bicycle and pedestrian safety. It is recommended that a safety and crash analysis based on the past five calendar years be conducted within the study area. Compare crash rates for the study area with statewide/municipality crash rates. Identify CRF to mitigate key locations. See Appendix Q, Section 4 – External References (Reference 6, 7) for additional information regarding safety analysis for Traffic Impact Analyses.
    Key safety questions to consider while conducting a safety

analysis for Traffic Impact Analyses include:

- What is the historical crash analysis in the study area?
- What are the existing crash types involving fatalities and serious injuries? Where are those crashes? What road user types are represented in those crashes?
- Will the project create additional multimodal conflict points?
- Will the project result in increased vehicular speeds?
- Will the project lead to longer queues that would affect through traffic and cause speed differentials?
- Based on crash estimation methods from the HSM methodologies, will the project potentially contribute to more crashes? Review locations that will be modified by the project and evaluate designs.
- What countermeasures would improve safety in the study area? Incorporate them in the project to improve safety.
- Is there a safety plan in place for the study area? If so, integrate recommendations from the safety plan in the project
- Are the crash rates in the study area above the statewide averages for similar roadways? Identify safety-focused mitigation measures.

Typical improvements include:

- Auxiliary Lane Improvements
  - Consider right-turn deceleration lanes when there are large numbers of right-turning vehicles into the project site. TxDOT's *Access Management Manual* outlines thresholds for right-turn lanes at new site driveways. This may involve ROW purchase at corners. See for the threshold values. An example of auxiliary lane analysis is shown in Appendix Q, Section 3 – TIA Example Problems.

Figure 16-1: Right-Turn Lane Thresholds

  - Left-turn deceleration lanes are typically considered for roadways with raised medians. For undivided roadways, reference the TxDOT *RDM* for left-turn lane volume thresholds and geometry.
  - Lengthening of storage lanes
- Median modifications
  - Median modifications are considered for both safety improvements and operational improvements. Traffic and safety analysis is performed to determine locations for directional median openings as an alternative to full access openings.
- Traffic Signal Modification
  - As traffic is increased and redirected based on new developments, any existing traffic signals are analyzed for operational deficiencies as well as placement changes that may help with LOS and traffic flow. Preferable traffic signal spacing is one-half of a mile.
- Road Widening
  - If the future demands along the nearby roadway segments are significantly impacted and the roadway is predicted to operate over capacity, widening can be considered to mitigate the extra vehicular traffic volume. ROW limitations and existing geometries are considered when widening is proposed for a project. Improvements, such as a right-turn lane, may necessitate additional ROW.
- Traffic Signal Installation
  - Consider traffic signal installation at unsignalized intersections with high or unacceptable vehicular delay. In these circumstances, complete a traffic signal warrant analysis following the process outlined in Chapter 10 of this manual.
- Additional Mitigation Measures
  - Revised striping
  - Turning lane restrictions
- Alternative Intersection and Interchange Application
  - Consider alternative intersections in place of a typical traffic signal intersection. Alternative intersection analysis can be performed following the process outlined in Chapter 10 of this manual. Roundabout

analysis is presented in Chapter 12 of this manual.

- Alternative interchanges can be considered in place of a signalized interchange. Perform alternative interchange analysis following the process outlined in Chapter 11 of this manual.

The benefits and costs of each alternative or improvement are monetized so that the options can be compared economically as well.

16.4.4 Analysis Tools

Common tools used for TIAs include Synchro, HCS, Vissim and Vistro. For guidance on tools used as part of a safety analysis in a TIA, see Chapter 5 and Chapter 6 of this manual.

Chapter 17
Reports and Documentation

17.1 Introduction

17.1.1 Overview

The Report and Documentation chapter includes an overview of traffic and safety analysis documentation, including various reports and technical memorandums. It provides guidance on the appropriate formatting of analysis outputs and provides guidelines on reporting. Reports provide a comprehensive summary of final recommendations as well as the methodology and data used in the decision-making process.

Information in reports and memorandums are presented in direct language in an organized, clean format that is both readable and understandable. An understanding of how data will be used by decision makers and the audience guides the development of documents. Audiences may include citizens, businesses, traffic and safety practitioners, government agencies, and lawmakers. For a non-technical audience, results and outcomes are typically the focus of the content, with corresponding graphics. It is also important to have a figure or graphic of the site area with adequate information to present the details of pre- and post-analysis improvements. Extensive, detailed technical information is typically attached as appendices to the report or memorandum to keep the main content direct and understandable. This additional information may include calculations, detailed outputs, and technical reference materials. It is recommended that the content and narrative of the reporting remain objective and free of biases.

Sample outlines for typical traffic and safety reports are provided in Appendix R, Section 1 – Traffic Analysis Report and Appendix R, Section 2 – Safety Analysis Report. This chapter also describes parameters for three formats for presenting traffic analysis results: tabular, graphical, and animated (microsimulation or microscopic analysis only), as well as general style directives for content.

Users can check for updated or revised versions of report outlines, templates, and other forms with the TxDOT project manager.

17.1.2 Purpose and Intended Use

This chapter is intended to be used as a resource and informational guide to develop consistent reports and documentation. The intended users of this chapter are engineers, planners, and designers who perform and document traffic and safety-related analyses for TxDOT projects. Procedures for conducting traffic and safety analyses are detailed in other chapters of this manual.

17.2 Analysis Documentation

17.2.1 Reports

Reports are developed to support traffic and safety analysis assumptions, conclusions, and

recommendations. Analysis reports typically include:

- **Traffic Analysis Report.** The project traffic analysis report includes analysis assumptions and approach, data collection, analysis results, and recommendations. The traffic analysis report, at a minimum, includes content detailed in the outline in Appendix R, Section 1 – Traffic Analysis Report.
- **Safety Analysis Report.** This report documents any safety analysis related to the study area, including data collection, approach, findings, and recommendations. The safety analysis report, at a minimum, includes content detailed in the outline in Appendix R, Section 2 – Safety Analysis Report.
- **Model Development Report.** The model development report documents analysis performed on projects using microsimulation (microscopic) tools. The model report usually provides information on the model to review and verify accuracy when compared to real-world conditions. This report also includes assumptions, methodology, data collection, results, and any critical lessons learned and best practices to benefit future uses of the model. This report may include the calibration and validation process and consequential modifications to the base model. Changes to default values and parameters are supported by adequate justification, including supportive statistics comparing field measures and calibration parameters. The model development report, at a minimum, includes content detailed in the outline in Appendix N, Section 2 – Model Development Report. The report deliverable includes all scenario datasets, with sufficient information for TxDOT staff to replicate results. See Chapter 13 for additional information on performing microsimulation (microscopic) traffic analysis. Users can coordinate with the TxDOT project manager to provide raw analysis files and data, if needed.
- **Traffic Impact Analysis (TIA) Report.** This report introduces the existing conditions (e.g., project area, access management, existing conditions), outlines trip generation as derived from the latest version of the *Institute of Transportation Engineers (ITE) Trip Generation Manual,* describes the determination of trip distribution and trip assignment, summarizes future operations and LOS, and provides recommendations if mitigation measures are necessary. A recommended outline for the TIA report is found in Appendix Q, Section 2 – TIA Report Outline.

17.2.2 Technical Memorandums

Technical memorandums are documents that give reviewers the opportunity to examine and provide feedback on study results before they are compiled into a final report. The type and complexity of the analysis will determine the contents of the technical memorandums. Technical memorandums vary in scope but are

often individual topics found in reports. It is recommended that content of the technical memorandums be reviewed and approved before proceeding to development of alternative scenarios. Technical memorandums typically include:

- **Methodology Technical Memorandum.** This serves as a summary of the Scoping Form (introductions, project description, preliminary data review, preliminary alternative identification, analysis tool considerations, initial MOE selection, traffic forecasting, and undetermined or unresolved project scoping elements). A recommended outline for the methodology technical memorandum is available in Appendix B, Section 2 – Methodology Technical Memorandum.
- **Traffic Projections Methodology Technical Memorandum.** Future year traffic projections are critical for the accurate evaluation of alternatives. This technical memorandum includes traffic projections methodology, assumptions, and recommendations. The memorandum contains a description of the historical growth rate TDM growth rate, and US census growth rates for the study area. Explanations of traffic projections for the alternatives are incorporated into the traffic projections methodology technical memorandum. Traffic projections can be approved prior to analyzing alternatives. A recommended outline for the traffic projections methodology technical memorandum is included in Appendix D, Section 2 – Traffic Projections Methodology Memorandum Outline.
- **Alternatives Analysis Technical Memorandum.** This technical memorandum documents the decision-making process where multiple alternatives are evaluated and a preferred alternative is selected. It provides context for the project and discusses tier 1 evaluation, tier 2 evaluation, and preferred alternative selection. A recommended outline for the alternatives analysis technical memorandum is available in Appendix I, Section 1 – Alternatives Analysis Tech Memo Sample Outline.
- **Model Development Technical Memorandum.** This technical memorandum documents the model development process, including data requirements, microsimulation network development, calibration and validation, alternatives analysis, and an appendix with raw traffic data, calibration calculations, and model outputs. A recommended outline for the model development technical memorandum is included in Appendix N, Section 2 – Model Development Report.

Technical memorandum deliverables can be accompanied by respective model datasets for TxDOT to replicate, as needed.

17.3 Presentation of Results

Traffic analysis results can be presented in three formats: tabular, graphical, and animated (microsimulation/microscopic analysis only). These visual presentation methods can be supported by text. Appendix R, Section 3 – Tool Outputs show examples of outputs from various software, including commonly used outputs from Synchro.

17.3.1 Tabular Summaries

Table summaries can organize data in a way that is easy for the reader to absorb and analyze. Raw data used to compile information in the tables can be included in the appendix for reference. A tabular format can be used to easily make comparisons between alternatives. Figure 17-1 provides an example of failing conditions noted with white text on a black cell background.

Figure 17-1: Pass and Fail Cell Formatting

Tables are one of the simplest forms of data presentation used to summarize a large amount of data. They help with explaining data so that the reader can easily find information and draw general conclusions. Borders for all tables can be solid black or white lines with a 1-point weight. Detailed spreadsheets and tables can be included in appendices. An example of tabular data is shown in Table 17-1.

Table 17-1: Example of Tabular Data Summary

Intersection	Approach	Turning Movement	Volume (veh)	Delay (sec/veh)	Approach Volume	Approach Delay	Approach LOS
Street A @ Street B	NB	NBL	30	66	94	46.5	D
		NBT	26	66			
		NBR	38	17			
	SB	SBL	893	45	1,254	38.7	D
		SBT	21	48			
		SBR	340	21			
	EB	EBL	259	64	1,654	48.4	D
		EBT	1,369	46			
		EBR	26	11			
	WB	WBL	56	46	1,733	28.1	C
		WBT	1,232	35			
		WBR	445	7			

17.3.2 Graphical Presentation

Diagrams and illustrations can show the results and allow the reader to draw general conclusions without reading the narrative. These graphics are an effective resource for quickly communicating assumptions, findings, and recommendations.

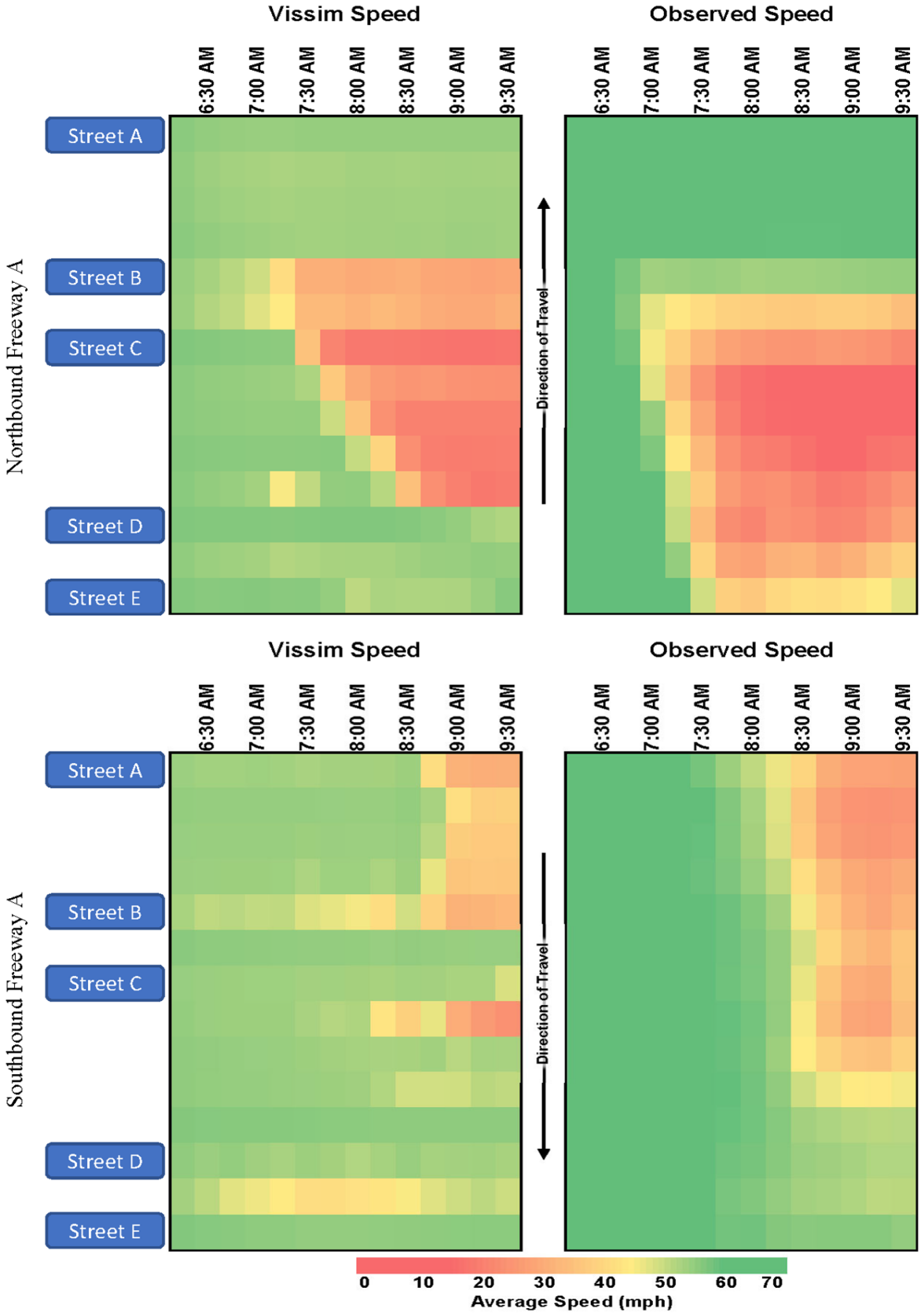
Common graphical exhibits in reports include:

- Area, land use, and zoning maps;
- Turning movements at intersections;
- Local streets and highway system;
- Lane schematics;
- Link-node diagrams;
- Circulation routes; and
- Centerline alignments

These graphical exhibits can be generated in tools such as Tableau, GIS, or a database inventory/repository.

To maximize readability and effectiveness, report illustrations can include text of a reasonable font size and be limited to three layers of information, such as average speed by location and time. Figure 17-2 shows an example of data in a graphical format.

Figure 17-2: Example of Speed Data as Graphical Presentation



17.3.3 Animation

Microsimulation animates individual trajectories from the model to demonstrate traffic operations and potential solutions. Animation is an effective visual tool to present traffic analysis results to non-technical audiences or to communicate complex geometries or alternative intersections. Animations can be created from portions of simulation results that most accurately illustrate results and findings. Effects of traffic operations improvement alternatives compared side-by-side using animations can be presented at public meetings or on project websites to further the goals of the project. Each side-by-side display can be prepared with the same traffic load to provide the most accurate comparison. It is recommended that animation only be used to enable a general understanding of operations – glitches or incorrect coding could cause the public to be distracted by insignificant details that are not representative of the proposed operations solution.

Animations can be used to complement graphics and/or tables but may not serve as the only method to communicate results for a study. Animation provides only a qualitative assessment of an alternative for a limited timeframe. Additionally, a simulation run shows a single output, while measures of effectiveness are typically calculated using the averages of multiple runs.

When presented in reports, screenshots of animations can be supported with explanatory text and descriptions. A screenshot of an animation from a Vissim model is shown in Figure 17-3 to illustrate a CGT.

Figure 17-3: Screenshot of a Vissim Animation

17.3.4 Style Guide

17.3.4.1 Branding and Wordmark

The TxDOT branding and logo are critical to the organization's identity. The correct wordmark or written identity for the Department is either "Texas Department of Transportation" or "TxDOT." As with other acronyms presented throughout the document, define TxDOT upon first reference. Never capitalize all letters in the Department acronym ("TXDOT").

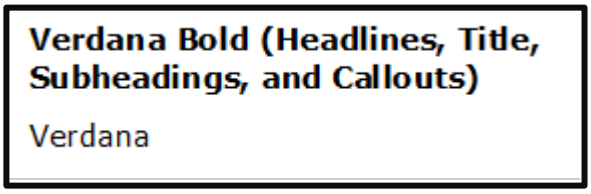
The official TxDOT logo has three layout options, vertical, horizontal, or icon. The vertical logo option is shown in Figure 17-4. Alteration of the logo—including disproportionate resizing, modifying logo colors, symbols, or fonts, adding effects to the logo, or deviating from one of the three layout options— is prohibited. The logo is intended to be incorporated in internal and external materials, including reports.

The preferred font is Verdana. Verdana Bold can be used for headlines, titles, subheadings, and callouts, and Verdana can be used for standard body copy (text). Preferred fonts are shown in Figure 17-5.

For more information on TxDOT branding guidelines, see Appendix R, Section 4 – External References (Reference 1).

Figure 17-4: TxDOT Vertical Logo

Figure 17-5: TxDOT Preferred Fonts



17.3.4.2 Printability

All document content, including graphical elements, are recommended to be readable and decipherable when printed and displayed in black and white. It is recommended that any colors used to highlight key information maintain a distinguishable shade from standard text when the document is reproduced in black and white.

17.3.4.3 Readability

Though information is typically reviewed and analyzed by TxDOT staff or practitioners partnering with TxDOT, content is recommended to be easy to understand by both technical and non-technical audiences.

17.3.4.4 Document Structure

To make content easy to follow, logically divide the document into an intuitive flow of narratives with supporting summary tables and graphics grouped according to topic. This not

only provides a readable format for the document but also makes it easier to reference sections or specific data.

17.3.4.5 Acronyms

Except for common, widely known and used acronyms, it is suggested that acronyms be limited. Common acronyms include TxDOT and HCM. The use of too many acronyms decreases narrative readability, even if readers understand their meaning. When using an acronym, define it when first used. For longer reports, consider attaching a glossary of all acronyms used in the appendix.

Chapter 0 - Appendix A – Preface

- **Section 1** – External References

Section 1 – External References

The websites below were last accessed on May 31, 2024

1. **The Highway Capacity Manual (HCM)**

   https://nap.nationalacademies.org/catalog/26432/highway-capacity-manual-7th-edition-a-guide-for-multimodal-mobility

   - A link to the Highway Capacity Manual 7th Edition purchasing page

2. **The Highway Safety Manual (HSM)**

   https://www.highwaysafetymanual.org/Pages/default.aspx

   - Homepage for the Highway Safety Manual. Contains information on what the HSM is, who uses it, how to use it, where it can be purchased, and frequently asked questions

3. **The Federal Highway Administration (FHWA) Traffic Analysis Toolboxes**

   https://ops.fhwa.dot.gov/trafficanalysistools/

   - Links to 15 of the FHWA's toolboxes as well as further guidance on application of traffic analysis methods

4. **The Texas Manual on Uniform Traffic Control Devices (TMUTCD)**

   https://www.txdot.gov/government/enforcement/signage/tmutcd.html

   - Homepage for the TMUTCD

Chapter 1 - Appendix B – Project Scoping

- **Section 1** – Scoping Form
- **Section 2** – Methodology Technical Memorandum
- **Section 3** – Example Project Schedule
- **Section 4** – External References

Section 1 – Scoping Form

The following form should be filled out prior to the project scoping meeting. Complete the applicable portions associated with traffic and safety analysis as outlined in Chapter 1 - Project Scoping. The completed form should be submitted to TxDOT Project Manager at least five business days before the scoping meeting.

Traffic and Safety Analysis Assumptions

Introductions Refer to Chapter 1, Section 2			
Project Manager (TxDOT)	Name		
	Phone		
	Email		
Project Lead/Manager (Delivering Organization/Consultant)	Name, Organization		
	Phone		
	Email		
Stakeholders	Name, Organization		
	Name, Organization		
	Name, Organization		
	Name, Organization		
Project Description Refer to Chapter 1, Section 2			
Project Name		Project CSJ or ID	
City, County		District	
Project Overview			
Project Development Stage (Select all that apply)	☐ Planning ☐ Preliminary Schematics ☐ PS&E ☐ Multi-level ☐ Other - _____		
Level of Detail (Select all that apply)	☐ Sketch Level or Macroscopic ☐ HCM Based (Mesoscopic) ☐ Microsimulation (Microscopic) ☐ Multi-resolution ☐ Other - _____		
Scope of Work (Select all that apply)	☐ New Roadway ☐ Add Capacity ☐ Operations Analysis ☐ Signal Analysis ☐ Corridor Study ☐ Planning Study ☐ Safety Study ☐ Toll Feasibility Analysis ☐ Other - _____		
Spatial Limits	Attach map (include project area and study area)		
Analysis Years and Peak Periods	Existing Year: Opening Year: Design Year: Interim Year: Let Date:	AM Peak Hour/Period (weekday): PM Peak Hour/Period (weekday): Other Peak: Crash Data Analysis Year(s):	
Background Factors that may influence the project	Project constraints, planned road improvements, planned developments, facility type, need for IAJR, project funding status, and other applicable background conditions		
Preliminary Project Schedule	Attach schedule (overall schedule which includes traffic/safety analysis schedule)		

Preliminary Data Review **Refer to Chapter 1, Section 3**		
Existing Traffic Data	☐ STARS Historical Traffic Counts ☐ K-Factors ☐ D-Factors ☐ T-Factors ☐ Site Observations ☐ Travel Times ☐ NPMRDS ☐ Big Data (e.g., 3rd party probe data) ☐ TxDOT Comprehensive Accessibility Program (TCAP) ☐ Other - _____	
Safety Analysis Data	☐ CRIS Crash Reports ☐ AADT ☐ Geometric Data ☐ Other - _____	
Field Data Collection Plan (Data collection plan should indicate the location and type)	**Attach map that specifies locations of applicable data to collect:** ☐ Turning Movement Counts ☐ Tube Counts ☐ Classification Counts ☐ Travel Time ☐ Speed ☐ Big Data (e.g., 3rd party probe data) - ☐ High Occupancy Vehicle (HOV) Data ☐ Other - _____ State QA/QC approach for field data collection - _____	
Preliminary Alternatives Identification **Refer to Chapter 1, Section 3**		
Alternatives to Consider	List what relevant alternatives may be considered as part of the project	
Analysis Tool Considerations **Refer to Chapter 1, Section 3**		
Traffic Analysis Software Tools (Select all that apply)	☐ CAP-X ☐ HCS ☐ Synchro ☐ SIDRA ☐ Visum ☐ Vissim ☐ Vistro ☐ Cube ☐ TransCAD ☐ SimTraffic ☐ CORSIM ☐ Other - _____	
Safety Analysis Software Tools (Select all that apply)	☐ SST ☐ SPICE ☐ HSM for Rural Multilane ☐ HSM for Urban/Suburban Arterials ☐ HSM for Rural Two Lane Roads ☐ ISATe ☐ HSS ☐ IHSDM ☐ Other - _____	
Microsimulation (Refer to Chapter 12 for conditions and situations requiring microsimulation)	Characteristics to calibrate	☐ Simulated Traffic Volume ☐ Simulated Travel Time ☐ Simulated Queue Length ☐ Other - _____
	Important location(s) to calibrate	List critical locations (v/c ratio > 1, weaving, bottleneck)
Other Traffic Analysis Tool (Specify, if applicable) -	Characteristics to calibrate	☐ Characteristic 1 - _____ ☐ Characteristic 2 - _____ ☐ Characteristic 3 - _____ ☐ Other - _____
	Important location(s) to calibrate	List critical locations (v/c ratio > 1, weaving, bottleneck)
Initial MOE Selection **Refer to Chapter 1, Section 3**		
Traffic MOEs (Select all that apply)	☐ v/c ratio ☐ Travel Time ☐ Speed ☐ Delay ☐ LOS ☐ Queue Length ☐ Trip Reliability ☐ Other - _____	
Safety MOEs (Select all that apply)	☐ Crash Frequency ☐ Crash Severity ☐ Crash Rate ☐ Safety Score ☐ Other - _____	

Traffic Forecasting Refer to Chapter 1, Section 3 and the TPP Traffic Forecasting Analysis SOP (see Chapter 3 Appendix)	
Traffic Forecasting Methodology	**Specify Option:** ☐ TPP Led ☐ District Led **Specify Methodology:** ☐ Traffic Projections from Nearby Projects ☐ Travel Demand Model Forecasts ☐ Traffic Projections from Historical Growth Rates ☐ Other - _____
Notes on Assumptions	
Calibration criteria:	
Other Assumptions:	

Approval

Project Manager (TxDOT)

Signed:_____ Date:_____

Print Name:_____

Project Lead/Manager (Delivering Agency)

Signed:_____ Date:_____

Print Name:_____

TxDOT District Traffic Engineer (if required)

Signed:_____ Date:_____

Print Name:_____

Director of Advanced Project Development (if required)

Signed:_____ Date:_____

Print Name:_____

Section 2 – Methodology Technical Memorandum

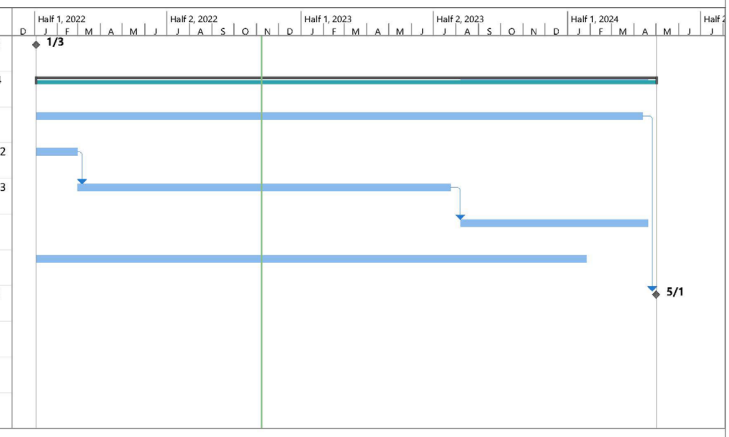
1. **Executive Summary**
2. **Introductions**
    a. Project Manager (TxDOT)
    b. Project Manager (Delivering Organization)
    c. Stakeholders
3. **Project Description**
    a. Project Overview
    b. Scope of Work
    c. Spatial Limits
    d. Analysis Years and Peak Periods
    e. Level of Detail
    f. Background Factors
4. **Preliminary Data Review**
    a. Existing Traffic Data
    b. Future Traffic Data
    c. Safety Analysis Data; and
    d. Field Data Collection Plan
5. **Preliminary Alternative Identification**
6. **Analysis Tool Considerations**
    a. Traffic Analysis Software Tools
    b. Safety Analysis Software Tools
    c. Microsimulation
7. **Initial MOE Selection**
    a. Traffic MOEs
    b. Safety MOEs
8. **Traffic Forecasting**
9. **Other**
    a. Unresolved Methodology Elements
10. **Conclusion**

Section 3 – Example Project Schedule

Contract No. 11-1AAA1111
Work Authorization No. 1

PS Contract No. 11111

ID	Task Name	Duration	Start	Finish
1	**Work Authorization Start Date**	0 days	Mon 1/3/22	Mon 1/3/22
2	**CORRIDOR STUDY**	**609 days**	**Mon 1/3/22**	**Wed 5/1/24**
3	PROJECT ADMINISTRATION AND COORDINATION	596 days	Mon 1/3/22	Fri 4/12/24
4	110.1 DATA COLLECTION	41 days	Mon 1/3/22	Mon 2/28/22
5	110.2 TRAFFIC PROJECTIONS	366 days	Tue 3/1/22	Mon 7/24/23
6	110.3 TRAFFIC ENGINEERING AND OPERATIONS STUDIES	185 days	Mon 8/7/23	Fri 4/19/24
7	110.4 AGENCY COORDINATION	541 days	Mon 1/3/22	Fri 1/26/24
8	**Work Authorization Termination Date**	0 days	Wed 5/1/24	Wed 5/1/24
9				
10				
11				



Delivering Agency

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

Page 1

Section 4 – External References

The websites below were last accessed on May 31, 2024

1. **TPP Traffic Forecasting Analysis Standard Operating Procedures (SOP)**

   https://txdot.sharepoint.com/sites/division-tpp/TrafficAnalysis/Shared Documents/Traffic Analysis/Corridor Analysis/TPP_TAB Corridor SOPs (2023)?csf=1&web=1&e=qy9j91&cid=52d919bc-922f-492b-99ca-af81b912489e

   - Internal TxDOT link to the SOP

Chapter 2 - Appendix C – Data Collection

- **Section 1** – Field Visit Checklist
- **Section 2** – INRIX Data Use Agreement
- **Section 3** – PMIS Data Request Form
- **Section 4** – PMIS Confidentiality Agreement
- **Section 5** – IHS Markit Data Release Form
- **Section 6** – External References
- **Section 7** – Traffic Management Center Data
- **Section 8** – Lonestar RVSD Detector Locations
- **Section 9** – Lonestar RVSD Detector Example Data Output

Section 1 – Field Visit Checklist

No	Item	Review	
		Checked By	Date
	Existing Geometry		
1	Number of lanes		
2	Lane assignments		
3	Turn bay lengths		
4	Sight distance at intersections		
5	Pedestrian ramps		
6	Bike lanes		
7	Pavement markings		
8	Above-ground utilities		
9	Other potential conflicts and environmental constraints		
10	Condition of existing elements		
11	General ROW limits		
12	Traffic forecasts are checked for reasonableness		
	Existing Operations		
12	Existing roadway and traffic elements, including traffic control types		
13	Speed limits		
14	Queuing and notable issues, such as queueing out of turn bays		
15	Traffic signal heads, including pedestrian signal heads		
16	General operation of the traffic signal		
17	Left turn phasing		
18	Land use and zoning in the vicinity of the project		
19	Lane utilization along each approach		
20	Turning movement speeds at non-conventional turning angles		
21	Atypical driving behavior		
	Other		
22	Adjacent developments around the project that may have an effect on traffic		

Section 2 – INRIX Data Use Agreement

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DATA USE AGREEMENT
Sublicensee Traffic Data Services by INRIX
Through _____

_____ (hereinafter **"Sublicensee"**) certifies that it is either (1) an authorized subcontractor of _____ (**"Agency"**), or (2) a government agency, and requires access/use of the data and services as procured under an agreement between Agency and INRIX, Inc. (**"INRIX Products"**). As a condition of use of the INRIX Products, Sublicensee, its agents and employees, understands and agrees to the following terms and conditions:

Sublicensee understands and agrees that access to, and utilization of, INRIX Products is governed by the data licensing terms and conditions specifically set forth in the License Agreement, as set forth in Attachment A. Sublicensee agrees that Sublicensee, its officers, employees and agents shall fully adhere to and comply with all such data licensing terms and conditions, and that INRIX, Inc. shall be a third party beneficiary of this License Agreement, and be permitted to directly enforce the terms of the License Agreement in the event of Sublicensee's failure to comply with any applicable terms or conditions.

Sublicensee understands and agrees that INRIX reserves the unilateral right to terminate the Sublicensee's access to and utilization of INRIX services and data in the future in the event of inappropriate use or unauthorized disclosure.

In the event Sublicensee becomes aware of an inappropriate use or unauthorized disclosure, Sublicensee agrees to provide immediate verbal notice and subsequent written notice within 24 hours to the following:

Legal@inrix.com

Signatures

I, the undersigned, am duly authorized to bind the _____to this Agreement and do so by affixing my Signature hereto.

Entered into _____

Signature: _____

Name: ABC Title: _____

Technical Contact Name: _____ Technical Contact Email:_____

Description of Why Access to INRIX Products is Required by Sublicensee:

_____

_____

_____

_____

_____

_____

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Attachment A
Additional Terms and Conditions
License Agreement

It is the intent of this contract to secure for Sublicensee, and their officially designated representatives full rights to the traffic data to use in support of internal organization operations consistent with the organizations' traffic management, planning, and operations responsibilities subject to the following terms and conditions. INRIX data license terms apply to all data services detailed in the License Agreement between INRIX and Agency.

1. INRIX, Inc., a Delaware corporation (and its suppliers) shall retain all intellectual property and other rights with respect to the INRIX Products and all related and derivative technology.
2. The INRIX license granted hereunder shall be for use solely by Sublicensee as part of its projects with Agency, and shall be nonexclusive, nontransferable and nonsublicensable. All presentations of the INRIX Products by the Sublicensee, with the exception of travel times on roadway signing, shall contain proprietary notices and logos and/or website links of INRIX and/or the INRIX suppliers in a form reasonably provided by INRIX from time to time. A single notation within a report that contains INRIX data and single logo on web pages that draw from INRIX data is acceptable. All use by Sublicensee customers shall be made available by the Sublicensee free-of-charge.
3. All INRIX Products are provided "AS IS", "with all faults", "as available" and without warranty or obligation of any kind, and to the maximum extent permitted by law, any and all representations, warranties and conditions of any kind whatsoever (including express, implied or statutory warranties of merchantability, fitness for a particular purposes, title, accuracy or quality) are expressly excluded.
4. The INRIX Products shall be the designated products that INRIX and Agency have expressly agreed upon in writing, and which INRIX customarily provides to its other customers (and which is therefore subject to modification from time-to-time).
5. The INRIX Products shall not be merged or combined with any other traffic data not provided by INRIX in a manner to produce a merged speed or travel time value without permission from INRIX. The INRIX Products may not be resold or openly posted to the public such that it would be available to private sector competitors of INRIX. INRIX shall not have any specific on-the-ground responsibilities.
6. If INRIX receives data from the Sublicensee hereunder, INRIX shall not receive any personally identifiable information in relation to the data (or the PII component would be deleted prior to transmission to INRIX).
7. Neither party nor its direct or indirect suppliers shall, under any circumstances, be liable to the other or its customers or any other third parties for consequential, incidental, special, punitive or any indirect damages (including damages for lost profits or anticipated revenues, business interruption or loss of business information) arising out of or related to the INRIX Products, or for any damages whatever arising out of or in relation to any malfunctions, data delays, loss of data or interruption of service, even if advised of the possibility of such damages, or if such possibility was reasonably foreseeable.
8. INRIX's suppliers shall not have any liability whatever in relation to the use of the INRIX Products hereunder. INRIX and its suppliers shall not be liable for any claim, loss or penalty resulting from use or delayed delivery of the INRIX Products by or to Sublicensee customers, and the Sublicensee would use all reasonable efforts to ensure such limited liability in its end user license agreements (or other applicable terms) with those customers, if any.
9. Under no circumstances shall INRIX's aggregate liability for all claims, acts and/or omissions arising out of related to this Agreement, regardless of whether any claim or action is based on contract, tort or otherwise, exceed the total amount paid by the Sublicensee to INRIX during the 12-month period prior to the date on which the claim arose.
10. There shall be no withholding or offsets by the Sublicensee with respect to any compensation due to INRIX, and no state income or other taxes withheld. INRIX reserves the right, at its sole discretion, to use third parties to provide data and services hereunder. Neither party shall be responsible for failures or delays due to circumstances beyond its reasonable control, except for the obligation to pay monies due. The parties each agree to do all things reasonably necessary to effectuate the intent of these terms, and to act in good faith.

Section 3 – PMIS Data Request Form

Dataset Name	TXDOT PMIS DATA
Date access requested	
TxDOT Data Contact Person	
Consultant User Firm/Agency	
Consultant Contact Persons	
Consultant User(s) Name	
Project Description	
Request Time Period	
Time Granularity	
Request Geography	
TxDOT Project Manager	

Section 4 – PMIS Confidentiality Agreement

Texas Department of Transportation

125 EAST 11TH STREET, AUSTIN, TEXAS 78701-2483 | 512.463.8588 | WWW.TXDOT.GOV

Texas Pavement Management Information System Data Confidentiality Agreement

This Confidentiality Agreement is made by and between the Texas Department of Transportation (the department) and _____ (the organization).

The organization understands that the department collects and maintains Pavement Management Information System (PMIS) data, which includes skid data, for the State of Texas.

The organization understands that PMIS data is confidential highway safety information subject to Section 409 of Title 23 of the United States Code, under which the information is privileged and for the confidential use of the department for highway safety purposes.

The organization understands that the PMIS data is being released to the organization pursuant to the intergovernmental transfer doctrine wherein information subject to the Texas Public Information Act (PIA), Texas Government Code, Chapter 552, may be transferred between governmental bodies without waiving exceptions to the public disclosure of that information.

If the organization receives an open records request under the PIA for any information obtained under this Agreement, the organization agrees to notify the department of the request in a timely manner in accordance with the PIA to permit the department to assert its rights under the PIA.

The organization agrees to hold the PMIS data confidential in the same manner that the organization holds its own confidential information. The organization will require the organization's employees to treat the data as secret and confidential. The organization will not, without prior written consent of the department, or unless ordered by a court of competent jurisdiction or an opinion of the Office of the Attorney General, or as otherwise required by law, disclose any PMIS data to the public or use any PMIS data for any unauthorized purpose.

The organization understands that the department can remove and/or limit access to the PMIS data at any time for any reason.

The organization understands and agrees that any conclusions resulting from analysis performed on the PMIS data will be represented as the organization's own and not those of the department.

The organization acknowledges that any unauthorized disclosure or use of the PMIS data may result in irreparable harm to the department. Therefore, the organization agrees that, in the event of a violation or threatened violation of this Agreement, without limiting any other rights and remedies, the department may seek a temporary restraining order and/or an injunction to enjoin disclosure of the PMIS data, and the organization will not raise the defense of an adequate remedy at law. The organization agrees and understands that in the event of a failure to comply with this Agreement, the department is entitled to pursue any and all rights and remedies available at law or equity, and such remedies shall be cumulative.

As a signatory to this agreement, I agree that by requesting and accepting access to the data, the organization will abide by all of the above.

OUR VALUES: *People • Accountability • Trust • Honesty*

OUR MISSION: *Through collaboration and leadership, we deliver a safe, reliable, and integrated transportation system that enables the movement of people and goods.*

An Equal Opportunity Employer

Section 5 – IHS Markit Data Release Form

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IHS Markit

ADDENDUM
CONSENT TO DELIVER TO THIRD PARTY

This ADDENDUM dated December 20, 2021 is issued pursuant to and forms an integral part of the Statement of Work with an Effective Date of November 8, 2021 ("SOW") which in turn forms an integral part of a services agreement dated November 8, 2021] ("Agreement") between **IHS Global Inc** (an IHS company) having its principal offices at 15 Inverness Way East, Englewood, CO 80112 ("IHS") and **Texas Department of Transportation** a corporation having its principal offices at 125 E 11th St, Austin, TX 78701 ("Client"), and shall be effective only upon signature by IHS.

WHEREAS Client desires to allow certain third parties identified below ("Recipient") access the Deliverables licensed under the Agreement, as specifically described below ("Deliverables") and IHS is willing to provide its consent to such access subject to the terms of this Addendum.

NOWTHEREFORE, in consideration of compliance by the Client and the Recipient with the terms of the Agreement and this Addendum and for other good and valuable consideration, receipt of which is hereby acknowledged, the parties agree as set forth herein.

1. For the purposes of this Addendum, "Party" means each of IHS, Client or Recipient and "Parties" mean IHS, Client and Recipient collectively. Unless otherwise defined herein all capitalized terms shall have the same meaning assigned in the Agreement.

2. The Recipient acknowledges and agrees that the Deliverables are the property of IHS and are protected by intellectual property laws and that no ownership rights are being transferred to it hereunder. Recipient's use of the Deliverables shall be subject to the terms of this Addendum. Recipient has no right to further disclose the Deliverables to any other third party.

3. Notwithstanding anything to the contrary in the Agreement, and subject to the provisions of this Addendum, IHS hereby grants its consent for Client to make available to the Recipient and for Recipient to receive the Deliverables identified herein upon signature of this Addendum by the Parties provided that i) the Deliverables or any part of it shall not be incorporated into a registration statement, prospectus, information memorandum, public or private debt issue documentation, any bond issue documentation or other offering document, and/or shall not be filed with any securities authorities and ii) the Deliverables shall never be used by the Client or Recipient to produce a commercial product or service.

4. The Deliverables is valuable proprietary information developed by IHS. Recipient hereby agrees to hold all Deliverables provided hereunder in the strictest confidence and not to publish, reproduce, divulge, disseminate or convey to any other party the Deliverables, in whole or in part, in any manner or format, nor to authorize or permit any use by any other third party unless Recipient or Client is otherwise required by law to produce the Deliverables. Client and Recipient agree to request an exemption from the Texas Attorney General for the production of the Deliverables pursuant to a request for such disclosure under the Texas Public Information Act under Section 552.110(b) of the Texas Government Code.

5. Client undertakes to IHS that Client will, to the extent allowed by law and the constitution of the State of Texas, indemnify, defend and hold IHS harmless from and against any claims resulting from or in relation to any use of the Deliverables or any part thereof outside of Client organization, including use by Recipient, and/or for any purpose other than Client's internal business purposes.

6. Client and Recipient acknowledge and agree that i) the Deliverables are provided for the benefit of the Client only and not for any other third party, ii) the Deliverables are provided "AS IS" without any warranty or guarantee of any kind and iii) neither provision of Services or Deliverables by IHS under the Agreement nor consent granted under this Addendum constitute investment or legal advice which Client and Recipient shall seek from other independent sources, and iv) IHS shall have no liability to Client, Recipient or any other third party for use of or reliance on the Deliverables provided hereunder.

7. Client and Recipient agree that IHS' total aggregate liability to Client, Recipient and any other third party shall not in any event exceed the fees paid by Client for the Deliverables. In no event shall IHS be liable to Client or Recipient or any other third party for consequential, indirect, special or punitive damages.

8. The parties hereby disclaim the application of the 1980 U.N. Convention on Contracts for the International Sale of Goods.

9. **Description of Deliverables to be delivered to Recipient [MUST be completed]:**

1. TRANSEARCH Freight Commodity Flow Database - Base year 2019 and 2020
2. TRANSEARCH Freight Commodity Flow Database - HAZMAT Identifier
3. TRANSEARCH Freight Commodity Flow Database - Forecast 2030, 2040, 2050
4. TRANSEARCH Freight Database - Freight Establishment Data
5. Deleted

MPO sharing: This fee grants TxDOT an extended use of license to provide any TRANSEARCH and Freight Finder to Texas MPO's for planning purposes. MPO's must sign a Restricted Use Licensing Agreement (RULA)

TxDOT and Consultants use: TxDOT is permitted to use the TRANSEARCH and Freight Finder in their projects and is permitted to share the TRANSEARCH and Freight Finder with its consultants working on TxDOT projects/studies. TxDOT Consultants shall be bound by the same terms and conditions as TxDOT, and must sign a RULA. MPOs and their consultants working on MPO projects/studies must also sign a RULA.

2017

Contracts - Consent to Deliver.doc

Section 6 – External References

The websites below were last accessed on May 31, 2024

1. **Traffic Count Database System (STARS II)**

   https://txdot.public.ms2soft.com/tcds/tsearch.asp?loc=Txdot&mod=

   - The TCDS records the type of certification data of a product in accordance with the Federal Aviation Administration.

2. **Railroad Commission of Texas**

   https://www.rrc.texas.gov/

   - RRC plays a critical role of protecting and enforcing the publics interests

3. **Texas Bicycle and Pedestrian Count Exchange**

   https://mobility.tamu.edu/bikepeddata/

   - The Texas Department of Transportation and TTI created a system where bicycle or pedestrian data counts are available for collection.

4. **Crash Records Information System**

   https://cris.dot.state.tx.us/public/Query/app/home

   - Perform specific queries and analysis using Texas traffic crash data

5. **Replica Sign Up Landing Page for TxDOT Employees**

   https://studio.replicahq.com/signup

6. **TxDOT On-Call Consultant Replica Access Request**

   https://form.nativeforms.com/mVDNIRUPmZiZwI2c3ZTNn1Db

   - Consultants can fill out this form to gain access to Replica data

7. **INRIX Access Request**

   https://powerforms.docusign.net/02b5e7c1-a3d5-419b-9577-08d6eda1891d?env=na2&accountId=cc0e941d-e8c2-40a1-8913-2440b026d753

   - Fill out this form to gain access to INRIX data

Section 7 – Traffic Management Center Data

There are datasets available through TxDOT's Traffic Management Centers that use detectors. These detectors are typically set up in metro/urban Districts like AUS, DAL, FTW, ELP and SAT Districts. These datasets can be used as a resource for project traffic operations and safety analysis needs.

The detectors listed in the spreadsheet are from the TxDOT Lonestar ITS implementation. Most of the detectors are radar detectors from Wavetronix. The data from these is available in various formats, however the most useful is often the "raw data flat files" in text csv format. This is the lowest level of data available per device.

For each working detector, data is available as follows:

- Data is per poll cycle. This is configurable per detector. Most detectors are set to either 20 or 30 seconds.
- Speed is available per lane. It is the average speed per lane during the poll cycle based on that point on the roadway.
- Volume is available per lane. It is the actual count per lane during the poll cycle of vehicles crossing the detector.
- Occupancy is available per lane. It is the average occupancy per lane during the poll cycle at the detector.
- "BIN" data is also available. This type of data is designed to track things such as trucks (length of vehicle), but Lonestar does not use this element at this time.

This raw data is typically consolidated by TRF Division staff or contractors and is placed into a csv file structure on Box.com (TxDOT's official file transfer method) to make it available to researchers, partners, etc., as well as internal TxDOT staff as needed. Please note that many of the devices listed in the spreadsheet are not operational.

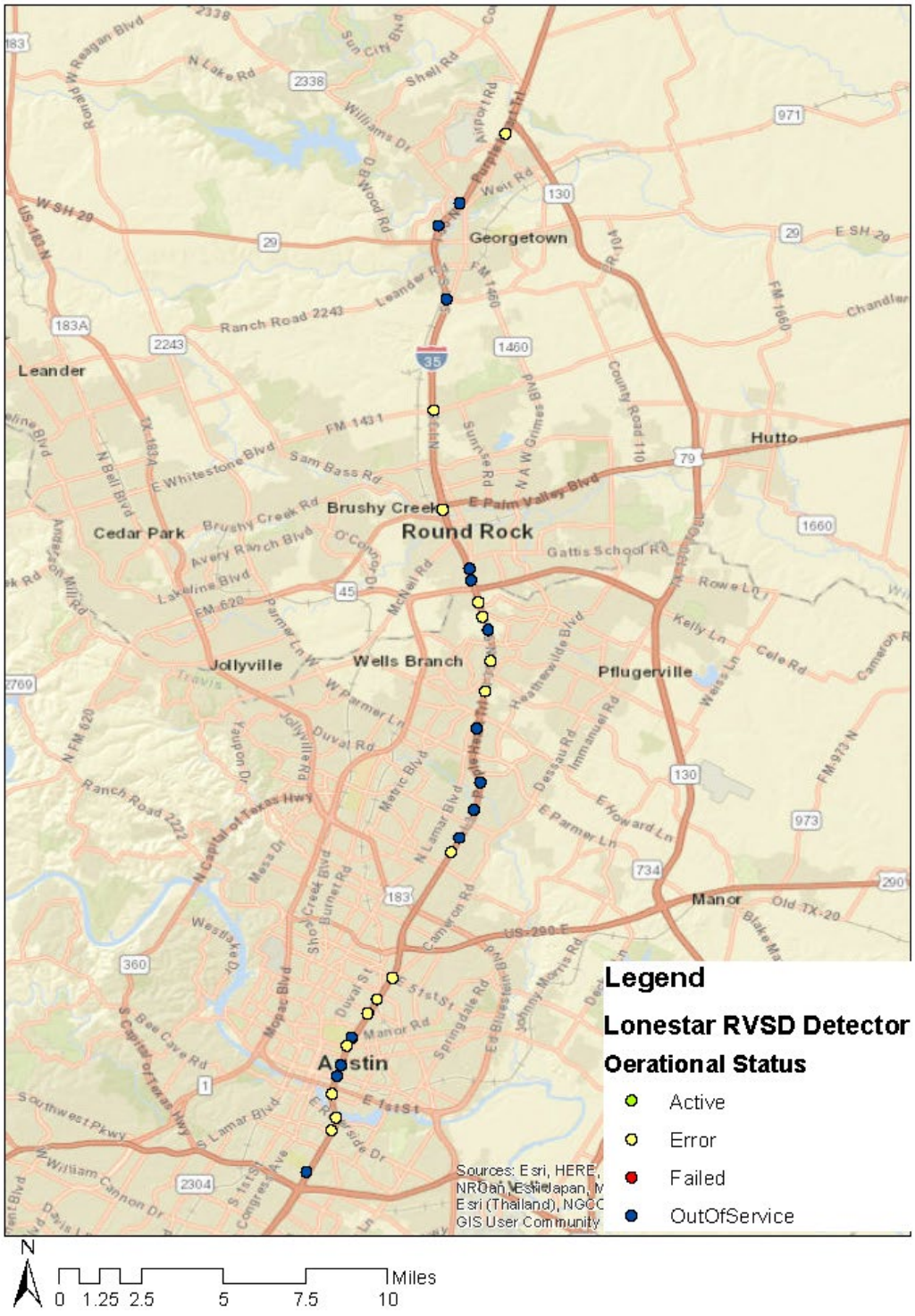
The detector locations can be mapped using GIS, and the raw data from the detectors can be exported to an Excel spreadsheet and the 15-minute speeds and volumes can be derived.

The Detector Spreadsheet has a data field named Operational_Status_Name. A legend for values in this field is shown here:

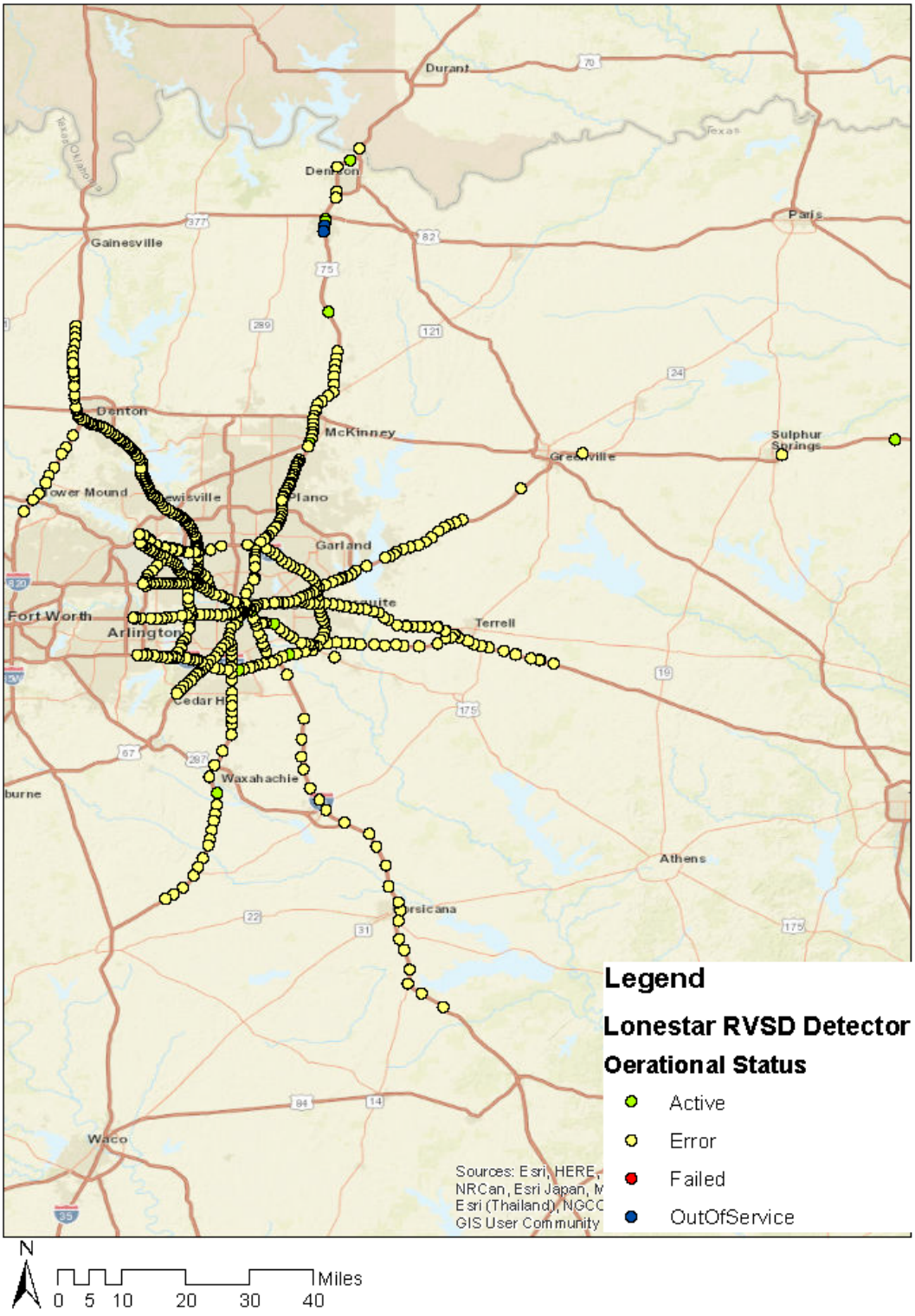
- Active = OK to be considered for usage. Data is available in the csv files.
- Error = OK to be considered for usage. Data is available in the csv files.
- Failed = Currently not operational.
- Out of Service = Currently not operational.

Section 8 – Lonestar RVSD Detector Locations

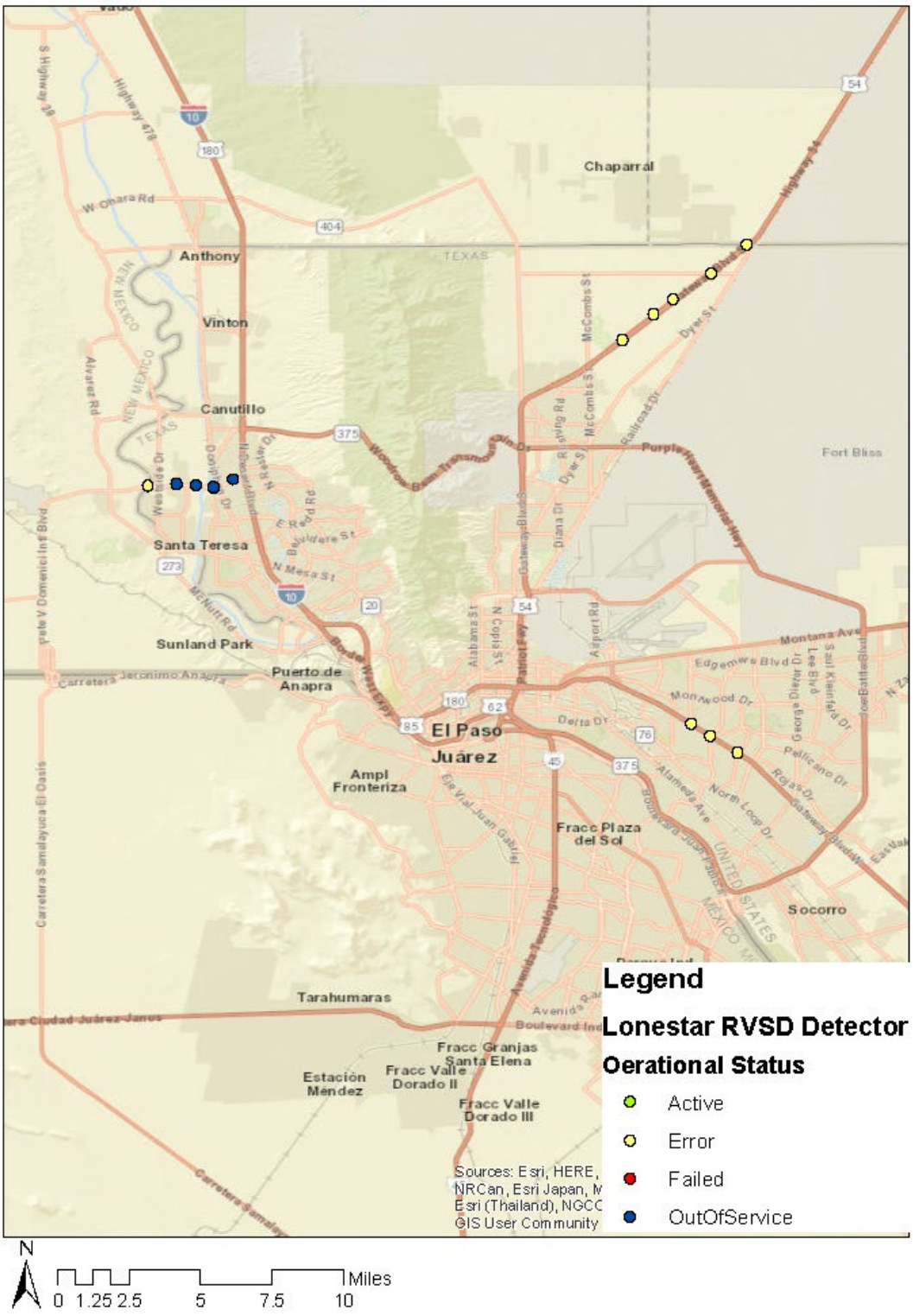
Lonestar RVSD Detector, Austin District



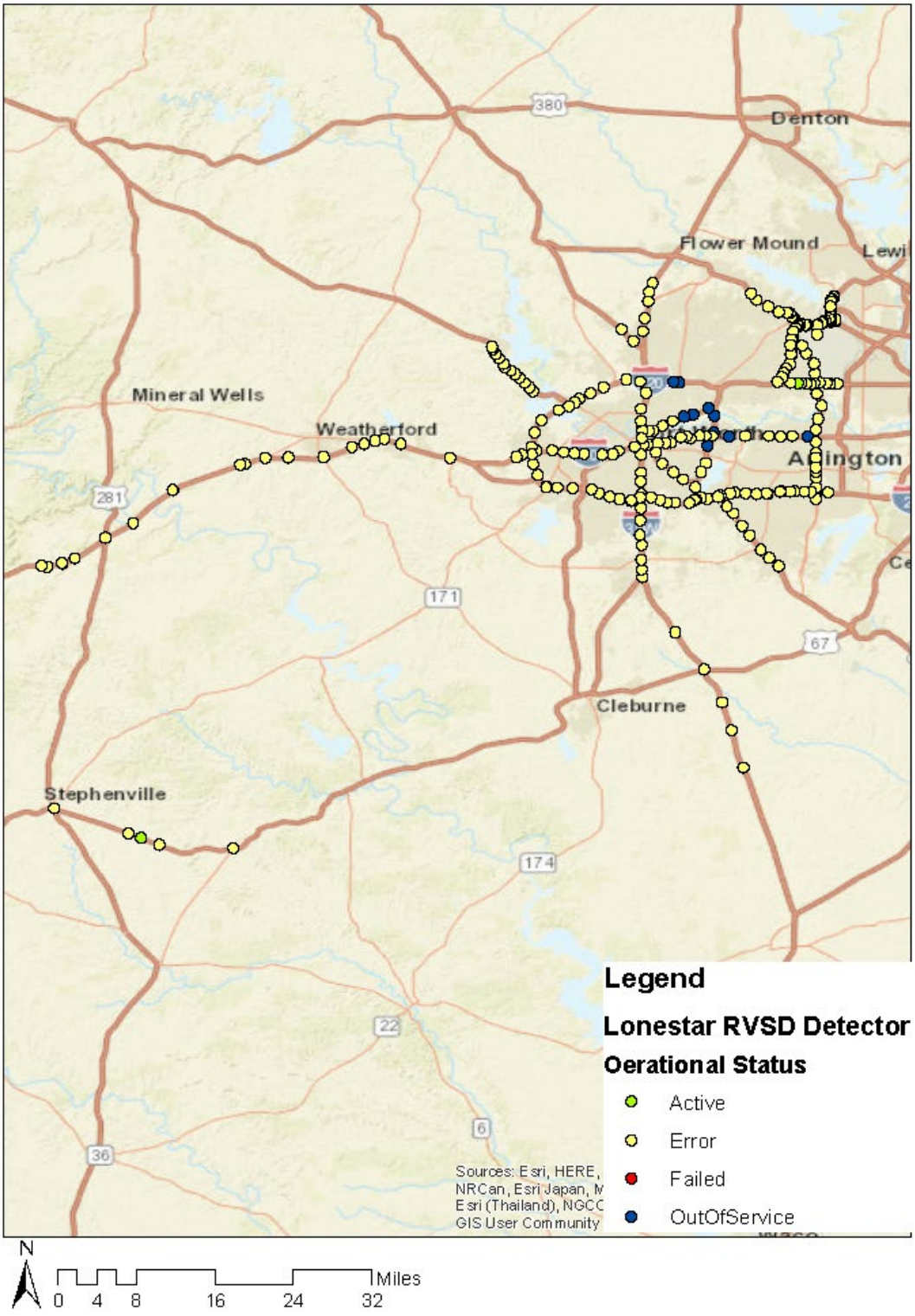
Lonestar RVSD Detector, Dallas District



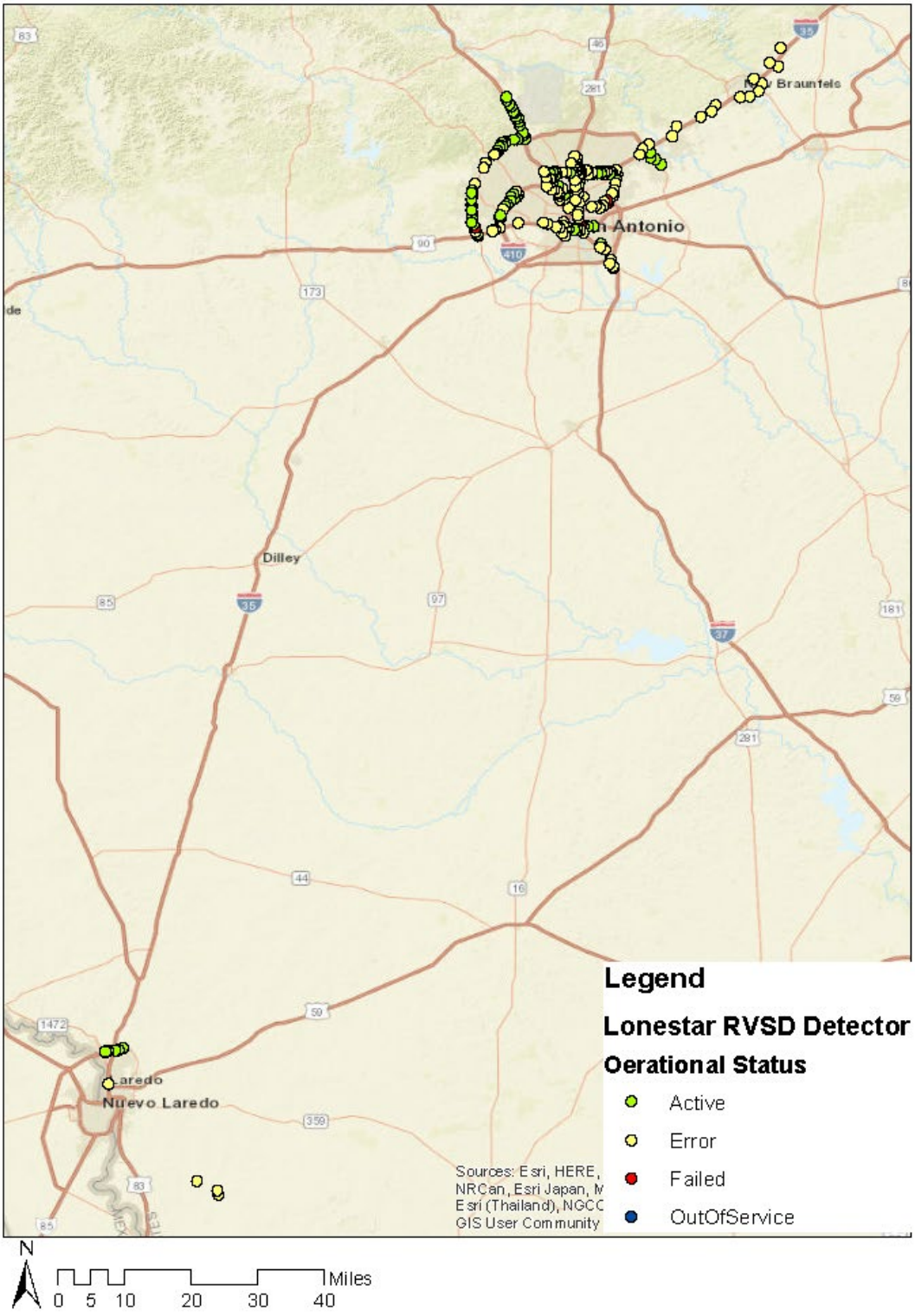
Lonestar RVSD Detector, El Paso District



Lonestar RVSD Detector, Fort Worth District



Lonestar RVSD Detector, San Antonio District



Section 9 – Lonestar RVSD Detector Example Data Output

detectorName	Latitude	Longitude	direction	speed 1st 15min	speed 2nd 15min	speed 3rd 15min	speed 4th 15min	Total Volume
IH-35 at MLK	30279052	-97730105	NB	58.6	59.6	59.5	58.5	52,877
IH-35 at MLK	30279052	-97730105	SB	59.5	58.9	58.8	59.2	59,077
IH-35 at University Blvd	30558540	-97691780	NB	67.9	67.6	67.6	67.9	45,197
IH-35 at University Blvd	30558540	-97691780	SB	72.4	59.1	39.1	37.7	25,969
IH-35 at Meadow Lark-1	30382670	-97674081	NB	68.2	68.4	69.3	70.0	43,569
IH-35 at Meadow Lark-1	30382670	-97674081	SB	22.4	20.4	35.2	39.0	45,502
IH-35 at Riverside Dr	30247141	-97734856	NB	25.3	23.5	22.4	23.5	39,246
IH-35 at Riverside Dr	30247141	-97734856	SB	62.6	61.2	60.9	60.5	40,345
IH-35 at N Lamar Blvd-1	30418606	-97672887	NB	63.8	65.1	63.2	63.5	48,905
IH-35 at N Lamar Blvd-1	30418606	-97672887	SB	42.0	21.7	21.2	58.4	30,901
IH-35 at Parker Dr-1	30474139	-97672245	NB	64.6	65.5	64.5	64.3	40,883
IH-35 at Parker Dr-1	30474139	-97672245	SB	68.6	70.2	69.8	70.6	38,574
IH-35 at Old US-81-1	30435018	-97669257	NB	69.1	69.8	68.3	69.2	38,249
IH-35 at Old US-81-1	30435018	-97669257	SB	52.9	60.2	42.7	55.1	60,947
IH-35 at Woodland Ave	30241610	-97736828	NB	25.4	23.0	21.3	23.2	46,371
IH-35 at Woodland Ave	30241610	-97736828	SB	57.9	57.2	57.4	58.0	42,013
IH-35 at Holly St	30257777	-97736726	NB	30.2	30.8	32.2	32.1	44,629
IH-35 at Holly St	30257777	-97736726	SB	55.5	54.5	54.5	54.7	43,777
IH-35 at Clarkson Ave	30299312	-97716674	NB	59.0	59.2	57.9	56.8	52,987
IH-35 at Clarkson Ave	30299312	-97716674	SB	30.1	32.2	29.0	28.8	65,271
IH-35 at SH-130	30680362	-97660190	NB	75.3	75.6	76.1	73.7	21,854
IH-35 at SH-130	30680362	-97660190	SB	76.4	75.6	75.5	73.5	36,912
IH-35 at Concordia Ave - Lower	30293389	-97720669	NB	61.5	61.9	60.8	60.5	31,028
IH-35 at Concordia Ave - Lower	30293389	-97720669	SB	51.9	50.2	52.8	51.6	31,437
IH-35 at Concordia Ave - Upper	30293214	-97721008	NB	61.4	61.7	63.7	60.8	23,214
IH-35 at Concordia Ave - Upper	30293214	-97721008	SB	39.6	41.5	38.8	38.1	34,288
IH-35 at Showplace Ln-1	30363985	-97684158	NB	70.0	69.5	68.8	69.9	32,032
IH-35 at Showplace Ln-1	30363985	-97684158	SB	32.7	56.3	49.8	30.6	65,736
IH-35 at US-79	30515043	-97687858	NB	57.9	63.0	65.9	65.0	48,917
IH-35 at US-79	30515043	-97687858	SB	31.4	26.4	25.0	26.3	38,342
IH-35 at 51st St	30308901	-97710012	NB	63.9	64.1	63.5	62.6	52,855
IH-35 at 51st St	30308901	-97710012	SB	20.4	23.1	20.4	19.4	41,257

Chapter 3 - Appendix D – Traffic Volume & Forecasting

- **Section 1** – Traffic Volume & Forecasting Checklist
- **Section 2** – Traffic Projections Methodology Memorandum Outline
- **Section 3** – Peak Hour Projection Calculations
- **Section 4** – Regression Calculations
- **Section 5** – Balancing Traffic Volumes Example Calculations

Section 1 - Traffic Volume & Forecasting Checklist

No	Item	Review	
		Checked By	Date
1	Obtain traffic data from STARS II		
2	Coordinate on and identify District Led versus TPP Led analysis		
3	Collect existing traffic counts, as needed		
4	Determine growth rate for traffic projections		
5	Develop traffic forecasts per TPP guidelines		
6	If travel demand model (TDM) is used for traffic forecasting, use the latest/approved TDM		

Section 2 – Traffic Projections Methodology Memorandum Outline

A suggested Traffic Projections Methodology Memo outline is as follows:

1. **Introduction**
2. **TxDOT TPP Standard Methodology**
3. **Growth Rate Calculations**
    a. Historical Growth Rate Calculation
    b. Corridor Future Growth Rate
    c. Corridor Growth Rate Adjustments
4. **Estimating K, D, and T Factors**
5. **Summary of Corridor Projected Volumes**

Appendix

A. Historical Count and Growth Rates
B. US Census Data
C. Traffic Counts

Section 3 – Peak Hour Projection Calculations

Data

Existing AM Peak Hour Counts

Existing Approach ADT = 16,000

NBL	NBT	NBR
250	1,000	250

Calculations

Existing AM Peak Hour Volume = 250 + 1,000 + 250 = 1,500

AM K Factor = Existing AM Peak Hour Volume/Existing Approach ADT

= 1,500/16,000

= .094

Growth Factor = 1.5

Projected Approach ADT = 16,000 * 1.5 = 24,000

AM Peak Hour Projections

.094*250*24,000/1,500	.094*1,000*24,000/1,500	.094*250*24,000/1,500
=376	=1,504	=376
NBL	NBT	NBR

Section 4 – Regression Calculations

TRAFFIC VOLUME REGRESSION WORKSHEET — May 1, 2024

Project: | District:
From Limit: | County:
To Limit:

Route												
Location												
2000	13,600	12,400	22,000	24,000	19,000							
2001	17,200	15,900	23,000	28,000	22,000							
2002	18,600	16,900	24,000	29,000	27,000							
2003	19,500	22,000	27,000	31,000	30,000							
2004	21,000	21,000	26,000	31,000	31,000							
2005	23,000	25,000	28,000	31,000	32,000							
2006	25,000	23,000	26,000	30,000	33,000							
2007	28,000	25,000	28,960	34,710	36,000							
2008	27,000	23,000	28,000	29,000	35,000							
2009	26,000	26,000	27,000	30,000	35,000							
2010	28,000	25,000	27,000	29,000	39,000							
2011	25,000	25,000	26,000	28,000	37,000							
2012	24,000	23,000	25,000	26,000	35,000							
2013	26,000	25,000	27,000	28,000	38,000							
2014	29,000	27,000	28,000	32,000	42,000							
2015	27,368	25,823	27,697	32,088	39,290							
2016	30,516	31,031	28,757	35,484	41,843							
2017	31,639	31,566	33,706	38,064	44,809							
2018	29,918	33,412	30,341	33,939	42,130							
2019	37,381	33,522	33,034	38,528	49,021							
2020	37,381	33,522	34,928	37,939	49,436							
	Regr01 X	Regr02 X	Regr03 X	Regr04 X	Regr05 X	Regr06 ☐	Regr07 ☐	Regr08 ☐	Regr09 ☐	Regr10 ☐	Regr11 ☐	Regr12 ☐
Confidence Level	**90%**											
20-Year Regression	Regr01	Regr02	Regr03	Regr04	Regr05	Regr06	Regr07	Regr08	Regr09	Regr10	Regr11	Regr12
Low Linear Annual Growth Rate	1.5%	1.5%	0.7%	0.5%	1.5%							
Forecast Lnr. An. Grwth Rate	**2.5%**	**2.5%**	**1.3%**	**1.2%**	**2.5%**							
High Linear Annual Growth Rate	3.6%	3.6%	2.0%	1.9%	3.5%							
Estimated Standard Deviation	2445.39	2232.54	1919.54	2888.04	2461.98							
B (Slope)	879	842	425	435	1192							
A (Intercept)	17166	16538	23435	26919	24154							
R=	0.912	0.920	0.809	0.683	0.949							
Margin of Error	362.642	344.603	197.936	239.935	472.868							
Years Analyzed*	**2000**	**-**	**2020**	**Avg. of Selected** Forecast Growth Rates:				**2.0%**	**Avg. of All** Forecast Growth Rates:			**2.0%**
10-Year Regression	Regr01	Regr02	Regr03	Regr04	Regr05	Regr06	Regr07	Regr08	Regr09	Regr10	Regr11	Regr12
Low Linear Annual Growth Rate	0.8%	1.1%	0.7%	1.0%	0.9%							
Forecast Lnr. An. Grwth Rate	**2.7%**	**3.0%**	**2.1%**	**2.8%**	**2.4%**							
High Linear Annual Growth Rate	4.6%	4.9%	3.6%	4.7%	3.9%							
Estimated Standard Deviation	2291.59	1935.31	1622.03	2337.56	2165.90							
B (Slope)	899	980	681	1051	1100							
A (Intercept)	24125	22949	25100	26662	34780							
R=	0.793	0.859	0.812	0.831	0.860							
Margin of Error	619.478	623.311	457.870	691.500	699.020							
Variable Years Analyzed*	**2009**	**-**	**2019**	**Avg. of Selected** Forecast Growth Rates:				**2.6%**	**Avg. of All** Forecast Growth Rates:			**2.6%**
5-Year Regression	Regr01	Regr02	Regr03	Regr04	Regr05	Regr06	Regr07	Regr08	Regr09	Regr10	Regr11	Regr12
Low Linear Annual Growth Rate	-0.2%	0.5%	-0.2%	-0.2%	-0.3%							
Forecast Lnr. An. Grwth Rate	**4.2%**	**4.6%**	**3.3%**	**3.1%**	**2.9%**							
High Linear Annual Growth Rate	8.6%	8.8%	6.7%	6.4%	6.0%							
Estimated Standard Deviation	2146.03	1298.15	1601.75	1839.77	2243.89							
B (Slope)	1448	1597	1087	1165	1331							
A (Intercept)	27350	26399	27538	32105	39854							
R=	0.784	0.917	0.786	0.764	0.743							
Margin of Error	1519.595	1432.741	1138.363	1254.101	1473.983							
Variable Years Analyzed*	**2014**	**-**	**2019**	**Avg. of Selected** Forecast Growth Rates:				**3.6%**	**Avg. of All** Forecast Growth Rates:			**3.6%**

***If counts were not obtained for all years indicated, the regression was performed using only the years with available counts.**

GR's for Non-Regression vol's only

PROJECTIONS OF ABOVE TRAFFIC VOLUME DATA TO FORECASTED YEARS

Use last Count Year from above. ☑
Do not use last Count Year from above. ☐
Enter any one of previous count years from above. 2010

Enter Base Year 2020

Pivot Growth Rate at 20 Years from Count Year (most commonly used). ☑
Pivot Growth Rate (GR) at other than 20 Years from Count Year. ☐
Enter years from Count Year for pivoting Growth Rate (e.g. for pivoting growth ten years from Count Year, enter 10) 10

Enter Earliest Variable Year 2025
Enter Latest Variable Year 2045

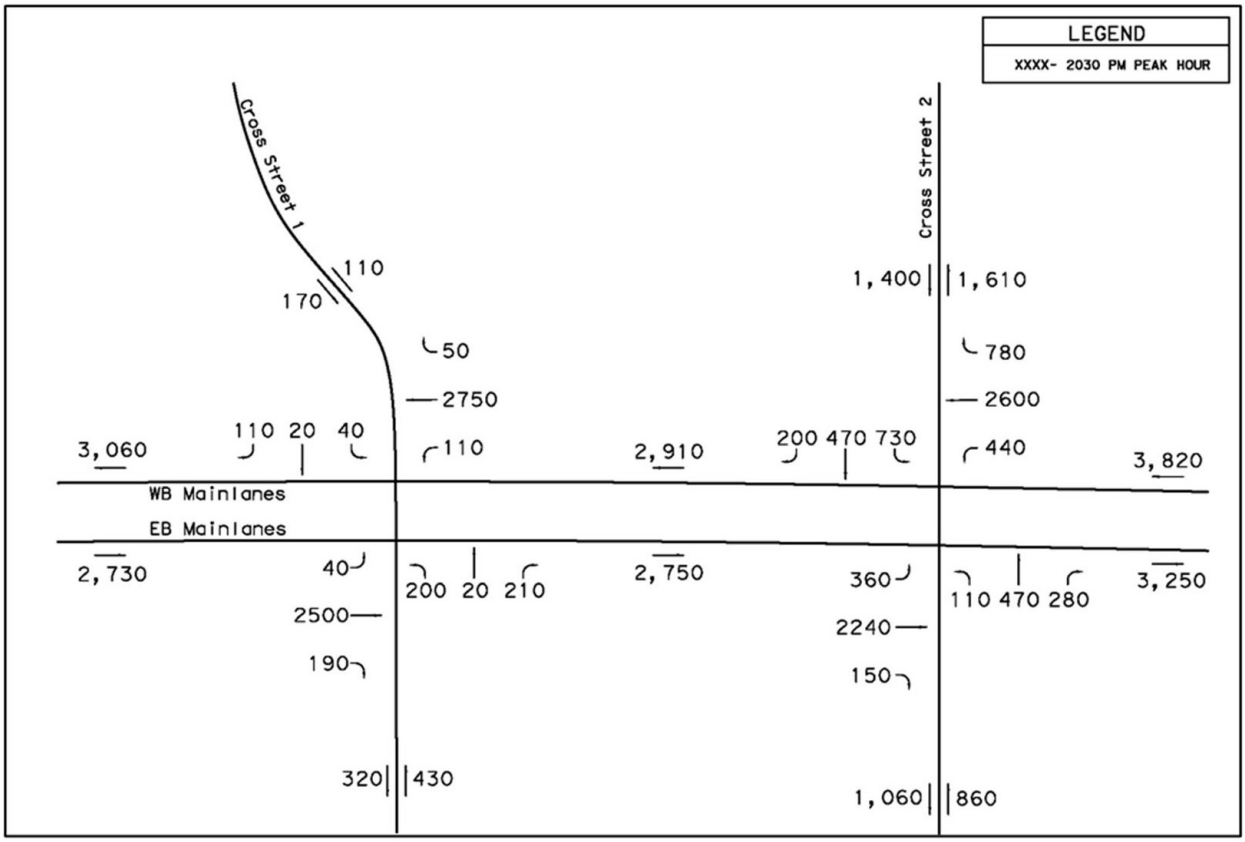
Pre-20/Pivot Yr Growth Rates Selection
Selections from above 20-Year Regression results.

Use Relative Low & Non-Regression GR's	○	
Use Relative Frcst & Non-Regression GR's	○	
Use Relative High & Non-Regression GR's	○	
Use Avg. of Selected Low Growth Rates	○	1.1%
Use Avg. of Selected Forecast Growth Rates	◉	**2.0%**
Use Avg. of Selected High Growth Rates	○	2.9%
Use Avg. of All Low Growth Rates	○	1.1%
Use Avg. of All Forecast Growth Rates	○	**2.0%**
Use Avg. of All High Growth Rates	○	2.9%
Use **Highest** Forecast Growth Rate	○	2.5%
Use **Lowest** Forecast Growth Rate	○	1.2%
Use Manually Selected Growth Rate	○	4.0%

Post-20/Pivot Year Growth Rate Note: If Pre-20/Pivot Yr GR is 2.0% or less, that rate is used in the projections, not the rate below.
Enter Growth Rate (2.0% most common) 2.0%

Route												
Location												
20/Pivot Yr. An. Growth Rate	2.0%	2.0%	2.0%	2.0%	2.0%							
Count Year - 2020	37381	33522	34928	37939	49436							
Base Year - 2020	37400	33500	34900	37900	49400							
Ten Year Forecast - 2030	44900	40200	41900	45500	59300							
Twenty Year Forecast - 2040	52300	46900	48900	53100	69200							
Thirty Year Forecast - 2050	59800	53600	55900	60700	79100							
Forty Year Forecast - 2060	67300	60300	62900	68300	89000							
GR Pivot Year Forecast - 2040	52300	46900	48900	53100	69200							
Earliest Var Yr Frcst - 2025	41100	36900	38400	41700	54400							
Latest Var Yr Frcst - 2045	56100	50300	52400	56900	74200							

Section 5 – Balancing Traffic Volumes Example Calculations



Network Balancing Calculations

Eastbound Mainlanes (West of Cross Street 2): Cross	360 + 2,240 + 150 = 2,750
Street 1 Turning onto Eastbound Mainlanes:	40 + 2,500 + 210 = 2,750
Westbound Mainlanes (East of Cross Street 1): Cross	50 + 2,750 + 110 = 2,910
Street 2 Turning onto Westbound Mainlanes:	110 + 2,600 + 200 = 2,910

Chapter 4 - Appendix E – Traffic Analysis Methodologies, Tools & Measures of Effectiveness

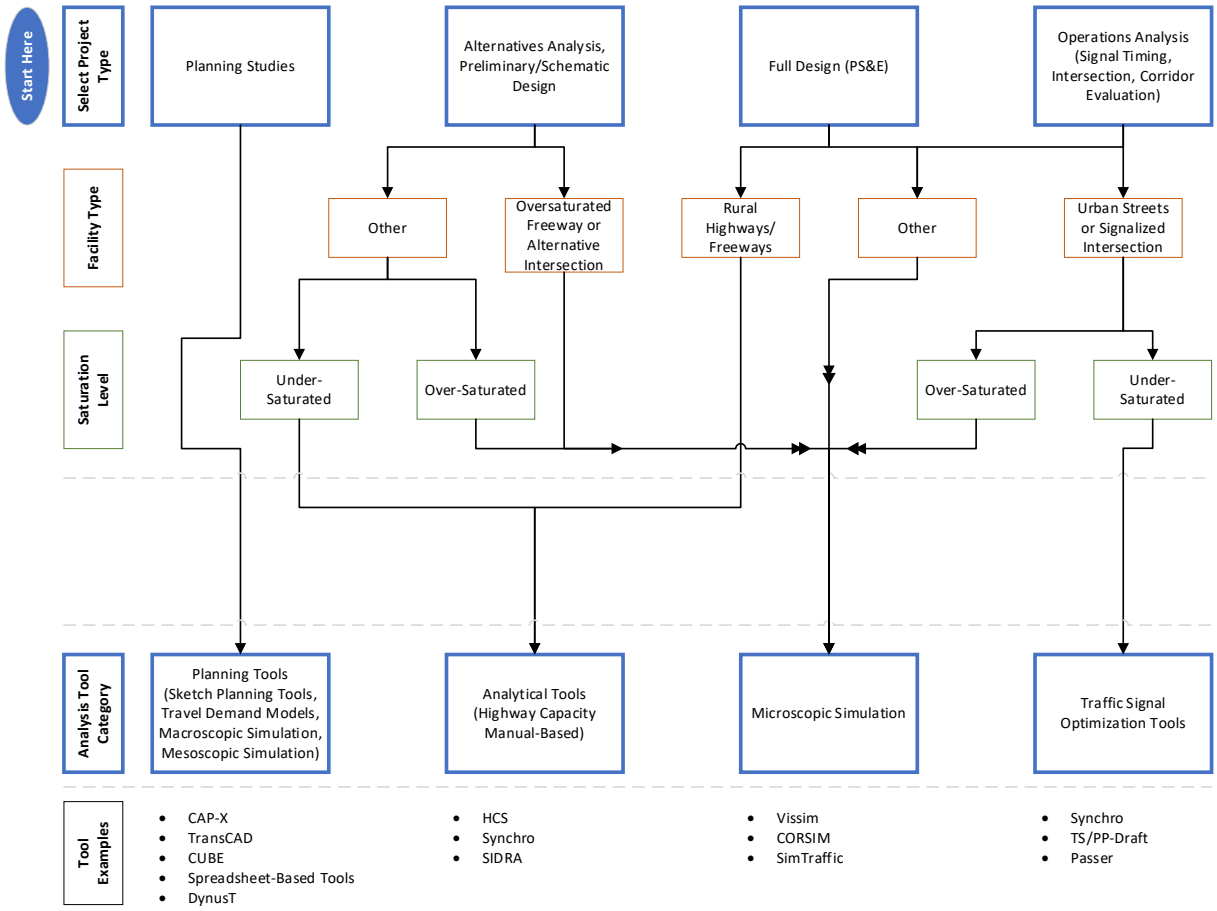
- **Section 1** – Additional Resources
- **Section 2** – Analysis Tool Selection Process

Section 1 – Additional Resources

The following resources may be used for additional guidance:

- **FHWA-HRT-04-039** – Traffic Analysis Toolbox Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools
- **FHWA-HRT-11-064** – Guide on the Consistent Application of Traffic Analysis Tools and Methods
- **FHWA-HOP-08-054** – Traffic Analysis Toolbox Volume VI: Definition, Interpretation, And Calculation of Traffic Analysis Tools Measures of Effectiveness
- **NCHRP Report 825**: Planning and Preliminary Engineering Applications Guide to the HCM
- **HCM 6th Edition**: A Guide to Multimodal Mobility Analysis

Section 2 – Traffic Analysis Tool Selection Process



Chapter 5 - Appendix F – Safety Analysis Concepts

- **Section 1** – SII Calculators
- **Section 2** – NCHRP 17-50 Project Example of HSM in Design
- **Section 3** – External References

Section 1 – SII Calculators

2022 SII Calculator (2019-2021 Crash Data)
Enter data in the shaded cells where applicable.

Years of Data
3

	Number of Crashes	Cost
Number of Fatal Crashes (K)		$4,000,000
Number of Incapacitating Injury Crashes (A)		$4,000,000
Number of Non-Incapacitating Injury Crashes (B)		$540,000

Reduction Factor	
Service Life	
Total ROW & Construction Cost	
Annual Maintenance Cost	
Present ADT	
Future ADT	0

SII Calculation **#VALUE!**

`

Crash IDs

List the Crash IDs included in crash counts.

K	A	B

Variable	Definition
S	annual savings in preventable crash costs (equal to crash cost savings per year less annual maintenance costs), as determined by the above formula
R	crash reduction factor (see following subsection for explanation)
F	number of preventable fatal and incapacitating injury crashes (see following subheading for explanation)
Cf	cost of a fatal or incapacitating injury crash (see following subheading for explanation)
I	number of preventable non-incapacitating injury crashes (see following subheading for explanation)
Ci	cost of a non-incapacitating injury crash (see following subheading for explanation)
Y	number of years of crash data
M	change in annual maintenance costs for the proposed project relative to the existing situation
Q	annual change in crash cost savings, as determined by the above formula
Aa	projected average annual Average Daily Traffic (ADT) at the end of the project service life
Ab	average annual ADT during the year before the project is implemented
L	project service life (see following subheading for explanation)
B	present worth of project benefits over its service life, as determined by the above formula
C	initial cost of the project.

$$S = \frac{R(CfF + CiI)}{Y} - M$$

$$B = \frac{S + \frac{1}{2}Q}{1.06} + \sum_{i=2}^{L} \left[\frac{\left(S + \frac{1}{2}Q\right) + (i-1)Q}{(1.06)^i} \right]$$

$$Q = \left(\frac{Aa - Ab}{Ab} \div L \right) S$$

$$SII = \frac{B}{C}$$

Section 2 – NCHRP 17-50 Project Example of HSM in Design

3.3 HSM in Design

3.3.1 Overview

Historically, the highway design process was based on the application of established design criteria. Adherence to design standards was viewed as the means to establish an acceptable level of safety. With the release of the HSM, designers are provided with tools to perform safety performance-based design. This allows development of solutions based not just on design standards, but also on quantifying the safety performance of different design considerations. For instance, designers can establish the safety impact of changing a design parameter, evaluate the impact of design exceptions on safety performance, assess the interactions of the road user with the highway, and evaluate design solutions based on user abilities and limitations using the human factors information included in the manual.

3.3.2 Example Problem 4 Evaluation of Curve Realignment versus Design Exception

Introduction

The example is a rural two-lane road that is being upgraded from a posted speed limit of 40 mph to 60 mph. Several changes in the roadway alignment are expected, particularly around curves. However, one curve location is adjacent to a high-quality wetland, and reconstructing such a curve may present a challenge from permitting, constructability, and cost points of view. The other option is to leave the existing curve geometry untouched and request a design exception. To mitigate the potential adverse effects of the design exception, some improvements are considered, including shoulder widening and paving shoulders. To better understand the safety benefits of reconstruction versus design exception, an analysis for both alternatives was conducted and is described in the following sections. Five years of crash data are available (2008 to 2012). In this example, the existing curve will be referred as Roadway Segment 1, the proposed curve will be referred to as Roadway Segment 2, and the existing curve with mitigation measures will be referred to as Roadway Segment 3.

Objectives

This example is focused on determining the safety performance of two design alternatives of a curve location to help design engineers with the decision-making process. The problem illustrates how to calculate the predictive and expected average crash frequency for two curve locations with different radii.

After reviewing this example, the user should be able to:

- Understand what input data are required and the assumptions that are commonly made regarding default values for the HSM procedures
- Calculate the predicted and expected crash frequency of rural two-lane curve segments using the HSM
- Understand how to reasonably interpret the results from an HSM analysis and how these results can be used to support a particular decision
- Understand the limitations of the HSM procedures and when it is appropriate to use other models or computational tools

Data Requirements

Roadway Segment Data

Table 67 contains the input data for this analysis.

TABLE 67
Example Problem 4 – Curve Segments Input Data

Characteristics	Input Data	
	Roadway Segment 1	Roadway Segment 2
Segment length (feet)	0.24	0.30
Traffic volume (vpd)	13,500	13,500
Lane width (feet)	12	12
Shoulder width (feet)	2	6
Shoulder type	Gravel	Paved
Length of horizontal curve (feet)	0.24	0.30
Radius of curvature (feet)	1,600	2,000
Spiral transition curve	Not present	Not present
Superelevation variance	0.02	0
Grade	2	2
Driveway density	0	0
Centerline rumble strips	Not present	Not present
Passing lanes	Not present	Not present
TWLTL	Not present	Not present
Roadside hazard rating (RHR)	4	3
Segment lighting	Not present	Not present
Auto speed enforcement	Not present	Not present
Calibration factor (C_r)	1.23	1.23
Observed crash data (crashes/year)	12	12

Analysis

Calculations for Roadway Segments 1 and 2 shown next are for year 2012. Details on the multiyear analysis are provided in the following sections.

Roadway Segments

Segment data required to apply the predictive method are summarized in Table 67. Roadway Segment 1 length is 0.24 mile with a curve radius of 1,600 feet. Roadway Segment 2 length is 0.3 mile with a curve radius of 2,000 feet. As part of the new realignment, Roadway Segment 2 shoulder type is upgraded from gravel to paved and widened from 2 feet to 6 feet. The superelevation and roadside hazard rating (RHR) for

Roadway Segment 2 are also upgraded. All remaining parameters are the same for both locations. Information on different recommendations related to data collection is presented in HSM Section 10.4.

Select and Apply SPFs

For the selected site, apply the appropriate SPF for rural two-lane, two-way roads. The SPF can be calculated using HSM Equation 10-6 (HSM p. 10-15):

$$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312}$$

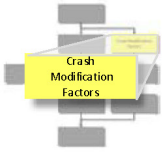
$$N_{spf\ seg\ 1} = 13{,}500 \times 0.24 \times 365 \times 10^{-6} \times e^{-0.312}$$

$$N_{spf\ seg\ 1} = 0.87\ crashes/year$$

$$N_{spf\ seg\ 2} = 13{,}500 \times 0.30 \times 365 \times 10^{-6} \times e^{-0.312}$$

$$N_{spf\ seg\ 2} = 1.08\ crashes/year$$

Apply HSM Part C Crash Modification Factors



Multiply the result obtained above by the appropriate CMFs to adjust the estimated crash frequency for base conditions to the site-specific geometry and traffic features.

Lane Width (CMF_{1r})

CMF_{1r} can be calculated using HSM Equation 10-11 (HSM p. 10-24) shown below:

$$CMF_{1r} = (CMF_{ra} - 1) \times p_{ra} + 1$$

CMF_{ra} is estimated using HSM Table 10-8 (HSM p. 10-24). For a 12-foot lane width and AADT greater than 2,000, the CMF for the effect of lane width on related crashes (such as single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes) is 1.00.

For this example, since the lane width is the same as the base conditions, the applicable CMF for both roadway segments is 1.00.

Shoulder Width and Type (CMF_{2r})

CMF_{2r} can be calculated using HSM Equation 10-12 (HSM p. 10-27). For this example, a 2-foot gravel shoulder yields a CMF_{wra} of 1.18 for Roadway Segment 1 and 1.00 for Roadway Segment 2 (shoulder width HSM Table 10-9 [HSM p. 10-25]) and CMF_{tra} of 1.0 (shoulder type HSM Table 10-10 [HSM p. 10-26]). The percentage of related crashes is the same as that calculated for the lane width CMF:

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1) \times p_{ra} + 1$$

$$CMF_{2r\ seg\ 1} = (1.3 \times 1.01 - 1) \times (0.521 + 0.016 + 0.037) + 1$$

$$CMF_{2r\ seg\ 1} = 1.18$$

$$CMF_{2r\ seg\ 2} = (1 \times 1 - 1) \times (0.574) + 1$$

$$CMF_{2r\ seg\ 2} = 1.00$$

Horizontal Curve (CMF_{3r})
For this example, Roadway Segment 1 length is 0.24 mile with a radius of curvature of 1,600 feet, and Roadway Segment 2 length is 0.30 mile with a radius of curvature of 2,000 feet. The CMF is calculated using HSM Equation 10-13 (HSM p. 10-27):

$$CMF_{3r} = \frac{1.55 \times L_c + \frac{80.2}{R} - 0.012 \times S}{1.55 \times L_c}$$

$$CMF_{3r\ seg\ 1} = \frac{1.55 \times 0.24 + \frac{80.2}{1{,}600} - 0.012 \times 0}{1.55 \times 0.24}$$

$$CMF_{3r\ seg\ 1} = 1.13$$

$$CMF_{3r\ seg\ 2} = \frac{1.55 \times 0.30 + \frac{80.2}{2{,}000} - 0.012 \times 0}{1.55 \times 0.30}$$

$$CMF_{3r\ seg\ 2} = 1.09$$

Superelevation (CMF_{4r})
The superelevation variance for Roadway Segment 1 is 0.02 feet per foot, and for Roadway Segment 2 it is 0. Therefore, the superelevation is calculated using HSM Equation 10-16 (HSM p. 10-28):

$$CMF_{4r\ SV \geq 0.02} = 1.06 + 3 \times (SV - 0.02)$$

$$CMF_{4r\ SV \geq 0.02} = 1.06 + 3 \times (0.02 - 0.02)$$

$$CMF_{4r\ seg\ 1} = 1.06$$

$$CMF_{4r\ seg\ 2 < 0.01} = 1.00$$

Grade (CMF_{5r})
A 2 percent grade section falls under the level grade category in HSM Table 10-11 (HSM p. 10-28), resulting in a CMF of 1.00 for both roadway segments.

Driveway Density (CMF_{6r})
Driveway density of less than five driveways per mile leads to a CMF_{6R} of 1.00. Otherwise, the CMF is calculated using HSM Equation 10-17 (HSM p. 10-29):

$$CMF_{6r} = \frac{0.322 + DD \times [0.05 - 0.005 \times ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times ln(AADT)]}$$

$$CMF_{6r\ seg\ 1} = 1.00$$

$$CMF_{6r\ seg\ 2} = 1.00$$

Centerline Rumble Strips (CMF_{7r})
The roadway segments do not have centerline rumble strips; therefore, a CMF of 1.00 is applied. See HSM p. 10-29 for additional details.

Passing Lanes (CMF_{8r})
Passing lanes are not present in the example; therefore, a CMF of 1.00 is appropriate for both roadway segments. See HSM p. 10-29 for additional details.

Two-Way, Left-Turn Lane (CMF_{9r})
TWLTLs are not present; therefore, a CMF of 1.00 is applied for this example. See HSM p. 10-29 for additional details.

Roadside Design (CMF_{10r})
The data in this example indicate a roadside hazard rating of 4 for Roadway Segment 1, and a rating of 3 for Roadway Segment 2. The CMF is calculated using HSM Equation 10-20 (HSM p. 10-30):

$$CMF_{10r} = \frac{e^{-0.6869+0.0668\times RHR}}{e^{-0.4865}}$$

$$CMF_{10r} = \frac{e^{-0.6869+0.0668\times 4}}{e^{-0.4865}}$$

$$CMF_{10r\ seg\ 1} = 1.07$$

$$CMF_{10r} = \frac{e^{-0.6869+0.0668\times 3}}{e^{-0.4865}}$$

$$CMF_{10r\ seg\ 2} = 1.00$$

Lighting (CMF_{11r})
Lighting is not present at this location; therefore, a CMF of 1.00 is applied. See HSM p. 10-30 for additional details.

Automated Speed Enforcement (CMF_{12r})
The site does not have automated speed enforcement available; therefore, a CMF of 1.00 is applied. See HSM p. 10-30 for additional details.

The combined CMF is then calculated by multiplying all the intersection CMFs:

$$CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times \cdots \times CMF_{12r}$$

$$CMF_{comb\ seg\ 1} = 1.0 \times 1.18 \times 1.13 \times 1.06 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.07 \times 1.0 \times 1.0 = 1.517$$

$$CMF_{comb\ seg\ 2} = 1.0 \times 1.0 \times 1.09 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 = 1.086$$

Apply Calibration Factor

Multiply the predicted average crash frequency and CMF results obtained in previous steps by the appropriate calibration factor. For this example, the calibration factor has been assumed to be 1.23.

Obtain the Predicted Crash Frequency for the Site

The predicted average crash frequency is calculated using HSM Equation 10-2 (HSM p. 10-3), combining results from previous steps:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r})$$

$$N_{predicted\ rseg\ 1} = 0.87 \times 1.23 \times (1.52)$$

$$N_{predicted\ rseg\ 1} = 1.62\ crashes/year$$

$$N_{predicted\ rseg\ 2} = 1.08 \times 1.23 \times (1.09)$$

$$N_{predicted\ rseg\ 2} = 1.45\ crashes/year$$

Multiyear Analysis

Since 5 years of data are available, all the previous steps need to be repeated four more times. In this example, a growth rate of 1.5 percent is assumed. Table 68 summarizes the calculations for the study period.

TABLE 68
Example Problem 4 – Roadway Segment 1 Multiyear Analysis Results

Roadway Segment 1	Year				
	2008	2009	2010	2011	2012
AADT	12,719	12,910	13,104	13,300	13,500
N_{spf}	0.816	0.828	0.84	0.853	0.866
CMF_{1r}	1.00	1.00	1.00	1.00	1.00
CMF_{2r}	1.18	1.18	1.18	1.18	1.18
CMF_{3r}	1.13	1.13	1.13	1.13	1.13
CMF_{4r}	1.06	1.06	1.06	1.06	1.06
CMF_{5r}	1.00	1.00	1.00	1.00	1.00
CMF_{6r}	1.00	1.00	1.00	1.00	1.00
CMF_{7r}	1.00	1.00	1.00	1.00	1.00
CMF_{8r}	1.00	1.00	1.00	1.00	1.00
CMF_{9r}	1.00	1.00	1.00	1.00	1.00
CMF_{10r}	1.07	1.07	1.07	1.07	1.07
CMF_{11r}	1.00	1.00	1.00	1.00	1.00
CMF_{12r}	1.00	1.00	1.00	1.00	1.00
CMF_{comb}	1.52	1.52	1.52	1.52	1.52
C_r	1.23	1.23	1.23	1.23	1.23
$N_{predicted\ seg}$	1.52	1.54	1.57	1.59	1.62

TABLE 69
Example Problem 4 – Roadway Segment 2 Multiyear Analysis Results

Roadway Segment 2	Year				
	2008	2009	2010	2011	2012
AADT	12,719	12,910	13,104	13,300	13,500
N_{spf}	1.019	1.035	1.050	1.066	1.082
CMF_{1r}	1.00	1.00	1.00	1.00	1.00
CMF_{2r}	1.00	1.00	1.00	1.00	1.00
CMF_{3r}	1.09	1.09	1.09	1.09	1.09
CMF_{4r}	1.00	1.00	1.00	1.00	1.00
CMF_{5r}	1.00	1.00	1.00	1.00	1.00
CMF_{6r}	1.00	1.00	1.00	1.00	1.00
CMF_{7r}	1.00	1.00	1.00	1.00	1.00
CMF_{8r}	1.00	1.00	1.00	1.00	1.00

TABLE 69
Example Problem 4 – Roadway Segment 2 Multiyear Analysis Results

Roadway Segment 2	Year				
	2008	2009	2010	2011	2012
CMF_{9r}	1.00	1.00	1.00	1.00	1.00
CMF_{10r}	1.00	1.00	1.00	1.00	1.00
CMF_{11r}	1.00	1.00	1.00	1.00	1.00
CMF_{12r}	1.00	1.00	1.00	1.00	1.00
CMF_{comb}	1.09	1.09	1.09	1.09	1.09
C_r	1.23	1.23	1.23	1.23	1.23
$N_{predicted\ seg}$	1.36	1.38	1.40	1.42	1.45

The average predicted crash frequency for Roadway Segments 1 and 2 are obtained through the arithmetic average of the annual predicted crash frequencies ($N_{predicted\ seg}$). The average for Roadway Segments 1 and 2 are 1.57 and 1.40 crashes per year, respectively.

Empirical Bayes Adjustment Method

The next step in the process is to update predictions based on the observed/reported crashes. Twelve roadway segment crashes occurred per year. The predictive models indicate that the total predicted average crash frequencies for Roadway Segments 1 and 2 are 1.57 and 1.40 crashes per year, respectively.

The predicted average crash frequency is then adjusted using the EB method by applying the following steps.

In this example, the proposed geometric upgrade represents a minor change in alignment; therefore, the EB method is applicable. Refer to HSM Section A.2.1 (HSM p. A-16) for additional details about the applicability of the EB method.

The site EB method is applicable. Refer to HSM Section A.2.5 (HSM p. A-20 to A-22) for additional details on the different EB methods.

The expected number of crashes for segments is calculated by HSM Equation A-4 (HSM p. A-19):

$$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed}$$

To complete this calculation, weighting adjustment factors are needed for the samples. Calculate using the previous crash predictions with HSM Equation A-5 (HSM p. A-19):

$$w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{predicted}}$$

For this calculation, the overdispersion parameter from each of the applied SPFs is needed. The overdispersion parameter for Roadway Segment 1 is 0.983 and for Roadway Segment 2 is 0.787. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. On a per-mile basis, the overdispersion parameter is calculated by using HSM Equation 10-7 (HSM p. 10-16):

$$k_{seg} = \frac{0.236}{L}$$

$$k_{seg\ 1} = \frac{0.236}{0.24}$$

$$k_{seg\ 1} = 0.983$$

$$k_{seg\ 2} = \frac{0.236}{0.30}$$

$$k_{seg\ 2} = 0.787$$

Using these overdispersion parameters, the weighting adjustment factors are found to be 0.115 and 0.153 for Roadway Segments 1 and 2, respectively:

$$w_{seg\ 1} = \frac{1}{1 + 0.983 \times (1.52 + 1.54 + 1.57 + 1.59 + 1.62)}$$

$$w_{seg\ 1} = 0.115$$

$$w_{seg\ 2} = \frac{1}{1 + 0.787 \times (1.36 + 1.38 + 1.40 + 1.42 + 1.45)}$$

$$w_{seg\ 2} = 0.153$$

Twelve observed/reported crashes per year were reported in the curve. The expected number of crashes for the roadway segments is then calculated as follows:

$$N_{expected\ seg} = w \times N_{predicted} + (1 - w) \times N_{observed}$$

$$N_{expected\ seg\ 1} = 0.115 \times 1.57 + (1 - 0.115) \times 12$$

$$N_{expected\ seg1} = 10.8\ crashes/year$$

$$N_{expected\ seg\ 2} = 0.153 \times 1.40 + (1 - 0.153) \times 12$$

$$N_{expected\ seg\ 2} = 10.4\ crashes/year$$

Results of the analysis can be found in the sample spreadsheets provided with the *Highway Safety Manual User Guide*.

Table 70 presents a summary of the predictive method calculations. Columns 2 through 4 contain the predicted average crash frequency for total crashes, fatal-and-injury, and PDO. The fifth column contains the observed/reported number of crashes per year. Columns 6 and 7 contain the overdispersion parameter and weighted adjustment to be used to obtain the expected average crash frequency (last column).

TABLE 70
Example Problem 4 – Predicted, Expected, and Observed Crash Frequency Calculations Summary (2008 to 2012)

Site Type	Predicted Average Crash Frequency (crashes/year)			Observed/ Reported Crashes ($N_{observed}$) (crashes/ year)	Over-dispersion Parameter (k)	Weighted Adjustment (w) (Equation A-5 from HSM Part C Appendix A)	Expected Average Crash Frequency ($N_{expected}$) (Equation A-4 from HSM Part C Appendix A)
	$N_{predicted}$ (Total)	$N_{predicted}$ (Fatal-&-Injury)	$N_{predicted}$ (PDO)				
Roadway Segment 1	1.568	0.503	1.065	12	0.983	0.115	10.8
2008	1.522	0.488	1.033	12	0.983		
2009	1.545	0.496	1.049	12	0.983		
2010	1.568	0.503	1.065	12	0.983		
2011	1.591	0.511	1.080	12	0.983		
2012	1.615	0.518	1.097	12	0.983		
Roadway Segment 2	1.404	0.451	0.953	12	0.787	0.153	10.4
2008	1.362	0.437	0.925	12	0.787		
2009	1.383	0.444	0.939	12	0.787		
2010	1.403	0.450	0.953	12	0.787		
2011	1.424	0.457	0.967	12	0.787		
2012	1.446	0.464	0.982	12	0.787		

Details about the predictive method calculations can be found in the *Highway Safety Manual User Guide* spreadsheets. Comparison of the predicted and observed crash frequencies shows that the site is experiencing more crashes than the average site with similar characteristics.

Application of Mitigation Measures

The next step is to calculate the safety effects of the mitigation measures on the existing roadway. The existing curve gravel shoulders are 2 feet wide. The proposed improvements include paving the shoulders and increasing the width to 4 feet. Since the changes only involve shoulder type and width, all the other steps shown in the previous section are the same.

Shoulder Width and Type (CMF_{2r})

CMF_{2r} can be calculated using HSM Equation 10-2 (HSM p. 10-3). For this example, a 4-foot paved shoulder yields a CMF_{wra} of 1.15 (shoulder width HSM Table 10-9 [HSM p. 10-25]) and CMF_{tra} of 1.0 (shoulder type HSM Table 10-10 [HSM p. 10-26]). The percentage of related crashes is the same as that calculated for the lane width CMF:

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1) \times p_{ra} + 1$$

$$CMF_{2r\ seg\ 1} = (1.15 \times 1 - 1) \times (0.574) + 1$$

$$CMF_{2r\ seg\ mit\ 1} = 1.09$$

Table 71 summarizes the results of the three scenarios. Roadway Segment 3 refers to the existing curve with the addition of mitigation measures to request the design exception.

TABLE 71
Example Problem 4 – Predicted, Expected, and Observed Crash Frequency Calculations Summary for the Three Scenarios (2008 to 2012)

Site Type	Predicted Average Crash Frequency (crashes/year)			Observed/ Reported Crashes ($N_{observed}$) (crashes/ year)	Over-dispersion Parameter (k)	Weighted Adjustment (w) (Equation A-5 from HSM Part C Appendix A)	Expected Average Crash Frequency ($N_{expected}$) (Equation A-4 from HSM Part C Appendix A)
	$N_{predicted}$ (Total)	$N_{predicted}$ (Fatal-&-Injury)	$N_{predicted}$ (PDO)				
Roadway Segment 1	1.568	0.503	1.065	12	0.983	0.115	10.80
2008	1.522	0.488	1.033	12	0.983		
2009	1.545	0.496	1.049	12	0.983		
2010	1.568	0.503	1.065	12	0.983		
2011	1.591	0.511	1.080	12	0.983		
2012	1.615	0.518	1.097	12	0.983		
Roadway Segment 2	1.404	0.451	0.953	12	0.787	0.153	10.37
2008	1.362	0.437	0.925	12	0.787		
2009	1.383	0.444	0.939	12	0.787		
2010	1.403	0.450	0.953	12	0.787		
2011	1.424	0.457	0.967	12	0.787		
2012	1.446	0.464	0.982	12	0.787		
Roadway Segment 3	1.444	0.463	0.980	12	0.983	0.123	10.70
2008	1.401	0.450	0.951	12	0.983		
2009	1.422	0.456	0.966	12	0.983		
2010	1.443	0.463	0.980	12	0.983		
2011	1.465	0.470	0.995	12	0.983		
2012	1.487	0.477	1.010	12	0.983		

The results, summarized in Table 72, indicate that the proposed curve will reduce the total expected crash frequency by about 4 percent (0.4 crash per year). The existing curve with mitigation measures reduces the total expected crash frequency by only 1 percent (0.1 crash per year).

TABLE 72
Example Problem 4 – Analysis Results Summary

Site Type	Length (miles)	$N_{observed}$	Crash Frequencies (crashes/year)	
			$N_{predicted}$	$N_{expected}$
Roadway Segment 1 – Existing Curve	0.24	12	1.6	10.8
Roadway Segment 2 – Proposed Curve	0.3	12	1.4	10.4
Roadway Segment 3 – Existing Curve with Mitigation Measures	0.24	12	1.4	10.7

Results and Discussion

The application of the HSM in the design stage provides engineers with valuable information in the decision-making process. NOTE: The HSM does not require agencies to implement specific alternatives based solely on safety performance evaluation but instead provides the means to make an informed decision.

The analysis conducted to determine the crash reduction impacts of upgrading the existing curve to comply with the current roadway design guidance indicates that more crashes are occurring at the site than the average site with similar characteristics. The predicted crash frequencies for curve Roadway Segments 1 and 2 are 1.6 and 1.4 crashes per year, respectively. However, the observed annual crash frequency for the site is 12 crashes per year.

After application of the EB adjustment, the expected crash frequency resulted in 10.8 and 10.4 crashes per year for Roadway Segments 1 and 2, respectively. To request a design exception, mitigation measures were applied to the existing curve Roadway Segment 1. Results of the application of the predictive method to the curve with mitigation measures show predicted and expected crash frequencies of 1.4 and 10.7 crashes per year, respectively.

For the analysis, the proposed curve alignment would reduce expected crash frequency by 4 percent, or 0.4 crashes per year. This reduction may not seem significant, so the analyst may need to look at other factors such as crash severity and specific collision types that are being addressed with the improved alignment or mitigation measures. In addition, this might be only one element of the entire corridor project, and significant differences may become obvious when reviewing the corridor as a whole.

Results may not always be favorable. A treatment (such as concrete median barriers) may increase the total crash frequency but reduce the severe crashes. Sound engineering judgment is ultimately the main driver of the decision-making process.

Results from this analysis offer engineers additional information to make an informed decision. The next step is to conduct an economic evaluation to determine the most cost-effective investment. Refer to HSM Chapter 7, Economic Appraisal, for methods to compare the benefits of potential crash countermeasures to crash costs.

Section 3 – External References

The websites below were last accessed on May 31, 2024

1. **Texas Strategic Highway Safety Plan**

   https://www.texasshsp.com/

   - Texas Department of Transportation and Department of Public Safety seek to develop strategic highway safety plans to drive down the number of fatalities.

2. **Crash Modification Factors Clearinghouse**

   http://www.cmfclearinghouse.org

   - CMF is used to compute the number of crashes after implementing a countermeasure on a road.

3. **Identifying Appropriate Crash Modification Factors**

   http://www.cmfclearinghouse.org/userguide_identify.cfm

   - Provides filters to enable users to narrow the search results of inappropriate CMFs.

4. **Highway Safety Manual Updates**

   http://www.highwaysafetymanual.org/Documents/HSM2_GeneralUpdate_20220209.pdf

   - HSM is guidance document for incorporating quantitative safety analysis within the transportation project.

5. **Highway Safety Engineering**

   https://www.txdot.gov/content/txdotreimagine/us/en/home/about/programs/highway-safety-engineering.html

   - Highway Safety Engineering uses crash data to implement projects with the intent to save lives and reduce crashes.

6. **Highway Safety Engineering Website**

   https://www.txdot.gov/inside-txdot/forms-publications/publications/highway-safety.html

   - Link to the Highway Safety Engineering website which includes information on the HSIP program (including the SII Calculator), SSWP, Safety Engineering Reports

7. **Texas Transportation Institute (TTI) "List of Safety Tools"**

   https://cts.tti.tamu.edu/project/list-of-safety-tools/

   - Link to the list of safety tools on TTIs website. These tools are designed to help the user identify roadway locations with the best opportunities to improve safety performance and to evaluate design alternatives for their impact on safety.

8. **Safe System Approach (FHWA)**

   https://www.transportation.gov/NRSS/SafeSystem

Chapter 6 - Appendix G – Safety Analysis, Methodologies, & Tools

- **Section 1** – Rural Multi-Lane Road Segment Safety Scoring Tool
- **Section 2** – Rural Two-Lane Road Segment Safety Scoring Tool
- **Section 3** – Urban Intersection Safety Scoring Tool
- **Section 4** – Example Crash Data Summary
- **Section 5** – External References
- **Section 6** – Safety Prediction Models
- **Section 7** – Safer By Design
- **Section 8** – IAJR SOP FAQ Webinar Slides

Section 1 - Rural Multi-Lane Road Segment Safety Scoring Tool

Preferred Schematic View to Display	Standard
Relative to	Existing

CHARACTERISTICS TO CONSIDER FOR ANALYSIS

INPUT INSTRUCTIONS	
Blue Boxes -- Select from pulldown options	Select from Pulldown
Yellow Boxes -- Type input information into box	Type Input Value

Rural Multi-Lane Road Segment -- Safety Score Input

General Information:	
Analyst:	0
Agency or Company:	0
Date:	1/0/1900
Description:	
Input additional site information here	

General Site Features	9 Missing Features and Curves
Location	
Design Speed (mph)	
Posted Speed (mph)	
E max (%)	
Design Year AADT (vehicles per day)	
Dist. from Centerline to Left ROW (feet)	
Dist. from Centerline to Right ROW (feet)	

Warning:
No speed warnings identified

To enter notes, use boxes to the right of the vortex

40 Total Available Points

Geometric Design Elements	Existing	Standard (Based on Multi-lane Divided)	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal (Based on Multi-lane Divided)
	19 Missing Elements		19 Missing Elements	19 Missing Elements		
Configuration of Multilane Roadway		Divided - Unsurfaced Median				Divided - Unsurfaced Median
Median Configuration (Width or Type)		30 ft			+9%	100 ft
Lane Width (feet)		12.0			+0%	12.0
Average Outside Shoulder Width (feet)		8.0			+18%	10.0
Average Inside Shoulder Width (feet)		4.0			+0%	10.0
Number of Lanes per Direction of Travel		2				2.0
Horizontal Curve Present?	--	--	--	--		--
Horizontal Curve Data for Controlling Element:	--	--	--	--		--
Radius (feet)					+0%	
Length of Horizontal Curve (feet)						
Calculated Deflection Angle Δ						
Vertical Curve Present?	--	--	--	--		--
Vertical Curve Data for Controlling Element:						
Approach (Entry) Grade, G1 (%)						
Departure (Exit) Grade, G2 (%)						
Length (feet)						
Calculated Rate of Change, K (ft/ft)						
Calculated Sag or Crest?						
Geometric Design Element (Partial Score)						
Total Safety Score						

20 Total Available Points

Traffic Elements	Existing	Standard	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal
Advance Static Curve Warning Signs		No			+0%	Yes
Chevron Signs on Horizontal Curves		No			+0%	Yes
Post-Mounted Delineators		No			+0%	Yes
Edgeline Pavement Markings or Profile Markings		No			+0%	Yes
Shoulder Rumble Strips		Yes			+2%	Yes
Centerline Rumble Strips		No			+0%	Yes
Driveway Density (driveways per mile)		10 Dwy / Mi			-22%	0 Dwy / Mi
Lighting		No			-2%	Yes
Pavement Friction (skid number) ***		37.0			+28%	54.0
Traffic Control Element (Partial Score):	12	12	12	12		20
Total Safety Score						

*** Pavement friction/skid numbers will not be subject to open records requests ***

40 Total Available Points

Roadside Elements	Existing	Standard	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal
Roadside Sideslope (Foreslope)		1V:4H			+16%	1V:6H
Roadside Backslope		1V:4H			+0%	1V:4H
Safety Edge		No			-2%	Yes
Roadside Lateral Clearance to Obstruction (ft)		30.0 ft			+6%	40.0
Roadside Obstruction Type		None			+0%	None/Removed
Roadside Element (Partial Score):	20	27	20	20		40
Total Safety Score						

ADDITIONAL SIDESLOPE INFORMATION						
Distance to Slope Toe from Shoulder (ft)		0.0	0.0	0.0		0.0
Minimum foreslope feasible within current ROW						
Additional R/W needed on left side						
Additional R/W needed on right side						

Section 2 – Rural Two-Lane Road Segment Safety Scoring Tool

CHARACTERISTICS TO CONSIDER FOR ANALYSIS	
INPUT INSTRUCTIONS	
Blue Boxes -- Select from pulldown options	Select from Pulldown
Yellow Boxes -- Type input information into box	Type Input Value

Preferred Schematic View to Display	Standard
Relative to	Existing

Rural Two-Lane Road Segment -- Safety Score Input

General Information:	
Analyst:	0
Agency or Company:	0
Date:	1/0/1900
Description:	

General Site Features		9 Missing Features and Curves
Location		
Design Speed (mph)		
Posted Speed (mph)		
E max (%)		
Design Year AADT (vehicles per day)		
Dist. from Centerline to Left ROW (feet)		
Dist. from Centerline to Right ROW (feet)		

Warning:

No warnings identified

To enter notes, use boxes to the right of the vortex

40 Total Available Points | 18 Missing Elements | 18 Missing Elements | 18 Missing Elements

Geometric Design Elements	Existing	Standard	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal
Lane Width (feet)		12.0			+0%	12.0
Shoulder Width (feet)		4.0			+16%	10.0
Cross-slope or Superelevation (%)		8.0				0.0
Horizontal Curve Present?	--	--	--	--		--
Horizontal Curve Data for Controlling Element:	--	--	--	--		--
Radius (feet)					+0%	
Length of Horizontal Curve (feet)						
Calculated Deflection Angle Δ						
Vertical Curve Present?	--	--	--	--		--
Vertical Curve Data for Controlling Element						
Approach (Entry) Grade, G1 (%)						
Departure (Exit) Grade, G2 (%)						
Length (feet)						
Calculated Rate of Change, K (ft/ft)						
Calculated Sag or Crest?						
TWLTL (two-way left-turn lane)		No			-41%	No
Passing Lane Type		No Passing Lane			+0%	Super 2
Geometric Design Element (Partial Score)						
Total Safety Score						

20 Total Available Points

Traffic Elements	Existing	Standard	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal
Advance Static Curve Warning Signs		No			+0%	Yes
Chevron Signs on Horizontal Curves		No			+0%	Yes
Post-Mounted Delineators		No			+0%	Yes
Edgeline Pavement Markings or Profile Markings		Yes			+14%	Yes
Shoulder Rumble Strips		Yes			+0%	Yes
Centerline Rumble Strips		No			-16%	Yes
Driveway Density (driveways per mile)		10 Dwy / Mi			-22%	0 Dwy / Mi
Lighting		No			-2%	Yes
Pavement Friction (skid number) ***		37.0			+28%	54.0
Traffic Control Element (Partial Score):	12	14				20
Total Safety Score						

*** Pavement friction/skid numbers will not be subject to open records requests ***

40 Total Available Points

Roadside Elements	Existing	Standard	Design 1	Design 2	Marginal Safety for Standard (compared to Existing)	Optimal
Sideslope (Foreslope)		1V:4H			+0%	1V:6H
Backslope		1V:4H			+0%	1V:4H
SafetyEdge		No			-3%	Yes
Lateral Clearance to obstruction (ft)		30.0 ft			+9%	40.0 ft
Obstruction Type		Other Fixed Object			+0%	None
Roadside Element (Partial Score):		27				40
Total Safety Score						

ADDITIONAL SIDESLOPE INFORMATION						
Distance to Slope Toe from Shoulder (ft)		0.0	0.0	0.0		0.0
Minimum foreslope feasible within current ROW						
Additional R/W needed on left side						
Additional R/W needed on right side						

Section 3 – Urban Intersection Safety Scoring Tool

Intersection -- Safety Score Input

INPUT INSTRUCTIONS	
Blue Boxes -- Select from pulldown options	**Select from Pulldown**
Yellow Boxes -- Type input information into box	**Type Input Value**
General Information	
Analyst:	Your Name
Agency / Company / District:	Your Agency
Date:	2/18/2022
Segment Limits (Limit up to 15 miles in length):	
Road Name:	Road Name
Category (4R, 3R) -- Future Enhancement	3R
Segment Beginning Mile Point (BMP):	9.00
Segment Ending Mile Point (EMP):	13.00
Number of Intersections	2

Note: A diamond intersection on frontage roadways needs to be analyzed as two separate intersections.

OK Reset

	https://kimleyhorn.sh	**Weighted Total Score:**					
Intersection Number	**Crossing Roadway**		**Intersection Safety Score**				
			Existing	**Standard**	**Design 1**	**Design 2**	**Optimal**
1							
2							

Section 4 – Example Crash Data Summary

Year	Non-Injury or Property Damage Only	Possible Injury (C)	Non-Incapacitating Injury (B)	Suspected Serious Injury (A)	Fatal (K)	Other	Total
2017	173	30	17	4	1	1	226
2018	193	34	23	11	1	1	263
2019	147	32	13	3	1	0	196
Total	513	96	53	18	3	2	685
% of Total	74.89%	14.01%	7.74%	2.63%	0.44%	0.29%	100.00%
Average Statewide Crashes by Severity for Similar Facility Type - Urban Interstate							
2017	68,181	17,196	9,239	2,153	590	1,563	98,922
2018	69,186	17,737	8,744	1,854	621	1,732	99,874
2019	65,976	17,101	8,127	1,825	566	1,635	95,230
Total	203,343	52,034	26,110	5,832	1,777	4,930	294,026
% of Total	69.16%	17.70%	8.88%	1.98%	0.60%	1.68%	100.00%

Section 5 – External References

The websites below were last accessed on May 31, 2024

1. **Crash Records Information System**

   https://cris.dot.state.tx.us/public/Query/

   - The TxDOT Crash Query Tool performs specific queries and analysis using Texas traffic crash data.

2. **Federal Highway Administration: Road Safety Audits**

   https://safety.fhwa.dot.gov/rsa

   - A Road Safety Audit estimates and reports on potential road safety issues and offers opportunities for improvement.

3. **Highway Safety Manual**

   http://www.highwaysafetymanual.org/Pages/Tools.aspx

   - The Highway Safety Manual assists in the calculations involved in the application of the HSM, AASHTO, FHWA, and NCHRP.

4. **Federal Highway Administration: Interactive Highway Safety Design Model**

   https://highways.dot.gov/research/safety/interactive-highway-safety-design-model/interactive-highway-safety-design-model-ihsdm-overview

   - The IHSDM is a suite of software analysis tools used to evaluate the safety and operational effects of the geometric design seen on highways.

5. **Crash Modification Factors Clearinghouse**

   http://www.cmfclearinghouse.org/resources_selection.cfm

   - The CMF Clearinghouse provides information regarding the crash modification factor basics.

6. **Texas Department of Transportation: Design Division**

   https://www.txdot.gov/business/resources/forms-guides/design-forms-and-guides.html

   https://www.txdot.gov/business/resources/design-tools-training/electronic-plan-set-guidance/pse-pre-submittal-preparation.html#waivers

   - The Design Division guides the development of construction projects.
   - 100% PS&E pre-submittal preparation

7. **Interstate Access Justification Report SOP, SOP FAQ, FHWA Access Guide, and FHWA Access Policy**

   https://ftp.txdot.gov/pub/txdot/des/iajr/sop.pdf

   https://www.txdot.gov/content/dam/docs/business/design-tools/interstate-access-justification-report-faq.pdf

   https://www.fhwa.dot.gov/design/interstate/pubs/access/access.pdf

- The purpose of the SOPs is to provide the policy guidance for development and review for Interstate Access Justification Reports.

8. **HSIP Guidelines: Traffic Safety Division**

   https://ftp.txdot.gov/pub/txdot-info/trf/hsip/hsip-guidance.pdf

   - The goal of the HSIP is to achieve a reduction in fatalities and injuries on Texas roadways.

9. **Crash Modification Factors Clearinghouse**

   http://www.cmfclearinghouse.org

   - The CMF Clearinghouse provides information regarding the crash modification factor basics.

10. **Crash Modification Factors Clearinghouse: Identifying Appropriate CMFs**

    http://www.cmfclearinghouse.org/userguide_identify.cfm

    - The purpose within identifying appropriate CMFs is to eliminate details that do not match the conditions of the site of interest.

11. **Texas Department of Transportation: Texas Motor Vehicle Crash Statistics**

    https://www.txdot.gov/inside-txdot/forms-publications/drivers-vehicles/publications/annual-summary.html

    - These statistics provide users with information regarding vehicle crashes within a year.

12. **Federal Highway Administration: Proven Safety Countermeasures**

    https://safety.fhwa.dot.gov/provencountermeasures/

    - FHWA's PSCi is a collection of countermeasures effective in reducing roadway crashes.

13. **Eligibility Matrix: Urban Intersection Safety Scoring Tool**

    https://ftp.dot.state.tx.us/pub/txdot/des/safety-score-tools/eligibility-matrix-urban-intersection.pdf

    - The eligibility matrix provides information regarding intersections with public streets within urban boundaries or city limits.

14. **Eligibility Matrix: Rural Highways**

    https://ftp.dot.state.tx.us/pub/txdot/des/safety-score-tools/eligibility-matrix-rural-highways.pdf

    - The eligibility matrix provides information over the scope of work with regards to rural highways.

15. **Texas Strategic Highway Safety Plan**

    https://www.texasshsp.com/

    - Information regarding countermeasures for several categories of crash types

Section 6 – Safety Prediction Models

This section includes information on the availability of several local calibration factors and newly developed SPFs for Texas roadways. Recently, TxDOT has developed local calibration factors for most of the SPFs in the HSM to apply for Texas roadways within both rural and urban areas. The calibration factors are also available by four different regions (East, West, North, and South Texas) separately for all facility types – rural two-lane and multi segments, urban segments, rural and urban intersections, and freeway main lanes. Since Texas has a large network of frontage road segments and different ramp configurations, new safety prediction models for one-way and two-way frontage roads and ramp segments are also available, with SPFs accounting for both single and multiple vehicle crashes separately. This provides an accurate estimate of the number of predicted crashes on Texas roadways.

Specific to urban freeway segments, the calibration factors for urban freeway segments with 4-10 lanes and new safety prediction models for urban freeway segments with 11 or more lanes and freeways with managed lanes are available. It provides a good resource for predicting crashes on urban freeway segments with even 11 or more lanes and including those with managed lanes. The details are provided in research reports 0-7067 and 0-7083. An analysis spreadsheet tool is under development to help practitioners implement the new models to facilitate analysis of all rural and urban roadway segments and intersections.

Section 7 – Safer By Design

Background - TxDOT has two types of SSTs available – segment and intersection. The segment SST applies to two-lane rural roadways and multi-lane rural roadways, whereas the intersection scoring tool applies to urban and suburban areas. The main purpose of the SST is to assist in making safety-driven decisions in the project design process to optimize safety before the project is constructed. The SSTs provide key information on the safety effects of several design elements and help to optimize safety before a project is constructed. It is not to achieve a certain score but rather to assist designers in making safety-driven decisions to enhance the safety of the roadway. The intent of tools is to get the highest score for a particular project, given the constraints. These tools make use of several SPFs and CMFs. The tools can be used for all phases of project development. However, using it during the initial scoping stages is the most valuable. Scores from the initial scoping phase and at the final PS&E are required for reporting purposes. Safety scorings are required for Rural PM, 2R, 3R, and 4R projects. These project types are defined in TxDOT's RDM.

Objective - The basic design approach of tools is to assign design elements to categories, define standard and optimal values for each component, calculate individual element scores, and ultimately combine scores from each category to determine the total score. It provides a platform to compare two different design alternatives to Standard and Optimal Design by defining the maximum practical value for each design parameter to get the optimal score from a safety perspective. An optimal score of 100 refers to the maximum score from a safety perspective. The tool increase awareness of how design changes can affect safety. However, the tool is not intended for a final decision-making tool, not a requirement for project approval, not a substitute for engineering judgement, and also not intended to compare Districts.

Tool Description - Within the rural roadway safety tool, roadway elements are classified into the following categories – geometric, traffic, and roadside. Geometric and roadside elements are weighted more heavily compared to traffic elements. The tool scores the project at the segment level with a maximum mile length. The tool is calibrated to a maximum of 15 miles, so more than one sheet has to be used to accommodate the total length of more than 15 miles. A merger tool combines the scores from both/multiple sheets and provides the weighted average. Similarly, the urban intersection tool incorporates geometric, traffic control, pedestrian, and bicycle elements in the tool. All elements are equally weighted in the tool. The total intersection score includes scores from all individual elements. Intersection scores from multiple intersections are weighted by the number of predicted crashes to give a corridor score. All the elements in both the tools were researched and quantified before incorporating into the tool.

Resources - All the scoring tools can be found on Safety Score Tools Homepage. The details of each two different tool type and an eligibility matrix to determine when a SST is applicable can be found in at the following links – Rural Roadways and Urban Intersections. Urban intersections tool requires crash data information from the TxDOT's crash data source - Crash Record Information System (CRIS). The necessary query instructions are available on CRIS Data Query Instruction. All other relevant information, like PowerPoint slides, webinar videos, and tool definitions, are available on the Safety Score Tools Homepage. At the time of this publication, safety scorings for an urban context is under development. Eventually, all the tools will be integrated into the same web-based platform.

Section 8 – IAJR SOP FAQ Webinar Slides

Interstate Access Justification Report (IAJR)

Standard Operating Procedures (SOP)
Frequently Asked Questions (FAQ)

Design Division

October 2023 1

Interstate Access Overview

- Why is Interstate Access Management important?
- Why is IAJR required?
- What is the IAJR Policy?

Design Division 2

IAJR SOP Background

Purpose

- Provide TxDOT Guidance based on FHWA Access Guide
- Provide consistent point of reference for Districts, DES, and FHWA (Tx Div)
- Improve probability and ease of acceptance by FHWA
- Clarify importance of Early coordination with DES and FHWA

Legal Background

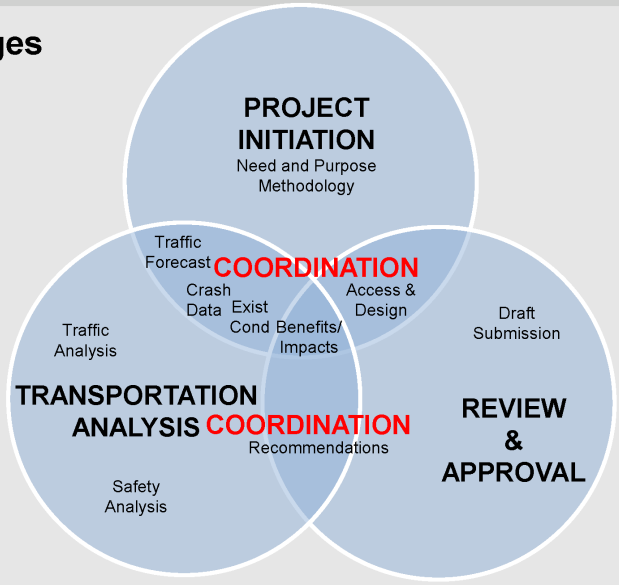
- Title 23, United States Code, Highway Section 111
  - State will not add any point of access w/o approval of Secretary USDOT
- Title 49, Code of Federal Regulation (CFR), Section 1.48
  - Secretary delegated the authority to FHWA

Policy Evolution

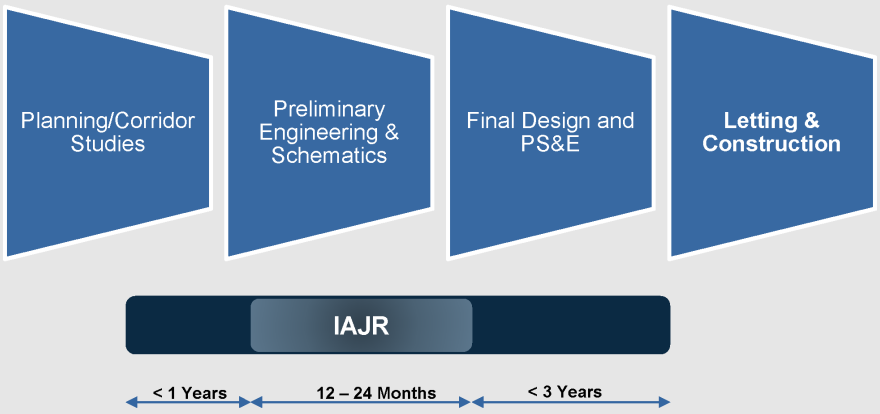
- FHWA Policy
  - October 22, 1990
  - February 1998
  - August 2009
  - May 2017
- TxDOT Policy
  - October 19, 2018 Memo
  - April 2020 IAJR SOP

IAJR Process

Key Stages

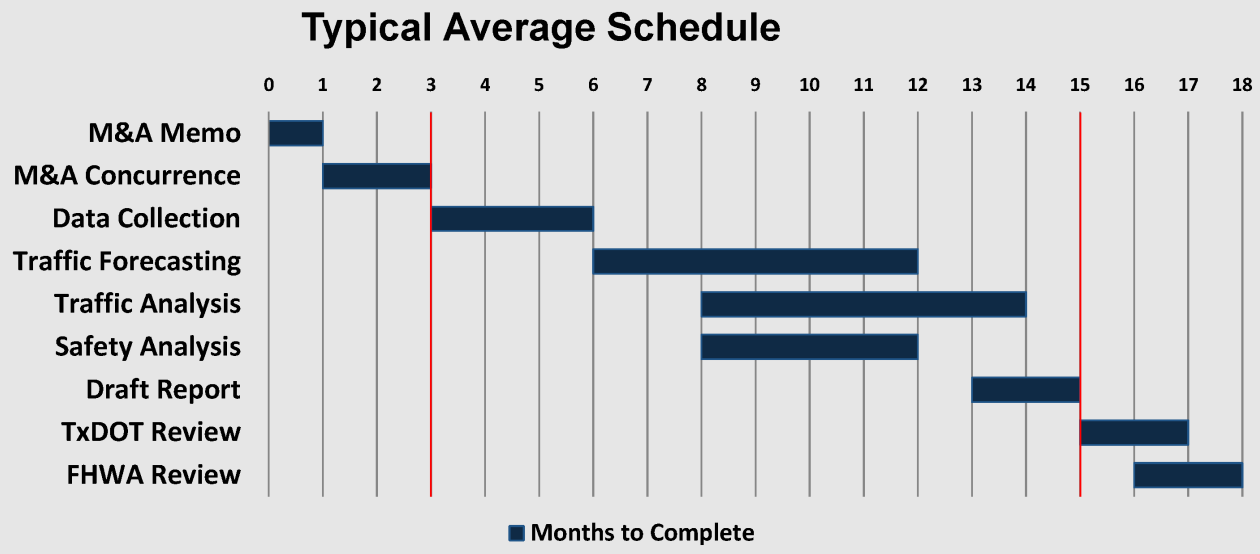


Project Development & IAJR Timeline



Design Division 5

Draft IAJR Schedule



Design Division 6

IAJR SOP FAQ Document

- Provides answers to commonly asked questions regarding IAJR and M&A
- Created in consultation with FHWA
- Is a 'living document' to be continuously updated
- FAQ can be found on DES Website (*will upload after the meeting*)

IAJR SOP FAQs

- What is an Interstate Access Point?
- What is an Interstate System Access Change Request?
- What is an Interstate Access Justification Report (IAJR)?
- Why is Interstate System Access Management important?
- Is there a legal authority for Interstate Access Policy?

IAJR SOP FAQs

- What is an Interstate Access Point?
  - *Each entrance or exit point on an interstate including access to collector-distributor and ramps is an access point. Access to the Interstate System is allowed only by interchange at selected public roads. Access to the Interstate System through rest areas from outside the Interstate Control access right of way is prohibited.*

IAJR SOP FAQs

- Who approves the IAJR?
- What are the requirements for an IAJR for TxDOT projects?
- Is this policy applicable to Toll Roads?
- What changes to the Interstate require FHWA review and action through an IAJR?
- What changes to the Interstate may not require FHWA review and action through an IAJR?

IAJR SOP FAQs

- What changes to the Interstate require FHWA review and action through an IAJR?
  - *Generally, any new or revised access to the Interstate System will require FHWA's review and action, including the following:*
    - *New interchange.*
    - *Modification of existing interchange configuration*
    - *Completion of basic movements at partial interchange, for example, completing a partial diamond interchange by adding a ramp.*
    - *Locked gate access, for example, access via locked gates for emergency response.*
    - *Access to special use lanes such as high occupancy vehicle (HOV), high-occupancy toll (HOT) or truck only lanes*

Design Division 11

IAJR SOP FAQs

- What changes to the Interstate may not require FHWA review and action through an IAJR?
  - *Some projects may not require FHWA review and action but require coordination with DES and FHWA*:
    - *Shift of a ramp's location within the same interchange configuration, which results in ramp spacing that meets FHWA's design criteria.*
    - *Addition of lanes to an on-ramp.*
    - *Addition of a single auxiliary lane between two adjacent interchange ramps where the single auxiliary lane does not function as a mainline travel lane.*
    - *Changes in access between managed lanes and general-purpose lanes on the Interstate.*
    - *Construction of overpasses or grade separation structures without ramps along Interstate facilities.*

Design Division 12

IAJR SOP FAQs

- What changes to the Interstate may not require FHWA review and action through an IAJR?
  - *For these projects neither FHWA review and action nor coordination with FHWA is needed:*
    - *Construction of new signing, striping, and/or resurfacing of an Interstate on-ramp or off-ramp, where geometric features are not changed.*
    - *Installation of roadside guardrail and concrete barriers.*
    - *Relocation of an on-ramp or off-ramp termini along the frontage road.*
    - *Addition of left-turn storage lanes, right-turn storage lanes, and through travel lanes at the terminus of existing ramps.*
    - *Improvement of traffic signals at ramp termini with local roads*

IAJR SOP FAQs

- Is this policy applicable for future Interstates?
- What is the ramp terminal intersection?
- What is the general development process for an IAJR?
- Can information developed during the NEPA process be referenced in the IAJR?
- When is an IAJR re-evaluation required?

IAJR SOP FAQs

- When is an IAJR re-evaluation required?

If the following conditions occur an IAJR re-evaluation may be required:

a) Changes in approved IAJR design concepts

- *Due to environmental impact or commitments*
- *Due to final design adjustment*
- *Due to design-build proposal*

b) Significant changes in the following conditions:

- *Traffic volumes or traffic conditions*
- *Land use*
- *Environment*

c) Time lapse before construction

- *If the project does not progress to construction within 3 years after FHWA approval*

IAJR SOP FAQs

- Can the 2004 version of FHWA's "Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulations Modeling Software" still be used?
- What geometric or traffic conditions necessitate the use of microsimulation for traffic operations analysis?
- Why does the area of influence include the adjacent intersections and interchanges?
- Should data collection or traffic analysis for the IAJR proceed prior to receiving DES and FHWA concurrence on the Methodology & Assumptions Technical Memorandum (M&A Tech Memo)?

IAJR SOP FAQs

- Can the 2004 version of FHWA's "Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulations Modeling Software" still be used?
  - *The recommendation is to use the latest 2019 FHWA TAT Volume III Guidelines.*
  - *However, the 2019 Guidelines require significantly more data than the 2004 Guidelines.*
  - *If sufficient data is not available or practical to collect, then coordination will be required with Design Division and FHWA to determine other options, which may include alternative methods/resources or the use of 2004 Guidelines.*

IAJR SOP FAQs

- What geometric or traffic conditions necessitate the use of microsimulation for traffic operations analysis?
  - *Microsimulation is generally required for projects in metropolitan areas.*
  - *The Highway Capacity Manual (HCM) is the primary tool for analysis of locations that:*
    - *are isolated,*
    - *do not require interaction between different users*
    - *do not have congestion*
  - *The HCM multi-period analysis can be used to analyze congested conditions to account for the effects of queuing in freeways.*
  - *Microsimulation tool should be considered if the following limitations to HCM exist:*
    - *Multiple bottlenecks, Systemwide oversaturation,*
    - *Complex geometry, Off-ramp queues extend to freeway*

IAJR SOP FAQs

- Why does the Area of Influence include the adjacent intersections and interchanges?
  - *The area of influence or AOI is defined as the area anticipated to experience significant change in operating conditions.*
  - *Typically, in urban area at least the first interchange at each end of the project is expected to be impacted.*
  - *In rural areas, the interchanges may be far enough apart from the project limits that they will not be affected by the proposed change.*
  - *The purpose is to ensure that the safety and operational impacts of the proposed change in access are adequately addressed.*

IAJR SOP FAQs

- Should data collection or traffic analysis for the IAJR proceed prior to receiving DES and FHWA concurrence on the Methodology & Assumptions Memorandum (M&A Tech Memo)?
  - *With preliminary feedback from DES and FHWA, data collection can be started concurrently with M&A development.*
  - *However, traffic analysis should start after concurrence from DES and FHWA on M&A*
  - *Note, there is some risk should there be no feedback from DES and FHWA on data collection.*

IAJR SOP FAQs

- TxDOT IAJR SOP provide reference to Crash Recording Information System (CRIS). Can Districts or consultants download the crash data from public query?
- TxDOT IAJR SOP recommend Option A (Predictive Analysis) as the preferred option for safety analysis if applicable. How do we determine if Option A is applicable or not?
- Who should I contact if I have questions during IAJR process?

IAJR SOP FAQs

- TxDOT IAJR SOP provide reference to Crash Recording Information System (CRIS). Can Districts or consultants download the crash data from public query?
  - *Crash data from the public query is available for downloading by districts and consultants and can be used for preliminary analysis and justification of the project.*
  - *However, for detailed safety analysis FHWA and TxDOT require that crash data be obtained using MicroStrategy. Data should be requested preferably from TxDOT Traffic Safety Division.*
  - *Design Division and several districts have staff authorized to use MicroStrategy who can help to extract the data.*

IAJR SOP FAQs

- TxDOT IAJR SOP recommend Option A (Predictive Analysis) as the preferred option for safety analysis if applicable. How do we determine if Option A is applicable or not?
  - *Option A is applicable unless limitations in HSM present weakness or flaws and can influence the outcome. Freeways with maximum number of lanes in urban areas, freeways with managed lanes, and maximum allowable AADT.*
  - *TxDOT with the help of TTI developed simple spreadsheet-based tools that addresses some of these limitations and expected to be released by February 2024.*
  - *Traffic and Safety Analysis Procedural (TSAP) Manual Chapter 6 provide guidance in determining the safety analysis approach best suited for projects.*

Questions?
Feedback

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Chapter 7 - Appendix H – Project and Corridor System Planning

- **Section 1** – External References

Section 1 – External References

The websites below were last accessed on May 31, 2024

1. **TxDOT's Transportation Planning and Programming (TPP) manual**
   http://onlinemanuals.txdot.gov/txdotmanuals/tpp/tpp.pdf
   - A link to the TPP manual
2. **Texas Demographic Center (TDC)**

   https://demographics.texas.gov/
   - Information on the demographics of Texas
3. **U.S. Census Bureau**

   https://www.census.gov/
   - Homepage to the Census Bureau
4. **TxDOT's Statewide Planning Map**

   https://www.txdot.gov/apps/statewide_mapping/StatewidePlanningMap.html
   - A map that contains many overlays such as speed limits, on-system roadways, and AADT
5. **TxDOT's Open Data Portal**

   https://gis-txdot.opendata.arcgis.com/
   - TxDOT's platform for exploring and downloading GIS datasets
6. **TxDOT's Project Tracker**

   https://apps3.txdot.gov/apps-cq/project_tracker/
   - TxDOT's platform for information about more than 11,000 TxDOT projects, providing 24/7-access to the public, employees and elected officials
7. **TxDOT's Unified Transportation Program (UTP)**

   https://www.txdot.gov/inside-txdot/division/transportation-planning/utp.html
   - A webpage that lists an overview of UTP and give UTP guidance by year
8. **National Institute of Statistics, Geography, and Informatics (INEGI)**

   https://en.www.inegi.org.mx/
   - This website has information related to demographics (education, employment, population), economy and productive sectors (trade, manufacturing, GDP, transport), geography and environment (maps, environment), and government-related information.
9. **TxDOT's Crash Reporting Information System (CRIS)**

   https://cris.dot.state.tx.us/public/Query/app/home

- TxDOT's CRIS database has crash-related information that may be queried by year and location.

10. Bureau of Labor Statistics (BLS)

https://www.bls.gov/

- The Bureau of Labor Statistics (BLS) provides information on employment, productivity, pay and benefits, inflation, prices, and much more. Data from BLS can be used to determine earnings by demographics or by industry, or employment within the study limits.

11. United States Bureau of Economic Analysis (BEA)

https://www.bea.gov/

- The United States Bureau of Economic Analysis (BEA) provides information on Gross Domestic Product (GDP), international trade and investment, industries, employment, and other topics. Data can be broken down by geographies and industries.

Chapter 8 - Appendix I – Alternatives Analysis

- **Section 1** – Alternatives Analysis Tech Memo Sample Outline
- **Section 2** – External References

Section 1 - Alternatives Analysis Tech Memo Sample Outline

1. **Introduction**
2. **Purpose and Need**
3. **Goals and Objectives**
4. **Scope and Study Area**
    a. Alternative Development
        i. Alternative Development Process
            1. Assumptions and Design Criteria
            2. Tier 1 Alternatives (Universe of Alternatives)
    b. Tier 1 Evaluation
        i. Tier 1 Evaluation Criteria
        ii. Tier 1 Analysis (preliminary analysis of existing, no build, and build alternatives)
        iii. Tier 1 Evaluation Results
        iv. Tier 2 Alternatives
    c. Tier 2 Evaluation
        i. Tier 2 Evaluation Criteria
        ii. Tier 2 Analysis (preliminary analysis of existing, no build, and build alternatives)
        iii. Tier 2 Evaluation Results
        iv. Preferred Alternative Selection
    d. Conclusion
        i. Recommendations
        ii. Next Steps

Appendix

A. Alternatives Considered but Dismissed

Section 2 – External References

The websites below were last accessed on May 31, 2024

1. **Road User Costs Texas Department of Transportation**

   https://www.txdot.gov/inside-txdot/division/construction/road-user-costs.html

   - TxDOT re-calculates road user cost, used in department sets for A+B bidding, incentives for milestones, and additional project-specific liquidated damages.

2. **Road User Costs**

   https://www.txdot.gov/content/txdotreimagine/us/en/home/business/resources/highway/road-user-costs.html

   - Road user cost table for cars and trucks, calculated by TxDOT.

Chapter 9 - Appendix J – Segments Analysis (Freeways, Multi-lane Highways, Two-lane Highways, Arterials, and Frontage Roads)

- **Section 1** – TTI Frontage Road Analysis Steps and Examples
- **Section 2** – HCS Data Inputs and Outputs by Segment Type
- **Section 3** – Service Volume Tables

Section 1 - TTI Frontage Road Analysis Steps and Examples

OPERATIONS APPLICATION

The procedure for determining frontage road level of service has been divided into seven steps (see Figure 7-1). The procedure listed in Figure 7-1 applies to both one-way and two-way frontage roads. The evaluation for two-way frontage roads differs from the one-way frontage road evaluation in the following areas: data requirements, computation of running time, and computation of delay at ramp junctions. In addition, the analysis procedure should be followed twice for two-way frontage roads (once for each direction).

The level-of-service criteria are based on average travel speed. Average travel speed is computed by dividing the length of the frontage road by the total travel time. The total travel time may be estimated either by using the procedure outlined in this chapter or by measuring it directly in the field. The following sections give descriptions of the steps for predicting the level of service for frontage road operations.

Step 1: Define Frontage Road Study Section

The first step in analyzing frontage road operations is to determine the location of the frontage road to be analyzed. The analyst must then choose the length of frontage road to include in the analysis. The frontage road area being analyzed may be bound by intersections controlled by signals or stop signs, or it may begin or end at any point, such as a freeway ramp.

After the frontage road boundaries have been defined, the frontage road study *section* should be divided into segments. Each *segment* should contain similar frontage road and traffic operational characteristics (i.e., traffic volume, speed limit, roadside development, etc.). Segments are typically bound by signalized intersections but may include any combination of links. A *link* is defined by

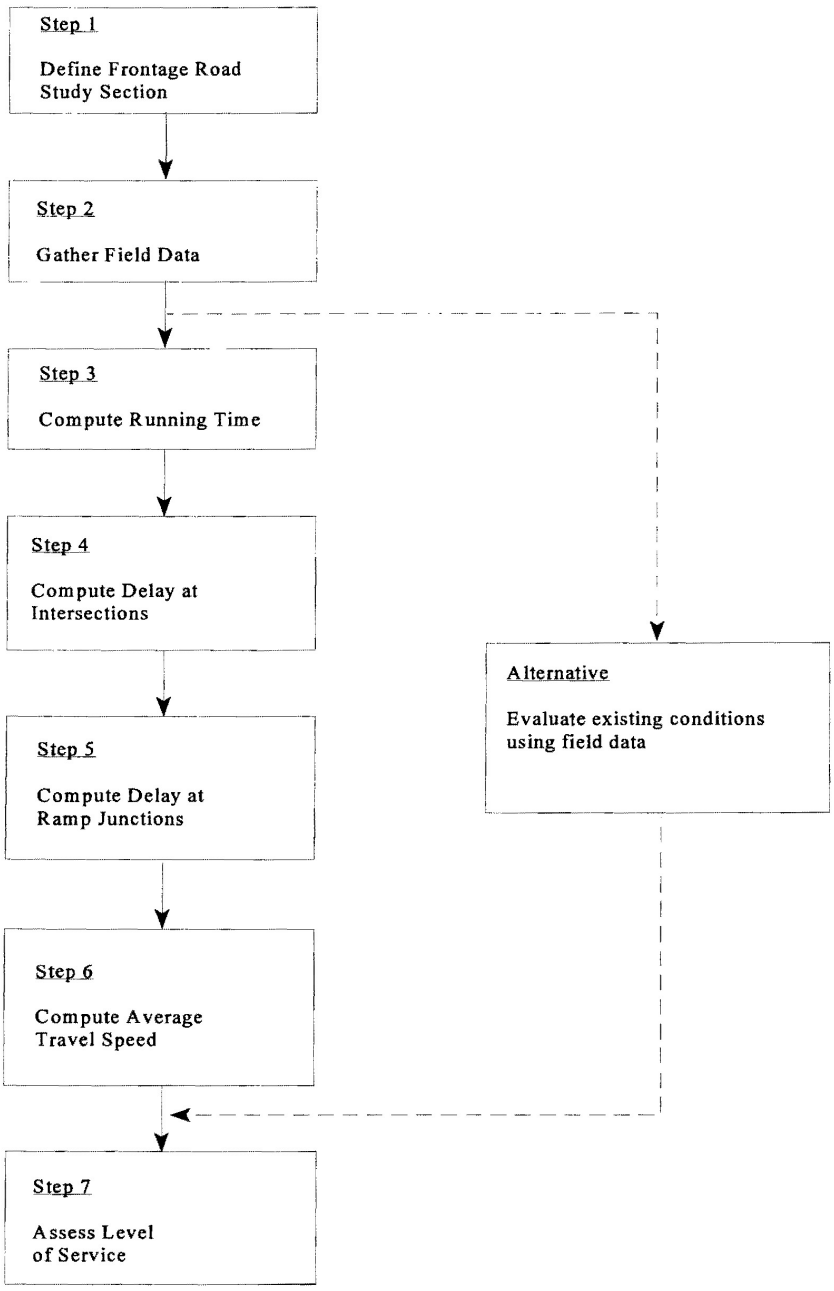


Figure 7-1. Level-of-Service Analysis Procedure.

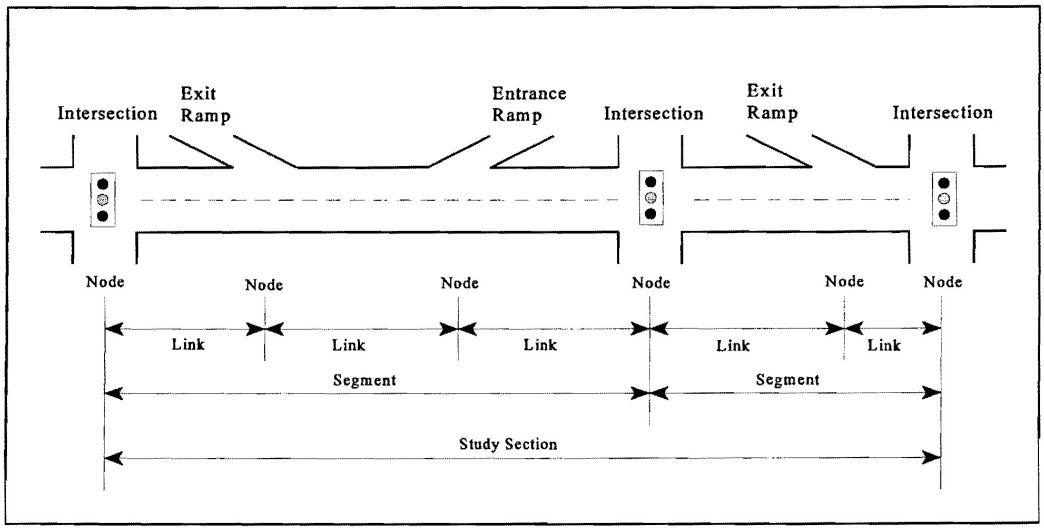


Figure 7-2. Terminology Used to Describe Frontage Roads.

its beginning and ending *nodes* (e.g., exit ramp, entrance ramp, signalized intersection, etc.). Figure 7-2 illustrates the use of the terms *node, link, segment, and study section.*

Step 2: Gather Field Data

This step involves gathering the data (e.g., roadway characteristics, traffic data, and signal data) required to perform the analysis. As mentioned earlier, total travel time may either be measured directly in the field or may be computed using the procedure in this chapter. Table 7-1 summarizes the required data for computing the total travel time for one-way and two-way frontage roads.

Step 3: Compute Running Time

The total frontage road travel time includes the running time, delay at intersections, and delay at freeway ramp junctions. The running time is the time it takes a vehicle to traverse a given section of roadway without being delayed by intersections or ramps. Procedures for estimating running time

Table 7-1. Data Required for Evaluating Frontage Road Operations.

Type of Data	Data Required	Frontage Road	
		One-Way	Two-Way
Roadway Characteristics	Segment length, km	✔	✔
	Type of traffic control at intersections (e.g., no-control, stop-controlled, or traffic signal)	✔	✔
	Number of all exit and entrance ramps		✔
	Number of exit ramps without auxiliary lanes	✔	
	Segment access density, acs/km (number of driveways and unsignalized intersections per kilometer)	✔	✔
Traffic Data	Frontage road approach volume at stop-controlled and signalized intersections, vph	✔	✔
	Ramp and frontage road volumes at all exit and entrance ramps, vph		✔
	Exit ramp and frontage road volumes at exit ramps without auxiliary lanes, vph	✔	
Signal Data	Signal progression data	✔	✔
	Intersection capacity (c) , vph	✔	✔
	Cycle length (C), sec	✔	✔
	Green/cycle time ratio (g/C)	✔	✔
	Volume/capacity ratio (v/c)	✔	✔

were developed by collecting travel time data at existing frontage road sites. Regression analyses showed that length significantly affected travel time. Other factors, such as volume and free flow speed, had minor effects on travel time when compared to length.

Results from the regression analyses were used to develop equations to predict running time for both one-way and two-way frontage roads. Table 7-2 shows these regression equations.

Table 7-2. Equations for Predicting Running Time on Frontage Roads.

Frontage Road	Regression Equation[a]
One-Way	RT = 0.0504 (L)
Two-Way	RT = 0.0519 (L)

[a] RT = running time (sec)
L = segment length (m)

For two-way frontage roads, plots of average speed versus frontage road volume revealed some correlation between speed and volume. For frontage road volumes above approximately 400 vphpl, maximum speeds begin to drop noticeably (and travel times increase). Below 400 vphpl, maximum speeds of 89 to 97 km/h were observed while above 400 vphpl, most speeds were below 72 km/h. Travel times were predicted to increase by as much as 10 percent for frontage road volumes above 400 vphpl.

The analyses also showed that access density had an effect on travel time. For both one-way and two-way frontage roads, a critical value of access density existed at which speeds began to drop and travel times increased significantly. The critical values for one-way and two-way frontage roads occurred at approximately 20 and 16 acs/km, respectively. Above these critical values, travel times may again increased by as much as 10 percent.

Table 7-3 contains estimated running times for one-way and two-way frontage roads. The segments lengths included in the field data ranged from approximately 0.2 to 2.0 km for one-way and 0.2 to 3.2 km for two-way; therefore, these ranges are included in the table. If the frontage road segment lengths being evaluated fall outside of this range, the analyst should consider redefining the segments. The travel times shown in Table 7-3 are increased by 10 percent when access

Table 7-3. Running Time for One-Way and Two-Way Frontage Road Segments.

	One-Way Frontage Roads		Two-Way Frontage Roads			
Access Density (acs/km)	≤ 20	> 20	≤ 16		> 16	
Frontage Road Volume (vphpl)	All	All	≤ 400	> 400	≤ 400	> 400
Segment Length[a] (km)	Running Time, RT[b] (sec)					
0.2	10	11	10	11	11	13
0.4	20	22	21	23	23	25
0.6	30	33	31	34	34	38
0.8	40	44	42	46	46	50
1.0	50	55	52	57	57	63
1.2	60	67	62	69	69	75
1.4	71	78	73	80	80	88
1.6	81	89	83	91	91	100
1.8	91	100	93	103	103	113
2.0	101	111	104	114	114	126
2.2	N/A	N/A	114	126	126	138
2.4	N/A	N/A	125	137	137	151
2.6	N/A	N/A	135	148	148	163
2.8	N/A	N/A	145	160	160	176
3.0	N/A	N/A	156	171	171	188
3.2	N/A	N/A	166	183	183	201

[a] If segment length falls outside of 0.2 to 2.0 km for one-way and 0.2 to 3.2 km for two-way, consider redefining segments.

[b] Equations used to determine values are listed in Table 7-2. The running time values are increased by 10 percent when there are greater than 20 acs/km for a one-way frontage road, greater than 16 acs/km for a two-way frontage road, or greater than 400 vphpl on a two-way frontage road.

density exceeds 20 acs/km for one-way frontage roads and exceeds 16 acs/km for two-way frontage roads. The travel times are again increased by 10 percent for two-way frontage roads when frontage road volumes exceed 400 vphpl.

Step 4: Compute Intersection Delay

For most frontage roads, intersections at major crossroads will be controlled either by a traffic signal or by stop signs. To estimate the approach delay at signalized intersections, the procedures outlined in Chapter 9 of the *HCM* are recommended. Chapter 10 of the *HCM* includes procedures for estimating approach total delay for two-way and all-way stop-controlled intersections. Updated procedures in Chapter 10 is expected to be available in late 1997. Following is a summary of the procedures in Chapter 9 of the *HCM* for calculating approach delay at signalized intersections.

Estimating Delay at Signalized Intersections

The total delay incurred at a signalized intersection includes the time that a vehicle is stopped (defined as stopped delay), as well as the time to decelerate from and accelerate to the driver's desired speed. The 1994 *HCM* defines intersection total delay as a function of stopped delay using the following equation:

$$D_I = 1.3 * d \qquad [7\text{-}1]$$

where:

D_I =intersection total delay, sec/veh

d = intersection stopped delay, sec/veh

Intersection stopped delay is calculated using the following equations:

$$d = d_1 DF + d_2 \qquad [7\text{-}2]$$

$$d_1 = \frac{0.38C[1-(g/C)]^2}{1-(g/C)[Min(X,1.0)]} \quad [7\text{-}3]$$

$$d_2 = 173X^2[(X-1)+\sqrt{(X-1)^2+mX/c}] \quad [7\text{-}4]$$

where:

d = stopped delay, sec/veh

d_1 = uniform delay, sec/veh

d_2 = incremental delay, sec/veh

DF = delay adjustment factor for either quality of progression or type of control (see Table 7-5)

X = volume/capacity ratio of lane group

C = cycle length, sec

c = capacity of lane group, vph

g = effective green time for lane group, sec

m = incremental delay calibration term representing effect of arrival type and degree of platooning (see Table 7-4)

The total delay incurred at signalized intersections will be based upon the arrival type. The arrival type is a function of the quality of progression. Table 7-4 lists the six arrival types defined in the *HCM*. The incremental delay calibration term (m) is a function of the arrival type and is also shown in this table.

The delay adjustment factor (DF) accounts for the effects of signal progression and controller type on uniform delay. To estimate the value of this factor, either the controller-type adjustment factor (CF) or the progression adjustment factor (PF) is used. Table 7-5 shows values of DF recommended in the *HCM*.

Table 7-4. Arrival Type and Incremental Delay Calibration Term (m) Values.

Arrival Type	Progression Quality	Incremental Delay Calibration Term, m
1	Very poor	8
2	Unfavorable	12
3	Random arrivals	16
4	Favorable	12
5	Highly favorable	8
6	Exceptional	4

Table 7-5. Uniform Delay Adjustment Factor (DF).

Controller-Type Adjustment Factor, CF		
Control Type	Non-Coordinated Intersections	Coordinated Intersections
Pretimed	1.00	PF as computed below
Semiactuated		
Traffic-actuated lane groups	0.85	1.00
Non-actuated lane groups	0.85	PF as computed below
Fully actuated	0.85	N/A

Progression Adjustment Factor, PF						
Green/Cycle Time Ratio, g/C	Arrival Type					
	1	2	3	4	5	6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000

Equations 7-1 through 7-4 should be used to compute total delay at all signalized intersections within the study section. Chapter 9 of the *HCM* contains complete descriptions of the variables used in the equations and further discussion on computing intersection delay.

Intersection Level of Service

The *HCM* defines intersection level of service in terms of average stopped delay per vehicle. Stopped delay may be computed using Equation 7-2. Table 7-6 shows level-of-service criteria for signalized intersections suggested in the *HCM.*

Table 7-6. Signalized Intersection Level-of-Service Criteria.

Intersection Level of Service	Stopped Delay per Vehicle (sec)
A	≤ 5.0
B	5.1 to 15.0
C	15.1 to 25.0
D	25.1 to 40.0
E	40.1 to 60.0
F	> 60.0

Step 5: Compute Ramp Delay

Delay incurred by frontage road vehicles at freeway ramps is more of a concern for two-way frontage roads than for one-way frontage roads. For two-way frontage roads, vehicles traveling in the same direction as freeway traffic will be required to yield only at exit ramps; however, vehicles traveling in the opposite direction will be required to yield at both exit ramps and entrance ramps. For one-way frontage roads, frontage road delay at ramps is typically only experienced at exit ramps that do not have auxiliary lanes or in those cities where all drivers on the frontage road consistently yield to exit ramp vehicles.

In a study conducted by Gattis et al. (2), procedures for predicting delay at ramps were developed. The recommended equations for predicting delay at ramps on one-way and two-way frontage roads are listed in Table 7-7.

As shown in Table 7-7, three values are calculated to estimate frontage road delay: frontage road capacity at ramp (C_R), average queuing system delay (W), and average total delay (D_R). These models were developed by assuming that the ramp-frontage road intersection area operates as a queuing system. Because of this assumption, the equations can only be used when the frontage road flow rate (a) does not exceed the service rate (u) (i.e., $u - a \geq 0$).

The resulting equations for predicting frontage road delay at ramps are expressed as a function of ramp volume and frontage road volume. Therefore, these are the only parameters that need to be obtained for estimating delay at ramps. For entrance ramp *opposing* delay on two-way frontage roads, the ramp volume should include all frontage road vehicles approaching the entrance ramp from the *with* direction, whether the vehicles actually enter the ramp or continue along the frontage road.

The equations in Table 7-7 were developed by assuming that ramp traffic arrivals could be described using the Poisson process and by estimating the gap acceptance tendencies of frontage road traffic. Actual delays at field sites may vary from the predicted delay depending upon the average accepted gap of frontage road drivers.

An evaluation of the equations for predicting frontage road delay at exit ramps on one-way frontage roads (see Chapter 4) revealed a limitation of the equations for predicting frontage road capacity (C_R). Capacity is calculated from these equations by multiplying a factor by the ramp volume and subtracting this product from the maximum frontage road flow rate (i.e., maximum flow rate - factor x ramp volume). When the ramp volume multiplied by the factor exceeds the maximum flow rate, a negative capacity value results. Maximum ramp volumes for which the capacity equations produce positive values are shown in Table 7-8. Using the capacity equations for ramp volumes above those in this table will produce invalid results.

Table 7-7. Equations for Predicting Frontage Road Delay at Ramps.

Case	Frontage Road	Scenario	Frontage Road Capacity, C_R (veh/hr)	Queuing Delay, W (sec/veh)	Total Delay, D_R (sec/veh)
1	One-Way	Exit Ramp without Auxiliary Lane	$N[1858-1.5259(Q_R)]$	1/(u-a)	-0.0719 + 1.0922(W)
2	Two-Way	Exit Ramp *With*	$1724 - 1.6120(Q_R)$	1/(u-a)	-0.0719 + 1.0922(W)
3	Two-Way	Exit Ramp *Opposing*	$1444 - 1.6564(Q_R)$	1/(u-a)	-1.6451 + 1.7785(W)
4	Two-Way	Entrance Ramp *Opposing*	$1535 - 1.3852(Q_R)$	1/(u-a)	0.0538 + 1.3027(W)

Note:
- N = number of frontage road through lanes
- C_R = frontage road capacity per direction, vph
- W = average queuing system delay, sec/veh
- D_R = average total delay, sec/veh
- Q_R = hourly ramp volume, vph (for Case 4, includes all vehicles that approach the entrance ramp from the *with* direction, whether they enter the ramp or not)
- u = service rate (C / 3600), veh/sec
- a = frontage road flow rate (volume / 3600), veh/sec

Table 7-8. Maximum Ramp Volumes to Be Used with Capacity Equations.

Case	Frontage Road	Scenario	Maximum Ramp Volume (vph)
1	One-Way	Exit Ramp	1200
2	Two-Way	Exit Ramp *With*	1050
3	Two-Way	Exit Ramp *Opposing*	850
4	Two-Way	Entrance Ramp *Opposing*	1100

Currently, techniques are not available to predict delays at high-volume ramps or at ramp junctions on one-way frontage roads where all lanes of traffic consistently yield to exiting ramp vehicles. A potential solution to determine delay at these types of ramp junctions is the revision to

HCM, Chapter 10 ("Unsignalized Intersections"), which will be included in the next revision of the *HCM.* Until available, engineering judgement should be used if a frontage road segment includes these types of ramp junctions.

Step 6: Compute Average Travel Speed

The average travel speed can be computed by dividing the total length of the frontage road under consideration by the total travel time. The total travel time is composed of the total running time, total delay at intersections, and total delay at ramps. The average travel speed may be computed using the following formula:

$$S = \frac{3{,}600(L)}{RT+D_I+D_R} \qquad [7\text{-}5]$$

where:

S = average travel speed, km/h

L = length of frontage road, km

RT = total running time, sec

D_I = total approach delay for all signalized and stop-controlled intersections, sec

D_R = total frontage road delay incurred at ramps, sec

Step 7: Assess Level of Service

Once the average travel speed has been computed, the level of service can be estimated using the criteria in Table 7-9. These criteria apply to both one-way and two-way frontage road operations. The criteria are not meant to represent exact divisions in level of service. The values are intended to provide a general idea of the level of service that might be expected for a particular frontage road section; therefore, engineering judgement should be used when applying these criteria.

Table 7-9. Frontage Road Level-of-Service Criteria.

Frontage Road Level of Service	Average Travel Speed (km/h)
A	≥ 56.0
B	45.0 to 55.9
C	35.0 to 44.9
D	27.0 to 34.9
E	21.0 to 26.9
F	< 21.0

Alternative Evaluation

An alternative to calculating average travel speed using the above procedure is to make travel time measurements directly in the field. Collecting field data is a more direct approach to evaluating existing frontage road operations and will produce more accurate results. An example would be to measure the total time to travel through a selected study site at various times during a peak period. After obtaining an average frontage road travel time, the travel speed would be computed by dividing the length of the study site by the average travel time. The average travel speed would then be compared to the criteria in Table 7-9 to assess the level of service.

PLANNING APPLICATIONS

The *HCM* planning level procedure for an arterial street level-of-service analysis can essentially be used for a similar analysis of frontage roads. The major simplifying assumption in the arterial street planning application is that left turns are accommodated by providing left-turn bays at major intersections and controlling the left-turn movement with a separate phase that is properly timed. As a result of this assumption, planning application results should not be used for intersection design or traffic operations analyses. Another assumption needed for a frontage road planning level of service is that ramp junctions do not significantly contribute to the delay along the frontage road

(i.e., that all exit ramps on one-way frontage roads have auxiliary lanes). For two-way frontage roads, estimates of delay at ramp junctions need to be added. Chapter 2 of this report includes a description of the planning application procedure presented in the *HCM*. Example Calculation 3 provides an example of a planning application for a one-way frontage road.

EXAMPLE CALCULATION 1—COMPUTATION OF FRONTAGE ROAD LEVEL OF SERVICE, ONE-WAY FRONTAGE ROAD

Step 1: Define Frontage Road Study Section

The frontage road to be considered is a 3.9 km length of a two-lane, one-way frontage road in an area of moderate development. Figure 7-3 illustrates the frontage road section to be analyzed. Each of the crossroad intersections shown are controlled by traffic signals.

The selected frontage road study section is divided into the following three segments (with each segment being bound by signalized intersections): Lemon to Georgia, Georgia to 39th, and 39th to University.

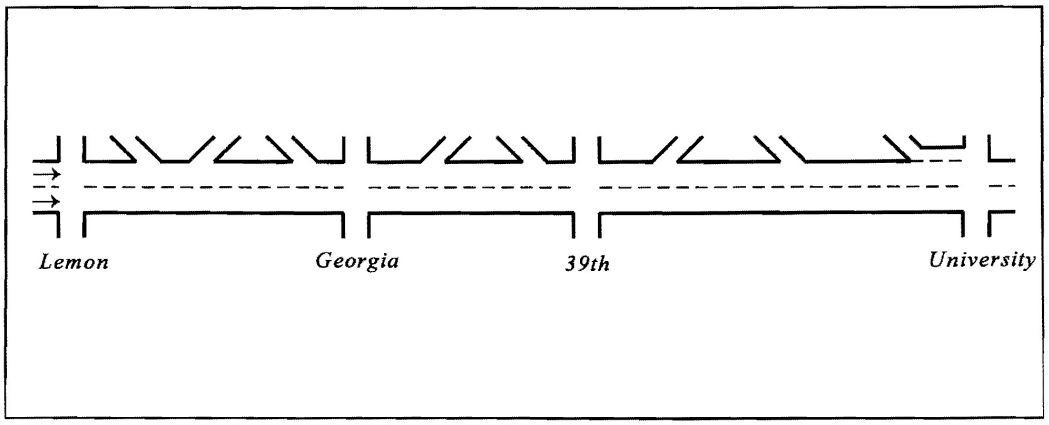


Figure 7-3. Schematic of One-Way Frontage Road Study Section.

Step 2: Gather Field Data

The required field data include roadway characteristics, traffic data, and signal data (see Table 7-1). Assumptions include random arrival and a saturation flow rate of 1800 vphpl. Tables 7-10 and 7-11 summarize collected field data.

Table 7-10. Roadway Characteristics and Traffic Data for One-Way Frontage Road Study Section.

Seg-ment	Segment Boundaries	Length (km)	Access Density (acs/km)	Number of Exit Ramps w/o Aux. Lanes	Exit Ramp Volume (vph)	Frontage Road Volume (vph)	
						At Exit Ramps	At Inter-sections
1	Lemon to Georgia	1.2	21.2	2	Exit 1: 358 Exit 2: 180	Exit 1: 193 Exit 2: 97	282
2	Georgia to 39th	1.1	18.2	1	214	115	372
3	39th to University	1.6	16.2	1	98	53	261

Table 7-11. Signal Data for One-Way Frontage Road Study Section.

Intersection	Cycle Length, C (sec)	Green/Cycle Time Ratio, g / C	Intersection Capacity, c[a] (vph)
Georgia	120	0.25	900
45th	100	0.34	1224
Western	75	0.26	936

[a] c = (Saturation flow rate)(# of lanes)(g/C)

Step 3: Compute Running Time

The segment lengths and access densities are entered on the Frontage Road Level-of-Service Worksheet (see Figure 7-4). Running times are obtained from Table 7-3.

Step 4: Compute Intersection Delay

Intersection delay is computed on the Signalized Intersection Delay Worksheet (see Figure 7-5). The first step is to enter cycle length (C), green/cycle time ratio (g/C), v/c ratio (X), capacity (c), and arrival type onto the worksheet. Arrival type is based on quality of progression and is estimated using the values in Table 7-4. Arrival Type 3 is selected because the vehicles are assumed to be random arrivals.

The next step is to compute the total delay (D_I) for each signalized intersection. Intersection total delay is computed using equations 7-1 through 7-4. Intersection level of service is based on stopped delay (d) and may be estimated using the criteria in Table 7-6. Intersection total delay is then entered on the Frontage Road Level-of-Service Worksheet.

Step 5: Compute Ramp Delay

Ramp delay is computed using the Ramp Junction Delay Worksheet (One-Way Frontage Roads). For one-way frontage roads, ramp delays are calculated for exit ramps without auxiliary lanes only. Segment 1 has two exit ramps without auxiliary lanes, and Segments 2 and 3 each have one exit ramp without an auxiliary lane. Delay for each ramp is calculated on a separate line of the worksheet (See Figure 7-6). Total ramp delay for each segment is entered in the "Ramp Delay" column on the Frontage Road Level-of-Service Worksheet.

FRONTAGE ROAD LEVEL-OF-SERVICE WORKSHEET

Location: IH-99 Direction: North - bound

Description: Between Lemon and University Type: One-Way

Date: 8-19-96 Prepared By: Sally

Segment	Segment Length (km) L	Access Density (acs/km)	Running Time[a] (sec) RT	Intersection Total Delay[b] (sec) D_I	Ramp Delay[c] (sec) D_R	Total Travel Time[d] (sec) T	Average Travel Speed[e] (km/h) S	Frontage Road LOS by Segment[f]
1	1.2	21.2	67					
2	1.1	18.2	55					
3	1.6	16.2	81					

[a] Use field data or values from Table 7-3
[b] From Signalized Intersection Delay Worksheet
[c] From Ramp Junction Delay Worksheet
[d] $T = RT + D_I + D_R$
[e] $S = 3600(L)/T$
[f] See LOS criteria in Table 7-9.

Sum of Travel Times, sec (ΣT) = _____

Total Frontage Road Length, km (ΣL) = _____

Average Frontage Road Speed, km/h = 3600 (ΣL) / (ΣT) = _____

Frontage Road LOS = _____

Figure 7-4. Compute Running Time.

SIGNALIZED INTERSECTION DELAY WORKSHEET

Location: IH-99 Direction: North - bound

Description: Between Lemon and University Type: One-Way

Date: 8-19-96 Prepared By: Sally

Segment	Cycle Length (sec) C	Green/ Cycle Time Ratio g/C	v/c Ratio X	Lane Group Capacity (vph) c	Arrival Type [a]	Uniform Delay[b] (sec) d_1	DF[c]	Incremental Delay[d] (sec) d_2	Intersection Stopped Delay[e] (sec) d	Intersection Total Delay[f] (sec) D_I	Intersection LOS[g]
1	120	0.25	0.316	900	3	27.9	1.0	0.1	28.0	36.4	D
2	100	0.34	0.304	1224	3	18.5	1.0	0.0	18.5	24.1	C
3	75	0.26	0.279	936	3	16.8	1.0	0.0	16.8	21.9	C

[a] Table 7-4

[b] Equation 7-3 $$d_1 = \frac{0.38C[1-(g/C)]^2}{1-(g/C)[Min(X,1.0)]}$$

[c] Table 7-5

[d] Equation 7-4 $$d_2 = 173X^2[(X-1)+\sqrt{(X-1)^2+mX/c}]$$

[e] Equation 7-2 $$d = d_1 DF + d_2$$

[f] Equation 7-1 $$D_I = 1.3 * d$$

[g] Table 7-6

Figure 7-5. Compute Intersection Delay.

RAMP JUNCTION DELAY WORKSHEET (ONE-WAY FRONTAGE ROADS)

Location: IH-99 Direction: North - bound

Description: Between Lemon and University Type: One-Way

Date: 8-19-96 Prepared By: Sally

Segment	Exit Ramp Hourly Volume[a] (veh/hr) Q_R	Frontage Road Hourly Volume (veh/hr) a	Potential Capacity of Frontage Road Lanes[b] (veh/hr) C_R	Queuing System Delay per Vehicle[c] (sec) W	Predicted Total Delay per Vehicle[d] (sec) D_R
1	358	193	2623	1.5	1.6
1	180	97	3167	1.2	1.2
2	214	115	3063	1.2	1.3
3	98	53	3418	1.1	1.1

[a] Q_R must be ≤ 1200; otherwise, use engineering judgement. If an auxiliary lane is present, delay is negligible.
[b] C_R = # Lanes (1858 - 1.5259 (Q_R))
[c] W = 3600 / (C_R - a)
[d] D_R = - 0.0719 + 1.0922 (W)

Figure 7-6. Calculate Ramp Delay.

Step 6: Compute Average Travel Speed

To calculate the average travel speed, the total travel time for each segment must be computed. The total travel time is the sum of the running time, intersection total delay, and ramp delay. Frontage road travel speed is calculated by dividing the total length of the frontage road study section by the total travel time (see Equation 7-5). This information is entered on the Frontage Road Level-of-Service Worksheet (see Figure 7-7).

Step 7: Assess Level of Service

The frontage road speeds for each segment are now compared to the criteria in Table 7-9 to determine the level of service by segment. The overall frontage road level of service is estimated by computing the average travel speed for the frontage road. As shown in Figure 7-7, the average travel speed for the frontage road is 48.3 km/h resulting in a LOS B.

FRONTAGE ROAD LEVEL-OF-SERVICE WORKSHEET

Location: IH-99 Direction: North - bound

Description: Between Lemon and University Type: One-Way

Date: 8-19-96 Prepared By: Sally

Segment	Segment Length (km) L	Access Density (acs/km)	Running Time[a] (sec) RT	Intersection Total Delay[b] (sec) D_I	Ramp Delay[c] (sec) D_R	Total Travel Time[d] (sec) T	Average Travel Speed[e] (km/h) S	Frontage Road LOS by Segment[f]
1	1.2	21.2	67	36.4	2.8	106.2	40.7	C
2	1.1	18.2	55	24.1	1.3	80.4	49.3	B
3	1.6	16.2	81	21.9	1.1	104.0	55.4	B

[a] Use field data or values from Table 7-3
[b] From Signalized Intersection Delay Worksheet
[c] From Ramp Junction Delay Worksheet
[d] $T = RT + D_I + D_R$
[e] $S = 3600(L)/T$
[f] See LOS criteria in Table 7-9.

Sum of Travel Times, sec (ΣT) = 290.6

Total Frontage Road Length, km (ΣL) = 3.9

Average Frontage Road Speed, km/h = 3600 (ΣL) / (ΣT) = 48.3

Frontage Road LOS = B

Figure 7-7. Assess Level of Service.

EXAMPLE CALCULATION 2—COMPUTATION OF FRONTAGE ROAD LEVEL OF SERVICE, TWO-WAY FRONTAGE ROAD

Step 1: Define Frontage Road Study Section

The frontage road to be considered is a 3.1 km length of two-lane, two-way frontage that is located in an area of low to moderate development. **This example illustrates the procedure to determine the level of service for the frontage road lane that flows *with* the direction of the freeway traffic. However, the lane *opposing* freeway traffic should also be analyzed because the level of service may be different.** Figure 7-8 illustrates the frontage road length to be analyzed.

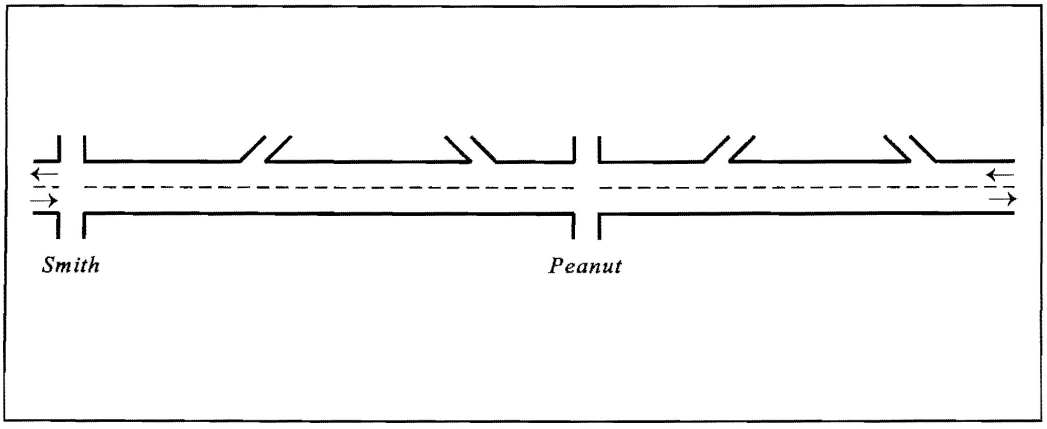


Figure 7-8. Schematic of Two-Way Frontage Road Study Section.

The selected frontage road study section is divided into the following two segments: Smith to Peanut, and Peanut to Exit Ramp.

Step 2: Gather Field Data

The required field data include roadway characteristics, traffic data, and signal data (see Table 7-1). The saturation flow rate is assumed to be 1800 vphgpl. Tables 7-12 and 7-13 summarize the required field data.

Table 7-12. Roadway Characteristics and Traffic Data for Two-Way Frontage Road Study Section.

Segment	Segment Boundaries	Length (km)	Access Density (acs/km)	Exit Ramp Volume (vph)	Frontage Road Volume (vph)	
					At Exit Ramps	At Intersections
1	Smith to Peanut	1.8	7.3	264	84	348
2	Peanut to Exit Ramp	1.3	15.9	204	96	--

Table 7-13. Signal Data for Two-Way Frontage Road Study Section.

Intersection	Cycle Length, C (sec)	g / C	Intersection Capacity, c[a] (vph)
Peanut	170	0.20	360

[a] c = (saturation flow rate)(# of lanes)(g/C)

Step 3: Compute Running Time

The segment lengths and access densities are entered on the Frontage Road Level-of-Service Worksheet (see Figure 7-9). Running times are computed from Table 7-3.

FRONTAGE ROAD LEVEL-OF-SERVICE WORKSHEET

Location: IH-50 Direction: North (With) - bound

Description: Smith to Exit Ramp Past Peanut Type: Two-Way

Date: 8-19-96 Prepared By: Sally

Seg-ment	Segment Length (km) L	Access Density (acs/km)	Running Time[a] (sec) RT	Inter-section Total Delay[b] (sec) D_I	Ramp Delay[c] (sec) D_R	Total Travel Time[d] (sec) T	Average Travel Speed[e] (km/h) S	Frontage Road LOS by Segment[f]
1	1.8	7.3	93					
2	1.3	15.9	68					

[a] Use field data or values from Table 7-3
[b] From Signalized Intersection Delay Worksheet
[c] From Ramp Junction Delay Worksheet
[d] $T = RT + D_I + D_R$
[e] $S = 3600(L)/T$
[f] See LOS criteria in Table 7-9.

Sum of Travel Times, sec (ΣT) = _____

Total Frontage Road Length, km (ΣL) = _____

Average Frontage Road Speed, km/h = 3600 (ΣL) / (ΣT) = _____

Frontage Road LOS = _____

Figure 7-9. Compute Running Time.

Step 4: Compute Intersection Delay

Intersection delay is computed on the Signalized Intersection Delay Worksheet (see Figure 7-10). The first step is to enter cycle length (C), green/cycle time ratio (g/C), v/c ratio (X), capacity (c), and arrival type onto the worksheet. Arrival type is based on quality of progression and is estimated using the values in Table 7-4. Arrival Type 3 is assumed.

The next step is to compute the total delay (D_I) for each signalized intersection. The total delay is computed using Equations 7-1 through 7-4. Intersection level of service is based on stopped delay (d) and may be estimated using the criteria in Table 7-6. The intersection total delay (D_I) is then entered on the Frontage Road Level-of-Service Worksheet.

Step 5: Compute Ramp Delay

Ramp delay is computed using the Ramp Junction Delay Worksheet (Two-Way Frontage Roads). For two-way frontage road lanes flowing *with* the frontage road traffic, ramp delays are calculated for exit ramps only (i.e., exit ramp *with*). Segments 1 and 2 each have one exit ramp. Delay for each ramp is calculated on a separate line of the worksheet (see Figure 7-11). Delay at each ramp is entered in the "Ramp Delay" column on the Frontage Road Level-of-Service Worksheet.

Step 6: Compute Average Travel Speed

To calculate the average travel speed, the total travel time for each segment must be computed. The total travel time is the sum of the running time, intersection total delay, and ramp delay. Frontage road travel speed is calculated by dividing the total length of the frontage road study section by the total travel time (see Equation 7-5). This information is entered on the Frontage Road Level-of-Service Worksheet (see Figure 7-12).

SIGNALIZED INTERSECTION DELAY WORKSHEET

Location: IH-50 Direction: North (With) - bound

Description: Smith to Exit Ramp Past Peanut Type: Two-Way

Date: 8-19-96 Prepared By: Sally

Segment	Cycle Length (sec) C	Green/ Cycle Time Ratio g/C	v/c Ratio X	Lane Group Capacity (vph) c	Arrival Type [a]	Uniform Delay[b] (sec) d_1	DF[c]	Incremental Delay[d] (sec) d_2	Intersection Stopped Delay[e] (sec) d	Intersection Total Delay[f] (sec) D_I	Intersection LOS[g]
1	170	0.20	0.233	360	3	43.7	1.0	0.0	43.7	56.9	E

[a] Table 7-4

[b] Equation 7-3 $$d_1 = \frac{0.38C[1-(g/C)]^2}{1-(g/C)[Min(X,1.0)]}$$

[c] Table 7-5

[d] Equation 7-4 $$d_2 = 173X^2[(X-1)+\sqrt{(X-1)^2+mX/c}]$$

[e] Equation 7-2 $$d = d_1 DF + d_2$$

[f] Equation 7-1 $$D_I = 1.3 * d$$

[g] Table 7-6

Figure 7-10. Compute Intersection Delay.

RAMP JUNCTION DELAY WORKSHEET (TWO-WAY FRONTAGE ROADS)

Location: IH-50 Direction: North (With) - bound

Description: Smith to Exit Ramp Past Peanut Type: Two-Way

Date: 8-19-96 Prepared By: Sally

Segment	Scenario[a]	Ramp Hourly Volume (vph) Q_R	Frontage Road Hourly Volume (vph) a	Potential Capacity of Frontage Road (vph) C_R	Queuing System Delay per Vehicle (sec) W	Predicted Total Delay per Vehicle (sec) D_R
1	Exit Ramp With	264	84	1298	2.96	3.2
2	Exit Ramp With	204	96	1395	2.77	3.0

[a] Scenarios and Equations:

Exit Ramp *With*:
$C_R = 1724 - 1.6120 (Q_R)$
$W = 3600 / (C_R - a)$
$D_R = -0.0719 + 1.0922 (W)$

Exit Ramp *Opposing*:
$C_R = 1444 - 1.6564 (Q_R)$
$W = 3600 / (C_R - a)$
$D_R = -1.6451 + 1.7785 (W)$

Entrance Ramp *Opposing*:
$C_R = 1535 - 1.3852 (Q_R)$ (Note: Q_R is assumed to be total frontage road *with* volume)
$W = 3600 / (C_R - a)$
$D_R = 0.0538 + 1.3027 (W)$

Figure 7-11. Calculate Ramp Delay.

FRONTAGE ROAD LEVEL-OF-SERVICE WORKSHEET

Location: IH-50 Direction: North (With) - bound

Description: Smith to Exit Ramp Past Peanut Type: Two-Way

Date: 8-19-96 Prepared By: Sally

Segment	Segment Length (km) L	Access Density (acs/km)	Running Time[a] (sec) RT	Intersection Total Delay[b] (sec) D_I	Ramp Delay[c] (sec) D_R	Total Travel Time[d] (sec) T	Average Travel Speed[e] (km/h) S	Frontage Road LOS by Segment[f]
1	1.8	7.3	93	56.9	3.2	153.2	42.3	
2	1.3	15.9	68	0.0	3.0	71.0	65.9	

[a] Use field data or values from Table 7-3
[b] From Signalized Intersection Delay Worksheet
[c] From Ramp Junction Delay Worksheet
[d] $T = RT + D_I + D_R$
[e] $S = 3600(L)/T$
[f] See LOS criteria in Table 7-9.

Sum of Travel Time, sec (ΣT) = _____

Total Frontage Road Length, km (ΣL) = _____

Average Frontage Road Speed, km/h = 3600 (ΣL) / (ΣT) = _____

Frontage Road LOS = _____

Figure 7-12. Compute Average Travel Speed.

Step 7: Assess Level of Service

The frontage road speeds for each segment are now compared to the criteria in Table 7-9 to determine the level of service by segment. The overall frontage road level of service is estimated by computing the average travel speed for the frontage road. As shown in Figure 7-13, the average travel speed for the frontage road is 49.8 km/h resulting in a LOS B.

FRONTAGE ROAD LEVEL-OF-SERVICE WORKSHEET

Location: IH-50 Direction: North (With) - bound

Description: Smith to Exit Ramp Past Peanut Type: Two-Way

Date: 8-19-96 Prepared By: Sally

Segment	Segment Length (km) L	Access Density (acs/km)	Running Time[a] (sec) RT	Intersection Total Delay[b] (sec) D_I	Ramp Delay[c] (sec) D_R	Total Travel Time[d] (sec) T	Average Travel Speed[e] (km/h) S	Frontage Road LOS by Segment[f]
1	1.8	7.3	93	56.9	3.2	153.2	42.3	C
2	1.3	15.9	68	0.0	3.0	71.0	65.9	A

[a] Use field data or values from Table 7-3
[b] From Signalized Intersection Delay Worksheet
[c] From Ramp Junction Delay Worksheet
[d] $T = RT + D_I + D_R$
[e] $S = 3600(L)/T$
[f] See LOS criteria in Table 7-9.

Sum of Travel Times, sec (ΣT) = 224.1

Total Frontage Road Length, km (ΣL) = 3.1

Average Frontage Road Speed, km/h = 3600 (ΣL) / (ΣT) = 49.8

Frontage Road LOS = B

Figure 7-13. Assess Level of Service.

EXAMPLE CALCULATION 3—PLANNING APPLICATION

Description

The following information has been determined for a one-way frontage road section.

- Traffic Characteristics
  - Annual average daily traffic, for both directions (AADT) = 30,000
  - Planning analysis peak hour factor (K100) = 0.09
  - Directional distribution factor, for northbound direction (D) = 0.55
  - Peak hour factor (PHF) = 0.925
  - Adjusted saturation flow = 1,850 pcphgpl
  - Percentage of turns from exclusive lanes = 15
- Roadway Characteristics
  - Through lanes = 2 lanes per direction
  - Section length = 3.2 km
  - Left-turn bays = yes
  - Access density is less than 20 acs/km
- Signal Characteristics
  - Signalized intersections = 4 (thus, average segment length = 0.8 km)
  - Arrival type = 3 (random arrival)
  - Signal types = non-coordinated, semiactuated
  - Cycle length (C) = 120 sec
  - Weighted effective green ratio (g/C) = 0.45

Solution

Use the following steps to determine the level of service for the northbound direction.

Step 1. Determine the two-way hourly volume for the planning analysis hour.

Two-Way Hourly Volume = AADT × K
= 30,000 × 0.09
= 2,700 vph

Step 2. Determine the hourly directional volume based on the predominant directional flow.

Directional Volume = Two-Way Hourly Volume × D
= 2,700 × 0.55
= 1,485 vph

Step 3. Determine the basic through-volume 15-minute flow rate.

Flow Rate = (Directional Volume / PHF) × (1 - percentage of turns)
= (1,485 / 0.925) × (1 - 0.15)
= 1,365 vph

Step 4. Determine running time.

The running time rate is obtained from Table 7-3 using one-way frontage road columns, less than 20 acs/km, and a segment length of 0.8 km. A running time of 40 sec per 0.8 km is obtained. For the 3.25 km segment, the running time is 162.5 seconds.

Step 5. Calculate total intersection delay.

The total delay (D) for all intersections is obtained using Equations 7-1 through 7-4. Following are the calculations performed to determine D.

Lane group capacity (c) = Saturation flow rate × number of lines × g/C
= 1,850 × 2 × 0.45
= 1,665

v/c ratio (X) = flow rate / lane group capacity
= 1,365 / 1,665
= 0.82

$$d_1 = \frac{0.38C[1-(g/C)]^2}{1-(g/C)[Min(X,1.0)]} \quad [7\text{-}3]$$

$$d_1 = \frac{0.38\times 120\times[1-(0.45)]^2}{1-(0.45)[0.82]}$$

$d_1 = 21.9$ sec

From Table 7-4, $m = 16$ for arrival type 3. From Table 7-5, $DF = 0.85$ for non-coordinated, semiactuated signals.

$$d_2 = 173X^2[(X-1)+\sqrt{(X-1)^2+mX/c}] \quad [7\text{-}4]$$

$$d_2 = 173(0.82)^2[(0.82-1)+\sqrt{(0.82-1)^2+(16)(0.82)/1554}]$$

$d_2 = 2.6$ sec

Determine intersection stopped delay (d).

$d = d_1 \times \text{DF} + d_2$ [7-2]

$d = 21.9 \times 0.85 + 2.6$

$d = 21.2$ sec

Determine intersection total delay (D_I) for all intersections (number of signalized intersections on this section is 4).

$D_I = 1.3 \times d$ [7-1]

$D_I = (1.3 \times 21.2) \times 4$

$D_I = 110$ sec

Step 6. Determine average travel speed using Equation 7-5.

$$S = \frac{3{,}600(L)}{RT + D_I + D_R}$$ [7-5]

$$S = \frac{3{,}600(3.2)}{162.5 + 110 + 0.0}$$

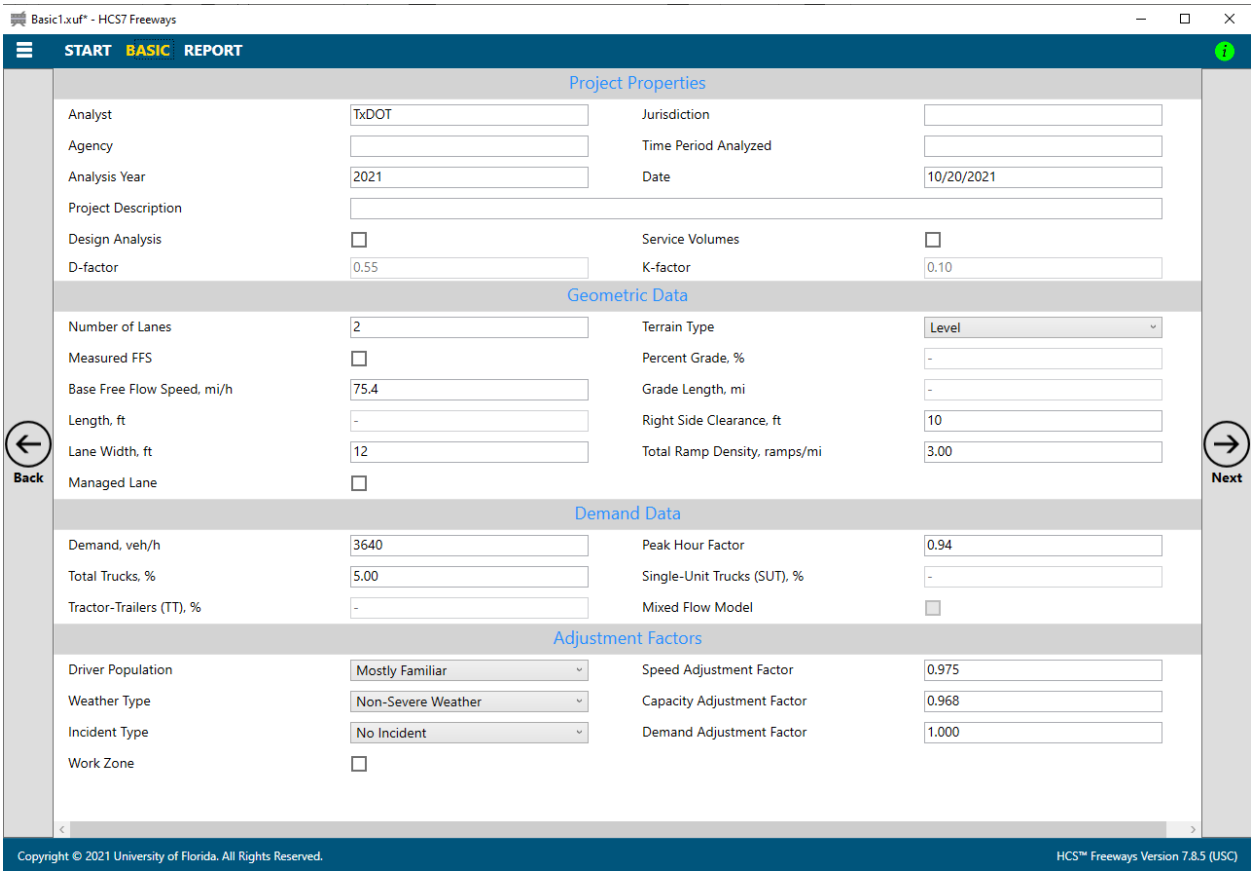
$S = 42.3$ km/h

Step 7. Determine the level of service for the section.

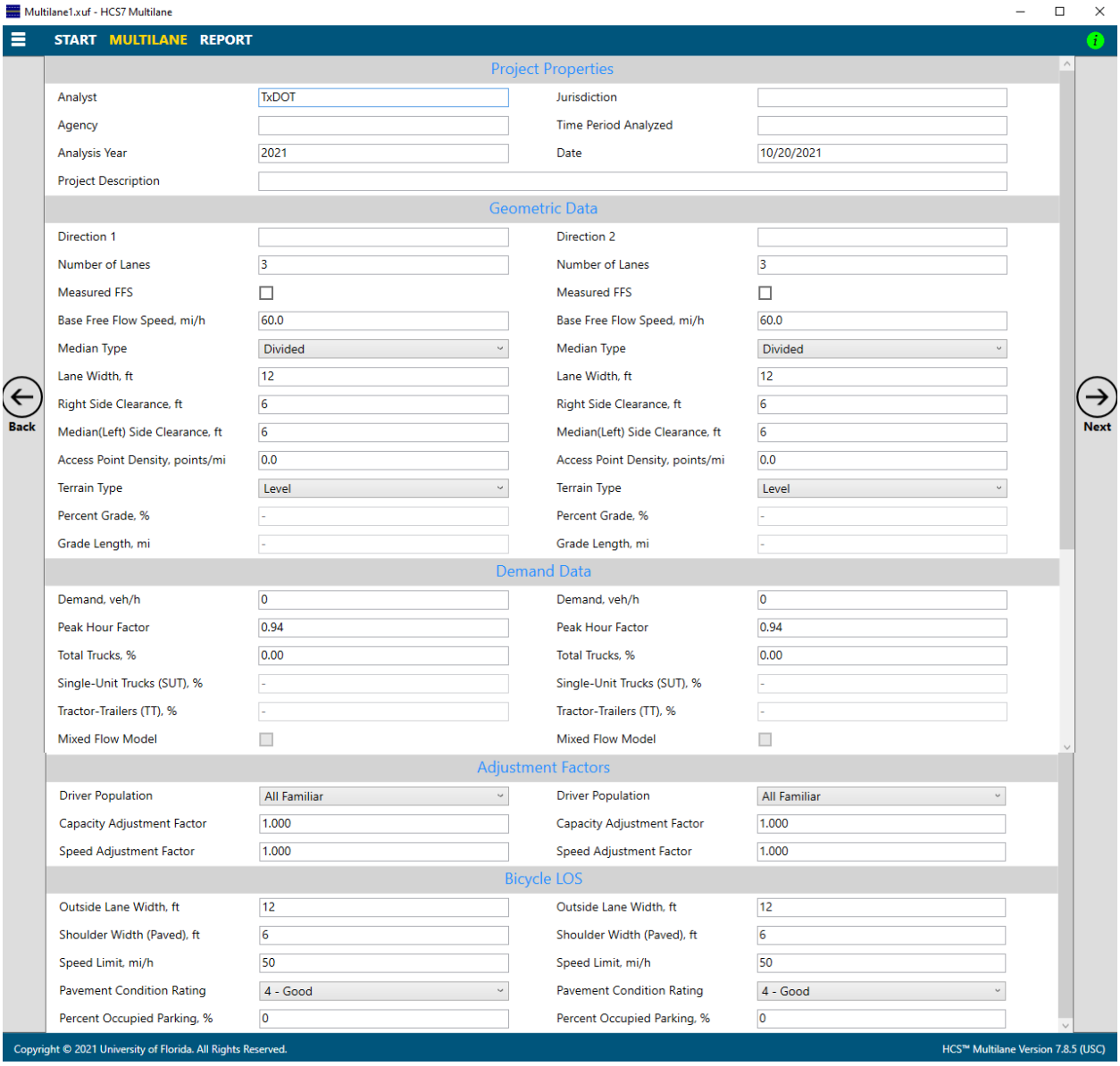
Based on an average travel speed of 42.3 km/h and the criteria in Table 7-9, the frontage road level of service is "C."

Section 2 – HCS Data Inputs and Outputs by Segment Type

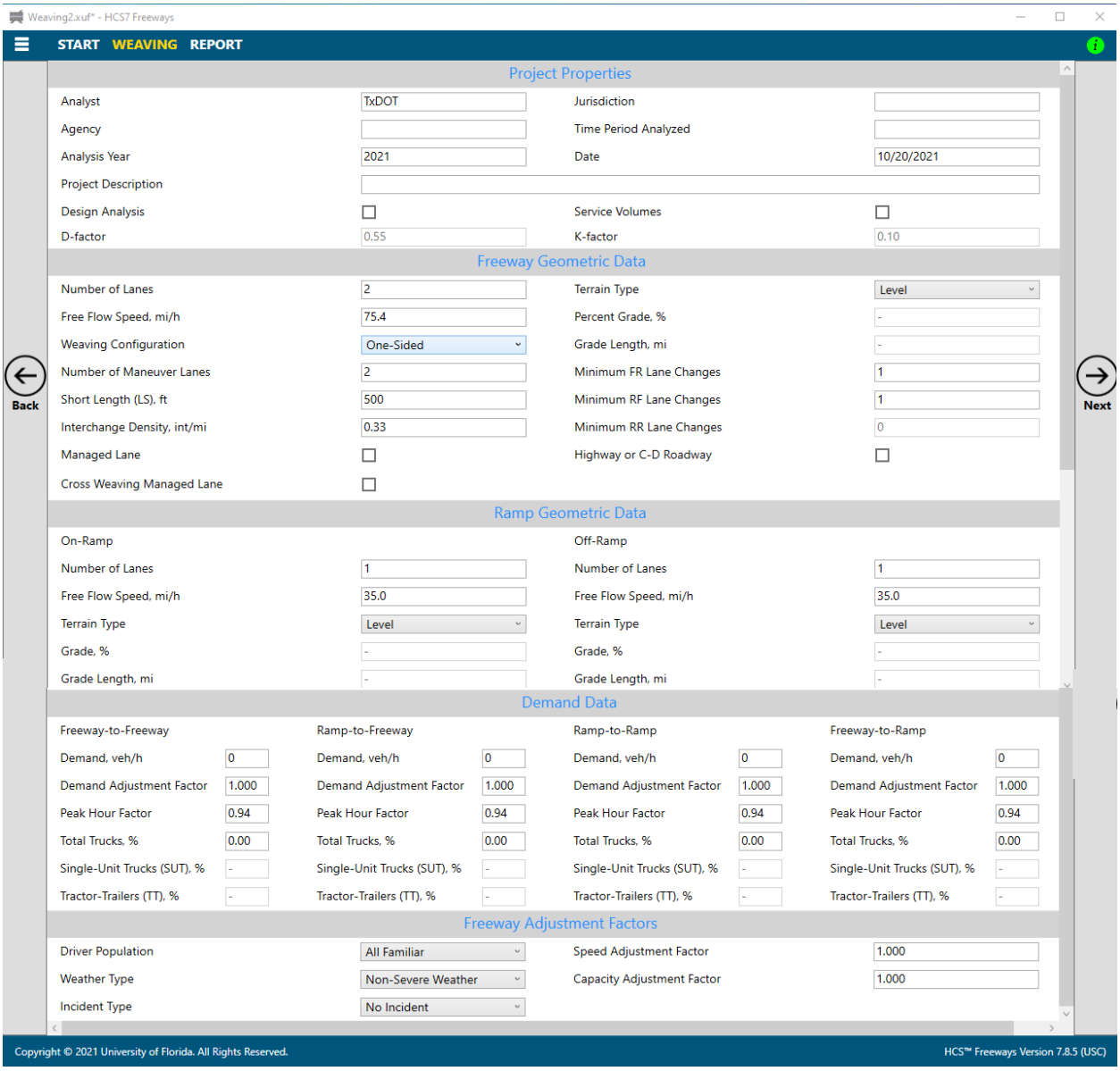
Freeways (Basic)



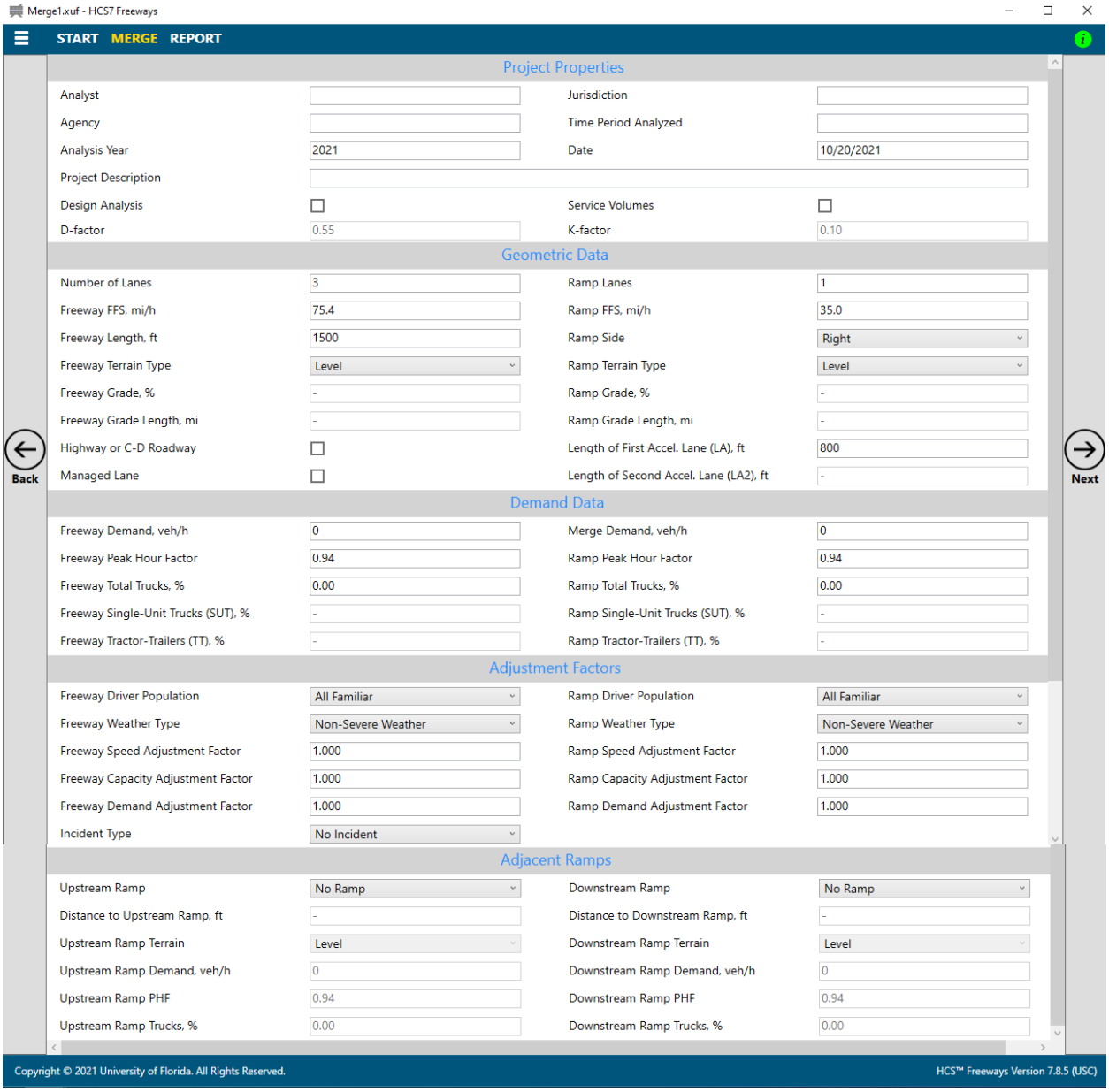
Multilane Highways (Basic)



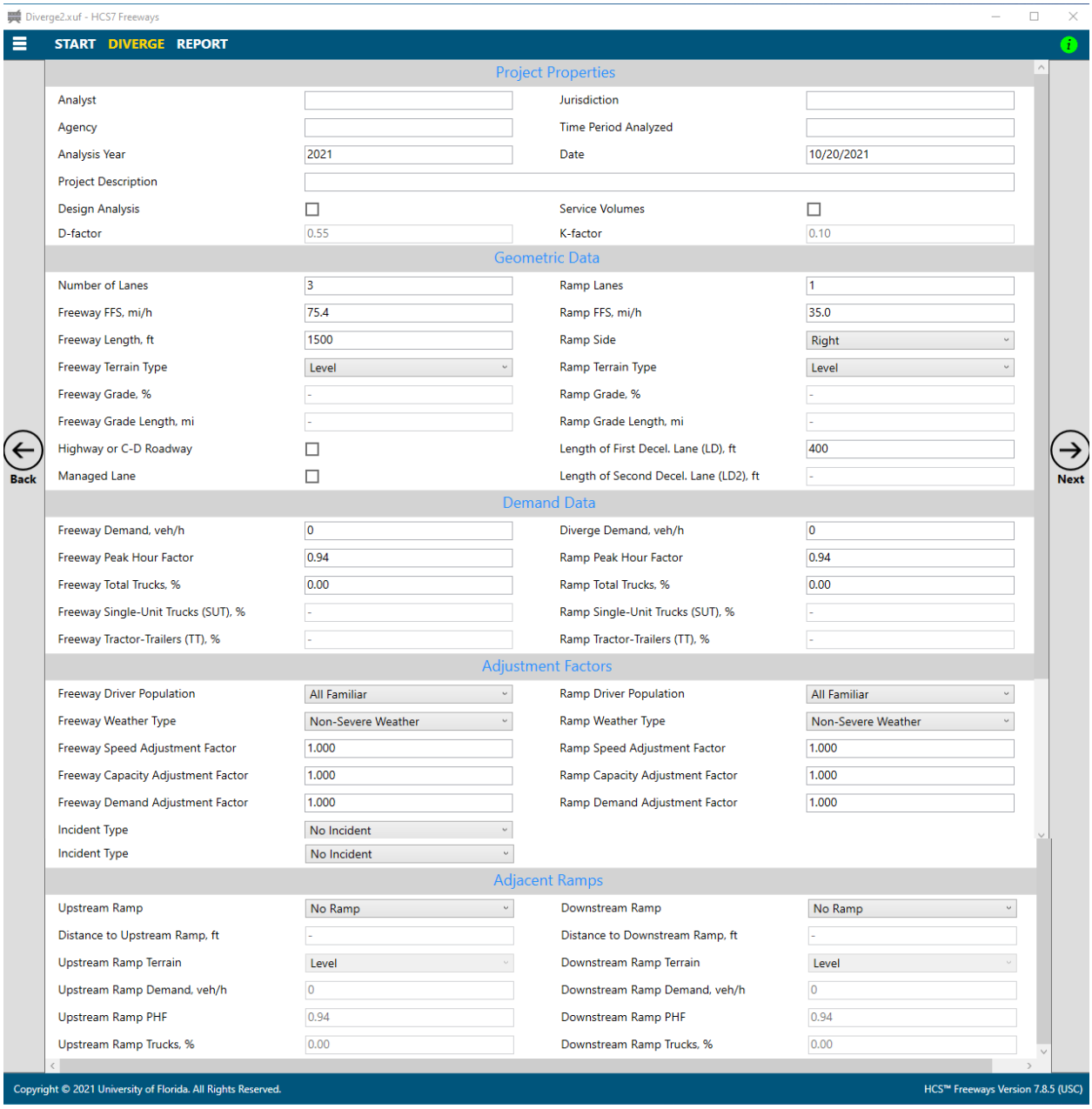
Weaving Segments

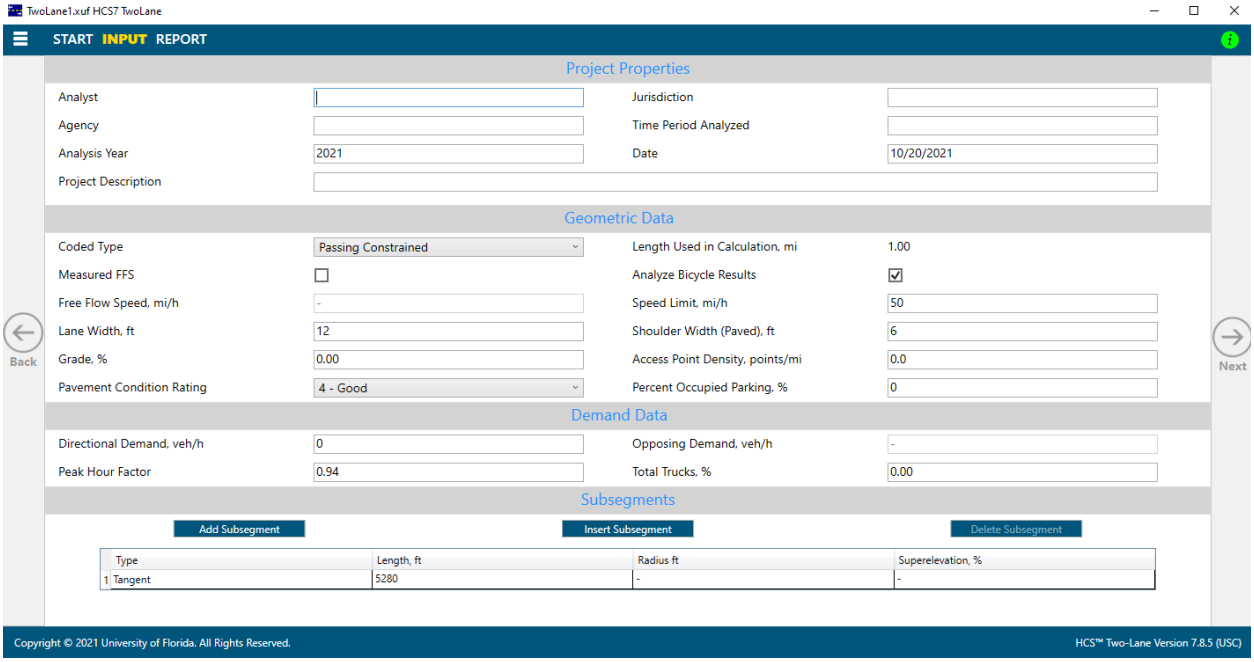


Merge Segments



Diverge Segments




TwoLane1.xuf HCS7 TwoLane
START INPUT REPORT
Project Properties
Analyst
Agency
Analysis Year
2021
Project Description
Jurisdiction
Time Period Analyzed
Date
10/20/2021
Geometric Data
Coded Type
Passing Constrained
Measured FFS
Free Flow Speed, mi/h
Lane Width, ft
12
Grade, %
0.00
Pavement Condition Rating
4 - Good
Length Used in Calculation, mi
1.00
Analyze Bicycle Results
Speed Limit, mi/h
50
Shoulder Width (Paved), ft
6
Access Point Density, points/mi
0.0
Percent Occupied Parking, %
0
Demand Data
Directional Demand, veh/h
0
Peak Hour Factor
0.94
Opposing Demand, veh/h
Total Trucks, %
0.00
Subsegments
Add Subsegment
Insert Subsegment
Delete Subsegment
Type
Length, ft
Radius ft
Superelevation, %
1 Tangent
5280
Back
Next
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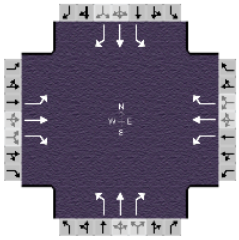
HCS™ Two-Lane Version 7.8.5 (USC)

Arterial Facilities

PRIMARY INPUT DATA

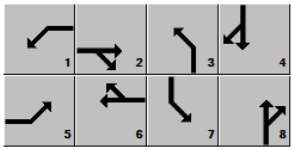
General

Urban Street			
Intersection			
Description			
Forward Direction	EB	Area Type	Other
Segment Length, ft	1000	Duration	0.250
All Segment Lengths		PHF	0.92



Phasing

Cycle, s	120							
Pre-Timed Signal	☐							
Offset, s	0							
Phase 2 Direction	EB							
Phase 4 Direction	SB							
Reference Phase	2							
Reference Point	End							
Force Mode	Fixed							



Phasing Wizard

Side Street Split Phasing ☐
Uncoordinated Intersection ☐
Field-Measured Phase Times ☐

Phase Duration

Green	116.0	0.0	0.0	0.0	0.0	0.0
Yellow	4.0	0.0	0.0	0.0	0.0	0.0
Red	0.0	0.0	0.0	0.0	0.0	0.0

Traffic

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Demand, veh/h	0	0	0	0	0	0	0	0	0	0	0	0
Lane Width, ft	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Storage Length, ft	0	0	0	0	0	0	0	0	0	0	0	0
Saturation, pc/h/ln	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Heavy Vehicles, %	0	0	0	0	0	0	0	0	0	0	0	0
Grade, %		0			0			0			0	
Buses, per h			0			0			0			0
Parking, per h	0	N	0	0	N	0	0	N	0	0	N	0
Bicycles, per h		0			0			0			0	
Pedestrians, per h		0			0			0			0	
Arrival Type	3	3	3	3	3	3	3	3	3	3	3	3
Upstream Filtering (I)		I-EB	1.00		I-WB	1.00		I-NB	1.00		I-SB	1.00
Initial Queue, veh	0	0	0	0	0	0	0	0	0	0	0	0
Speed Limit, mi/h		35			35			35			35	
Detector, ft	40	40	40	40	40	40	40	40	40	40	40	40
RTOR, veh/h			0			0			0			0
Unsignalized Movement	☐		☐	☐		☐	☐		☐	☐		☐
Unsignalized Delay	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0

Timing

	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	(5)	(2)	(1)	(6)	(3)	(8)	(7)	(4)
Phase Split, s	20.0	50.0	20.0	50.0	20.0	30.0	20.0	30.0
Yellow Change, s	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Red Clearance, s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minimum Green, s	6	6	6	6	6	6	6	6
Lag Phase	☐ EL	☐ ET	☐ WL	☐ WT	☐ NL	☐ NT	☐ SL	☐ ST
Passage Time, s	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Recall Mode	Off	Min	Off	Min	Off	Off	Off	Off
Dual Entry	☐ EL	☑ ET	☐ WL	☑ WT	☐ NL	☑ NT	☐ SL	☑ ST
Dallas/FYA Phasing	☐ E/W	☐ N/S			Simultaneous Gap	☑ E/W	☑ N/S	

DETAILED INPUT DATA

General

Analyst	
Agency/Co	
Date	Wed, October 27, 2021
Time Period	
Analysis Year	2021
Jurisdiction	
Data File	Streets1.xus

General

Number of Calculation Iterations	15
Critical Merge Gap, s	3.70
Stored Vehicle Lane Length, ft	25.0
Length of Detected Vehicle, ft	17.0
Stored Heavy Vehicle Length, ft	45
Queue Length Percentile	50
Acceleration Rate, ft/s2	3.50
Stop Threshold Speed, mi/h	5.0
Pedestrians Pushing Button, prop	0.51
Speed Limit to Base FFS Ratio	0.90
Sneakers per Cycle, veh	2.0
Platoon Minimum Headway, s/veh	1.50
Platoon Maximum Headway, s/veh	3.60
Platoon Dispersion Factor	0.138
Demand Growth, %	+ - 0

Intersection

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes	1	1	1	1	1	1	1	1	1	1	1	1
Shared Lane	☐		☐	☐		☐	☐		☐	☐		☐
Percent Turns in Shared Lane	0		0	0		0	0		0	0		0
Percent Unopposed Left Turns	0			0			0			0		
Heaviest Lane Volume, veh/h	0	0	0	0	0	0	0	0	0	0	0	0
Start-Up Lost Time, s	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Extension of Effective Green, s	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Walk Interval, s		0.0			0.0			0.0			0.0	
Pedestrian Clear Interval, s		0.0			0.0			0.0			0.0	
Receiving Lanes		1			1			1			1	
Turn Radius, ft	112		32	112		32	112		32	112		32
Work Zone Active		☐			☐			☐			☐	
Left/Thru Lanes Open		2			2			2			2	
Approach Width, ft		24.0			24.0			24.0			24.0	
Bus Blockage Time, s			14.4			14.4			14.4			14.4
Parking Maneuver Time, s	18		18	18		18	18		18	18		18
Opposing Right-Turn Lane Influence	☐			☐			☐			☐		
Field Proportion Arriving on Green	0.00	0.00	0.00	0.00	0.97	0.97	0.00	0.00	0.00	0.00	0.00	0.00

Segment

Name

	EB	WB
Upstream Width, ft	50	50
Restrictive Median, ft	0	0
Right-Hand Curb, %	70	70
Right-Hand Access Points	0	0
Mid-Segment Delay, s/veh	0.0	0.0
Field Travel Speed, mi/h	35.06	35.06
Field Free-Flow Speed, mi/h	38.20	38.20
On-Street Parking, %	0	0
Speed Calibration Factor, mi/h	0.0	0.0

Signal

Exclusive Pedestrian Phase Time, s	0.0
Deceleration Rate, ft/s2	4.00
Critical Headway (permitted left turn), s	4.5
Follow-Up Headway (permitted left turn), s	2.5

Access Point

Critical Headway (left from major), s	4.1
Follow-Up Headway (left from major), s	2.2
Right-Turn Equivalency Factor	2.20
Maximum Turn Bay Length, ft	250
Deceleration Rate, ft/s2	6.7
Right-Turn Speed, ft/s	20

Access Points

Active

PHF | ← | → | Count: 0 | New | Delete

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Flow Rate, veh/h												
Lanes												

Name | Location, ft

Optimization

Include this Intersection in Optimization	☑	Minimum Cycle, s	120	Number of Generations	200
Objective Function	Percent Base FFS	Maximum Cycle, s	120	Population Size	10
Cycle Length	☐ Safety and Emission	Cycle Increment, s	10	Crossover Probability, %	30
Splits	☑ Phasing Sequence ☐	Master Intersection	1	Mutation Probability, %	1.0
Offsets	☑ Dallas Phasing ☐	Forward Weighting, %	50	Convergence Threshold, %	0.010
		Reverse Weighting, %	50	Random Number Seed	7781

Origin-Destination

Direction		Upstream L	Upstream T	Upstream R	Upstream M
EB	L	0.02	0.10	0.05	0.02
Downstream	T	0.91	0.78	0.92	0.97
Downstream	R	0.05	0.10	0.02	0.01
Downstream	M	0.02	0.02	0.01	0.00

Interchanges and Alternative Intersections

Interchanges

Interchange Intersection ☐

Interchange Type: Diamond

EDTT Data

Alternative

Alternative Intersection ☐

Intersection Type

Section 3 – Service Volume Tables

Table 1: HCM's Daily Service Volume Table for Urban Basic Freeway Segments (1,000 veh/day)

K	D	Four-Lane Freeways				Six-Lane Freeways				Eight-Lane Freeways			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Level Terrain													
0.08	0.50	56.4	77.4	94.4	107.4	84.6	116.2	141.7	161.1	112.8	154.9	188.9	214.9
	0.55	51.3	70.4	85.9	97.7	76.9	105.6	128.8	146.5	102.5	140.8	171.7	195.3
	0.60	47	64.5	78.7	89.5	70.5	96.8	118.1	134.3	94	129.1	157.4	179.0
	0.65	43.4	59.6	72.7	82.6	65.1	89.4	109.0	124.0	86.8	119.1	145.3	165.3
0.09	0.50	50.1	68.8	84	95.5	75.2	103.3	125.9	143.2	100.3	137.7	167.9	191.0
	0.55	45.6	62.6	76.3	86.8	68.4	93.9	114.5	130.2	91.2	125.2	152.6	173.6
	0.60	41.8	57.4	70	79.6	62.7	86	104.9	119.4	83.6	114.7	139.9	159.2
	0.65	38.6	52.9	64.6	73.5	57.8	79.4	96.9	110.2	77.1	105.9	129.2	146.9
0.10	0.50	45.1	62	75.6	85.9	67.7	92.9	113.3	128.9	90.2	123.9	151.1	171.9
	0.55	41	56.3	68.7	78.1	61.5	84.5	103.0	117.2	82	112.6	137.4	156.3
	0.60	37.6	51.6	63	71.6	56.4	77.4	94.4	107.4	75.2	103.3	125.9	143.2
	0.65	34.7	47.7	58.1	66.1	52.1	71.5	87.2	99.2	69.4	95.3	116.2	132.2
0.11	0.50	41	56.3	68.7	78.1	61.5	84.5	103.0	117.2	82	112.6	137.4	156.3
	0.55	37.3	51.2	62.4	71	55.9	76.8	93.7	106.5	74.6	102.4	124.9	142.1
	0.60	34.2	46.9	57.2	65.1	51.3	70.4	85.9	97.7	68.4	93.9	114.5	130.2
	0.65	31.6	43.3	52.8	60.1	47.3	65	79.3	90.1	63.1	86.6	105.7	120.2
0.12	0.50	37.6	51.6	63	71.6	56.4	77.4	94.4	107.4	75.2	103.3	125.9	143.2
	0.55	34.2	46.9	57.2	65.1	51.3	70.4	85.9	97.7	68.4	93.9	114.5	130.2
	0.60	31.3	43	52.5	59.7	47	64.5	78.7	89.5	62.7	86	104.9	119.4
	0.65	28.9	39.7	48.4	55.1	43.4	59.6	72.7	82.6	57.8	79.4	96.9	110.2
Rolling Terrain													
0.08	0.50	53.8	73.9	90.2	102.5	80.8	110.9	135.2	153.8	107.7	147.8	180.3	205.1
	0.55	48.9	67.2	82	93.2	73.4	100.8	122.9	139.8	97.9	134.4	163.9	186.4
	0.60	44.9	61.6	75.1	85.5	67.3	92.4	112.7	128.2	89.7	123.2	150.3	170.9
	0.65	41.4	56.9	69.3	78.9	62.1	85.3	104.0	118.3	82.8	113.7	138.7	157.8
0.09	0.50	47.9	65.7	80.1	91.2	71.8	98.6	120.2	136.7	95.7	131.4	160.3	182.3
	0.55	43.5	59.7	72.9	82.9	65.3	89.6	109.3	124.3	87	119.5	145.7	165.7
	0.60	39.9	54.8	66.8	76	59.8	82.1	100.2	113.9	79.8	109.5	133.6	151.9
	0.65	36.8	50.5	61.6	70.1	55.2	75.8	92.5	105.2	73.6	101.1	123.3	140.2
0.10	0.50	43.1	59.1	72.1	82	64.6	88.7	108.2	123.1	86.1	118.3	144.2	164.1
	0.55	39.2	53.8	65.6	74.6	58.7	80.6	98.4	111.9	78.3	107.5	131.1	149.2
	0.60	35.9	49.3	60.1	68.4	53.8	73.9	90.2	102.5	71.8	98.6	120.2	136.7
	0.65	33.1	45.5	55.5	63.1	49.7	68.2	83.2	94.7	66.3	91	111.0	126.2
0.11	0.50	39.2	53.8	65.6	74.6	58.7	80.6	98.4	111.9	78.3	107.5	131.1	149.2
	0.55	35.6	48.9	59.6	67.8	53.4	73.3	89.4	101.7	71.2	97.7	119.2	135.6
	0.60	32.6	44.8	54.6	62.1	48.9	67.2	82	93.2	65.3	89.6	109.3	124.3
	0.65	30.1	41.4	50.4	57.4	45.2	62	75.7	86.1	60.2	82.7	100.9	114.7
0.12	0.50	35.9	49.3	60.1	68.4	53.8	73.9	90.2	102.5	71.8	98.6	120.2	136.7
	0.55	32.6	44.8	54.6	62.1	48.9	67.2	82	93.2	65.3	89.6	109.3	124.3
	0.60	29.9	41.1	50.1	57	44.9	61.6	75.1	85.5	59.8	82.1	100.2	113.9
	0.65	27.6	37.9	46.2	52.6	41.4	56.9	69.3	78.9	55.2	75.8	92.5	105.2

Note: Assumed 5% trucks, PHF = 0.94, FFS = 70 mi/h

Table 2: HCM's Daily Service Volume Table for Rural Basic Freeway Segments (1,000 veh/day)

K	D	Four-Lane Freeways				Six-Lane Freeways				Eight-Lane Freeways			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Level Terrain													
0.08	0.50	52.9	72.6	88.5	100.7	79.3	108.9	132.8	151.1	105.8	145.2	177.1	201.4
	0.55	48.1	66	80.5	91.6	72.1	99	120.7	137.3	96.1	132.0	161.0	183.1
	0.60	44.1	60.5	73.8	83.9	66.1	90.7	110.7	125.9	88.1	121.0	147.6	167.9
	0.65	40.7	55.8	68.1	77.5	61	83.8	102.2	116.2	81.3	111.7	136.2	154.9
0.09	0.50	47	64.5	78.7	89.5	70.5	96.8	118.1	134.3	94	129.1	157.4	179
	0.55	42.7	58.7	71.6	81.4	64.1	88	107.3	122.1	85.5	117.3	143.1	162.8
	0.60	39.2	53.8	65.6	74.6	58.8	80.7	98.4	111.9	78.3	107.6	131.2	149.2
	0.65	36.2	49.6	60.5	68.9	54.2	74.5	90.8	103.3	72.3	99.3	121.1	137.7
0.10	0.50	42.3	58.1	70.8	80.6	63.5	87.1	106.3	120.9	84.6	116.2	141.7	161.1
	0.55	38.5	52.8	64.4	73.2	57.7	79.2	96.6	109.9	76.9	105.6	128.8	146.5
	0.60	35.3	48.4	59	67.1	52.9	72.6	88.5	100.7	70.5	96.8	118.1	134.3
	0.65	32.5	44.7	54.5	62	48.8	67	81.7	93	65.1	89.4	109.0	124
0.11	0.50	38.5	52.8	64.4	73.2	57.7	79.2	96.6	109.9	76.9	105.6	128.8	146.5
	0.55	35	48	58.5	66.6	52.4	72	87.8	99.9	69.9	96	117.1	133.2
	0.60	32	44	53.7	61	48.1	66	80.5	91.6	64.1	88	107.3	122.1
	0.65	29.6	40.6	49.5	56.3	44.4	60.9	74.3	84.5	59.2	81.2	99.1	112.7
0.12	0.50	35.3	48.4	59	67.1	52.9	72.6	88.5	100.7	70.5	96.8	118.1	134.3
	0.55	32	44	53.7	61	48.1	66	80.5	91.6	64.1	88	107.3	122.1
	0.60	29.4	40.3	49.2	56	44.1	60.5	73.8	83.9	58.8	80.7	98.4	111.9
	0.65	27.1	37.2	45.4	51.6	40.7	55.8	68.1	77.5	54.2	74.5	90.8	103.3
Rolling Terrain													
0.08	0.50	47.8	65.6	80	91	71.6	98.4	120.0	136.5	95.5	131.1	160.0	181.9
	0.55	43.4	59.6	72.7	82.7	65.1	89.4	109.1	124.0	86.8	119.2	145.4	165.4
	0.60	39.8	54.6	66.6	75.8	59.7	82	100.0	113.7	79.6	109.3	133.3	151.6
	0.65	36.7	50.4	61.5	70	55.1	75.7	92.3	105.0	73.5	100.9	123.0	140
0.09	0.50	42.5	58.3	71.1	80.9	63.7	87.4	106.6	121.3	84.9	116.6	142.2	161.7
	0.55	38.6	53	64.6	73.5	57.9	79.5	96.9	110.3	77.2	106.0	129.3	147
	0.60	35.4	48.6	59.2	67.4	53.1	72.9	88.9	101.1	70.8	97.1	118.5	134.8
	0.65	32.7	44.8	54.7	62.2	49	67.3	82	93.3	65.3	89.7	109.4	124.4
0.10	0.50	38.2	52.5	64	72.8	57.3	78.7	96	109.2	76.4	104.9	128.0	145.5
	0.55	34.7	47.7	58.2	66.2	52.1	71.5	87.2	99.2	69.5	95.4	116.3	132.3
	0.60	31.8	43.7	53.3	60.6	47.8	65.6	80	91	63.7	87.4	106.6	121.3
	0.65	29.4	40.4	49.2	56	44.1	60.5	73.8	84	58.8	80.7	98.4	112
0.11	0.50	34.7	47.7	58.2	66.2	52.1	71.5	87.2	99.2	69.5	95.4	116.3	132.3
	0.55	31.6	43.4	52.9	60.1	47.4	65	79.3	90.2	63.2	86.7	105.8	120.3
	0.60	28.9	39.7	48.5	55.1	43.4	59.6	72.7	82.7	57.9	79.5	96.9	110.3
	0.65	26.7	36.7	44.7	50.9	40.1	55	67.1	76.3	53.4	73.4	89.5	101.8
0.12	0.50	31.8	43.7	53.3	60.6	47.8	65.6	80	91	63.7	87.4	106.6	121.3
	0.55	28.9	39.7	48.5	55.1	43.4	59.6	72.7	82.7	57.9	79.5	96.9	110.3
	0.60	26.5	36.4	44.4	50.5	39.8	54.6	66.6	75.8	53.1	72.9	88.9	101.1
	0.65	24.5	33.6	41	46.7	36.7	50.4	61.5	70	49	67.3	82	93.3

Note: Assumed 12% trucks, PHF = 0.94, FFS = 70 mi/h

Table 3: HCM's Generalized Daily Service Volumes for Urban Multilane Highways (1,000 veh/day)

K	D	Four-Lane Freeways				Six-Lane Freeways				Eight-Lane Freeways			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Level Terrain													
0.08	0.50	48.9	69.2	85.5	99.5	73.3	103.8	128.3	149.3	97.7	138.4	171	199
	0.55	44.4	62.9	77.7	90.5	66.6	94.4	116.6	135.7	88.8	125.8	155.5	181
	0.60	40.7	57.7	71.3	82.9	61.1	86.5	106.9	124.4	81.4	115.4	142.5	165.9
	0.65	37.6	53.2	65.8	76.6	56.4	79.9	98.7	114.8	75.2	106.5	131.5	153.1
0.09	0.50	43.4	61.5	76	88.5	65.1	92.3	114	132.7	86.9	123	152	176.9
	0.55	39.5	55.9	69.1	80.4	59.2	83.9	103.6	120.6	79	111.9	138.2	160.8
	0.60	36.2	51.3	63.3	73.7	54.3	76.9	95	110.6	72.4	102.5	126.7	147.4
	0.65	33.4	47.3	58.5	68.1	50.1	71	87.7	102.1	66.8	94.7	116.9	136.1
0.10	0.50	39.1	55.4	68.4	79.6	58.6	83.1	102.6	119.4	78.2	110.7	136.8	159.2
	0.55	35.5	50.3	62.2	72.4	53.3	75.5	93.3	108.6	71.1	100.7	124.4	144.8
	0.60	32.6	46.1	57	66.3	48.9	69.2	85.5	99.5	65.1	92.3	114	132.7
	0.65	30.1	42.6	52.6	61.2	45.1	63.9	78.9	91.9	60.1	85.2	105.2	122.5
0.11	0.50	35.5	50.3	62.2	72.4	53.3	75.5	93.3	108.6	71.1	100.7	124.4	144.8
	0.55	32.3	45.8	56.5	65.8	48.5	68.6	84.8	98.7	64.6	91.5	113.1	131.6
	0.60	29.6	41.9	51.8	60.3	44.4	62.9	77.7	90.5	59.2	83.9	103.6	120.6
	0.65	27.3	38.7	47.8	55.7	41	58.1	71.7	83.5	54.7	77.4	95.7	111.4
0.12	0.50	32.6	46.1	57	66.3	48.9	69.2	85.5	99.5	65.1	92.3	114	132.7
	0.55	29.6	41.9	51.8	60.3	44.4	62.9	77.7	90.5	59.2	83.9	103.6	120.6
	0.60	27.1	38.5	47.5	55.3	40.7	57.7	71.3	82.9	54.3	76.9	95	110.6
	0.65	25.1	35.5	43.8	51	37.6	53.2	65.8	76.6	50.1	71	87.7	102.1
Rolling Terrain													
0.08	0.50	46.6	66.1	81.6	95	70	99.1	122.4	142.5	93.3	132.1	163.2	190
	0.55	42.4	60.1	74.2	86.4	63.6	90.1	111.3	129.5	84.8	120.1	148.4	172.7
	0.60	38.9	55.1	68	79.2	58.3	82.6	102	118.8	77.7	110.1	136	158.3
	0.65	35.9	50.8	62.8	73.1	53.8	76.2	94.2	109.6	71.7	101.6	125.6	146.2
0.09	0.50	41.5	58.7	72.5	84.4	62.2	88.1	108.8	126.7	82.9	117.5	145.1	168.9
	0.55	37.7	53.4	66	76.8	56.5	80.1	98.9	115.2	75.4	106.8	131.9	153.5
	0.60	34.5	48.9	60.5	70.4	51.8	73.4	90.7	105.6	69.1	97.9	120.9	140.7
	0.65	31.9	45.2	55.8	65	47.8	67.8	83.7	97.4	63.8	90.3	111.6	129.9
0.10	0.50	37.3	52.9	65.3	76	56	79.3	97.9	114	74.6	105.7	130.6	152
	0.55	33.9	48	59.4	69.1	50.9	72.1	89	103.6	67.8	96.1	118.7	138.2
	0.60	31.1	44	54.4	63.3	46.6	66.1	81.6	95	62.2	88.1	108.8	126.7
	0.65	28.7	40.7	50.2	58.5	43	61	75.3	87.7	57.4	81.3	100.4	116.9
0.11	0.50	33.9	48	59.4	69.1	50.9	72.1	89	103.6	67.8	96.1	118.7	138.2
	0.55	30.8	43.7	54	62.8	46.3	65.5	80.9	94.2	61.7	87.4	107.9	125.6
	0.60	28.3	40	49.5	57.6	42.4	60.1	74.2	86.4	56.5	80.1	98.9	115.2
	0.65	26.1	37	45.7	53.1	39.1	55.4	68.5	79.7	52.2	73.9	91.3	106.3
0.12	0.50	31.1	44	54.4	63.3	46.6	66.1	81.6	95	62.2	88.1	108.8	126.7
	0.55	28.3	40	49.5	57.6	42.4	60.1	74.2	86.4	56.5	80.1	98.9	115.2
	0.60	25.9	36.7	45.3	52.8	38.9	55.1	68	79.2	51.8	73.4	90.7	105.6
	0.65	23.9	33.9	41.9	48.7	35.9	50.8	62.8	73.1	47.8	67.8	83.7	97.4

Note: Assumed 5% trucks, PHF = 0.95, FFS = 60 mi/h

Table 4: HCM's Generalized Daily Service Volumes for Rural Multilane Highways (1,000 veh/day)

K	D	Four-Lane Freeways				Six-Lane Freeways				Eight-Lane Freeways			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Level Terrain													
0.08	0.50	42.4	60.1	74.3	86.4	63.6	90.2	111.4	129.6	84.9	120.2	148.5	172.9
	0.55	38.6	54.6	67.5	78.6	57.9	82	101.3	117.9	77.1	109.3	135.0	157.1
	0.60	35.4	50.1	61.9	72	53	75.1	92.8	108.0	70.7	100.2	123.8	144
	0.65	32.6	46.2	57.1	66.5	49	69.4	85.7	99.7	65.3	92.5	114.2	133
0.09	0.50	37.7	53.4	66	76.8	56.6	80.1	99	115.2	75.4	106.9	132.0	153.7
	0.55	34.3	48.6	60	69.8	51.4	72.9	90	104.8	68.6	97.1	120.0	139.7
	0.60	31.4	44.5	55	64	47.1	66.8	82.5	96	62.9	89	110.0	128
	0.65	29	41.1	50.8	59.1	43.5	61.6	76.2	88.6	58	82.2	101.5	118.2
0.10	0.50	33.9	48.1	59.4	69.1	50.9	72.1	89.1	103.7	67.9	96.2	118.8	138.3
	0.55	30.9	43.7	54	62.9	46.3	65.6	81	94.3	61.7	87.4	108.0	125.7
	0.60	28.3	40.1	49.5	57.6	42.4	60.1	74.3	86.4	56.6	80.1	99	115.2
	0.65	26.1	37	45.7	53.2	39.2	55.5	68.5	79.8	52.2	74	91.4	106.4
0.11	0.50	30.9	43.7	54	62.9	46.3	65.6	81	94.3	61.7	87.4	108.0	125.7
	0.55	28.1	39.7	49.1	57.1	42.1	59.6	73.6	85.7	56.1	79.5	98.2	114.3
	0.60	25.7	36.4	45	52.4	38.6	54.6	67.5	78.6	51.4	72.9	90	104.8
	0.65	23.7	33.6	41.5	48.4	35.6	50.4	62.3	72.5	47.5	67.3	83.1	96.7
0.12	0.50	28.3	40.1	49.5	57.6	42.4	60.1	74.3	86.4	56.6	80.1	99	115.2
	0.55	25.7	36.4	45	52.4	38.6	54.6	67.5	78.6	51.4	72.9	90	104.8
	0.60	23.6	33.4	41.3	48	35.4	50.1	61.9	72	47.1	66.8	82.5	96.0
	0.65	21.8	30.8	38.1	44.3	32.6	46.2	57.1	66.5	43.5	61.6	76.2	88.6
Rolling Terrain													
0.08	0.50	38.3	54.3	67.1	78.1	57.5	81.4	100.6	117.1	76.6	108.6	134.1	156.1
	0.55	34.8	49.4	61	71	52.3	74	91.5	106.5	69.7	98.7	121.9	141.9
	0.60	31.9	45.2	55.9	65.1	47.9	67.9	83.8	97.6	63.9	90.5	111.8	130.1
	0.65	29.5	41.8	51.6	60	44.2	62.6	77.4	90.1	59	83.5	103.2	120.1
0.09	0.50	34.1	48.3	59.6	69.4	51.1	72.4	89.4	104.1	68.1	96.5	119.2	138.8
	0.55	31	43.9	54.2	63.1	46.5	65.8	81.3	94.6	61.9	87.7	108.4	126.2
	0.60	28.4	40.2	49.7	57.8	42.6	60.3	74.5	86.7	56.8	80.4	99.4	115.7
	0.65	26.2	37.1	45.9	53.4	39.3	55.7	68.8	80.1	52.4	74.2	91.7	106.8
0.10	0.50	30.7	43.4	53.7	62.5	46	65.1	80.5	93.7	61.3	86.9	107.3	124.9
	0.55	27.9	39.5	48.8	56.8	41.8	59.2	73.2	85.2	55.7	79	97.5	113.5
	0.60	25.5	36.2	44.7	52	38.3	54.3	67.1	78.1	51.1	72.4	89.4	104.1
	0.65	23.6	33.4	41.3	48	35.4	50.1	61.9	72.1	47.2	66.8	82.5	96.1
0.11	0.50	27.9	39.5	48.8	56.8	41.8	59.2	73.2	85.2	55.7	79	97.5	113.5
	0.55	25.3	35.9	44.3	51.6	38	53.8	66.5	77.4	50.7	71.8	88.7	103.2
	0.60	23.2	32.9	40.6	47.3	34.8	49.4	61	71	46.5	65.8	81.3	94.6
	0.65	21.4	30.4	37.5	43.7	32.2	45.6	56.3	65.5	42.9	60.7	75	87.3
0.12	0.50	25.5	36.2	44.7	52	38.3	54.3	67.1	78.1	51.1	72.4	89.4	104.1
	0.55	23.2	32.9	40.6	47.3	34.8	49.4	61	71	46.5	65.8	81.3	94.6
	0.60	21.3	30.2	37.3	43.4	31.9	45.2	55.9	65.1	42.6	60.3	74.5	86.7
	0.65	19.7	27.8	34.4	40	29.5	41.8	51.6	60	39.3	55.7	68.8	80.1

Note: Assumed 12% trucks, PHF = 0.88, FFS = 60 mi/h

Table 5: HCM's Generalized Daily Service Volumes for Urban Street Facilities

		Daily Service Volume by Lanes, LOS, and Speed (1,000 veh/day)											
K	*D*	Two-Lane Streets				Four-Lane Streets				Six-Lane Streets			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
Posted Speed = 30 mi/h													
0.09	0.55	NA	1.7	11.8	17.8	NA	2.2	24.7	35.8	NA	2.6	38.7	54.0
	0.60	NA	1.6	10.8	16.4	NA	2.0	22.7	32.8	NA	2.4	35.6	49.5
0.10	0.55	NA	1.6	10.7	16.1	NA	2.0	22.3	32.2	NA	2.4	34.9	48.6
	0.60	NA	1.4	9.8	14.7	NA	1.8	20.4	29.5	NA	2.2	32.0	44.5
0.11	0.55	NA	1.4	9.7	14.6	NA	1.8	20.3	29.3	NA	2.1	31.7	44.1
	0.60	NA	1.3	8.9	13.4	NA	1.7	18.6	26.9	NA	2.0	29.1	40.5
Posted Speed = 45 mi/h													
0.09	0.55	NA	7.7	15.9	18.3	NA	16.5	33.6	36.8	NA	25.4	51.7	55.3
	0.60	NA	7.1	14.5	16.8	NA	15.1	30.8	33.7	NA	23.4	47.4	50.7
0.10	0.55	NA	7.0	14.3	16.5	NA	14.9	30.2	33.1	NA	23.0	46.5	49.7
	0.60	NA	6.4	13.1	15.1	NA	13.6	27.7	30.3	NA	21.0	42.7	45.6
0.11	0.55	NA	6.3	13.0	15.0	NA	13.5	27.5	30.1	NA	20.9	42.3	45.2
	0.60	NA	5.8	11.9	13.8	NA	12.4	25.2	27.6	NA	19.1	38.8	41.5

Chapter 10 - Appendix K – Intersection Analysis

- Section 1 – ICE Report Outlines
  - Stage 1 ICE Example
  - Full report outline
  - Full report example
- Section 2 – Intersection Type Additional Resources
- Section 3 – Intersection Analysis Checklist
- Section 4 – Intersection Analysis Tool Sample Output
- Section 5 – TMUTCD Signal Warrant Analysis Guidelines
- Section 6 – TMUTCD Signal Warrant Analysis Spreadsheet
- Section 7 – Intersection Type Graphics
- Section 8 – External References
- Section 9 – Crash Diagram Template

Section 1 - ICE Report Outlines

Stage 1 ICE Example

Coordinate with the TxDOT Project Manager to determine the level of effort and scope of the ICE.

Below is an abbreviated version of an ICE report. It covers the Stage 1 requirements and generates a preferred type of intersection control without requiring more detail that Stage 2 generates. When both the safety (SPICE) and operations (CAP-X) analyses generate a clear preference for intersection control, Stage 2 ICE investigation is not necessary, and the project can proceed to concept design and detailed cost estimation.

Location: US 123 at CR 456

Background:

- A local agency is proposing intersection improvements. They submitted a white paper to the TxDOT area office, justifying a roundabout.
- White paper was forwarded to TxDOT Design Division Roundabout and Alternative Intersection Design (RAID) for review.

FHWA SPICE Tool:

Assumptions:

- Kept all default settings, no calibration of SPFs or CMFs
- AADT: no consistent AADT provided - used peak hour volumes from combined spreadsheet (TIA Analysis) to extrapolate to an ADT and use as AADT to input in the tool:

Peak Hour Volumes: Projected Site Totals + No Build (2024)

			AM	104	14	5		
			PM	51	7	3		
AM	PM						AM	PM
30	94			CR 456			2	4
291	417		US 123			US 123	446	262
615	600			CR 456			138	102
			AM	510	4	91		
			PM	777	13	142		

Total Entering Volume (TEV) =

	US 123	CR 456
AM	1,522	728
PM	1,479	996

Assume*:
ADT = TEV/f
f = 8% to 12%

US 123 ADT =

1522/.08 = 19025	1479/.08 = 18487
1522/.12 = 12683	1479/.12 = 12325

Average = **15,630**

CR 456 ADT =

728/.08 = 9,100	996/.08 = 12,450
728/.12 = 6,067	996/.12 = 8,300

Average = **8,979**

SPICE Results:

Safety Performance for Intersection Control Evaluation Tool

Results

Summary of crash prediction results for each alternative

Project Information

Project Name:		**Intersection Type**	At-Grade Intersections
Intersection:		**Opening Year**	2025
Agency:		**Design Year**	--
Project Reference:		**Facility Type**	On Urban and Suburban Arterial
City:		**Number of Legs**	4-leg
State:			
Date:			
Analyst:			

Crash Prediction Summary

Control Strategy	Crash Type	Opening Year	Design Year	Total Project Life Cycle	AADT Within Prediction Range?
1-lane Roundabout	Total	2.53	--	--	N/A
	Fatal & Injury	0.51	--	--	
2-lane Roundabout	Total	2.76	--	--	N/A
	Fatal & Injury	0.33	--	--	
Minor Road Stop	Total	2.38	--	--	No
	Fatal & Injury	0.99	--	--	
Traffic Signal	Total	3.41	--	--	Yes
	Fatal & Injury	1.14	--	--	
Displaced Left-Turn (DLT)	Total	3.00	--	--	N/A
	Fatal & Injury	1.00	--	--	
Median U-Turn (MUT)	Total	2.90	--	--	N/A
	Fatal & Injury	0.80	--	--	
Signalized RCUT	Total	2.90	--	--	N/A
	Fatal & Injury	0.89	--	--	
Unsignalized RCUT	Total	1.55	--	--	N/A
	Fatal & Injury	0.45	--	--	

SPICE Summary:

Lowest Total Crashes:

1. **(1.55) Unsignalized RCUT**

   (2.38) Minor Road Cut - don't count per red "No" in table

2. (2.53) 1-lane roundabout
3. (2.76) 2-lane roundabout

Lowest Fatal & Injury Crashes:

1. **(0.33) 2-lane roundabout**
2. (0.45) Unsignalized RCUT
3. (0.51) 1-lane roundabout

Highest Total Crashes:

1. Traffic Signal
2. Displaced Left-Turn
3. MUT and Signalized RCUT

Highest Fatal & Injury Crashes:

1. Traffic Signal
2. Displaced Left-Turn
3. Signalized RCUT

FHWA CAP-X Tool:

Assumptions:

- Used peak hour volumes from combined spreadsheet (CR 456 TIA Analysis)
- Did not analyze intersection types not included in SPICE tool (such as Quadrant Road)
- Kept all default factors.

Results:

TYPE OF INTERSECTION	Overall V/C Ratio	V/C Ranking	Pedestrian Accommodations	Bicycle Accommodations
Displaced Left Turn	0.58	1	Good	Excellent
2 X 2 Roundabout	0.95	2	Good	Excellent
Signalized Restricted Crossing U-Turn E-W	1.03	3	Good	Excellent
1NS X 2EW Roundabout	1.05	4	Good	Excellent
Median U-Turn E-W	1.08	5	Good	Excellent
1 X 1 Roundabout	1.18	6	Excellent	Excellent
Traffic Signal	1.23	7	Good	Excellent
Unsignalized Restricted Crossing U-Turn E-W	1.65	8	Good	Excellent
Two-Way Stop Control E-W	10.89	9	Fair	Good
75 ICD	61.00	10	Excellent	Good

Summary:

- Only two intersection types under 1.0 V/C Ratio: **DLT and 2 x 2 Roundabout**
- Three intersection types very close to 1.0 V/C Ratio:
  - Signalized RCUT
  - Multi-lane roundabout (1 lane north-south, 2 lanes east-west)
  - MUT

Summary of SPICE and CAP-X Analysis:

- A 2 x 2 roundabout may provide the best combination of safety and capacity.
- A DLT may provide the best capacity but has one of the highest levels of total crashes and fatal/severe crashes.
- An unsignalized RCUT has the lowest total crashes, but has a very poor V/C ratio (1.65)
- A multi-lane roundabout (1 lane north-south, 2 lanes east-west) is just over 1.0 V/C (1.05) but provides high safety benefits and would be worth consideration.

Comments on White Paper and Roundabout Design:

- Traffic
  - Recommend developing design-year traffic projections - 10 year and 20 year and evaluating roundabout performance for each.
  - Recommend a review of proposed lane configuration based on traffic analysis.
- Design
  - Design shows geometric problems (listed below) – *recommend local agency gets a peer review of the roundabout traffic analysis (for lane configuration) and geometric design.*
  - Exhibit does not give any dimensions, so a review of roundabout size and other geometrics is limited - request a more detailed schematic that includes the following:
    - Roundabout key dimensions (ICD, entry & exit flare widths, typical lane widths, deflection, and entry curve radii, circulating lane widths, truck apron widths, pedestrian refuge island widths)
    - Striping
    - Sidewalk widths

        - Vertical profiles and roadway cross slopes
    - Striping as shown does not make sense - circulatory stripe touches the top of the west leg splitter island so lane configuration is unclear.
    - Limited-to-no deflection on west and south legs - provide better speed control.
    - Exhibit cuts off north leg, so review not possible.
    - Pedestrian crossings are too far back - place them 20' back from circulatory roadway.
    - Recommend documenting and reviewing roundabout performance measures:
        - Fastest paths - plan view and radius/speed calculations
        - Truck turning movements - design and check vehicle - plan view.
        - Path-overlap check for multilane entrances.
        - Sight distance triangles and calculations
    - Sidewalk widths seem narrow to be considered a shared use path, but dimensions not so. If less than 10', need to identify bicycle facilities.
- General comment:
    - Recommending construction in 2024, but ROW acquisition may slow that down.

Review Summary:

- Based on high-level analysis, a 2-lane roundabout will likely provide the best combination of safety benefits and capacity, and a multi-lane roundabout (1 lane north-south, 2 lanes east-west) would also be worth consideration.
- The roundabout design needs to be looked at much more closely - first on lane configuration based on traffic analysis, and second on the geometrics. Poor lane configuration and/or design may result in a less-than-optimally functioning roundabout.

Section 1 - ICE Report Outline

Full Report Outline

1. Executive Summary
2. Introduction
    a. Purpose and Need
    b. Background
        i. Existing Conditions
        ii. Collected Data
        iii. Analysis Years
            1. Growth Rate (as applicable)
    c. Intersection Control Types and Alternatives under Consideration
        i. Assumptions for each Intersection Type
3. Analysis of Control Types and Alternatives
    a. Operational Analysis
        i. CAP-X Results
        ii. Detailed Analysis Results (optional)
            1. HCS, Synchro, Vissim, SIDRA (as applicable)
    b. Safety Analysis
        i. Historical Crash Analysis
        ii. Intersection Crash Rate
        iii. Collision Diagram
        iv. Predictive Crash Analysis
            1. Applicable HSM SPFs and CMFs
            2. SPICE Results
    c. Multimodal Analysis
        i. CAP-X Results
        ii. Detailed Analysis Results (optional)
            1. HCS, Synchro, Vissim, Sidra (as applicable)
    d. Other Considerations
        i. Applicable Warrants, Right-of-Way Needs, Environmental Risks, Long-Range Plan Consistency, Stakeholder and Public Concerns (as applicable)
    e. Cost Benefit Analysis
        i. OPCC, Life Cycle Cost, SII (as applicable)
4. Conclusion
    a. Summary and Comparison of Alternatives
    b. Intersection Control Recommendation
        i. Justification

Appendix

A. Traffic Count Data
B. Crash Data
C. Analysis Reports (CAP-X, HCS, Synchro, Vissim, SIDRA, SPICE)
D. Cost Benefit Analysis Reports

Full Report Example

This is an example of a long form report format and content. It also addresses how a series of intersections can be handled using the ICE process then combining results as adjacent intersection types affect one another.

Roundabout Corridor ICE Report

Contract No.

Date:

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PART A: CORRIDOR SUMMARY

- Give ~3 sentences describing the need and purpose for study of the intersections in this corridor.

1.1. *Overview and Key Findings*

1.1.1. Corridor Location

- Provide a map showing where the corridor is relative to the District.
- Provide a map showing where each intersection in the corridor is.

Table 1-1 – List of Intersection Locations and Existing Intersection Control

Header			
First Row			
First Column			

- A GIS-based project map can summarize all spatial considerations, with hyperlinks to project schematics. To view the GIS interactive map, click here. (Include hyperlink to map)

1.1.2. Corridor Safety Context

- What safety aspects affect the whole corridor? Common problems/need, common solutions

1.1.3. Corridor Operations Context

- What operations aspects affect the whole corridor?

1.1.4. Corridor Qualitative Factors and Context

- What else? ROW, environmental, future use, franchise utilities, drainage, constructability, railroads, etc.

1.2. *Purpose and Goals of ICE*

- Purpose and goals of ICE

1.3. *ICE Methodology*

1.3.1. ICE Stage 1: Scoping

- Give an overview of Stage 1.

1.3.2. ICE Stage 2: Alternative Development

- Give an overview of Stage 2.

1.4. *Intersection Stage 2 Conclusions*

- Have a paragraph or bullet point for the recommended traffic control at each intersection. "For more detail, see Part X: Intersection X-X."

1.4.1. Considerations for Adjacent intersection Alternatives in the Corridor

- Discuss how the selected interaction types affect adjacent intersection alternative types and choices, to integrate the alternatives in a corridor context.

Table 1-2 – List of Intersection Locations and Proposed Intersection Control

Header			

PART B, C, D, ETC.: INTERSECTION X-X

(Repeat this section for as many intersections as are in the corridor)

CHAPTER 2: INTERSECTION X-X SCOPING – ICE STAGE 1

2.1. *X-X Overview*

- What were the alternatives considered in stage 1? Include ones that were not even seriously considered, so we can describe why they weren't good options.

2.2. *Intersection X-X Location and Roadway Characteristics*

2.2.1. Maps of Intersection X-X Extents

- Show corridor map and highlight this intersection.

- Provide an aerial overview of existing conditions at the intersection location.

2.2.2. Intersection X-X Conditions with site observations

- Existing conditions. Are there any unsafe or inefficient conditions that should be described up front?

2.3. *X-X Traffic Data*

2.3.1. Intersection X-X TCDS Volume Analysis and Selected Growth Rate

- Traffic Counts, sources of info, growth factor/rate, trucks, interim year, ultimate year defined, MTPs. Include TMC figures here.

2.3.2. Intersection X-X TPP Line Diagrams (and Synchro-Compatible Format)

- TPP line diagrams

2.4. *Intersection X-X Capacity Analysis for Planning of Junctions (CAP-X)*

- Results summary table (everything else in Appendix) This is a pass/fail review of alternative intersection types. Preserve the list of intersections that pass LOS criteria to advance to Stage 2 ICE.

2.5. *Intersection X-X Design Vehicle and Design Speed*

- Design vehicle and design speed

2.6. *Intersection X-X Safety*

2.6.1. Intersection X-X Crash History

Crash history with frequency, severity and rates. Provide analysis, e.g. spatial patterns, target crash patterns that are mitigatable with a change in intersection control.

2.6.2. Intersection X-X FHWA SPICE

- SPICE spreadsheet results ranking the most promising alternatives with regard for crash reduction potential.

2.7. *Intersection X-X Stage 1 Results*

- Which of the evaluated options will be progressing to Stage 2 Analysis?

CHAPTER 3: INTERSECTION X-X ALTERNATIVE SELECTION – ICE STAGE 2

3.1. *Intersection X-X Stage 2 Overview*

- Which options are evaluated at stage 2? What factors are studied for stage 2?

3.2. *X-X Concept Designs*

3.2.1. Intersection X-X Preliminary Design Criteria

- What design criteria were true for all options?

3.2.2. Intersection X-X Roundabout Concept Design

- Describe RAB. Refer to Appendix J.

3.2.3. Intersection X-X Signal Concept Design

- Describe signal. Refer to Appendix K.

3.2.4. Intersection X-X Other Concept Design

- CGT? Other? If not, remove.

3.3. *Intersection X-X Opinion of Probable Construction Cost (OPCC)*

- OPCC

3.4. *Intersection X-X Operational Analysis – Level of Service*

- LOS and delay tables per approach and overall, color-coded

3.5. *Intersection X-X Safety Performance*

3.5.1. Intersection X-X Conflict Points

- Use Conflict Point Diagrams (vehicles, peds) to compare alternatives and recognize different speeds of various conflict points.

3.6. *Intersection X-X TxDOT Benefit-Cost Analysis*

- SII comparison analysis and results

3.7. *Intersection X-X Multimodal Accommodations*

- Discuss ped/bikes

3.8. *Intersection X-X Qualitative Benefits*

What qualities are pros/cons for each intersection type that aren't quantifiable? Consider potential future developments, right of way acquisition, franchise utility coordination, driveway impacts, constructability, etc.

Include Summary Evaluation of Qualitative Criteria table.

3.9. *Intersection X-X Stage 2 Results*

- Summarize findings. Which alternative is best in each area of comparison?

- Include Stage 2 Results Summary table.

CHAPTER 4: INTERSECTION X-X STAGE 1 AND 2 CONCLUSIONS

Based on the results, which alternative is recommended?

The information provided in this ICE Report should be carried forward to the public and used as a tool to educate local elected officials, citizens, and project stakeholders as to the advantages and disadvantages of varying types of intersection control methods. Both quantitative and qualitative data should be sourced to determine the preferred method of intersection control at these subject intersections.

PART X: CORRIDOR CONCLUSIONS

- Corridor map

- Restate Stage 2 options of each intersection.

- Provide a bullet summary (or table?) listing why our recommendation is best for each intersection based on safety, operations, cost, and other factors.

- Describe and document results showing how the coordination of intersection choice and recommended intersection controls will improve the corridor.

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APPENDIX L:	Site Photos

Section 2 – Intersection Analysis Resources

1. **Safety Performance for Intersection Control Evaluation**

   https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-026%20SPICE%20Tool%20User%20Guide%20(Final).pdf

   Spreadsheet Tool: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-026%20SPICE%20Tool%20(v1.4.1).xlsm

2. **Capacity Analysis for Planning of Junctions (CAP-X) Tool User Manual**

   User Guide: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-067%20CAP-X%202018%20Tool%20User%20Guide%20(Final).pdf

   https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-067%20CAP-X%202018%20Tool%20(v3.0.1).xlsm

3. **2023 Highway Safety Program SII Calculator**

   https://www.txdot.gov/about/programs/highway-safety-engineering.html

4. **Intersection Scoring Tool**

   https://ftp.txdot.gov/pub/txdot/des/safety-score-tools/

   https://ftp.dot.state.tx.us/pub/txdot/des/safety-score-tools/intersection-tool-faq.pdf

5. **Use of Innovative Intersection Designs for Improving Mobility and Reducing Roadway Traffic Congestion**

   https://cammse.charlotte.edu/wp-content/uploads/sites/191/2023/06/CAMMSE-UNCC-2017-UTC-Project-Report-08-Qi-Final.pdf

6. **FHWA Guide for Roundabouts, NCHRP 1043, 2023**

   https://nap.nationalacademies.org/download/27069#

   - A state of the practice guide for planning, design, construction, maintenance, and public outreach for roundabout projects.

7. **Roundabout Analysis Tool (HCM Methodology) powered by Georgia DOT**

   http://www.dot.ga.gov/DriveSmart/Roundabouts/AnalysisToolv4-2.zip

Section 3 – Intersection Analysis Checklist

Two checklists are provided: the fist is for ICE type studies; the second, a larger outline is for other studies including system optimization studies.

Basic informational elements usually necessary or helpful to complete **ICE Stage 1** include:

- Location, Context, Roadway Functional Classification, and Project Description
- Traffic Data (AADT, DHV, vehicle classification, percent trucks)
- Basic Roadway Characteristics (geometric elements, existing traffic control devices, pedestrian or bicycle features, unique conditions, or constraints, etc.) obtained from roadway inventory or online mapping.
- Pedestrian and bicycle information, such as activity, volumes, generators, etc. (when available)
- Existing Safety Performance
    - Long-term (minimum 5 years) crash history summary and diagram for intersection(s) under study
    - If available, findings and recommendations from a previously completed Road Safety Audit or other expressed safety concerns about the location(s), such as feedback from the local maintenance office or the general public.
    - Connection to the emphasis areas, goals or strategies included in the latest Texas SHSP https://www.texasshsp.com/. Specifically, describe how the project addresses the Serious Crash Type – Intersection Safety emphasis area (SEAs).

Elements included in **Stage 2** (for each of the short-listed Stage 1 alternatives) include:

- Preparation of high-level conceptual design/sketch for each short-listed alternative
    - Summarize and compare any right-of- way impacts and extent/significance of land acquisition
    - Include the essential elements or treatments for pedestrians and bicyclists
    - Critical/turning movement analysis of design vehicle and check vehicle(s) (i.e., oversize permit load scenarios)
- Identify significant environmental impacts (wetlands, parks, historic, etc.)
- Prepare capital cost estimate and summarize lifecycle maintenance and operation costs.
- Perform operational analysis to determine intersection delay and V/C ratio; and therefore, operational performance.
- Perform safety analysis to determine expected reduction in number of crashes, with an emphasis on the difference in severe crashes (i.e., those resulting in fatalities or injuries)

- Identify level of support from different stakeholders, including TxDOT, local government and other key stakeholders.

This is an informational checklist for studies including system optimization.

No	Item	ICE Analysis	Intersection Analysis	Review	
				Checked By	Date
1	**Methodology Coordination**				
1.1	Methodology & Assumptions Coordination Meeting (M&A) conducted and meeting notes documented	X	X		
1.2	M&A Memo includes a project description along with a project location map	X	X		
1.3	Need and Purpose supported by data and justifies the project	X	X		
1.4	Study area includes intersections as per M&A	X	X		
1.5	Analysis years per M&A	X	X		
1.6	Intersection control types to be considered and their assumptions per M&A	X			
1.7	Operational, safety, and multimodal analysis tools selected per M&A	X	X		
1.8	Cost benefit analysis tools selected per M&A	X			
2	**Background Data**				
2.1	Existing traffic count and crash data collected per M&A	X	X		
2.2	Growth rates developed from historical data and approved by TxDOT	X	X		
2.3	Long-range plans and improvements identified in the study area	X			
3	**Operational Analysis**				
3.1	Traffic operational analysis tools selected per M&A	X	X		
3.2	Latest guidelines/standards have been used	X	X		
3.3	If microsimulatoon tool was used, the report includes the calibration memo	X	X		
3.4	Measure of Effectiveness (MOEs) are consistent with analysis tools and project settings	X	X		
3.5	The results of traffic analysis have been reviewed for reasonableness	X	X		
3.6	The results of traffic analysis are compared across every alternative under consideration	X			
3.7	The traffic analysts software files checked to verify input and parameters	X	X		
4	**Safety Analysis**				
4.1	Safety analysis tools selected per M&A	X	X		
4.2	Histoncal crash data and analysis conducted for latest 3 to 5 years	X	X		
4.3	Intersection crash rate computed for latest 3 to 5 years	X	X		
4.4	Collision diagram created for latest 3 to 5 years	X	X		
4.5	Safety analysis includes predicted crash frequency or evaluation of CMF	X			
4.6	**Other Considerations**				
5.0	Applicable warrant analyses completed for considered alternatives	X			
5.1	Appicable questions answered under the Ch 9 "Other Considerations" section	X			
5.2	**Cost Benefit Analysis**				
5.3	Cost Benefit analysis tools selected per M&A	X			
5.4	Assumptions for each tool have been documented	X			
5.5	The results of cost benefit analysis are compared across every alternative under consideration	X			
6.0	**Report**				
6.1	Refer to ICE Report Outline	X			

Section 4 – Intersection Analysis Tools Sample Output

CAP-X Output for an Intersection Improvement Project

Capacity Analysis for Planning of Junctions

Dynamic Results Summary

TYPE OF INTERSECTION	Overall V/C Ratio	V/C Ranking	Pedestrian Accommodations	Bicycle Accommodations
3 X 3 Roundabout	0.31	1	Fair	Excellent
2 X 2 Roundabout	0.46	2	Good	Excellent
Traffic Signal	0.58	3	Good	Excellent
2NS X 1EW Roundabout	0.61	4	Good	Excellent
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--

HCM Analysis Output Sample

#	INTERSECTION	TURNING MOVEMENT	TURNING MOVEMENT VOLUME	95TH PERCENTILE QUEUE LENGTH (ft)	CONTROL DELAY (sec)	APPROACH VOLUME	APPROACH DELAY (sec/veh)	APPROACH LOS
1	Main Street & First Street	EBL	50	0	0.0	100	35.3	D
		EBT	30	48	34.8			
		EBR	20	0	0.0			
		WBL	5	0	0.0	16	30.9	C
		WBT	6	26	30.4			
		WBR	5	0	0.0			
		NBL	7	0	0.0	197	730.3	F
		NBT	173	250	730.3			
		NBR	17	0	0.0			
		SBL	222	175	192.2	527	150.5	F
		SBT	291	240	96.1			
		SBR	14	0	0.0			
					Overall Intersection	840	270.2	F

Section 5 – TMUTCD Signal Warrant Analysis Guidelines

CHAPTER 4C. TRAFFIC CONTROL SIGNAL NEEDS STUDIES

Section 4C.01 Studies and Factors for Justifying Traffic Control Signals

Standard:

01 An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.

02 The investigation of the need for a traffic control signal shall include an analysis of factors related to the existing operation and safety at the study location and the potential to improve these conditions, and the applicable factors contained in the following traffic signal warrants:

Warrant 1, Eight-Hour Vehicular Volume
Warrant 2, Four-Hour Vehicular Volume
Warrant 3, Peak Hour
Warrant 4, Pedestrian Volume
Warrant 5, School Crossing
Warrant 6, Coordinated Signal System
Warrant 7, Crash Experience
Warrant 8, Roadway Network
Warrant 9, Intersection Near a Grade Crossing

03 The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a **traffic control signal.**

Support:

04 Sections 8C.09 and 8C.10 contain information regarding the use of traffic control signals instead of gates and/or flashing-light signals at highway-rail grade crossings and highway-light rail transit grade crossings, respectively.

Guidance:

05 *A traffic control signal should not be installed unless one or more of the factors described in this Chapter are met.*

06 *A traffic control signal should not be installed unless an engineering study indicates that installing a traffic control signal will improve the overall safety and/or operation of the intersection.*

07 *A traffic control signal should not be installed if it will seriously disrupt progressive traffic flow.*

08 *The study should consider the effects of the right-turn vehicles from the minor-street approaches. Engineering judgment should be used to determine what, if any, portion of the right-turn traffic is subtracted from the minor-street traffic count when evaluating the count against the signal warrants listed in Paragraph 2.*

09 *Engineering judgment should also be used in applying various traffic signal warrants to cases where approaches consist of one lane plus one left-turn or right-turn lane. The site-specific traffic characteristics should dictate whether an approach is considered as one lane or two lanes. For example, for an approach with one lane for through and right-turning traffic plus a left-turn lane, if engineering judgment indicates that it should be considered a one-lane approach because the traffic using the left-turn lane is minor, the total traffic volume approaching the intersection should be applied against the signal warrants as a one-lane approach. The approach should be*

considered two lanes if approximately half of the traffic on the approach turns left and the left-turn lane is of sufficient length to accommodate all left-turn vehicles.

10 *Similar engineering judgment and rationale should be applied to a street approach with one through/left-turn lane plus a right-turn lane. In this case, the degree of conflict of minor-street right-turn traffic with traffic on the major street should be considered. Thus, right-turn traffic should not be included in the minor-street volume if the movement enters the major street with minimal conflict. The approach should be evaluated as a one-lane approach with only the traffic volume in the through/left-turn lane considered.*

11 *At a location that is under development or construction and where it is not possible to obtain a traffic count that would represent future traffic conditions, hourly volumes should be estimated as part of an engineering study for comparison with traffic signal warrants. Except for locations where the engineering study uses the satisfaction of Warrant 8 to justify a signal, a traffic control signal installed under projected conditions should have an engineering study done within 1 year of putting the signal into stop-and-go operation to determine if the signal is justified. If not justified, the signal should be taken out of stop-and-go operation or removed.*

12 *For signal warrant analysis, a location with a wide median, even if the median width is greater than 30 feet, should be considered as one intersection.*

Option:

13 At an intersection with a high volume of left-turn traffic from the major street, the signal warrant analysis may be performed in a manner that considers the higher of the major-street left-turn volumes as the "minor-street" volume and the corresponding single direction of opposing traffic on the major street as the "major-street" volume.

14 For signal warrants requiring conditions to be present for a certain number of hours in order to be satisfied, any four sequential 15-minute periods may be considered as 1 hour if the separate 1-hour periods used in the warrant analysis do not overlap each other and both the major-street volume and the minor-street volume are for the same specific one-hour periods.

15 For signal warrant analysis, bicyclists may be counted as either vehicles or pedestrians.

Support:

16 When performing a signal warrant analysis, bicyclists riding in the street with other vehicular traffic are usually counted as vehicles and bicyclists who are clearly using pedestrian facilities are usually counted as pedestrians.

Option:

17 Engineering study data may include the following:

A. The number of vehicles entering the intersection in each hour from each approach during 12 hours of an average day. It is desirable that the hours selected contain the greatest percentage of the 24-hour traffic volume.

B. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, public-transit vehicles, and, in some locations, bicycles), during each 15-minute period of the 2 hours in the morning and 2 hours in the afternoon during which total traffic entering the intersection is greatest.

C. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in Item B and during hours of highest pedestrian volume. Where young, elderly, and/or persons with physical or visual disabilities need special consideration, the pedestrians and their crossing times may be classified by general observation.

D. Information about nearby facilities and activity centers that serve the young, elderly, and/or persons with disabilities, including requests from persons with disabilities for accessible crossing improvements at the location under study. These persons might not be adequately reflected in the pedestrian volume count if the absence of a signal restrains their mobility.
E. The posted or statutory speed limit or the 85th-percentile speed on the uncontrolled approaches to the location.
F. A condition diagram showing details of the physical layout, including such features as intersection geometrics, channelization, grades, sight-distance restrictions, transit stops and routes, parking conditions, pavement markings, roadway lighting, driveways, nearby railroad crossings, distance to nearest traffic control signals, utility poles and fixtures, and adjacent land use.
G. A collision diagram showing crash experience by type, location, direction of movement, severity, weather, time of day, date, and day of week for at least 1 year.

18 The following data, which are desirable for a more precise understanding of the operation of the intersection, may be obtained during the periods described in Item B of Paragraph 17:

A. Vehicle-hours of stopped time delay determined separately for each approach.
B. The number and distribution of acceptable gaps in vehicular traffic on the major street for entrance from the minor street.
C. The posted or statutory speed limit or the 85$_{th}$-percentile speed on controlled approaches at a point near to the intersection but unaffected by the control.
D. Pedestrian delay time for at least two 30-minute peak pedestrian delay periods of an average weekday or like periods of a Saturday or Sunday.
E. Queue length on stop-controlled approaches.

Section 4C.02 Warrant 1, Eight-Hour Vehicular Volume

Support:

01 The Minimum Vehicular Volume, Condition A, is intended for application at locations where a large volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

02 The Interruption of Continuous Traffic, Condition B, is intended for application at locations where Condition A is not satisfied and where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or conflict in entering or crossing the major street.

03 It is intended that Warrant 1 be treated as a single warrant. If Condition A is satisfied, then Warrant 1 is satisfied and analyses of Condition B and the combination of Conditions A and B are not needed. Similarly, if Condition B is satisfied, then Warrant 1 is satisfied and an analysis of the combination of Conditions A and B is not needed.

Standard:

04 **The need for a traffic control signal shall be considered if an engineering study finds that one of the following conditions exist for each of any 8 hours of an average day:**

A. The vehicles per hour given in both of the 100 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; or

B. The vehicles per hour given in both of the 100 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

In applying each condition the major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of these 8 hours.

Option:

05 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 70 percent columns in Table 4C-1 may be used in place of the 100 percent columns.

Guidance:

06 *The combination of Conditions A and B is intended for application at locations where Condition A is not satisfied and Condition B is not satisfied and should be applied only after an adequate trial of other alternatives that could cause less delay and inconvenience to traffic has failed to solve the traffic problems.*

Standard:

07 The need for a traffic control signal shall be considered if an engineering study finds that both of the following conditions exist for each of any 8 hours of an average day:

A. The vehicles per hour given in both of the 80 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; and

B. The vehicles per hour given in both of the 80 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

These major-street and minor-street volumes shall be for the same 8 hours for each condition; however, the 8 hours satisfied in Condition A shall not be required to be the same 8 hours satisfied in Condition B. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Table 4C-1. Warrant 1, Eight-Hour Vehicular Volume

Condition A—Minimum Vehicular Volume

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)				Vehicles per hour on higher-volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a]	80%[b]	70%[c]	56%[d]	100%[a]	80%[b]	70%[c]	56%[d]
1	1	500	400	350	280	150	120	105	84
2 or more	1	600	480	420	336	150	120	105	84
2 or more	2 or more	600	480	420	336	200	160	140	112
1	2 or more	500	400	350	280	200	160	140	112

Condition B— Interruption of Continuous Traffic

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)				Vehicles per hour on higher-volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a]	80%[b]	70%[c]	56%[d]	100%[a]	80%[b]	70%[c]	56%[d]
1	1	750	600	525	420	75	60	53	42
2 or more	1	900	720	630	504	75	60	53	42
2 or more	2 or more	900	720	630	504	100	80	70	56
1	2 or more	750	600	525	420	100	80	70	56

a Basic minimum hourly volume
b Used for combination of Conditions A and B after adequate trial of other remedial measures
c May be used when the major-street speed exceeds 40 mph or in an isolated community with a population of less than 10,000
d May be used for combination of Conditions A and B after adequate trial of other remedial measures when the major-street speed exceeds 40 mph or in an isolated community with a population of less than 10,000

Option:

08 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 56 percent columns in Table 4C-1 may be used in place of the 80 percent columns.

Section 4C.03 Warrant 2, Four-Hour Vehicular Volume

Support:

01 The Four-Hour Vehicular Volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

Standard:

02 **The need for a traffic control signal shall be considered if an engineering study finds that, for each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) all fall above the applicable curve in Figure 4C-1 for the existing combination of approach lanes. On the minor street, the higher volume shall not be required to be on the same approach during each of these 4 hours.**

Option:

03 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4C-2 may be used in place of Figure 4C-1.

Section 4C.04 Warrant 3, Peak Hour

Support:

01 The Peak Hour signal warrant is intended for use at a location where traffic conditions are such that for a minimum of 1 hour of an average day, the minor-street traffic suffers undue delay when entering or crossing the major street.

Standard:

02 **This signal warrant shall be applied only in unusual cases, such as office complexes, manufacturing plants, industrial complexes, or HOV facilities that attract or discharge large numbers of vehicles over a short time.**

03 **The need for a traffic control signal shall be considered if an engineering study finds that the criteria in either of the following two categories are met:**

A. If all three of the following conditions exist for the same 1 hour (any four consecutive 15-minute periods) of an average day:

1. The total stopped time delay experienced by the traffic on one minor-street approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach or 5 vehicle-hours for a two-lane approach; and
2. The volume on the same minor-street approach (one direction only) equals or exceeds 100 vehicles per hour for one moving lane of traffic or 150 vehicles per hour for two moving lanes; and
3. The total entering volume serviced during the hour equals or exceeds 650 vehicles per hour for intersections with three approaches or 800 vehicles per hour for intersections with four or more approaches.

B. The plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 4C-3 for the existing combination of approach lanes.

Option:

04 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4C-4 may be used in place of Figure 4C-3 to evaluate the criteria in the second category of the Standard.

05 If this warrant is the only warrant met and a traffic control signal is justified by an engineering study, the traffic control signal may be operated in the flashing mode during the hours that the volume criteria of this warrant are not met.

Guidance:

06 *If this warrant is the only warrant met and a traffic control signal is justified by an engineering study, the traffic control signal should be traffic-actuated.*

Section 4C.05 Warrant 4, Pedestrian Volume

Support:

01 The Pedestrian Volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street.

Standard:

02 The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that one of the following criteria is met:

A. For each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) all fall above the curve in Figure 4C-5; or
B. For 1 hour (any four consecutive 15-minute periods) of an average day, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) falls above the curve in Figure 4C-7.

Option:

03 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 35 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4C-6 may be used in place of Figure 4C-5 to evaluate Criterion A in Paragraph 2, and Figure 4C-8 may be used in place of Figure 4C-7 to evaluate Criterion B in Paragraph 2.

Standard:

04 The Pedestrian Volume signal warrant shall not be applied at locations where the distance to the nearest traffic control signal or STOP sign controlling the street that pedestrians desire to cross is less than 300 feet, unless the proposed traffic control signal will not restrict the progressive movement of traffic.

05 **If this warrant is met and a traffic control signal is justified by an engineering study, the traffic control signal shall be equipped with pedestrian signal heads complying with the provisions set forth in Chapter 4E.**

Guidance:

06 *If this warrant is met and a traffic control signal is justified by an engineering study, then:*

A. If it is installed at an intersection or major driveway location, the traffic control signal should also control the minor-street or driveway traffic, should be traffic-actuated, and should include pedestrian detection.
B. If it is installed at a non-intersection crossing, the traffic control signal should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs, and should be pedestrian-actuated. If the traffic control signal is installed at a non-intersection crossing, at least one of the signal faces should be over the traveled way for each approach, parking and other sight obstructions should be prohibited for at least 100 feet in advance of and at least 20 feet beyond the crosswalk or site accommodations should be made through curb extensions or other techniques to provide adequate sight distance, and the installation should include suitable standard signs and pavement markings.
C. Furthermore, if it is installed within a signal system, the traffic control signal should be coordinated.

Option:

07 The criterion for the pedestrian volume crossing the major street may be reduced as much as 50 percent if the 15th-percentile crossing speed of pedestrians is less than 3.5 feet per second.

08 A traffic control signal may not be needed at the study location if adjacent coordinated traffic control signals consistently provide gaps of adequate length for pedestrians to cross the street.

Section 4C.06 Warrant 5, School Crossing

Support:

01 The School Crossing signal warrant is intended for application where the fact that school children cross the major street is the principal reason to consider installing a traffic control signal. For the purposes of this warrant, the word “school children” includes elementary through high school students.

Standard:

02 **The need for a traffic control signal shall be considered when an engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at an established school crossing across the major street shows that the number of adequate gaps in the traffic stream during the period when the school children are using the crossing is less than the number of minutes in the same period (see Section 7A.03) and there are a minimum of 20 school children during the highest crossing hour.**

Before a decision is made to install a traffic control signal, consideration shall be given to the implementation of other remedial measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing.

04 **The School Crossing signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 300 feet, unless the proposed traffic control signal will not restrict the progressive movement of traffic.**

Guidance:

05 *If this warrant is met and a traffic control signal is justified by an engineering study, then:*

A. If it is installed at an intersection or major driveway location, the traffic control signal should also control the minor-street or driveway traffic, should be traffic-actuated, and should include pedestrian detection.
B. If it is installed at a non-intersection crossing, the traffic control signal should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs, and should be pedestrian-actuated. If the traffic control signal is installed at a non-intersection crossing, at least one of the signal faces should be over the traveled way for each approach, parking and other sight obstructions should be prohibited for at least 100 feet in advance of and at least 20 feet beyond the crosswalk or site

accommodations should be made through curb extensions or other techniques to provide adequate sight distance, and the installation should include suitable standard signs and pavement markings.
C. Furthermore, if it is installed within a signal system, the traffic control signal should be coordinated.

Section 4C.07 Warrant 6, Coordinated Signal System

Support:

01 Progressive movement in a coordinated signal system sometimes necessitates installing traffic control signals at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.

Standard:

02 **The need for a traffic control signal shall be considered if an engineering study finds that one of the following criteria is met:**

A. On a one-way street or a street that has traffic predominantly in one direction, the adjacent traffic control signals are so far apart that they do not provide the necessary degree of vehicular platooning.
B. On a two-way street, adjacent traffic control signals do not provide the necessary degree of platooning and the proposed and adjacent traffic control signals will collectively provide a progressive operation.

Guidance:

03 *The Coordinated Signal System signal warrant should not be applied where the resultant spacing of traffic control signals would be less than 1,000 feet.*

Section 4C.08 Warrant 7, Crash Experience

Support:

01 The Crash Experience signal warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal.

Standard:

02 **The need for a traffic control signal shall be considered if an engineering study finds that all of the following criteria are met:**

A. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency; and
B. Five or more reported crashes, of types susceptible to correction by a traffic control signal, have occurred within a 12-month period, each crash involving personal injury or property damage apparently exceeding the applicable requirements for a reportable crash; and
C. For each of any 8 hours of an average day, the vehicles per hour (vph) given in both of the 80 percent columns of Condition A in Table 4C-1 (see Section 4C.02), or the vph in both of the 80 percent columns of Condition B in Table 4C-1 exists on the major-street and the higher-volume minor-street approach, respectively, to the intersection, or the volume of pedestrian traffic is not less than 80 percent of the requirements specified in the Pedestrian Volume warrant. These major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Option:

03 If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 56 percent columns in Table 4C-1 may be used in place of the 80 percent columns.

Section 4C.09 Warrant 8, Roadway Network

Support:

01 Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a roadway network.

Standard:

02 The need for a traffic control signal shall be considered if an engineering study finds that the common intersection of two or more major routes meets one or both of the following criteria:

A. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 vehicles per hour during the peak hour of a typical weekday and has 5-year projected traffic volumes, based on an engineering study, that meet one or more of Warrants 1, 2, and 3 during an average weekday; or
B. The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a non-normal business day (Saturday or Sunday).

03 A major route as used in this signal warrant shall have at least one of the following characteristics:

A. It is part of the street or highway system that serves as the principal roadway network for through traffic flow.
B. It includes rural or suburban highways outside, entering, or traversing a city.
C. It appears as a major route on an official plan, such as a major street plan in an urban area traffic and transportation study.
D. It connects areas of principal traffic generation.
E. It has surface street freeway or expressway ramp terminals.

Section 4C.10 Warrant 9, Intersection Near a Grade Crossing

Support:

01 The Intersection Near a Grade Crossing signal warrant is intended for use at a location where none of the conditions described in the other eight traffic signal warrants are met, but the proximity to the intersection of a grade crossing on an intersection approach controlled by a STOP or YIELD sign is the principal reason to consider installing a traffic control signal.

Guidance:

02 *This signal warrant should be applied only after adequate consideration has been given to other alternatives or after a trial of an alternative has failed to alleviate the safety concerns associated with the grade crossing. Among the alternatives that should be considered or tried are:*

A. Providing additional pavement that would enable vehicles to clear the track or that would provide space for an evasive maneuver, or
B. Reassigning the stop controls at the intersection to make the approach across the track a non-stopping approach.

Standard:

03 The need for a traffic control signal shall be considered if an engineering study finds that both of the following criteria are met:

A. A grade crossing exists on an approach controlled by a STOP or YIELD sign and the center of the track nearest to the intersection is within 140 feet of the stop line or yield line on the approach; and
B. During the highest traffic volume hour during which rail traffic uses the crossing, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the minor-street approach that crosses the track (one direction only, approaching the intersection) falls above the applicable curve in Figure 4C-9 or 4C-10 for the existing combination of approach lanes over the track and the distance D, which is the clear storage distance as defined in Section 1A.13.

Guidance:

04 *The following considerations apply when plotting the traffic volume data on Figure 4C-9 or 4C-10:*

A. Figure 4C-9 should be used if there is only one lane approaching the intersection at the track crossing location and Figure 4C-10 should be used if there are two or more lanes approaching the intersection at the track crossing location.

B. After determining the actual distance D, the curve for the distance D that is nearest to the actual distance D should be used. For example, if the actual distance D is 95 feet, the plotted point should be compared to the curve for D = 90 feet.

C. If the rail traffic arrival times are unknown, the highest traffic volume hour of the day should be used.

Option:

05 The minor-street approach volume may be multiplied by up to three AFs as provided in Paragraphs 6 through 8.

06 Because the curves are based on an average of four occurrences of rail traffic per day, the vehicles per hour on the minor-street approach may be multiplied by the adjustment factor shown in Table 4C-2 for the appropriate number of occurrences of rail traffic per day.

07 Because the curves are based on typical vehicle occupancy, if at least 2% of the vehicles crossing the track are buses carrying at least 20 people, the vehicles per hour on the minor-street approach may be multiplied by the adjustment factor shown in Table 4C-3 for the appropriate percentage of high-occupancy buses.

08 Because the curves are based on tractor-trailer trucks comprising 10% of the vehicles crossing the track, the vehicles per hour on the minor-street approach may be multiplied by the adjustment factor shown in Table 4C-4 for the appropriate distance and percentage of tractor-trailer trucks.

Standard:

09 **If this warrant is met and a traffic control signal at the intersection is justified by an engineering study, then:**

A. The traffic control signal shall have actuation on the minor street;
B. Preemption control shall be provided in accordance with Sections 4D.27, 8C.09, and 8C.10; and
C. The grade crossing shall have flashing-light signals (see Chapter 8C).

Guidance:

10 *If this warrant is met and a traffic control signal at the intersection is justified by an engineering study, the grade crossing should have automatic gates (see Chapter 8C).*

Table 4C-2. Warrant 9, Adjustment Factor for Daily Frequency of Rail Traffic

Rail Traffic per Day	Adjustment Factor
1	0.67
2	0.91
3 to 5	1.00
6 to 8	1.18
9 to 11	1.25
12 or more	1.33

Table 4C-3. Warrant 9, Adjustment Factor for Percentage of High-Occupancy Buses

% of High-Occupancy Buses* on Minor-Street Approach	Adjustment Factor
0%	1.00
2%	1.09
4%	1.19
6% or more	1.32

* A high-occupancy bus is defined as a bus occupied by at least 20 people.

Table 4C-4. Warrant 9, Adjustment Factor for Percentage of Tractor-Trailer Trucks

% of Tractor-Trailer Trucks on Minor-Street Approach	Adjustment Factor	
	D less than 70 feet	D of 70 feet or more
0% to 2.5%	0.50	0.50
2.6% to 7.5%	0.75	0.75
7.6% to 12.5%	1.00	1.00
12.6% to 17.5%	2.30	1.15
17.6% to 22.5%	2.70	1.35
22.6% to 27.5%	3.28	1.64
More than 27.5%	4.18	2.09

Section 6 – TMUTCD Signal Warrant Analysis Spreadsheet

TRAFFIC SIGNAL WARRANT ANALYSIS (2011 TXMUTCD)

MAJOR STREET:	Street 1	EB	WB	# OF APPROACH LANES:	3
MINOR STREET:	Street 2	NB	SB	# OF APPROACH LANES:	2
CITY, STATE:					
COMMENTS:					

ISOLATED COMMUNITY WITH POPULATION LESS THAN 10,000 (Y OR N): N

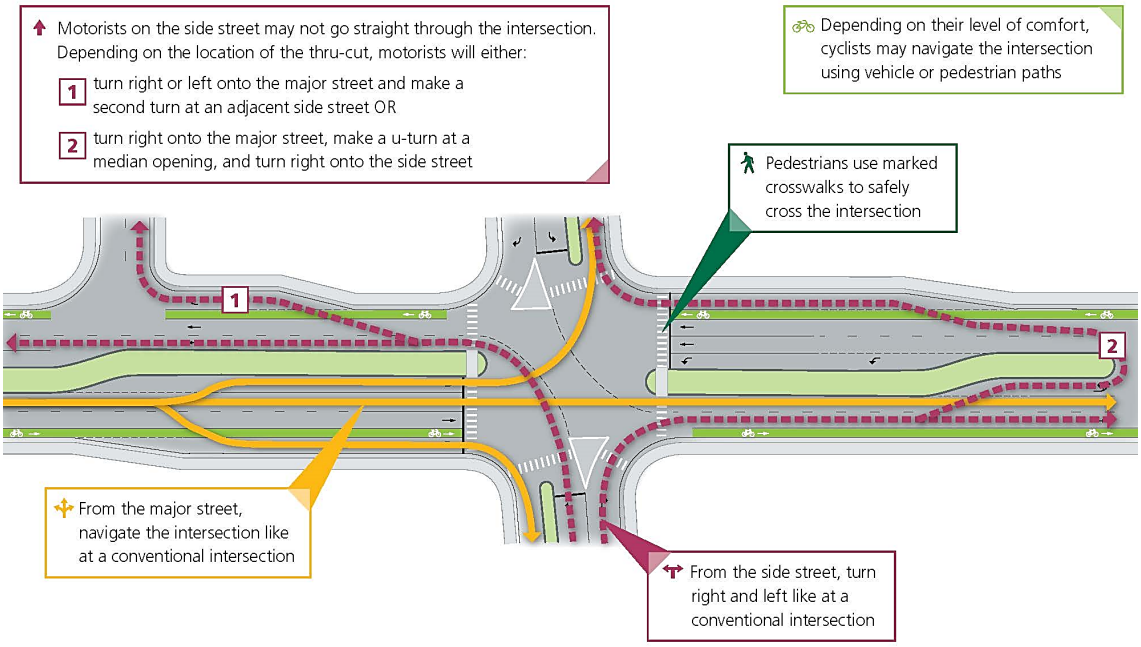
85TH PERCENTILE SPEED OR POSTED SPEED LIMIT GREATER THAN 40 MPH ON MAJOR STREET (Y OR N): Y

			Street 1			Street 2		
			EB Approach	WB Approach	Total	NB Approach	SB Approach	Minor Street Heavy Leg
06:00 AM	TO	07:00 AM	727	269	996	12	43	43
07:00 AM	TO	08:00 AM	969	376	1345	12	79	79
08:00 AM	TO	09:00 AM	759	409	1168	15	83	83
09:00 AM	TO	10:00 AM	543	382	925	17	90	90
10:00 AM	TO	11:00 AM	489	394	883	14	103	103
11:00 AM	TO	12:00 PM	512	483	995	16	128	128
12:00 PM	TO	01:00 PM	556	487	1043	16	126	126
01:00 PM	TO	02:00 PM	515	449	964	11	92	92
02:00 PM	TO	03:00 PM	535	515	1050	14	90	90
03:00 PM	TO	04:00 PM	531	614	1145	11	201	201
04:00 PM	TO	05:00 PM	490	808	1298	19	158	158
05:00 PM	TO	06:00 PM	463	936	1399	13	140	140
06:00 PM	TO	07:00 PM	488	708	1196	12	61	61
07:00 PM	TO	08:00 PM	408	443	851	13	14	14
08:00 PM	TO	09:00 PM	347	307	654	9	9	9
09:00 PM	TO	10:00 PM	262	248	510	13	16	16

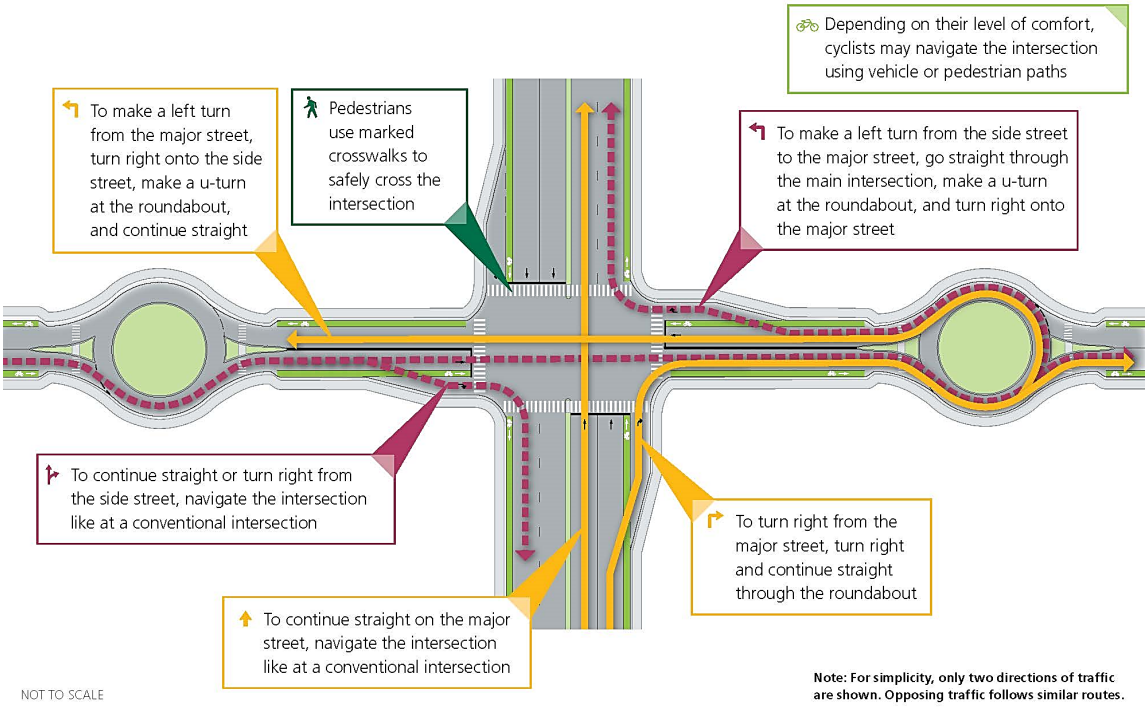
Warrant	Description	Warrant Met?
1	Eight-Hour Volume	WARRANT MET
2	Four-Hour Volume	WARRANT MET
3	Peak Hour Volume	N/A
4	Pedestrian Volume	Warrant NOT Met
5	School Crossing	N/A
6	Coordinated Signal System	N/A
7	Crash Experience	Warrant NOT Met
8	Roadway Network	Warrant NOT Met
9	Intersection Near a Grade Crossing	N/A

10/13/22

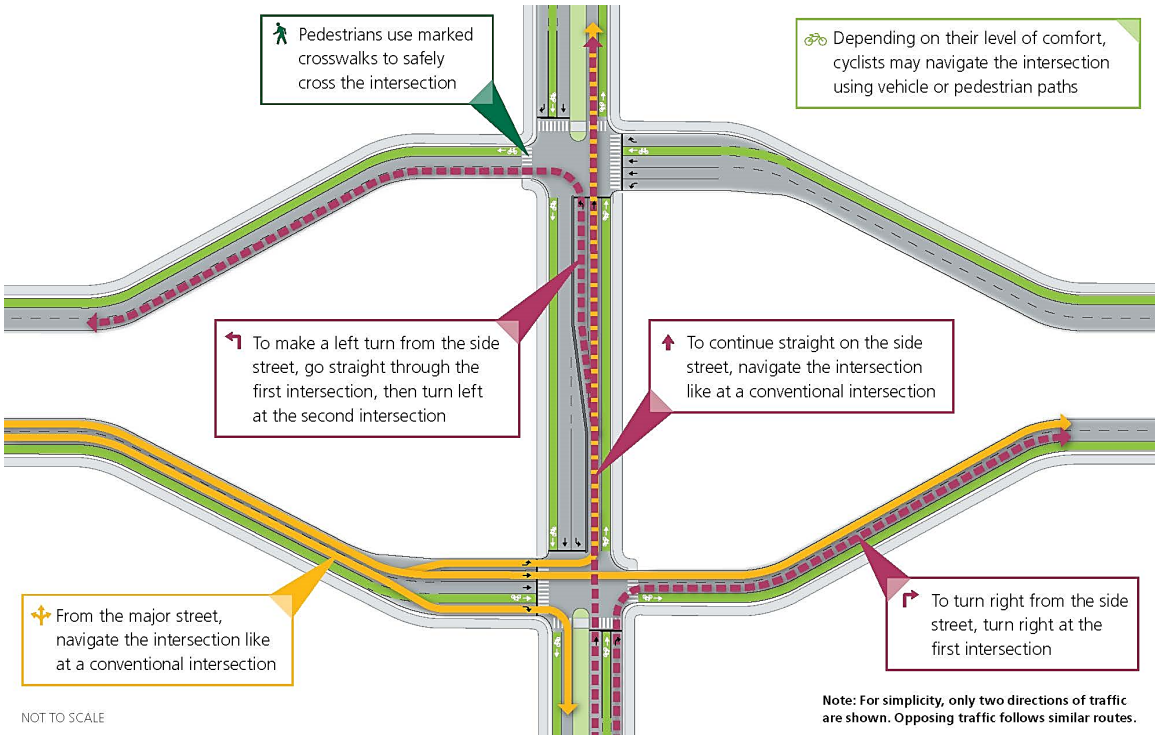
Section 7 – Intersection Type Graphics



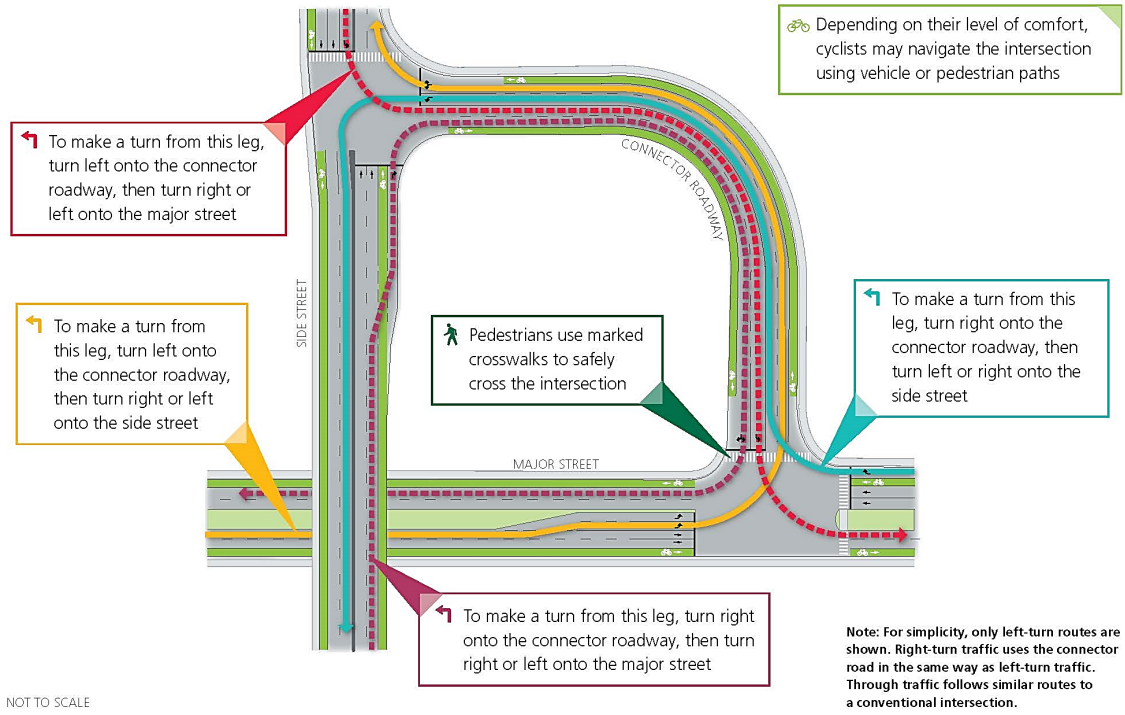
Source: Virginia Department of Transportation, 03/05/2024 (Thru Cut Intersection)



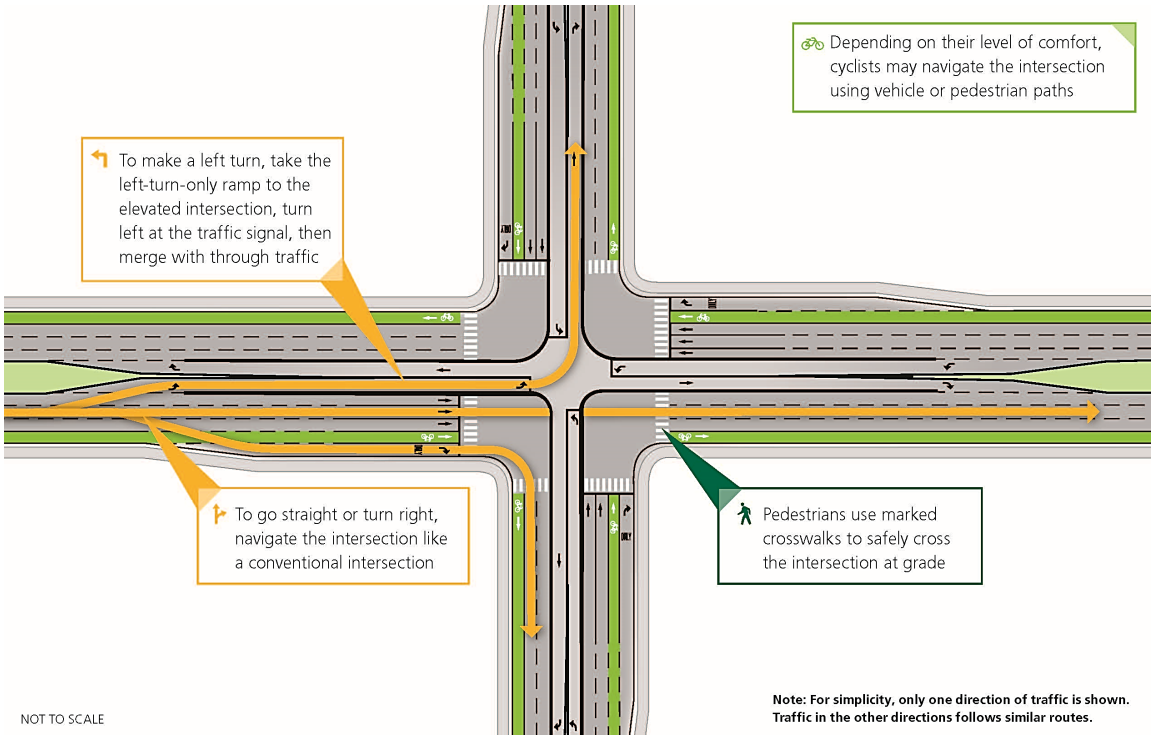
Source: Virginia Department of Transportation, 03/05/2024 (Bowtie Intersection)



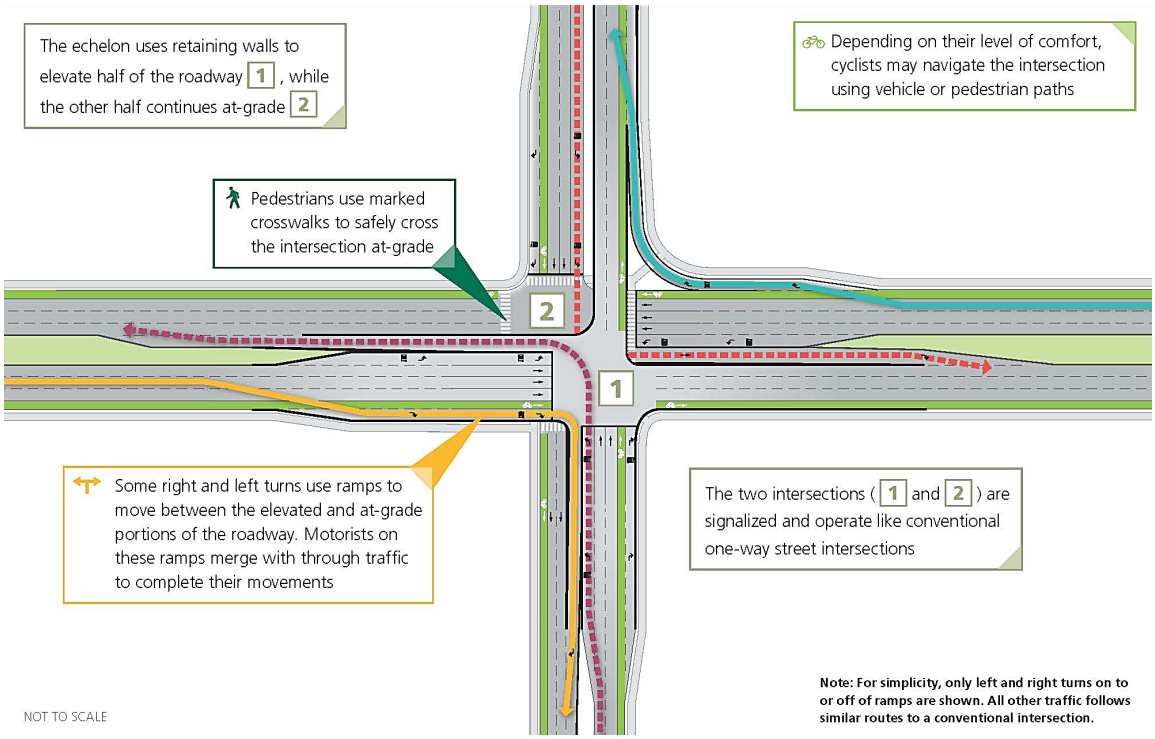
Source: Virginia Department of Transportation, 03/05/2024 (Split Intersection)



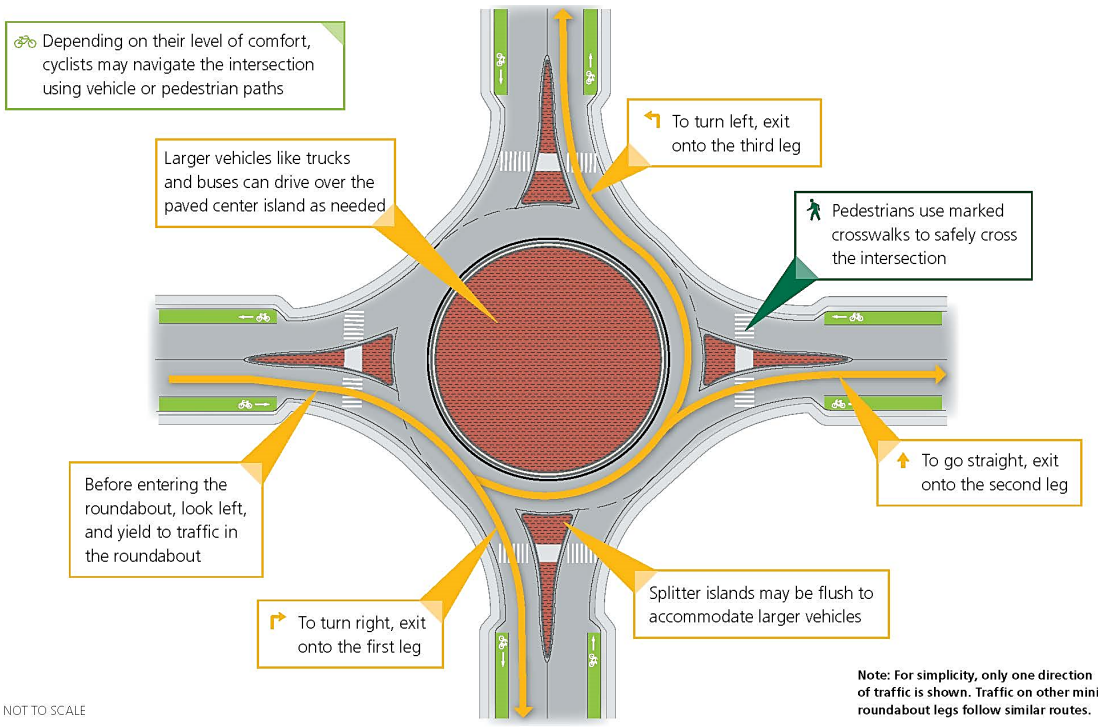
Source: Virginia Department of Transportation, 03/05/2024 (Quadrant Roadway)



Source: Virginia Department of Transportation, 03/05/2024 (Center Turn Overpass Intersection)



Source: Virginia Department of Transportation, 03/05/2024 (Echelon Intersection)



Source: Virginia Department of Transportation, 03/05/2024 (Mini Roundabout)

Section 8 – External References

The websites below were last accessed on May 31, 2024

1. **Intersection Control Evaluation Federal Highway Administration**

   https://safety.fhwa.dot.gov/intersection/ice/

   - ICE is a data-driven framework to screen intersection alternatives for optimal performance.

2. **Alternative Intersections/Interchanges: Informational Report**

   https://www.fhwa.dot.gov/publications/research/safety/09060/

   - The informational report covers four intersections and two interchange designs that offer substantial advantages over conventional intersections and diamond interchanges.

3. **The Federal Highway Administration Displaced Left-Turn Intersection**

   https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14068.pdf

   - This document is a technical summary of the FHWA report on the displaced left turn.

4. **Federal Highway Administration Restricted Crossing U-Turn Intersection Guide**

   https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa14070.pdf

5. **Federal Highway Administration Median U-Turn Intersection Guide**

   https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa14069.pdf

6. **Quadrant Roadway Intersection Guide, 2020**

   https://safety.fhwa.dot.gov/intersection/other/fhwasa19029.pdf

7. **Estimating the Life-Cycle Cost and Impact of Intersection Designs**

   https://nap.nationalacademies.org/download/21928

   https://rosap.ntl.bts.gov/view/dot/31058

8. **Evaluating the Performance of Corridors with Roundabouts, NCHRP 772, 2014**

   https://nap.nationalacademies.org/catalog/22348/evaluating-the-performance-of-corridors-with-roundabouts

   - Evaluating the Performance of Corridors with Roundabouts provides measurement and evaluation methods for comparing the performance of a corridor with a functionally interdependent series of roundabouts to a corridor with signalized intersections in order to arrive at a design solution.

9. **Roadway Design Manual, December 2022**

   http://onlinemanuals.txdot.gov/txdotmanuals/rdw/index.htm

   - This manual contains geometric design recommendations.

10. Texas Manual on Uniform Traffic Control Devices Revision 2, October 2014

https://ftp.dot.state.tx.us/pub/txdot-info/trf/tmutcd/2011-rev-2/revision-2.pdf

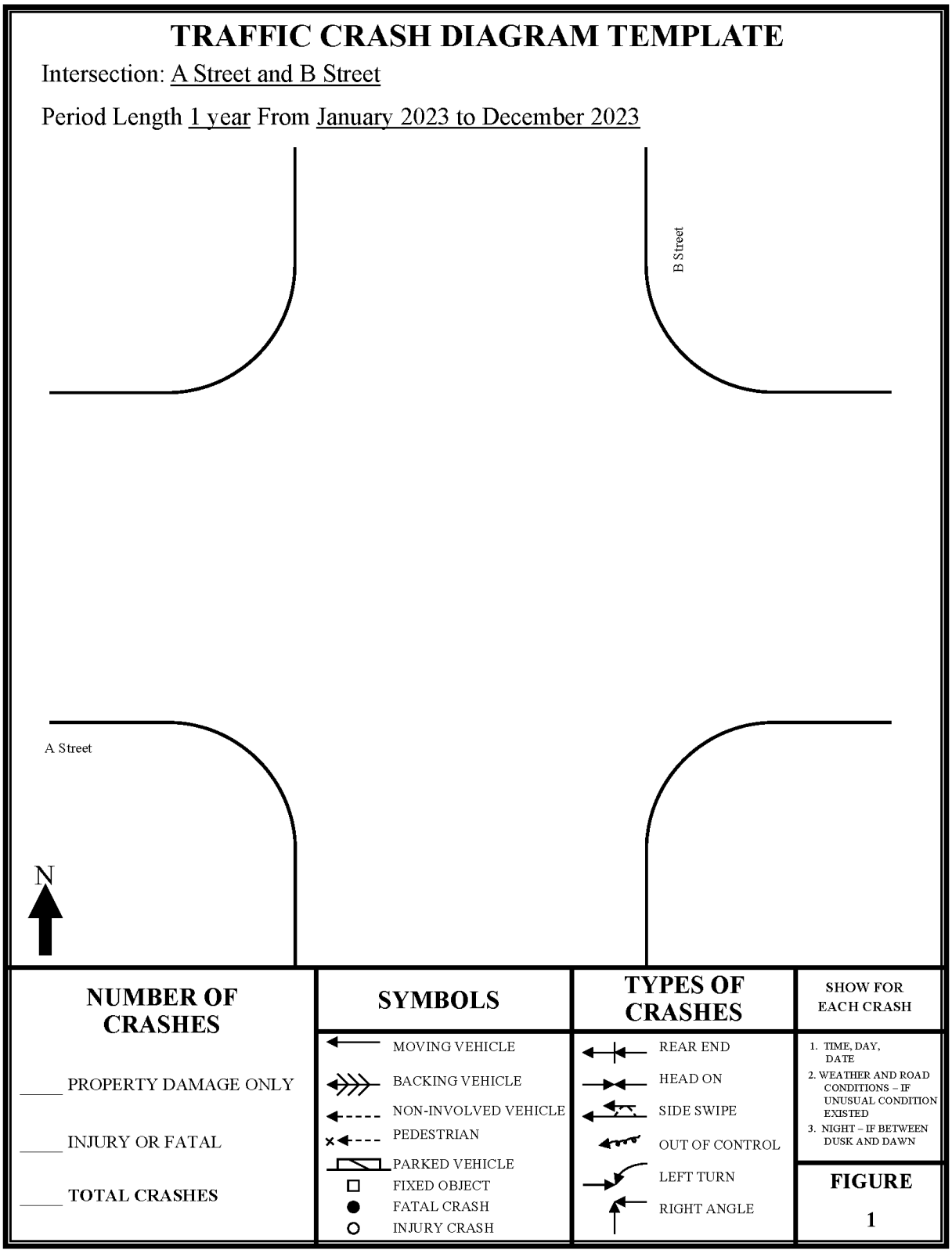
- The MUTCD is a document issued by the FHWA to specify the standards by which traffic signs, road surface markings, and signals are designed, installed, and used.

11. Texas Intersection Inventory

https://app.powerbi.com/view?r=eyJrIjoiYTVjYWNlYzgtMjRjYi00ZTk3LWJkMGQtMDM5M2RkM2Q4NTVkIiwidCI6IjdlMjIwZDMwLTBiNTktNDdlNS04YTgxLWE0YTlkOWFmYmRjNCIsImMiOjN9

- An inventory of alternative intersections within Texas

Section 9 – Crash Diagram Template



Chapter 11 - Appendix L – Interchange Analysis

- Section 1 – Interchange Analysis Checklist
  - Interchange Analysis Checklist – ICE (See Chapter 10, Appendix K for sample reports)
  - Interchange Analysis Checklist – Other Studies
- Section 2 – Diverging Diamond Intersections Factsheet
- Section 3 – Single-Point Urban Interchange Factsheet
- Section 4 – External References

Section 1 – Interchange Analysis Checklist ICE

Basic informational elements usually necessary or helpful to complete **ICE Stage 1** include:

- Location, Context, Roadway Functional Classification, and Project Description
- Traffic Data (AADT, DHV, vehicle classification, percent trucks)
- Basic Roadway Characteristics (geometric elements, existing traffic control devices, pedestrian or bicycle features, unique conditions, or constraints, etc.) obtained from roadway inventory or online mapping.
- Pedestrian and bicycle information, such as activity, volumes, generators, etc. (when available)
- Existing Safety Performance
  - Long-term (minimum 5 years) crash history summary and diagram for intersection(s) under study
  - If available, findings and recommendations from a previously completed Road Safety Audit or other expressed safety concerns about the location(s), such as feedback from the local maintenance office or the public.
  - Connection to the emphasis areas, goals or strategies included in the latest Texas SHSP https://www.texasshsp.com/. Specifically, describe how the project addresses the Serious Crash Type – Intersection Safety emphasis area.

Elements required for **Stage 2** (for each of the short-listed Stage 1 alternatives) include:

- Prepare high-level conceptual design/sketch for each short-listed alternative
  - Summarize and compare any right-of- way impacts and extent/significance of land acquisition
  - Include the essential elements or treatments for pedestrians and bicyclists
  - Critical/turning movement analysis of design vehicle and check vehicle(s) (i.e., oversize permit load scenarios)
- Identify significant environmental impacts (wetlands, parks, historic, etc.)
- Prepare capital cost estimate and summarize lifecycle maintenance and operation costs.
- Perform operational analysis to determine intersection delay and V/C ratio; and therefore, operational performance.
- Perform safety analysis to determine expected reduction in number of crashes, with an emphasis on the difference in severe crashes (i.e., those resulting in fatalities or injuries)
- Identify level of support from different stakeholders, including TxDOT, local government and other key stakeholders.

Section 1 (Continued) – Interchange Analysis Checklist – Other Studies

No	Item	Review	
		Checked By	Date
1	**Methodology Coordination**		
1.1	Methodology & Assumptions Coordination Meeting (M&A) conducted and meeting notes documented		
1.2	M&A Memo includes a project description along with a project location map		
1.3	Need and Purpose supported by data and justifies the project		
1.4	Study area includes surrounding intersections as per M&A		
1.5	Analysis years per M&A		
1.6	Interchange control types to be considered and their assumptions per M&A		
1.7	Operational, safety, and multimodal analysis tools selected per M&A		
1.8	Cost benefit analysis tools selected per M&A		
2	**Data Input & Parameters**		
2.1	Existing turning movement counts or O-D data and crash data collected per M&A		
2.2	Growth rates developed from historical data and approved by TxDOT		
2.3	Long-range plans and improvements identified in the study area		
3	**Operational Analysis**		
3.1	Traffic operational analysis tools selected per M&A		
3.2	Latest guidelines/standards have been used		
3.3	Turning movement volumes converted to O-D volumes if comparing multiple itnerchange types		
3.4	If microsimulatoon tool was used, the report includes the calibration memo		
3.5	Manual calculation of ETT completed when automated software results are not available		
3.6	Measure of Effectiveness (MOEs) are consistent with analysis tools and project settings		
3.7	The results of traffic analysis have been reviewed for reasonableness		
3.8	The results of traffic analysis are compared across every alternative under consideration		
3.9	The traffic analysts software files checked to verify input and parameters		
4	**Safety Analysis**		
4.1	Safety analysis tools selected per M&A		
4.2	Histoncal crash data and analysis conducted for latest 3 to 5 years		
4.3	Safety analysis includes predicted crash frequency or evaluation of CMF		
5	**Multimodal Analysis**		
5.1	Multimodal analysis tools selected per M&A		
5.2	Latest guidelines/standards have been used		
5.3	If microsimulatoon tool was used, the report includes the calibration memo		
5.4	Measure of Effectiveness (MOEs) are consistent with analysis tools and project settings		
5.5	The results of multimodal analysis have been reviewed for reasonableness		
5.6	The results of multimodal analysis are compared across every alternative under consideration		
5.7	The traffic analysts software files checked to verify input and parameters		
6	**Other Considerations**		
6.1	Other MOEs (Including Cost Benefit Analysis)		
7	**Report**		
7.1	Summarize results and findings in report format		

Section 2 – Diverging Diamond Interchange Factsheet

Diverging Diamond Interchange

A diverging diamond interchange, or DDI, is a new, innovative design that addresses congestion by allowing vehicles to travel more quickly through an intersection. DDIs are particularly effective at locations that have a high volume of left-turn traffic. A DDI increases traffic flow by temporarily shifting traffic to the left side of the road, allowing through-traffic and left-turning traffic to proceed through the intersection simultaneously. This eliminates the need for left-turn arrows. The intersection design increases safety by reducing the number of potential conflict points between cross-traffic and left-turn movements.

Driving in a Diverging Diamond Interchange

While driving through a diverging diamond interchange is different, it is not difficult to understand and navigate once you get used to it. Also, it's proven to have reduced crashes by 50 percent in some areas. A DDI creates a diamond-shaped pattern in the intersection and temporarily shifts traffic to the left side of the roadway prior to entering the intersection.

How it works:

1st Diverging Diamond Interchange in the USA. Opened June 21, 2009 at I-44 & Hwy 13, Springfield, Missouri. Photo courtesy of MoDOT.

- Two phase traffic signals are installed at the roadway crossover points.
- Once on the left side of the road, drivers can freely turn left, rather than waiting for oncoming traffic to clear or for a left-turn signal. Or drivers can continue straight and will switch back to the right side of the roadway once they've cleared the intersection.
- U-turn lanes are also included in a DDI, making left-turns from the cross-streets safer and more efficient.
- Through-traffic on the frontage road bypasses the intersection via a collector-distributor lane, or intersection bypass lane, and proceeds straight through the cross-street intersection, allowing drivers to avoid the traffic signal.

Advantages of a Diverging Diamond Interchange

A DDI enhances safety and mobility by reducing potential crash points at intersections and by allowing more cars to move through an intersection. This means a reduction in delays and travel time. Other benefits include:

- Motorists are able to bypass the intersection without stopping at a traffic signal
- Improved travel time because additional "green time" at traffic signals allow more vehicles to pass through the intersection
- Additional sidewalks will increase safety and better accommodate pedestrians and bicyclists
- Relatively low-cost improvement

Section 3 – Single-Point Urban Interchange Factsheet

Single-Point Urban Interchange

A SPUI is an intersection design that allows a large volume of vehicles to travel through the intersection safely and efficiently by reducing conflict points and the number of traffic signal phases. Similar to a DDI, the SPUI allows opposing left turns to proceed simultaneously. Unlike a DDI, streams of left-turning traffic in a SPUI do not cross. Opposing left turns can be made at the same time; with only one set of traffic signals, allowing more vehicles to clear the intersection in one traffic signal cycle.

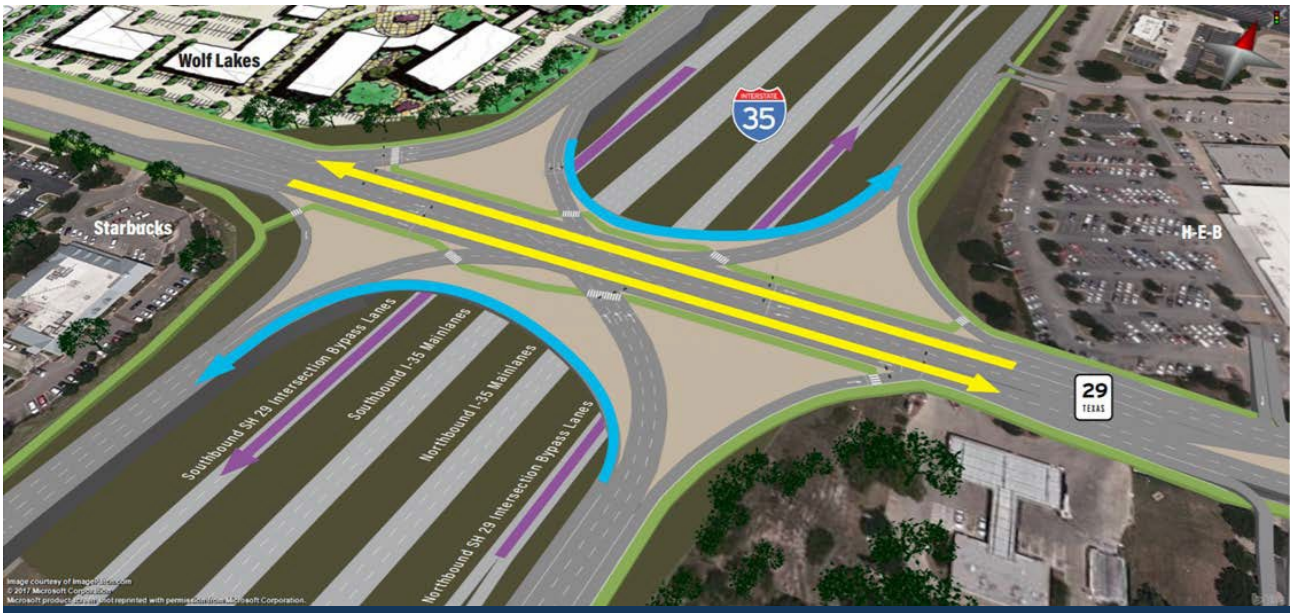
Benefits

The benefits of a SPUI include:

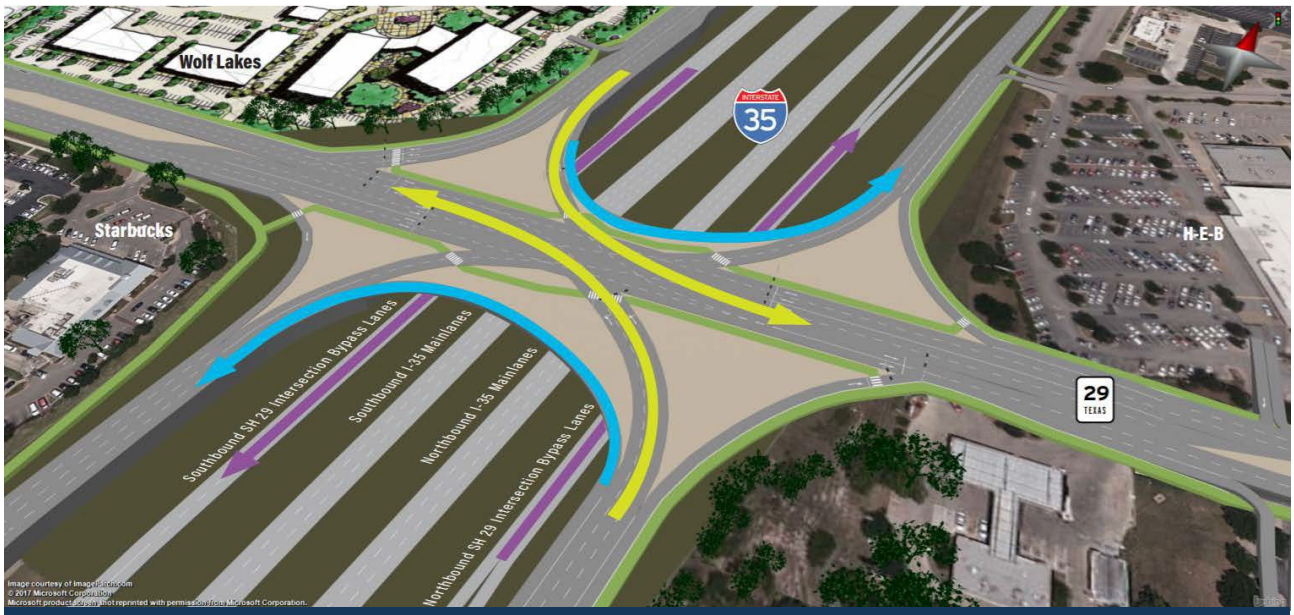
- Improving safety: With only one signalized intersection rather than two at a conventional diamond interchange, vehicles only cross paths at one location.
- Improving travel time: Additional "green time" at traffic signals allows more vehicles to pass through the intersection.
- Wider turns for large vehicles.
- Reduced right-of-way requirements.

Driving a Single Point Urban Interchange

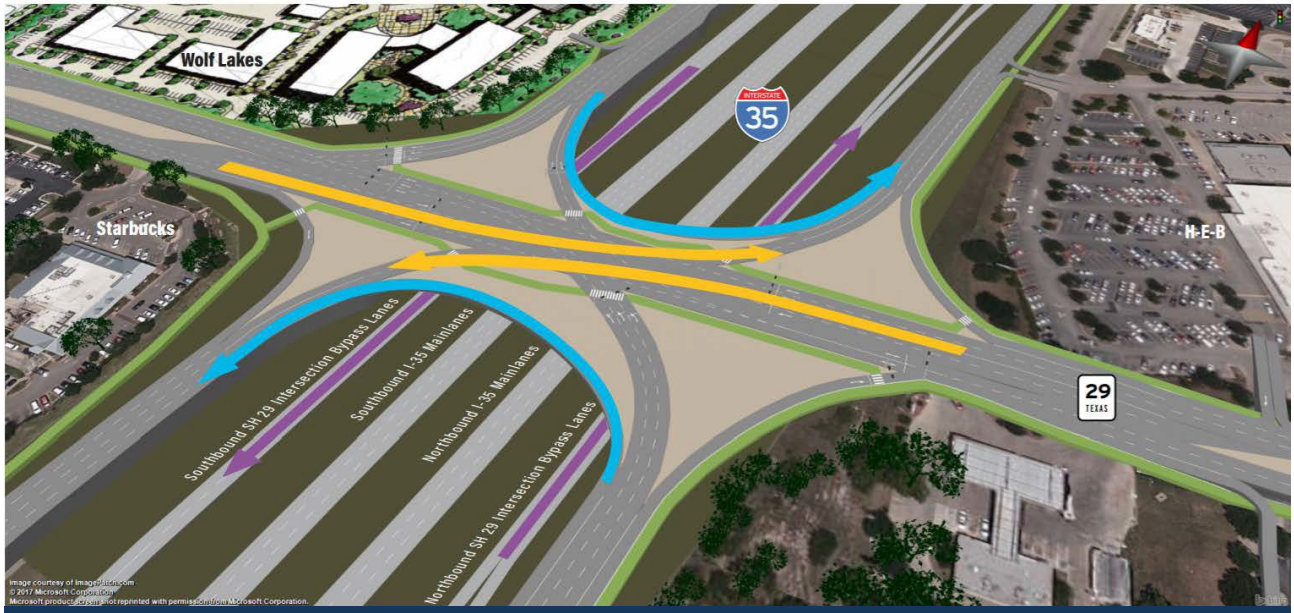
A SPUI operates with a single, three-phase traffic signal:



The first phase involves cross street traffic traveling through the intersection.



The second movement involves opposing left-turn lanes from the frontage road and/or exit traveling through the traffic signal onto the cross street.



The last movement is for the second set of opposing left-turn lanes traveling from the cross street onto the frontage road. Through-traffic on the frontage road is handled via

Section 4 – External References

The websites below were last accessed on May 31, 2024

1. **Intersection Control Evaluation Federal Highway Administration**
   https://safety.fhwa.dot.gov/intersection/ice/
   - ICE is a data-driven framework to screen intersection alternatives for optimal performance.
2. **Alternative Intersections/Interchanges: Informational Report**
   https://www.fhwa.dot.gov/publications/research/safety/09060/
   - The informational report covers four intersections and two interchange designs that offer substantial advantages over conventional intersections and diamond interchanges.
3. **The Federal Highway Administration Displaced Left-Turn Intersection**

   https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14068.pdf
   - This document is a technical summary of the FHWA report on the displaced left turn.
4. **Virginia Department of Transportation Innovative Intersections and Interchanges**

   https://www.virginiadot.org/innovativeintersections/
   - Information about various intersection and interchange types. Information includes graphics, what it is, when it should be considered, benefits, how to navigate, conflict points graphic, and additional resources.
5. **Estimating the Life-Cycle Cost and Impact of Intersection Designs**

   NCHRP 03-110: https://nap.nationalacademies.org/catalog/21928/estimating-the-life-cycle-cost-of-intersection-designs
6. **Capacity Analysis for Planning of Junctions (CAP-X) Tool User Manual**

   User Guide: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-067%20CAP-X%202018%20Tool%20User%20Guide%20(Final).pdf

   Spreadsheet Tool: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-067%20CAP-X%202018%20Tool%20(v3.0.1).xlsm
7. **Safety Performance for Intersection Control Evaluation (Stage 1 ICE)**

   User Guide: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-026%20SPICE%20Tool%20User%20Guide%20(Final).pdf

   Spreadsheet Tool: https://www.cmfclearinghouse.org/collateral/FHWA-SA-18-026%20SPICE%20Tool%20(v1.4.1).xlsm
8. **Federal Highway Administration (FHWA) Interchange Safety Comparison Tool (Stage 2 ICE)**

   https://highways.dot.gov/research/publications/safety/FHWA-Interchange-Safety-Comparison-Tool
9. **Techbrief: Publication No.: FHWA-HRT-16-069 - HCM Manual Chapter on Alternative Intersections And Interchanges:**
   https://www.fhwa.dot.gov/publications/research/operations/16069/16069.pdf

10. **TxDOT Intersection Scoring Tool**

    https://ftp.txdot.gov/pub/txdot/des/safety-score-tools/

    https://ftp.dot.state.tx.us/pub/txdot/des/safety-score-tools/intersection-tool-faq.pdf

11. **Use of Innovative Intersection Designs for Improving Mobility and Reducing Roadway Traffic Congestion**

    https://cammse.charlotte.edu/wp-content/uploads/sites/191/2023/06/CAMMSE-UNCC-2017-UTC-Project-Report-08-Qi-Final.pdf

12. **FHWA Guide for Roundabouts, NCHRP 1043, 2023**

    https://nap.nationalacademies.org/download/27069#

    - A state of the practice guide for planning, design, construction, maintenance, and public outreach for roundabout projects. This link does require you to input your email as a guest to download.

13. **Interchange Safety Analysis Tool Enhanced (ISATe)**

    https://highways.dot.gov/safety/data-analysis-tools/rsdp/rsdp-tools/interchange-safety-analysis-tool-enhanced-isate

14. **Roundabout Analysis Tool (HCM Methodology) powered by Georgia DOT**

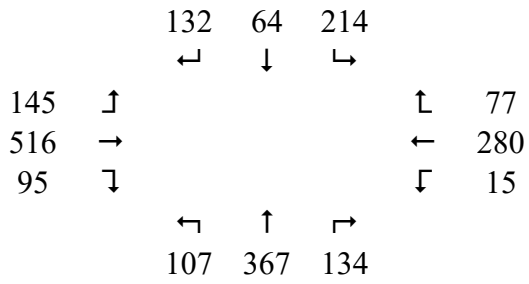
    http://www.dot.ga.gov/DriveSmart/Roundabouts/AnalysisToolv4-2.zip

Chapter 12 - Appendix M – Roundabout Analysis

- **Section 1** – Peak Hour Capacity Evaluation
- **Section 2** – Description and Settings for Roundabout Analysis Software Models

Section 1 – Peak Hour Capacity Evaluation

Data Requirements:
Peak Hour Factor (PHF) = .92
Percent heavy vehicles for all movements = 1.5%
Turning movement counts (TMC):



Step 1: Convert Turning Movement Counts into Flow Rates
Each of the turning movements should be divided by the PHF to convert turning movement counts into flow rates (northbound through is illustrated):

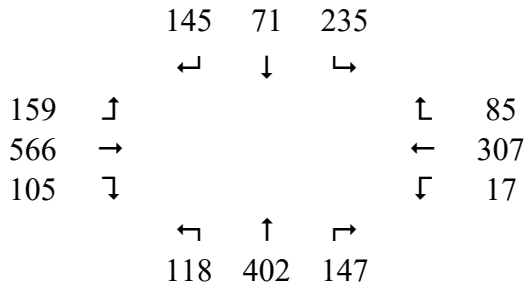
$$v_{NBT} = \frac{V_{NBT}}{PHF} = \frac{367}{.92} = 399 \text{ pc/h}$$

Step 2: Adjust Flow Rates for Heavy Vehicles
The flow rates can be adjusted for heavy vehicles by using the following formula (northbound through is illustrated):

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} = \frac{1}{1 + .015(1.5 - 1)} = 0.993$$

$$v_{NBT,pce} = \frac{v_{NBL}}{f_{HV}} = \frac{399}{.993} = 402 \text{ pc/h}$$

The adjusted flows are now as follows:



Step 3: Calculate Entry Flow Rates
The entry flow rates are calculated by summing each movement in an approach.

$$v_{e,NB,pce} = v_{,NBU,pce} + v_{,NBL,pce} + v_{,NBT,pce} + v_{,NBR,pce}$$

$$v_{e,NB,pce} = 0+118+402+147=667$$

Step 4: Calculate Circulating Flow Rates

The circulating flow rates are calculated by summing up the conflicting movements at each approach.

$$v_{c,NB,pce} = v_{,WBU,pce} + v_{,SBL,pce} + v_{,SBU,pce} + v_{,EBT,pce} + v_{,EBL,pce} + v_{,EBU,pce}$$

$$v_{e,NB,pce} = 0+235+0+566+159+0=960$$

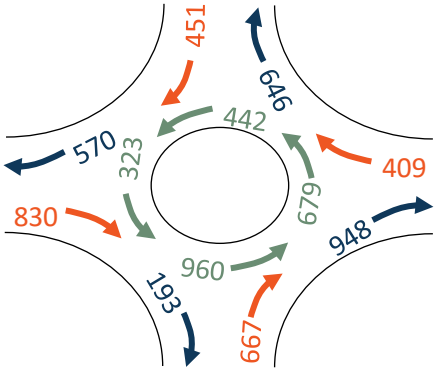
Step 5: Calculate Exiting Flow Rates

The exiting flow rates are calculated by summing up the flow rates that will be exiting at each leg.

$$v_{ex,NB,pce} = v_{,NBU,pce} + v_{,WBL,pce} + v_{,SBT,pce} + v_{,EBR,pce}$$

$$v_{ex,NB,pce} = 0+17+71+105=193$$

The entering, circulating, and exiting roundabout volumes are as follows:



Legend

Blue	Exiting Flows
Orange	Entering Flows
Green	Circulating Flows

Step 6: Calculate Sum of Entering and Circulating Flows (volume range)

$$v_{NB,pce} = 667 + 960 = 1{,}627$$

$$v_{EB,pce} = 830 + 323 = 1{,}153$$

$$v_{SB,pce} = 451 + 442 = 893$$

$$v_{WB,pce} = 409 + 679 = 1{,}088$$

Step 7: Compare Entering and Circulating Flows to Capacity Tables

Using Exhibit 8.9 of NCHRP 1043, determine if a roundabout is feasible based on turning movement counts. As a rule of thumb, if the sum of the entering and circulating flows is less than 1,800 for each approach, a roundabout is feasible.

Sum of Peak Period Entering and Conflicting Flows (veh/hr)	Type of Roundabout and Number of Lanes
700 or less	Single-lane roundabout with traversable or non-traversable central island is likely sufficient
701 to 900	Single-lane roundabout with non-traversable central island is likely sufficient; single-lane roundabout with traversable central island may be sufficient
901 to 1,300	Single-lane roundabout with non-traversable central island may be sufficient
1,301 to 1,600	Two-lane entry into multilane roundabout is likely sufficient; detailed turning movement analysis recommended
1,601 to 2,300	Two-lane entry into multilane roundabout may be sufficient; detailed turning movement analysis recommended
Greater than 2,300	Three-lane entry into multilane roundabout may be sufficient; detailed turning movement analysis recommended

Multilane Roundabout Planning Considerations

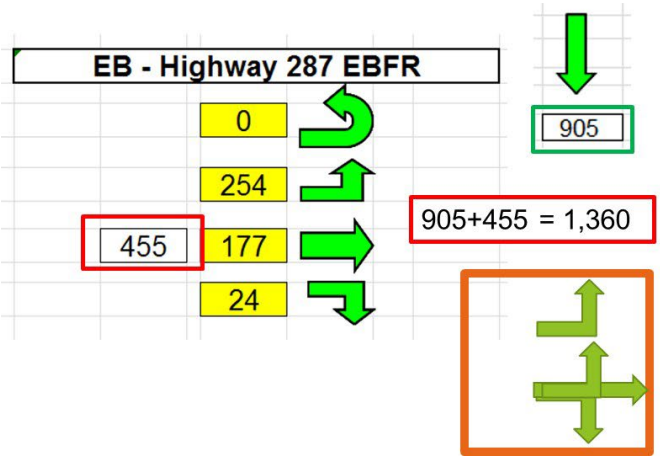
The traffic analysis and geometry for a multilane roundabout operational analysis proceeds from the determination of the lane configuration. When sizing a roundabout for the number of entering and circulating lanes, each approach leg of the roundabout is evaluated individually to determine the number of entering lanes that are required. Determination of the lane configuration for multilane roundabouts follows these steps:

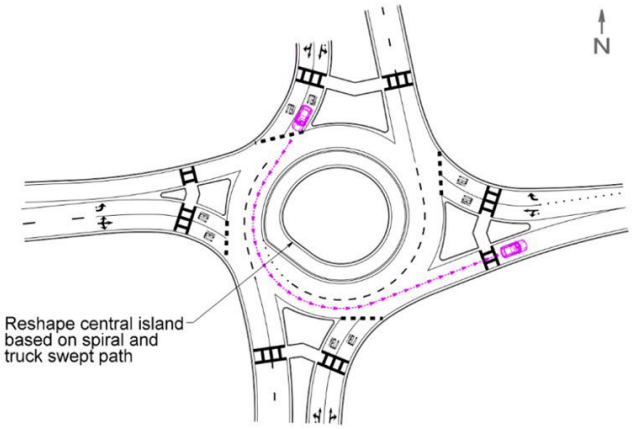
- Analyze both AM and PM peak hours and the Build Year, Build Plus Ten and the Design Year forecasted traffic.
- For each approach or entry, divide the total approach volume by the number of lanes (rough check of capacity of approach i.e. single lane versus multi-lane). If the sum of entering and circulating traffic flows exceeds 1300, a multilane roundabout is likely required.
- An operational criterion for roundabouts as at most intersection is to ensure balanced queuing and demand lane by lane by designating lanes as shared or exclusive to match the expected peak hour flows.
- Divide the sum of entering and circulating flow by the number of lanes, two if the flows justify a two-lane entry.
- Draw very rough lane configuration sketches to accompany the traffic volume diagram and above-noted volume checks.
- Account for future changes in traffic patterns and volume. Consider proposing an expandable single lane roundabout if the expected flows in 10 years do not justify multilane operation.
- Complicated lane configurations compound geometric design challenges and ultimately human factors are affected. Avoid clever lane configurations that are too complex for marking maintenance ease of use by drivers.

- Development of the required lane configuration is an iterative process to determine the appropriate number of lanes and lane assignments by checking HCM 7th Edition LOS results until they are within the acceptable and a desirable range.
- Strive for simple, low conflict layouts – hybrids (1x2) vs. full 2x2 multilane layouts for safety.

The resulting lane configuration and sketch has a form like the diagram below.

Lane Configuration Planning Analysis for a Two-lane Entry

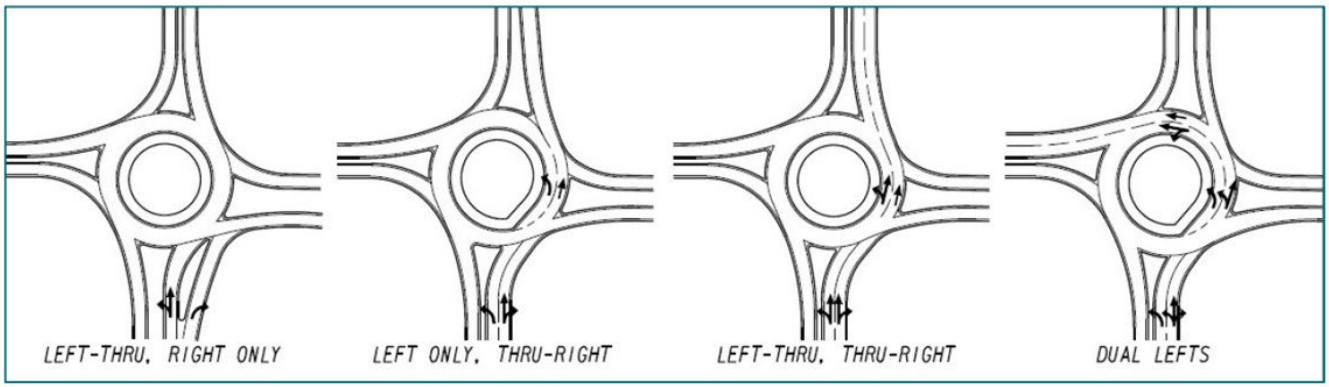




Lane Configuration & Geometry Sketch EB approach
(Dual lefts requires a spiral geometry)

As seen from the example above, the lane configuration alternatives for multilane roundabouts affects the geometric design. The diagram below shows alternative lane configurations for the same two-lane entry flows. Each one gives a different LOS result when modeled with the HCM 6 roundabout capacity equations.

Lane Configuration Options for Two-lane Entries



Section 2 – Description and Settings for Roundabout Analysis Software Models

HCM Methodology and Limitations

The operational analysis method for analyzing motor vehicles presented in Chapter 22 of the HCM, 6th Edition allow analysts to assess the operational performance of an existing or planned one-lane or two-lane roundabout given traffic-demand levels. The HCM capacity method employs simple, empirical regression models to reflect the capacity of roundabouts with up to two lanes. The HCM also includes models for estimating the performance of yield-controlled, right-turn bypass lanes.

All the software models that employ the HCM capacity methodology share the same constraint on use when oversaturation (v/c > 0.85) prevails. A volume-to-capacity ratio of 0.90 is considered the practical capacity of a roundabout entry. Higher capacities may be achievable but require more detailed operational analysis. In such cases the HCM recommends the use of alternative models or simulation. The Junctions (ARCADY) model has both HCM and an independent model, the U.K. empirical model that can address oversaturation of a roundabout entry. The ARCADY model accounts for the effect of a carryover of queues from one time slice to the next using an iterative approach that is not established in the HCM methodology. Sidra Standard also has an iterative capacity method, but it has not been field validated in the U.S.; hence, the results have not been proven to be reliable for U.S. roundabouts.

For performance measures, the HCM estimates the volume-to-capacity ratio, the control delay, and the 95th-percentile queue on a lane-by-lane basis and assigns LOS for each lane based on the control delay of that lane. The HCM also estimates control delay and LOS aggregated to the approach level and the intersection level.

The HCM identifies that its analytic methods have several key scope limitations for which it recommends using alternative tools, such as the methods described in the following sections of this chapter. These scope limitations include the following:

- Pedestrian signals or hybrid beacons at roundabout crosswalks.
- Metering signals on one or more approaches.
- Adjacent signals or roundabouts.
- Priority reversal under extremely high flows.
- High pedestrian or bicyclist activity levels.
- More than two entry lanes on an approach.

Flared entry lanes, such as an entry that widens from one approach lane to two entry lanes over a short distance.

SIDRATM Intersection Software (HCM Methodology)

SIDRA Intersection is a software package containing a deterministic model that is commonly used to analyze roundabouts. A SIDRA Intersection analysis can be conducted in Stage 2 of the ICE process and when a more detailed analysis is necessary.

Two capacity models are used to analyze roundabouts in SIDRA Intersection: the SIDRA Standard model and the US HCM model. The SIDRA Standard model (an Australian-based model) has not been field-validated, nor calibrated to U.S. roundabouts and driving conditions. Because of this, the US HCM model is prescribed for TxDOT roundabout analyses.

Due to limitations in the US HCM model for oversaturated conditions, Junctions/ARCADY or microsimulation (microscopic) analysis can supplement the Sidra-HCM analysis. Simulation (VISSIM or Sim Traffic) is also useful to account for the effects of adjacent intersections with signals or other innovative intersections and traffic control devices. The SIDRA settings and default input values shown in Table M-1 can be used as a starting point in an analysis. Typical outputs for SIDRA include v/c ratio, control delay, LOS, and 95 percent queue length.

Table M-1: Sidra Inputs

Input Table	Characteristic	Value
Lane Geometry - Lane Configuration	Single Lane Entry Width	17 foot minimum
	Multilane Entry Width	13 foot minimum (each)
Roundabout Inputs - Options	Roundabout Capacity Model	Check “US HCM”
	Roundabout LOS Method	Check “Same as Unsignalized Intersections”
	Delay Model	Uncheck “Exclude Geometric Delay”
Roundabout Inputs - Roundabout Data	Circulating Single Lane Width	20 foot minimum
	Circulating Multilane Width	15 foot minimum (each)
	Island Diameter	Single Lane – 80 foot Multilane – 100 foot
	Environment Factor	Opening Year – 1.1 Design Year – 1.0
Parameter Settings Inputs - Options	Site LOS Method	Delay and Degree of Saturation
	Site LOS Target	LOS D
	Pedestrian LOS Target	LOS D
	Performance Measure	Delay
	Percentile Queue	95%
Model Settings Inputs -Model Parameters	Delay and Queue	Uncheck “Exclude Geometric Delay” and “HCM Delay Formula”

SynchroTM (HCM Methodology)

Synchro is a deterministic tool that can be used to analyze roundabouts. A Synchro analysis is conducted after the daily service volume evaluation and peak hour volume evaluation (computational steps) have been completed and a more detailed analysis is necessary. Roundabout analysis using Synchro is based on methodology found in the HCM 7th Edition. Default headway values provide for in the HCM model research are satisfactory until studies of TxDOT roundabouts justify calibration for local conditions. Typical outputs for Synchro include v/c ratio, control delay, LOS, and 95 percent queue length.

HCM Methodology

HCS is also a deterministic tool that can be used to analyze roundabouts. An HCM analysis is typically conducted after the daily service volume evaluation and peak hour volume evaluation (computational steps) have been completed and a more detailed analysis is necessary. The analysis time period and PHF are entered on the General window; roundabout configurations are entered on the Geometry window; and traffic volumes, pedestrian crossing volumes, critical headway, and follow-up headway parameters are entered in the Traffic window. Roundabout analysis using HCS is based on methodology found in the HCM.

HCS computes control delay and LOS for each entering lane, approach, and the whole roundabout. Additionally, the 95th percentile queue is obtained in terms of number of vehicles for each entering lane. The 95th percentile queue are multiplied by the length of a vehicle to compute the queue length in feet.

For general information on modeling roundabouts and changing other analysis parameters, refer to the HCS user guide.

JunctionsTM (ARCADY) – HCM Methodology and U.K. Empirical Model with Calibration

The ARCADY module is a part of the Junctions 10 software created by Transport Research Laboratory (TRL). It can be used as an alternative to SIDRA-HCM and Synchro as well as a tool for validating the results of a microsimulation model. Typical ARCADY inputs are shown in Table M-2 below. Typical outputs for Junctions include v/c ratio, control delay, LOS, 95 percent queue length, and crash exposure. Refer to the Junctions 10 user manual for information on developing a roundabout model and generating results.

Calibration to U.S. driving conditions is simple to accomplish if there are nearby roundabouts with saturated entries. In the absence of readily available field data, calibration is typically facilitated by adjusting the capacity equation Y-Intercept percentage to 90 percent for existing year conditions and

95 percent for design year conditions. Recent comparisons with HCM indicate that the two models correlate well.

It is recommended for ARCADY users to be aware that the default model relies on a ONEHOUR profile type under the Traffic Demand settings. This can be changed from ONEHOUR to PHF so that customized PHF values can be applied to the analysis.

When switching the analysis from the Junctions Standard Roundabout model to the HCM Roundabout model, lane assignments will need to be applied for multilane entries. The outside or curb lane is designated as the nearside lane type, while the inner lane or left lane is designated as the offside lane type. A right turn bypass lane is also be assigned per approach as a yielding bypass or as a non-yielding bypass (free flow).

Table M-2: Typical ARCADY Inputs

Characteristic	Value
V – Approach road half-width	12 feet (two-lane corridor) 24 feet (four-lane corridor)
E – Entry width	13 feet (single-lane entry) 26 feet (two-lane entry)
I' – Effective flare length	65 feet (single-lane entry) 135 feet (two-lane entry)
R – Entry radius	As-designed value
D – Inscribed circle diameter (ICD)	As-designed value for single-lane or circular 2x2 lane configuration ICD value to the left of entry for 2x1, 1x2, 2x3, 3x2 or elliptical-shaped lane configuration
PHI – Conflict (entry) angle	As-designed value

VissimTM

Vissim is a microsimulation software that can be used to model roundabouts. Roundabout analysis using Vissim is often considered for oversaturated conditions; when modeling the network effects of closely spaced roundabouts; for complex roadway geometry; or when a visual representation of roundabout operations is necessary. The output of Vissim is delay, which can be converted into LOS and average travel time for vehicles. A Vissim analysis is typically not a standalone tool used for roundabout analysis and is typically accompanied by the results from a deterministic tool such as SIDRA, Synchro, or Junctions.

An advantage of Vissim over other roundabout analysis tools is the visual component that shows vehicles flowing through the network. Animations of roundabout operations can be recorded and serve as a visual perspective on operations. See Chapter 13 for more information on microsimulation.

Headway values are an input in Vissim and have a considerable impact on roundabout performance. Headway values adjusted to match local conditions can be used as well. A visual inspection of gap acceptance and headways in the field is used to adjust values as necessary.

Typical outputs for Vissim include average vehicle travel time (sec) and average total delay per vehicle (sec).

SimTrafficTM (Synchro Simulation)

SimTraffic is a microsimulation software that can be used to model roundabouts as standalone intersections or in networks with traffic signals nearby. Roundabout analysis using SimTraffic is often considered for oversaturated conditions; when modeling the network effects of closely spaced roundabouts; for complex roadway geometry; or when a visual representation of roundabout operations is necessary.

SimTraffic models individual cars, trucks, buses and pedestrians traveling through a network of freeways, streets and multiple types of intersections. Delays, vehicular queues, travel times and other measures of effectiveness are computed for these modeled users over a defined simulation period and can be determined for roadway segments and corridors, in addition to individual intersections. SimTraffic produces 2-D and 3-D animations of the transportation model.

Typical outputs for SimTraffic include average vehicle travel time (sec) and average total delay per vehicle (sec).

Chapter 13 - Appendix N – Microsimulation Analysis

- **Section 1** – Model Debugging Checklist
- **Section 2** – Model Development Report
- **Section 3** – Calibration Criteria Calculations Example
- **Section 4** – External References
- **Section 5** – Lonestar Data in Cluster Analysis Case Study

Section 1 – Model Debugging Checklist

- **Geometry and Traffic Control checks**
  - Verify Link Geometry;
    - Lengths, number of lanes, link types, connectors
  - Verify Speed Coding;
    - DSD, reduced speed areas
  - Verify intersection controls;
    - RBCs, stop signs
  - Verify Traffic Control Coding; and
    - Right turn on red, lane use restrictions
  - Verify Conflict Areas/Priority Rules
- **Vehicular Demand checks**
  - Verify vehicle compositions at each link/node;
  - Verify routing decisions; and
  - Verify inputs
- **Vehicle Type and Behavior**
  - Verify traffic compositions;
  - Verify vehicle types and classes; and
  - Verify vehicle model distributions

Section 2 – Model Development Report

A suggested Model Development Report outline is as follows:

- **Title Page**
- **Table of Contents**
  - List of Chapters and Sections
  - List of Figures
  - List of Tables
- **Executive Summary**
- **Introduction**
  - Description of the proposed project
  - Analysis objective and project scope
  - Project location map
- **Data Requirements**
  - Data requirements and data sources
  - Data collection methodology
  - Summary of data collection and field observations
- **Microsimulation Network Development**
- **Assumptions**
- **Model Calibration and Validation**
  - Seeding period
  - Calibration criteria
  - Driving behavior and network modifications
  - Changes to default values
  - Validation methodology and results
  - Model Output and Calibration Results
  - Critical lessons learned/best practices to benefit future users of the model
- **Alternatives Analysis**
- **Conclusion**
- **Appendices:**
- **Raw Traffic Data (Counts, Travel Times, Historical Data)**
- **Calibration Calculations**
- **Model Outputs**

Section 3 – Calibration Criteria Calculations Example

The first step to calibration is identifying a representative day from the cluster analysis. Cluster analysis is a statistical method that helps group (or cluster) data based on similarity between different parameters (travel time, throughput, weather, incidents, etc.). Each cluster represents a different set of travel conditions (weather-related, incident-related, normal, etc.) and will have a varying number of days associated with it. Multiple clusters that represent various driving scenarios may exist in the data set, depending on project scope, more than one cluster may be calibrated to and analyzed. Consult with the TxDOT project manager during scoping to determine the appropriate number of clusters to calibrate for.

The example shown in this appendix shows the calculation from one travel condition and determines the representative day for that travel condition using one key measure and route, in this case, travel time in the southbound direction. However, to determine the representative day for a model, this calibration calculation should be done for a variety of key measures (travel time, speed, throughput, etc.) collected for all applicable routes and locations within the study area. Table N-1 below shows data from Cluster 1 of the cluster analysis. The table includes travel time from each day within the cluster and the analysis time period. Table N-1 shows a total of 24 days for the travel condition. However, it is important to note that the cluster analysis used to develop different travel conditions (weather-related, incident-related, normal, etc.) should be based on at least 100 days' worth of data.

Below are the variables listed that are used across the different equations provided in the steps to calculate the representative day. The variables and equations are from FHWA's Traffic Analysis Toolbox Volume III*: Guidelines for Applying Traffic Microsimulation Modeling Software 2019 Update*. The example and calculations have been modified to make it easier to follow the steps set out in the FHWA guidance.

Step 1 – Calculate average travel time per time interval

Below is the equation for calculating the average for each 15-minute time interval across all days in the cluster.

$$\bar{m}_{t,j} = \frac{\sum_i m_{i,j}(t)}{N_{cluster}} \; \forall m, t, j \qquad (1)$$

M	Set of measures of effectiveness considered for representative day
m	Specific measure analyzed (travel time in this example)
J	Set of routes and locations (only one route and location in this example)
j	Specific route and location analyzed (only one route in this example)

i	Observed day
t	Time interval
$N_{cluster}$	Number of days in cluster

Calculation results from equation (1) are shown in the last column of Table N-1, which is the average travel time per time interval across all days in the cluster data set.

Step 2 – Calculate percentage difference between average value and observed value

The next step is to calculate the percentage difference between average travel time for the time interval and the observed travel time for a particular day and the same time interval. This shown in equation (2) below.

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

Below is an example of solving equation (2) for Day 1, Route 1, and the time interval 15:00:00.

$$\dot{m}_{Day\ 1,Route\ 1}(15{:}00{:}00) = \frac{\sqrt{(5.6 - 5.3)^2}}{5.3}$$

$$\dot{m}_{Day\ 1,Route\ 1}(15{:}00{:}00) = 0.0566\ or\ 5.66\%$$

This value is shown in Table N-2. This calculation is repeated for each observed day and time interval, until all values are filled out in Table N-2.

Step 3 – Calculate the average difference for each observed day and determine representative day

Determine the individual observed day that has the lowest average percentage. This can be done by averaging all routes, locations, and measures together for all the time intervals analyzed. Equation (3) below shows the formula to calculate this.

$$i = min_i\left[\sum_m \sum_i \sum_t m_{i,j}(t)\right] \qquad (3)$$

Because this example only uses one route and measure, only the travel time was averaged together for all time intervals for an observed day. If there were multiple routes, locations, and measures, all

the different percentage differences calculated in Step 2 for the different measures, routes, and locations would be averaged together.

The last row in Table N-2 shows this calculation. As explained in Step 2, the percentages developed in Table N-2 were calculated by taking the absolute difference between the Average Travel Time (the last column in Table N-1) and the observed day travel time for the same time interval. In Step 3, these percentages are then averaged across all time intervals for the same day. The lowest average percentage is then considered the representative day. Day 9 had the lowest average at 4.2 percent; it is considered the representative day.

Table N-1. Travel Times from Cluster 1

	Observed Travel Times for Route 1 (State Highway Route Southbound from Airport Drive to Canyon Drive) on Each Day, 24 Days																							
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	**Average Travel Time**
15:00:00	5.6	4.9	4.7	5.7	5.8	5.8	5.3	5.3	5.2	5.7	4.9	5.3	5.6	5.3	5.1	5.2	5.6	4.7	5.3	5.2	5.6	5.2	4.7	5.2	**5.3**
15:15:00	4.9	4.9	5.1	5.2	5.4	6.4	5.2	4.9	5.3	5.4	4.7	5.3	5.3	5.1	5.1	5.1	5.4	5.0	5.0	5.0	5.3	5.1	5.0	5.2	**5.2**
15:30:00	5.6	5.4	5.0	5.2	5.3	5.6	5.4	5.4	5.1	5.1	5.0	5.6	5.6	4.9	5.7	5.4	6.4	5.5	5.6	5.4	5.2	5.6	5.3	5.7	**5.4**
15:45:00	7.1	6.2	5.4	6.9	5.8	6.2	7.0	7.3	6.6	5.6	6.6	7.1	6.9	5.9	7.2	6.8	6.3	7.9	7.2	5.6	6.1	6.4	5.9	7.6	**6.6**
16:00:00	6.2	5.5	5.0	5.4	4.8	6.2	6.0	5.9	6.3	5.3	5.5	5.6	6.0	5.2	7.0	6.0	5.4	7.1	6.1	5.3	7.1	5.9	5.7	7.3	**5.9**
16:15:00	5.3	6.5	5.6	5.8	5.5	7.8	6.2	5.8	5.5	6.2	5.4	5.8	5.7	5.4	6.1	5.6	5.3	5.5	7.2	5.1	8.5	5.5	5.7	6.6	**6.0**
16:30:00	5.5	5.7	5.0	5.0	5.4	8.4	5.3	5.5	5.6	5.4	5.3	5.3	6.0	5.7	5.6	5.4	5.2	5.1	5.4	5.0	7.4	5.2	5.2	5.2	**5.6**
16:45:00	7.2	6.9	5.2	6.2	7.0	8.7	7.0	7.3	6.4	5.4	7.6	7.2	5.8	6.3	6.8	5.8	6.8	5.8	7.0	7.6	6.8	6.2	5.7	7.3	**6.7**
17:00:00	6.7	7.3	5.1	6.6	7.3	8.7	6.4	8.2	6.3	5.7	7.1	6.1	5.9	5.8	6.1	5.7	6.4	6.3	7.8	7.2	7.2	5.8	6.2	6.5	**6.6**
17:15:00	7.5	8.9	8.7	8.7	10.5	9.0	7.0	9.3	8.2	8.0	8.9	8.0	7.3	8.3	7.9	8.1	8.2	8.4	9.7	9.7	9.3	8.9	7.5	8.9	**8.5**
17:30:00	7.2	7.3	8.5	8.3	9.1	7.8	6.2	9.0	7.3	7.9	8.1	7.4	8.0	8.7	7.7	8.1	7.2	7.2	8.0	8.0	8.6	8.1	6.4	7.6	**7.8**
17:45:00	5.1	5.2	6.6	6.6	6.3	6.4	5.3	7.5	5.7	5.7	5.7	5.6	6.6	6.9	6.3	5.5	5.6	6.1	5.8	6.5	6.3	7.2	5.1	5.8	**6.1**
Peak Average	**6.3**	**6.7**	**6.2**	**6.6**	**7.0**	**7.9**	**6.2**	**7.3**	**6.4**	**6.2**	**6.7**	**6.4**	**6.4**	**6.5**	**6.7**	**6.3**	**6.3**	**6.4**	**7.1**	**6.8**	**7.7**	**6.6**	**5.9**	**6.9**	**6.6**

Table N-2. Percentage Difference Between Average Travel Time and Observed Travel Time

	Eucledean Distance Expressed as a Percentage of Average Travel Time																							
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
15:00:00	5.9%	7.3%	11.1%	7.8%	9.7%	9.7%	0.2%	0.2%	1.7%	7.8%	7.3%	0.2%	5.9%	0.2%	3.5%	1.7%	5.9%	11.1%	0.2%	1.7%	5.9%	1.7%	11.1%	1.7%
15:15:00	5.4%	5.4%	1.5%	0.4%	4.3%	23.6%	0.4%	5.4%	2.3%	4.3%	9.3%	2.3%	2.3%	1.5%	1.5%	1.5%	4.3%	3.5%	3.5%	3.5%	2.3%	1.5%	3.5%	0.4%
15:30:00	3.4%	0.3%	7.7%	4.0%	2.2%	3.4%	0.3%	0.3%	5.8%	5.8%	7.7%	3.4%	3.4%	9.5%	5.2%	0.3%	18.2%	1.5%	3.4%	0.3%	4.0%	3.4%	2.2%	5.2%
15:45:00	8.1%	5.6%	17.8%	5.1%	11.7%	5.6%	6.6%	11.2%	0.5%	14.7%	0.5%	8.1%	5.1%	10.2%	9.6%	3.6%	4.1%	20.3%	9.6%	14.7%	7.1%	2.5%	10.2%	15.7%
16:00:00	4.9%	6.9%	15.4%	8.6%	18.8%	4.9%	1.6%	0.1%	6.6%	10.3%	6.9%	5.2%	1.6%	12.0%	18.5%	1.6%	8.6%	20.2%	3.2%	10.3%	20.2%	0.1%	3.5%	23.6%
16:15:00	11.4%	8.6%	6.4%	3.1%	8.1%	30.4%	3.6%	3.1%	8.1%	3.6%	9.7%	3.1%	4.7%	9.7%	1.9%	6.4%	11.4%	8.1%	20.3%	14.8%	42.1%	8.1%	4.7%	10.3%
16:30:00	1.3%	2.2%	10.3%	10.3%	3.1%	50.7%	4.9%	1.3%	0.4%	3.1%	4.9%	4.9%	7.6%	2.2%	0.4%	3.1%	6.7%	8.5%	3.1%	10.3%	32.7%	6.7%	6.7%	6.7%
16:45:00	8.0%	3.5%	22.0%	7.0%	5.0%	30.5%	5.0%	9.5%	4.0%	19.0%	14.0%	8.0%	13.0%	5.5%	2.0%	13.0%	2.0%	13.0%	5.0%	14.0%	2.0%	7.0%	14.5%	9.5%
17:00:00	1.5%	10.6%	22.7%	0.0%	10.6%	31.8%	3.0%	24.2%	4.5%	13.6%	7.6%	7.6%	10.6%	12.1%	7.6%	13.6%	3.0%	4.5%	18.2%	9.1%	9.1%	12.1%	6.1%	1.5%
17:15:00	12.2%	4.2%	1.9%	1.9%	23.0%	5.4%	18.0%	8.9%	4.0%	6.3%	4.2%	6.3%	14.5%	2.8%	7.5%	5.1%	4.0%	1.6%	13.6%	13.6%	8.9%	4.2%	12.2%	4.2%
17:30:00	7.9%	6.7%	8.7%	6.1%	16.4%	0.3%	20.7%	15.1%	6.7%	1.0%	3.6%	5.4%	2.3%	11.2%	1.5%	3.6%	7.9%	7.9%	2.3%	2.3%	10.0%	3.6%	18.2%	2.8%
17:45:00	15.8%	14.2%	8.9%	8.9%	4.0%	5.6%	12.5%	23.8%	5.9%	5.9%	5.9%	7.6%	8.9%	13.9%	4.0%	9.2%	7.6%	0.7%	4.3%	7.3%	4.0%	18.8%	15.8%	4.3%
Average	**7.2%**	**6.3%**	**11.2%**	**5.3%**	**9.7%**	**16.8%**	**6.4%**	**8.6%**	**4.2%**	**8.0%**	**6.8%**	**5.2%**	**6.7%**	**7.6%**	**5.3%**	**5.2%**	**7.0%**	**8.4%**	**7.2%**	**8.5%**	**12.4%**	**5.8%**	**9.0%**	**7.2%**

After determining the representative day, the analyst can start calibrating the model. The analyst will be calibrating against the measures used to determine representative day (travel time, in this example).

The 2019 FHWA guidance has four calibration criteria. Each criterion should be met for all the different measures, routes, and locations for the model to be considered calibrated. The variables and equations are from the FHWA 2019 guidance for microsimulation, but the example provided and calculations were modified to make it easier to follow the steps set out in the FHWA guidance.

Criterion I – Control for Time-Variant Outliers

Below is the summary of Criterion I, as well as an example.

Rationale and Criteria:

- Why: The purpose of this criteria is to control for maximum number of outliers associated with simulation results.
- Criteria: 95 percent of all simulated outputs should fall within the time-variant envelope created by the ~2 Sigma Band. Note that if fewer than 20-time intervals are used for the analysis, a maximum of one value may fall outside the time-variant envelope.

Variables and equations:

$c_r(t)$	Observed travel times from the representative day
$\sigma(t)$	Standard deviation for MOE for each time interval
$Z_{95\%}$	Z-Statistic for 95% of the observed variation

Equations for calculating ~2 Sigma Band:

~2 Sigma Band Maximum Value: $\hat{I}_{\sim 2}(t) = c_r(t) + Z_{95\%}\big(\sigma(t)\big)$ (4)

~2 Sigma Band Minimum Value: $\check{I}_{\sim 2}(t) = c_r(t) - Z_{95\%}\big(\sigma(t)\big)$ (5)

Example calculation

Step 1 – Calculate the standard deviation per time interval.

To calculate the standard deviation, the analyst must use the values from Table N-1. Below is the equation for standard deviation of a population. Note that the FHWA guidance uses a standard deviation of a population equation and not for a sample.

$$\sigma(t) = \sqrt{\frac{\sum(x_i - \mu)^2}{N}} \qquad (6)$$

Where,

$\sigma(t)$	population standard deviation per time interval
x_i	each value from the population (observed travel time)
μ	the population mean (average travel time from last column in Table N-1)
N	size of the population (total number of days in cluster)

A sample calculation for standard deviation for one time interval is provided below.

$$\sigma(15{:}00{:}00) = \sqrt{\frac{(5.6 - 5.3)^2 + (4.9 - 5.3)^2 + (4.7 - 5.3)^2 + (5.7 - 5.3)^2 \ldots}{24}} = 0.3$$

This calculation is repeated for each time interval. Results can be found in the third column of Table N-3.

Step 2 – Calculate ~ 2 sigma band max and min for each time interval

Equations (4) and (5) above can be used to calculate the ~2 Sigma Bands. The $Z_{95\%}$ statistic is provided in the FHWA guidance and is 1.96. An example calculation for the 15:00:00 time interval for these equations is shown below. The standard deviation calculated in the previous step is used for the ~2 sigma band calculations.

~2 Sigma Band Maximum Value: $\hat{I}_{\sim 2}(15{:}00{:}00) = 5.2 + 1.96(0.3) = 5.9\ min$

~2 Sigma Band Minimum Value: $\check{I}_{\sim 2}(15{:}00{:}00) = 5.2 - 1.96(0.3) = 4.5\ min$

Columns four and five in Table N-3 below show the results of the ~2 sigma band calculations for all the time intervals. The variation envelope developed using the ~2 sigma band is shown in Figure N-1.

Table N-3. Criterion I Calculation Results

Time of Trip Start	Rep. Day Travel Time	Standard Deviation	~2 Sigma Band (max)	~2 Sigma Band (min)	Simulated Travel Times	Simulated Value Within ~2 Sigma Band?
15:00:00	5.2	0.3	5.9	4.5	5.4	YES
15:15:00	5.3	0.3	5.9	4.7	5.8	YES
15:30:00	5.1	0.3	5.7	4.5	5.5	YES
15:45:00	6.6	0.7	7.9	5.3	6.7	YES
16:00:00	6.3	0.7	7.6	5.0	7.3	YES
16:15:00	5.5	0.8	7.1	3.9	6.9	YES
16:30:00	5.6	0.8	7.1	4.1	6.2	YES
16:45:00	6.4	0.8	8.0	4.8	6.6	YES
17:00:00	6.3	0.8	7.9	4.7	7.0	YES
17:15:00	8.2	0.8	9.8	6.6	7.8	YES
17:30:00	7.3	0.7	8.7	5.9	7.4	YES
17:45:00	5.7	0.6	7.0	4.4	6.0	YES

As seen in the Table N-3 above, all the simulated travel times for the different time intervals fall within the time variant envelopes created by the ~2 sigma band. Because there are fewer than 20 time-intervals, the FHWA criterion allows one simulated travel time to fall outside of the ~2 sigma band. Based on the calculations, Criterion I is satisfied.

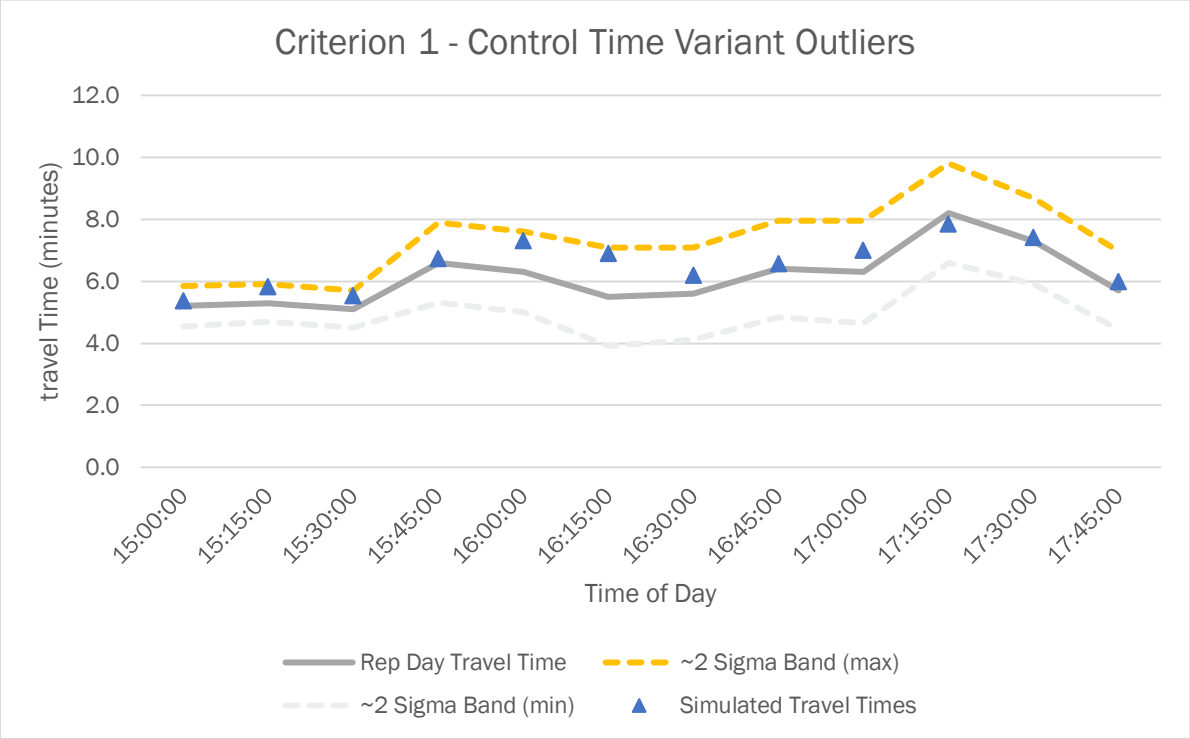


Figure N-1. Criterion I Time Variant Envelope

Criterion II – Control for Time-Variant "Inliers"

Below is the summary of Criterion II, as well as an example.

Rationale and Criteria:

- Why: The purpose of this criteria is to constrain simulated results to fall closely in line with the representative day.
- Criteria: 2/3 of all simulated outputs and simulated results for 2 critical time intervals must fall within the time-variant envelope created by the ~1 Sigma Band. Note that the two critical time intervals must be non-adjacent maximum values from the representative day.

Variables and equations:

$c_r(t)$	Observed travel times from the representative day
$\sigma(t)$	Standard deviation for MOE for each time interval

Equations for calculating ~2 Sigma Band:

1 Sigma Band Maximum Value: $\hat{I}_1(t) = c_r(t) + \sigma(t)$ (6)

1 Sigma Band Minimum Value: $\check{I}_1(t) = c_r(t) - \sigma(t)$ (7)

Example calculation

Step 1 – Calculate 1 sigma band maximum and minimum values.

Because standard deviation was already calculated as part of Criterion I, there is no need to calculate it again. Below is an example calculation for equations (6) and (7).

1 Sigma Band Maximum Value: $\hat{I}_1(15{:}00{:}00) = 5.2 + 0.3 = 5.5\ min$

1 Sigma Band Minimum Value: $\check{I}_1(15{:}00{:}00) = 5.2 - 0.3 = 4.9\ min$

Columns four and five in Table N-4 below show the results of the 1 sigma band calculations for all time intervals. The variation envelope developed using the 1 sigma band is shown in Figure N-2.

Table N-4. Criterion II Calculation Results

Time of Trip Start	Rep. Day Travel Time	Standard Deviation	1 Sigma Band (max)	1 Sigma Band (min)	Simulated Travel Times	Simulated Value Within 1 Sigma Band?
15:00:00	5.2	0.3	5.5	4.8	5.4	YES
15:15:00	5.3	0.3	5.7	5.0	5.8	NO
15:30:00	5.1	0.3	5.4	4.8	5.5	NO
15:45:00	6.6	0.7	7.3	6.0	6.7	YES
16:00:00	6.3	0.7	7.0	5.6	7.3	NO
16:15:00	5.5	0.8	6.3	4.7	6.9	NO
16:30:00	5.6	0.8	6.3	4.8	6.2	YES
16:45:00	6.4	0.8	7.2	5.6	6.6	YES
17:00:00	6.3	0.8	7.1	5.4	7.0	YES
17:15:00	8.2	0.8	9.0	7.4	7.8	YES
17:30:00	7.3	0.7	8.0	6.6	7.4	YES
17:45:00	5.7	0.6	6.3	5.0	6.0	YES

As seen in Table N-4 above, eight out of the 12 simulated travel times fall within the 1 sigma band time-variant envelope. The criterion calls for 2/3 of all simulated results to fall within the 1 sigma band, which is satisfied.

The second part of this criterion calls for two non-consecutive critical outputs to also fall within the 1 sigma band. The critical outputs are determined by two maximum non-consecutive travel times from the representative day. The first critical output to check the simulated travel time against is at 17:15:00 time interval, when the representative day travel time is at the highest, 8.2 minutes. The second critical output occurs at 17:30:00 time interval, when the representative day travel time is at 7.3 minutes. However, this value cannot be used because it is adjacent to the first critical value. The next critical output occurs at 15:45:00, when the representative day travel time is 6.6 minutes. The simulated travel time at 17:15:00 and at 15:45:00 falls within the 1 sigma band.

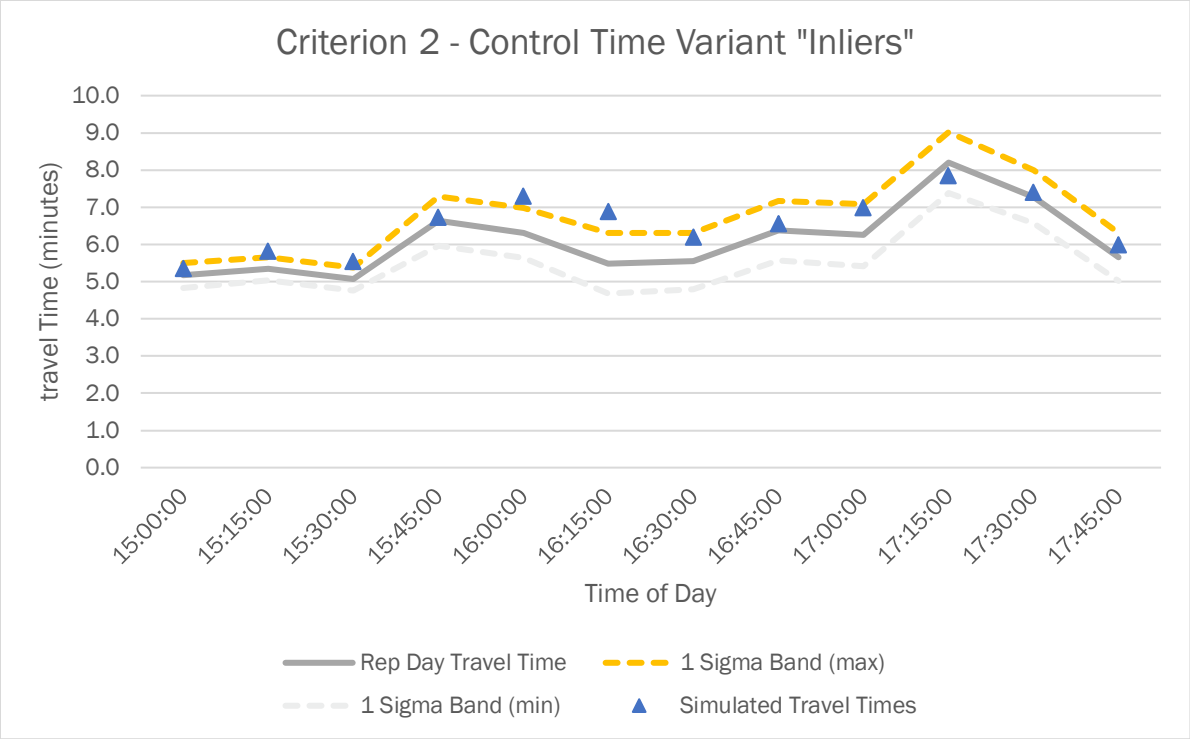


Figure N-Error! No text of specified style in document.-2. Criterion II Time Variant Envelope

Criterion III – Bounded Dynamic Absolute Error (BDAE)

Below is the summary of Criterion III, as well as an example.

Rationale and Criteria:

- Why: To determine on average, the simulated results are close to the representative day.
- Criteria: Average simulated absolute error from the representative day overall time intervals is less than or equal to the BDAE. The BDAE is the differences from the representative day seen across all days in the cluster for all time intervals.

Variables and equations:

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

BDAE threshold equation:

$$\frac{\sum_{i \neq r} \sum_t \frac{|c_r(t) - c_i(t)|}{N_T}}{N_{cluster} - 1} \qquad (8)$$

Average simulated absolute error equation:

$$\frac{\sum_t |c_r(t) - \tilde{c}_i(t)|}{N_T} \qquad (9)$$

Criterion III is met when:

$$\frac{\sum_t |c_r(t) - \tilde{c}_i(t)|}{N_T} \leq \frac{\sum_{i \neq r} \sum_t \frac{|c_r(t) - c_i(t)|}{N_T}}{N_{cluster} - 1}$$

Or in other words, Criterion III is met when the average simulated absolute error is less than or equal to the BDAE threshold.

Example Calculation

Step 1 – Calculate the average simulated absolute error.

To calculate average simulated absolute error, take the absolute value between the difference of the simulated travel time and the representative day travel time for each time interval, sum all the absolute value differences together for all time intervals, and divide by the total number of time intervals. This calculation is provided below; results are shown in Table N-5.

Below is the calculation for the average simulated absolute error from equation (9).

$$\frac{|5.2-5.4|+|5.3-5.8|+|5.1-5.5|+|6.6-6.7|+|6.3-7.3|+|5.5-6.9|+|5.6-6.2|+|6.4-6.6|+|6.3-7.0|+|8.2-7.9|+|7.3-7.4|+|6.0-5.7|}{12}$$

$$\frac{0.2+0.5+0.4+0.1+1.0+1.4+0.6+0.2+0.7+0.3+0.1+0.3}{12}=0.50$$

The average simulated absolute error is equal to 0.5.

Table N-5. Average simulated absolute error calculation results.

Time of Trip Start	Simulated Travel Time	Rep. Day Travel Time	Absolute Difference
15:00:00	5.4	5.2	0.2
15:15:00	5.8	5.3	0.5
15:30:00	5.5	5.1	0.4
15:45:00	6.7	6.6	0.1
16:00:00	7.3	6.3	1.0
16:15:00	6.9	5.5	1.4
16:30:00	6.2	5.6	0.6
16:45:00	6.6	6.4	0.2
17:00:00	7.0	6.3	0.7
17:15:00	7.9	8.2	0.3
17:30:00	7.4	7.3	0.1
17:45:00	6.0	5.7	0.3
		Average	0.5

Step 2 – Calculate the BDAE threshold

The BDAE is a more involved calculation but can be done easily with a spreadsheet program such as Microsoft Excel. The first part of the calculation is to take the absolute difference between the representative day and the observed day within the cluster and divide by the total number of time intervals. This is then done for all the days that do not equal the representative day and all-time intervals within the cluster. This part of the calculation is shown below.

$$\sum_{i \neq r} \sum_{t} \frac{|c_r(t) - c_i(t)|}{N_T}$$

$$\frac{|c_r(15{:}00{:}00) - c_1(15{:}00{:}00)|}{N_T} + \frac{|c_r(15{:}00{:}00) - c_2(15{:}00{:}00)|}{N_T} + \cdots$$

$$\frac{|5.2 - 5.6|}{12} + \frac{|5.2 - 4.9|}{12} + \cdots = 12.9$$

The next part of the calculation is to divide this result by the number of days in the cluster minus 1.

$$BDAE\ Threshold = \frac{12.9}{N_{cluster} - 1} = \frac{12.9}{24 - 1} = 0.56$$

Criterion III is met when the average simulated absolute error is less than or equal to the BDAE threshold:

$$0.50 \ \leq \ 0.56, Criterion\ III\ is\ met.$$

Criterion IV – Bounded Dynamic Systematic Error

Below is the summary of Criterion IV, as well as an example.

Rationale and Criteria:

- Why: To ensure the simulation is not over- or under-estimating the representative day.
- Criteria: Average simulated error from the representative day over all time intervals is less than or equal to 1/3 the BDAE.

Variables and equations:

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

Average simulated absolute error equation:

$$\left|\frac{\sum_t c_r(t) - \tilde{c}_i(t)}{N_T}\right| \qquad (10)$$

The dissimilarity between equation (9) and equation (10) is that the absolute value in equation (10) is taken after averaging the differences together, whereas in equation (9) the absolute value is taken after the difference and those values are summed together, and then the average is taken. Below is the calculation for the average simulated error from equation (10).

$$\left|\frac{\begin{array}{c}(5.2-5.4)+(5.3-5.8)+(5.1-5.5)+(6.6-6.7)+(6.3-7.3)+(5.5-6.9)+(5.6-6.2)\\ +(6.4-6.6)+(6.3-7.0)+(8.2-7.9)+(7.3-7.4)+(5.7-6.0)\end{array}}{12}\right|$$

$$\left|\frac{-0.2-0.5-0.4-0.1-1.0-1.4-0.6-0.2-0.7+0.3-0.1-0.3}{12}\right| = \left|\frac{-5.2}{12}\right| = 0.43$$

Criterion IV is met when the average simulated error is less than or equal to the 1/3 BDAE threshold:

$$0.43 \;\leq\; 0.56 \times \frac{1}{3}$$

$$0.43 \leq 0.19, Criterion\ IV\ is\ not\ met$$

Criterion IV is not met, and the simulation is an overestimation of the representative day travel time. The analyst would have to go back to the microsimulation software and modify parameters to make the travel time more closely match with the representative day.

Section 4 – External References

The websites below were last accessed on May 31, 2024

1. **PTV Vissim**

https://cgi.ptvgroup.com/vision-help/VISSIM_11_ENG/

- PTV Vissim is a microscopic stimulation program for modeling multimodal transport operations, under Vision Traffic Suite Software.

2. **Federal Highway Administration Calibration**

https://ops.fhwa.dot.gov/trafficanalysistools/tat_vol4/sec5.htm

- Calibration is the adjustment of model parameters to improve the model's ability to reproduce local traffic conditions.

Section 5 – Lonestar Data in Cluster Analysis Case Study

TxDOT Fort Worth District – Use of Lonestar Advanced Traffic Management System (ATMS) Data in a cluster analysis.

The Fort Worth District has many microwave traffic detectors set up around Tarrant County freeways. Traffic count data can be collected from these detectors and is available for historical counts and microsimulation model development.

The I-30 (I-820 to Chisholm Trail Parkway) project team, with the assistance of TxDOT and TxDOT's traffic and ITS group, utilized Lonestar data collection to support the simulation and calibration of a microsimulation model that represented the I-30 corridor in terms of standards of validation set by FHWA traffic analysis toolbox (2019). The ATMS data obtained from TxDOT is one input into the cluster analysis required by FHWA. The Project Team determined that there are fifteen traffic detectors in or near the IH 30 IAJR project area of influence (AOI). The location of the detectors along IH 30 and IH 820 are shown in Table N-6.

Table N-6: Detector Locations

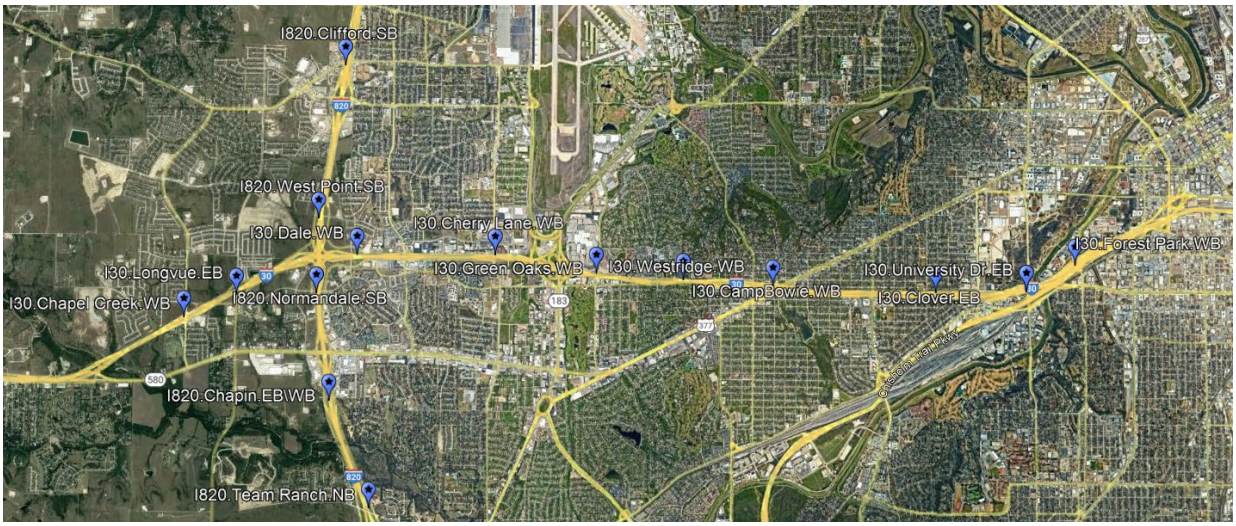
Equipment ID	Equipment Name	Latitude	Longitude	Protocol Name
2233	I30.Chapel Creek.WB	32.72962	-97.503918	WavetronixHD
2683	I30.Longvue.EB	32.73292	-97.495420	WavetronixHD
972	I30.Dale.WB	32.73849	-97.474918	WavetronixHD
968	I30.Cherry Lane.WB	32.73843	-97.451535	WavetronixHD
976	I30.Green Oaks.WB	32.73583	-97.434442	WavetronixHD
982	I30.Westridge.WB	32.73460	-97.418555	WavetronixHD
1802	I30.CampBowie.WB	32.73402	-97.404607	WavetronixHD
970	I30.Clover.EB	32.73278	-97.377106	WavetronixHD
981	I30.University Dr.EB	32.73325	-97.361801	WavetronixHD
975	I30.Forest Park.WB	32.73805	-97.353355	WavetronixHD
1018	I820.Clifford.SB	32.76557	-97.477134	WavetronixHD
1035	I820.West Point.SB	32.74366	-97.481464	WavetronixHD
1025	I820.Normandale.SB	32.73298	-97.481751	WavetronixHD
1017	I820.Chapin.EB\WB	32.71870	-97.479800	WavetronixHD
1031	I820.Team Ranch.NB	32.70262	-97.472646	WavetronixHD

For each working detector, data is available as follows:

- Data is per poll cycle. This is configurable per detector. Most detectors are set to either 20 or 30 seconds.
- Speed is available per lane. It is the average speed per lane during the poll cycle based on that point on the roadway.
- Volume is available per lane. It is the actual count per lane during the poll cycle of vehicles crossing the detector.
- Occupancy is available per lane. It is the average occupancy per lane during the poll cycle at the detector.

For this IH 30 study the project team requested the data for hourly counts for the entire year of 2022. The raw count data was consolidated by TRF Division staff/contractors, and it was placed into six csv files on Box.com (TxDOT's official file transfer method) for downloading by the project team. Each csv file covered about two months of data for all fifteen locations, and the files were about 2 megabits each in size. A Google image of the IH 30 and IH 820 corridors and the fifteen detector locations are shown in Figure N-3.

Figure N-3: Area map of IH 30 and IH 820 Detector Locations



Data Returned (.xlsx format):

- Timestamp
- Hour (1-hour bin data)
- Detector Name with directionality
- Lane assignment
- Requested Data (Volumes and/or Speed)

Volume (ATMS) Data obtained from TxDOT, the project team selected one location that coincided with a known bottleneck and summarized the per lane volume data directionally. This volume data is combined with other data sets (precipitation, crash data, and travel time data) in a cluster analysis that normalizes all data sets in representative and non-representative clusters.

Precipitation Data was collected from the Automated Surface Observing System (ASOS) program. The modeling included precipitation data from (NFW) Fort Worth NAS weather station of Texas ASOS Network. The precipitation variable in the modeling was considered as the accumulative precipitation levels in inches during the peak period (whether it is AM or PM), on a given day.

Crash Data for the area of influence was acquired from TxDOT's Traffic Safety Division, ranging from year 2018 through 2022, to conduct a historical crash statistic summary. Data from year 2022 was utilized within the cluster analysis.

Speed Data from January 1 to December 31, 2022, was obtained from the NPMRDS for the I-30 mainlane project limits. Speed data is divided into TMC segments that represent sections of the project corridor. This segmentation ensures that clustering can make note of any outlier sections and days that may impact the clustering results.

Data Normalization

The volume, speed, and precipitation data are normalized using a scale between 0 and 1. A linear scale, as presented in FHWA TAT III guidelines, is used for the normalization. See the following equation:

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

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

After the data has been normalized, it is reviewed for redundancy and attributes that have no impact on the cluster analysis. From the review, it was observed that the precipitation data would not be a controlling data set and was removed from the cluster analysis. Based on the results of the cluster analysis and identifying the data points in the representative cluster, a single day that is closest to the mean is selected as the representative day. The data (volume and travel time) associated with the representative day and standard deviation of the remaining days in the

representative cluster is used to define the 1-sigma, 2-sigma envelopes, along with the BDAE tolerances for model validation.

Figure 2. Clustered Yearly Volume Data

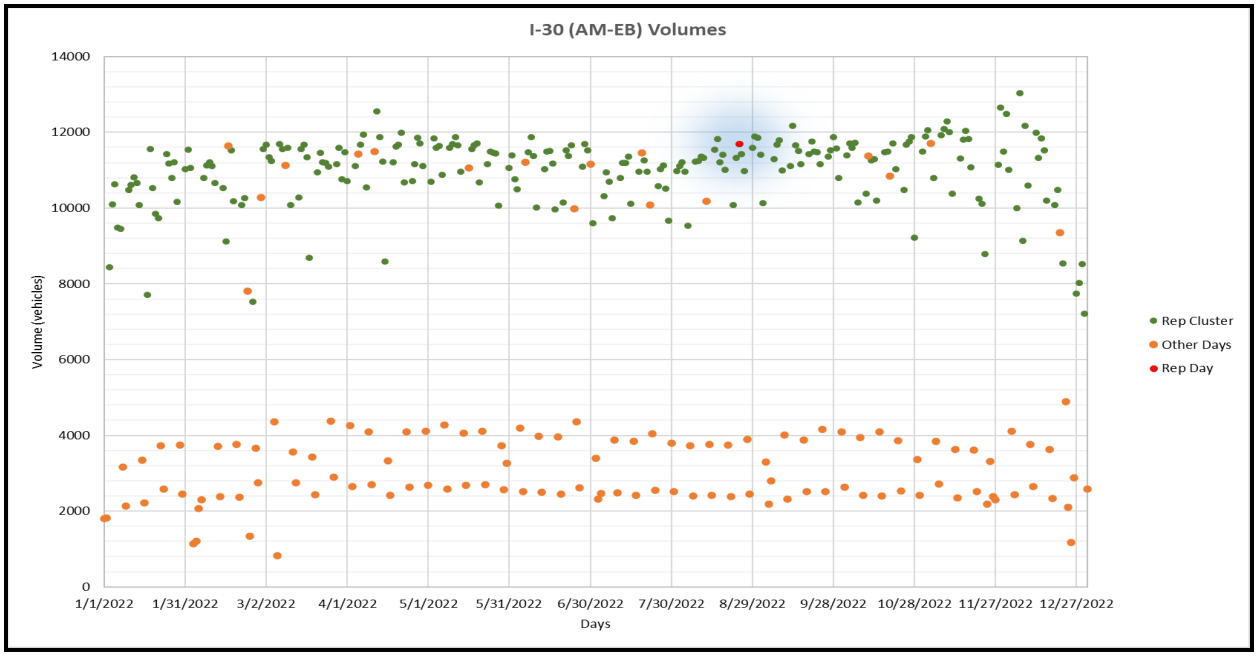
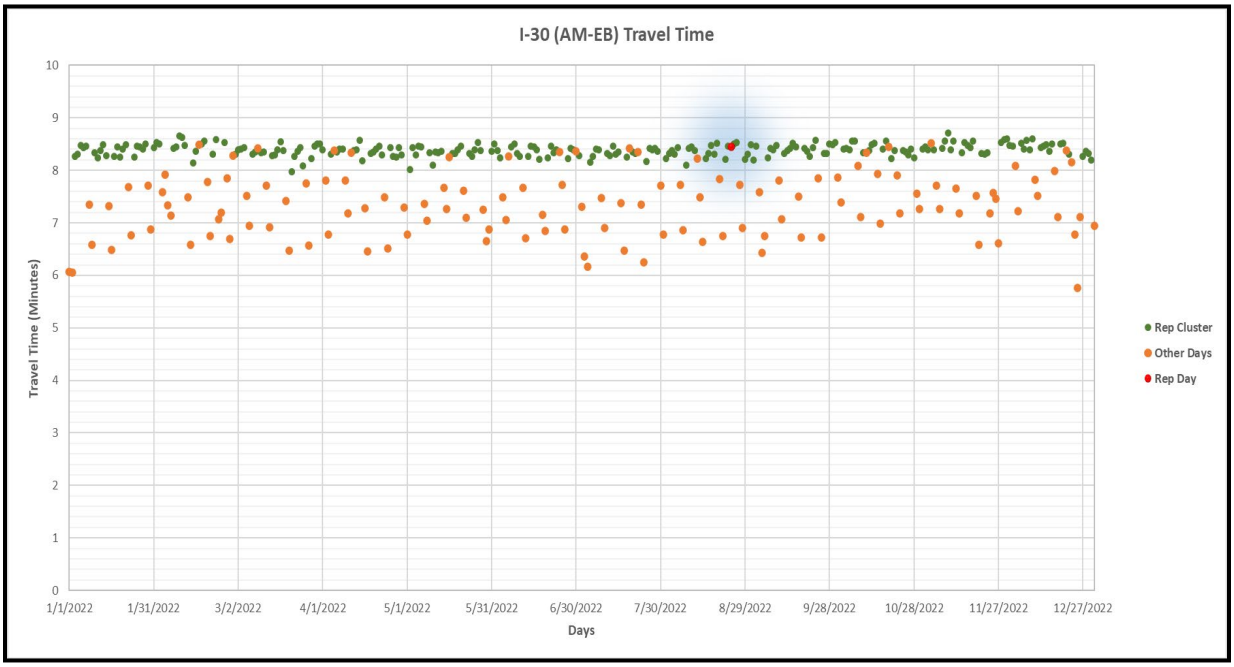


Figure 3. Clustered Yearly Travel Time



Conclusions

The project team found that the volume data for the entire year of 2022 allowed for confirmation that the traffic volume on the corridor is minimally impacted throughout the year (school vs no school, any times with heavy recreational use), and it shows as expected, commuting days (Monday through Friday) vs weekend volume is noticeably different.

The project team found that requesting, downloading, and processing the data was easily managed, and there were no issues with downloading the six data files through Box.com and processing them for use in the clustering analysis.

Chapter 14 - Appendix O – Multimodal Analysis

- **Section 1** – Pedestrian Level of Traffic Stress (PLTS) Inventory and Classification
- **Section 2** – Pedestrian and Bicycle Safety Resources
- **Section 3** – Bicycle Level of Traffic Stress Inventory and Classification
- **Section 4** – Shared-Use Path Level of Service Calculator Guidance
- **Section 5** – External References

Section 1 – Pedestrian Level of Traffic Stress (PLTS) Inventory and Classification

This form should be used to inventory a pedestrian facility when conducting a pedestrian level of traffic stress analysis. Only data applicable to the pedestrian facility should be filled out. For analysis of signalized midblock crossings or segment facilities, the sidewalk condition and width, buffer type and width, speed, number of lanes, and adjacent land use type are needed. For analysis of unsignalized intersection crossings or midblock crossing, the speed, adjacent roadway lanes value, ADT, and crossing treatments are needed. For characteristic definitions and other information regarding this inventory, see Chapter 14.

Facility[1]:				
Characteristic		**Value**	**PLTS Reference Table**	**PLTS Classification**
Sidewalk	Condition		Table 14-7	
	Width (ft)			
Buffer	Type		Table 14-8	
	Off-Street Width (ft)		Table 14-9	
	On-Street Width (ft)			
	Total Width (ft)			
Adjacent Roadway	Speed (mph)		Used in various tables	-
	Number of Lanes		Table 14-10	
Adjacent Land Use	Type		Table 14-11	
Overall PLTS Classification				

[1]Applicable to signalized midblock crossings and segment facilities

Facility[2]:				
Characteristic		**Value**	**PLTS Reference Table**	**PLTS Classification**
Adjacent Roadway	Speed (mph)		Table 14-12, 14-13, or 14-14	
	Number of Lanes			
	ADT (vpd)			
	Rased Median			
Crossing Treatment(s)			Table 14-15	
Overall PLTS Classification				

[2]Applicable unsignalized intersection crossings or unsignalized midblock crossings (includes midblock crossings with PHB or RRFB)

Section 2 – Pedestrian and Bicycle Safety Resources

PEDSAFE is a pedestrian safety guide and countermeasure selection system endorsed by the FHWA. The guide portion of the tool contains information on background, analysis, statistics, and implementation. The countermeasures portion of the tool contains a selection tool, a countermeasure list, and selection matrices.

BIKESAFE is a bicycle safety guide and countermeasure selection system endorsed by the FHWA. The guide portion of the tool contains information on background, analysis, statistics, and implementation. The countermeasures portion of the tool contains a selection tool, a countermeasure list, and selection matrices.

The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) is a crash analysis tool that includes an input form designer, group crash typing, location data inputs, crash reports, countermeasures, system tools to help select appropriate countermeasures, and import/export capabilities. Beginning in 2021 CRIS data will include crash groups and types, which will aid in PBCAT safety analysis of pedestrian and bicycle facilities. Download requires registration.

The Pedestrian and Bicyclist Safety Information Search Tool is a search engine for more than 100 pedestrian and bicyclist reports, each of which meets FHWA's standards. This tool can be used when searching for pedestrian safety information.

Additional pedestrian and bicycle safety resources are listed below.

- NCHRP 893 - Systemic Pedestrian Safety Analysis
    - Systemic approach that enables agencies to select appropriate countermeasures for locations with limited crash data. Similar to a PLTS.
- NCHRP Report 926 - Guidance to Improve Pedestrian and Bicyclist Safety at Intersections
    - Provides pedestrian and bicycle safety solutions for different intersection designs and operational treatments.
- NCHRP Report 948 - Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges
    - Provides guidance on adjusting intersection and interchange geometric features to reduce confusion and increase safety for all users.
- NCHRP 03-133 - Traffic Signal Design and Operations for Non-Motorized Users
    - Identifies gaps in current design to address the comfort and safety of an increasing number of pedestrians and bicyclists.

- NCHRP 17-56 - Development of CMF for Uncontrolled Pedestrian Crossing Treatments
    - Ongoing research indicating the importance of enhancing crossing treatments.
- NCHRP 17-84 - Pedestrian and Bicycle Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities
    - Discussion of crash and fatality rates to inform the national infrastructure improvements needed to combat increasing pedestrian and bicyclist fatalities.
- NCHRP 17-87 - Enhancing Pedestrian Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities
    - A scalable guide for tangible improvements to achieve safe and sustainable communities.
- NCHRP 17-97 - Strategies to Improve Pedestrian Safety at Night
    - Examines the root cause of the increase in nighttime fatalities and identifies ways to address the issue with limited funding.
- NCHRP 22-37 - Development of a MASH Barrier to Shield Pedestrians, Bicyclists, and Other Vulnerable Users from Motor Vehicles
    - Research on the development of safe, cost effective, sensible crash barriers that address the safety of all users.
- NCHRP 03-141 - Guidance on Midblock Pedestrian Signals (MPS)
    - Develops solutions and expands options to improve safety at midblock crossings while attending to transportation users of all ages and abilities.
- NCHRP 20-102(33) - Safety of Vulnerable Road Users in a C/AV Future
    - Research that explores technologies that may help protect pedestrians and bicyclists who may not have a receiver that communicates with C/AV technology.
- FHWA-SA-17-072 - Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations
    - Research analysis and suggested solutions for implementation of safety measures at uncontrolled crossings.
- FHWA-HRT-04-100 - Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines
    - Provides guidance on crosswalk criteria that may improve pedestrian and motorist safety.
- FHWA-SA-20-042 - Pedestrian and Bicyclist RSA Guide and Prompt Lists
    - Identifies user mistakes and misjudgments and reduces the severity of their consequences through improvements to infrastructure.
- FHWA-SA-18-032 - Guide for Scalable Risk Assessment Methods for Pedestrians and Bicyclists
    - Calculating risk values to inform decisions on pedestrian and bicyclist infrastructure
- FHWA-SA-14-099 - A Resident's Guide for Creating Safer Communities for Walking and Biking

    - Identifying pedestrian and bicyclist safety issues to what is needed to enact the necessary improvements

- FHWA-SA-07-017 - Pedestrian Safety Guide for Transit Agencies
    - Describes common safety issues in areas where transit is operational with examples of existing improvements that have been effectively implemented
- FHWA-SA-18-077 - Bikeway Selection Guide
    - Examines tradeoffs relating to the selection of bikeway options in matters of safety, implementation, and advocating for its place in future transportation projects
- FHWA-SA-21-010 - Supplement to the Bikeway Selection Guide
    - Includes common performance metrics and spatial needs of bikeways at intersections with safety and equity design principles in mind

Section 3 – Bicycle Level of Traffic Stress Inventory and Classification

This form should be used to inventory a bicycle accommodation when conducting a bicycle level of traffic stress analysis. Only data applicable to the bicycle accommodation should be filled out (for characteristic definitions and other information regarding this inventory, see Chapter 14. Add more rows for repeat facility types as needed.

Facility[1]:			
Characteristic	**Value**	**BLTS Reference Table**	**BLTS Classification**
Bike Lane Width (ft)		(Table 14-22 or Table 14-23)[2]	
On-Street Parking Width (ft)			
Through Lanes Per Direction			
Posted Speed (mph)			
Facility[3]:			
Characteristic	**Value**	**BLTS Reference Table**	**BLTS Classification**
Through Lanes Per Direction		(Table 14-24)	
Posted Speed (mph)			
Facility[4]:			
Characteristic	**Value**	**BLTS Reference Table**	**BLTS Classification**
Right-Turn Length (ft)[6]		(Table 14-25, Table 14-26, or Table 14-27)[5]	
Lanes Crossed[7]			
Posted Speed (mph)			
Facility[8]:			
Characteristic	**Value**	**PLTS Reference Table**	**BLTS Classification**
Posted Speed		(Table 14-28, 14-29, or 14-30)[9]	
Number of Lanes			
ADT (vpd)			
Crossing Treatment(s)		Table 14-31	
Overall PLTS Classification			

[1]Applicable to bike accommodations that are adjacent to vehicular traffic (does not include bicycle lanes separated by a large vertical barrier)

[2]Use Table 14-22 if facility is adjacent to on-street parking or Table 14-23 if facility is not adjacent to on-street parking

[3]Applicable to mixed traffic bicycle accommodations

[4]Applicable to bicycle facilities at intersection approaches

5Use Table 14-25 if accommodations is a pocket bike lane (a bike lane positioned between a right-turn lane and a through lane at an intersection), use Table 14-26 for mixed traffic bicycle facilities at intersection right-turns, use Table 14-27 for mixed traffic bicycle facilities at intersection left-turns

6Right-turn length should only be collected if analyzing bicycle accommodations with right-turn at intersection approach

7Lanes crossed is the number of through lanes crossed to go from the bicycle accommodation to the left-turn lane, should only be collected if analyzing bicycle accommodation with left-turn at intersection approach

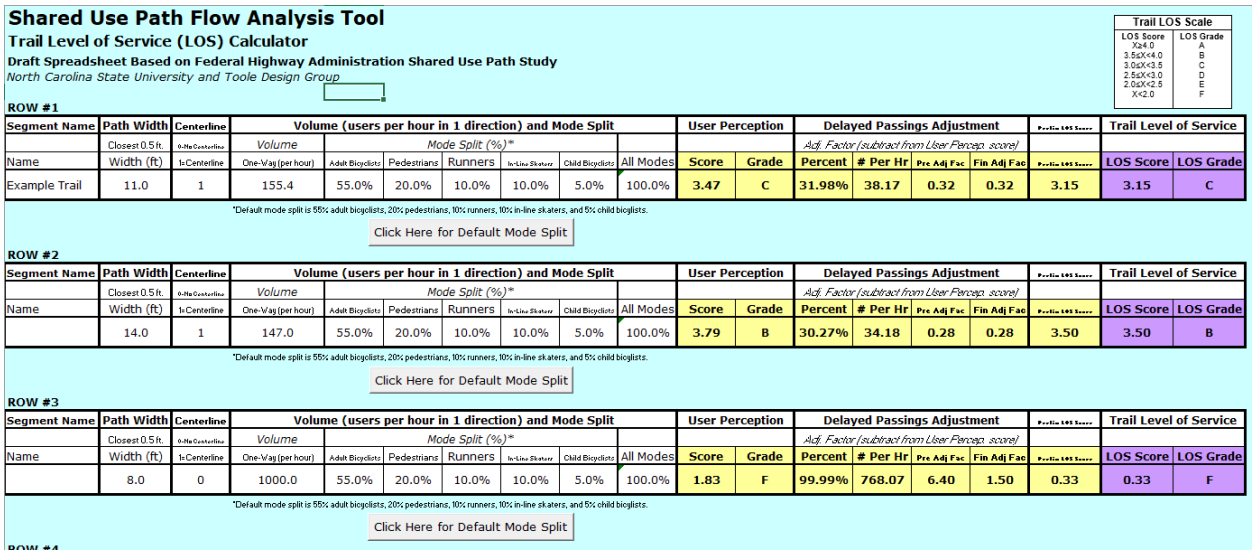
[8]Applicable to locations that are unsignalized intersection crossings or midblock crossings

9Use Table 14-28 if the accommodation is an unsignalized intersection crossing or midblock crossing with no raised median, use Table 14-29 if the accommodation is an unsignalized crossing or midblock crossing with a raised median (1 to 2 lanes), use Table 14-30 if the accommodation is an unsignalized intersection crossing or midblock crossing with a raised median (3 or more lanes)

Section 4 – Shared-Use Path Level of Service Calculator Guidance

The SUPLOS calculator can be found at this link: https://www.fhwa.dot.gov/publications/research/safety/pedbike/05138/SharedUsePathsTLOSCalculator.xls

An image of the home page of the SUPLOS calculator can be seen in Figure 0-1.



Shared Use Path Flow Analysis Tool
Trail Level of Service (LOS) Calculator
Draft Spreadsheet Based on Federal Highway Administration Shared Use Path Study
North Carolina State University and Toole Design Group

Trail LOS Scale

LOS Score	LOS Grade
X≥4.0	A
3.5≤X<4.0	B
3.0≤X<3.5	C
2.5≤X<3.0	D
2.0≤X<2.5	E
X<2.0	F

ROW #1

Segment Name	Path Width	Centerline	Volume (users per hour in 1 direction) and Mode Split							User Perception		Delayed Passings Adjustment					Trail Level of Service	
	Closest 0.5 ft.	0=No Centerline	Volume	Mode Split (%)*								Adj. Factor (subtract from User Percep. score)						
Name	Width (ft)	1=Centerline	One-Way (per hour)	Adult Bicyclists	Pedestrians	Runners	In-Line Skaters	Child Bicyclists	All Modes	Score	Grade	Percent	# Per Hr	Pre Adj Fac	Fin Adj Fac	Prelim. LOS Score	LOS Score	LOS Grade
Example Trail	11.0	1	155.4	55.0%	20.0%	10.0%	10.0%	5.0%	100.0%	3.47	C	31.98%	38.17	0.32	0.32	3.15	3.15	C

*Default mode split is 55% adult bicyclists, 20% pedestrians, 10% runners, 10% in-line skaters, and 5% child bicyclists.

Click Here for Default Mode Split

ROW #2

Segment Name	Path Width	Centerline	Volume (users per hour in 1 direction) and Mode Split							User Perception		Delayed Passings Adjustment					Trail Level of Service	
	Closest 0.5 ft.	0=No Centerline	Volume	Mode Split (%)*								Adj. Factor (subtract from User Percep. score)						
Name	Width (ft)	1=Centerline	One-Way (per hour)	Adult Bicyclists	Pedestrians	Runners	In-Line Skaters	Child Bicyclists	All Modes	Score	Grade	Percent	# Per Hr	Pre Adj Fac	Fin Adj Fac	Prelim. LOS Score	LOS Score	LOS Grade
	14.0	1	147.0	55.0%	20.0%	10.0%	10.0%	5.0%	100.0%	3.79	B	30.27%	34.18	0.28	0.28	3.50	3.50	B

*Default mode split is 55% adult bicyclists, 20% pedestrians, 10% runners, 10% in-line skaters, and 5% child bicyclists.

Click Here for Default Mode Split

ROW #3

Segment Name	Path Width	Centerline	Volume (users per hour in 1 direction) and Mode Split							User Perception		Delayed Passings Adjustment					Trail Level of Service	
	Closest 0.5 ft.	0=No Centerline	Volume	Mode Split (%)*								Adj. Factor (subtract from User Percep. score)						
Name	Width (ft)	1=Centerline	One-Way (per hour)	Adult Bicyclists	Pedestrians	Runners	In-Line Skaters	Child Bicyclists	All Modes	Score	Grade	Percent	# Per Hr	Pre Adj Fac	Fin Adj Fac	Prelim. LOS Score	LOS Score	LOS Grade
	8.0	0	1000.0	55.0%	20.0%	10.0%	10.0%	5.0%	100.0%	1.83	F	99.99%	768.07	6.40	1.50	0.33	0.33	F

*Default mode split is 55% adult bicyclists, 20% pedestrians, 10% runners, 10% in-line skaters, and 5% child bicyclists.

Click Here for Default Mode Split

ROW #4

Figure 0-1: Shared Use Path Calculator Home Page

The Federal Highway Administration has created a thorough guide on using the SUPLOS calculator. The guide can be found at this link: https://www.fhwa.dot.gov/publications/research/safety/pedbike/05138/05138.pdf

The guidance includes the following content:

- Introduction
  - How to Use This Guide
  - For What Types of Shared-Use Paths Is This Study Applicable?
  - Chapter Summaries
  - Other Reports and Products Generated by This Study
- An Overview of the Research
  - Problem Statement
  - Purpose

    - Approach
    - Findings
- LOS For Shared-Use Paths
    - What is LOS?
    - The Shared-Use Path LOS Model
    - Interpreting Shared-Use Path LOS Grades
    - LOS Scores for 15 Study Trails
- Applying the Model to Your Trail
    - Link Analysis
    - Data Requirement
    - Assumptions and Defaults
    - Shared-Use Path LOS Look-Up Tables
- Instructions for Using the Shared-Use Path LOS Calculator
    - Introduction
    - Step-by-Step Instructions
- Implications of This Research for Trail Design
    - Trail Width
    - Centerline Striping
    - Multilane Striping
    - Multiple Treadways
    - Trailway Operations and Management
- Example Applications: Fictional Case Studies
    - Case Study 1: Testing Design Options for the Stone Creek Trail Upgrade
    - Case Study 2: Testing Design Options for the De Soto River Waterfront Trail
- Appendix A. Study Trail Profiles
- Appendix B. Factors Used in the LOS Model
- Appendix C. LOS Look-Up Tables
- References

Section 5 – External References

The websites below were last accessed on May 31, 2024

1. **Union Pacific Railroad Public Projects Manual**

   https://www.up.com/cs/groups/public/@uprr/@corprel/documents/up_pdf_nativedocs/pdf_up_public_projects_manual.pdf

   - The Union Pacific Railroad Public Projects Manual is intended to be a guide for assisting communities or private entities in coordinating and implementing construction projects that involve Railroad Property.

2. **Rail-Highway Operations Manual**

   http://onlinemanuals.txdot.gov/txdotmanuals/rho/rho.pdf

   - The TxDOT Rail-Highway Operations Manual is intended to cover responsibilities and practices on projects that impact roadway and railroad ROW.

3. **Texas Bicycle and Pedestrian Count Exchange**

   https://mobility.tamu.edu/bikepeddata/

   - The Texas Department of Transportation and TTI created a system where bicycle or pedestrian data counts are available for collection.

4. **TxDOT Pedestrian Safety Action Plan**

   https://www.txdot.gov/about/advisory-committees/bicycle-pedestrian-advisory-committee/pedestrian-safety-action-plan.html

   - The Texas Department of Transportation has created the Pedestrian Safety Action Plan (PSAP) to address the rising number of pedestrian related crashes.

5. **TxDOT Pedestrian Safety Action Plan Screening Tool**

   https://amrgeo.jacobs.com/portal/apps/experiencebuilder/experience/?id=d0aa4ae93bcd45298540dc21ba1c713e

   - Dashboard to review PSAP analysis results, filter attributes, and isolate geographic conditions.

Chapter 15 - Appendix P – Transportation System Management and Operations (TSMO) and Transportation Demand Management

- **Section 1** – TSMO and Transportation Demand Management Strategies; Additional Guidance Documents
- **Section 2** – External References

Section 1 – TSMO and Transportation Demand Management Strategies; Additional Guidance Documents

The references provided in this document may serve as additional guidance on various TSMO and Transportation Demand Management strategies. The references are broken into two categories, corridor management references and systems management references.

Corridor Management References

- FHWA-HOP-09-055
  - Improving Traffic Signal Management and Operations: A Basic Service Model. Guide for achieving a basic service model for traffic signal management and operations.
- FHWA-HOP-09-006
  - Traffic Signal Operations and Maintenance Staffing Guidelines. Estimating the resources necessary to operate and maintain traffic signal systems.
- FHWA-HOP-11-027
  - The FHWA Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems. Design, implementation, and testing of adaptive control systems.
- NCHRP 560
  - Guide to Contracting ITS Projects. Guidance on the procurement of intelligent transportation systems (ITS).
- FHWA-HOP-09-007
  - Regional Traffic Signal Operations: An Overview. Developing and sustaining an RTSOP.
- NCHRP Synthesis 420
  - Operational and Institutional Agreements That Facilitate Regional Traffic Signal Operations. Case studies that show critical attributes of successful RTSOPs.
- TxDOT Traffic Signal Manual
  - Chapter 4, Section 2 provides guidance on coordinated signal operation.
- NCHRP Report 812
  - Traffic Signal Timing Manual Second Edition. Guidance on the development of signal timing to address the needs of various users.
- FHWA-HOP-07-006
  - Traffic Signal Timing on a Shoestring. Step-by-step guide on signal timing with minimal data requirements. Intended for organizations with limited transportation funds for signal timing.

Section 2 – External References

The websites below were last accessed on May 31, 2024

1. **Transportation Systems Management and Operations**

   https://ftp.txdot.gov/pub/txdot-info/trf/tsmo/tsmo-statewide-strategic-plan.pdf

   - TSMO aims to improve the project delivery process by integrating mobility-focused solutions throughout the phases of construction.

2. **Texas Department of Transportation: Transportation Systems Management and Operations**

   https://www.txdot.gov/safety/tsmo.html

   - The TxDOT TRF Division oversees the development and implementation of TSMO for TxDOT Divisions and Districts.

3. **Federal Highway Administration: Tool for Operations Benefit Cost Analysis**

   https://ops.fhwa.dot.gov/plan4ops/topsbctool/

   - The TOPS-BC is a tool intended to provide guidance to transportation practitioners in the application of benefit/cost analysis for operational strategies.

4. **Texas Department of Transportation: Transportation Systems Management and Operations Evaluation Tool**

   https://ftp.txdot.gov/pub/txdot-info/trf/tsmo/tsmo-evaluation-tool.pdf

   - This document will introduce a TSMO evaluation process and context for the tool in the Modernize Portfolio and Project Management initiative.

5. **Organizing for TSMO – Case Study Conducted by the FHWA**

   https://ops.fhwa.dot.gov/publications/fhwahop19065/chapter_1.htm

   - FHWA gives three case studies to help users understand how to assess and improve their TSMO capabilities

6. **Federal Highway Administration: Transportation Demand Management**

   https://ops.fhwa.dot.gov/plan4ops/trans_demand.htm

   - FHWA defines transportation demand management and gives additional resources to learn more about it

7. **National Operations Center of Excellence: Case Studies**

   https://transportationops.org/nocoe-case-studies

   - These case studies were developed in partnership with the authoring organization.

Chapter 16 - Appendix Q – Traffic Impact Analysis

- **Section 1** – TIA Quality Control Checklist
- **Section 2** – TIA Report Outline
- **Section 3** – TIA Example Problems
- **Section 4** – External References

Section 1 – TIA Quality Control Checklist

No	ITEM	Description	Review	
			Checked By	Date
		Methodology		
1	Project description (Should briefly discuss alternative scenarios if needed)			
2	Site Plan			
3	Traffic analysis objective			
4	Area of influence including adjacent interchanges & intersections			
5	Data requirements			
6	Data collection (Include dates,time of collection ,and locations)			
7	Analysis tool(s) and approach			
8	Trip generation table for the proposed development			
9	Traffic forecasting (Growth rate and Projection methods)			
10	Measures of effectiveness (MOEs)			
11	Traffic analysis report and technical documentation			
		Traffic Impact Analysis Report		
1	Introduction			
2	Executive Summary			
Project Description				
1	Site Plan	Land use, site and study area boundaries and driveways.		
2	Area of influence includes adjacent interchanges & intersections	Depending on the anticipated number of trips generated by the site, all roadways within a radius of X miles must be included in the analysis.Include all roadways where projected site traffic is equal to or greater than X percent of the maximum service volume at the adopted LOS standard for the facility. Refer to guidelines.		
3	Phasing and Timing			
Study Area Conditions				
1	Existing and Anticipated Land Use	Existing land use on both sides of boundary streets for all parcels within the study area .Proposed land use on both sides of boundary streets for all parcels within the study area .		
2	Existing and Future Roadway System	Includes all major driveways and intersecting streets adjacent to the proposed development.Aerial photograph showing the study area.		
Existing Operations				
1	Roadway Conditions and Traffic Controls			
2	Alternate Modes			
3	Traffic Volumes			
4	Level of Service			
5	Safety			

Projected Traffic				
1	Site Generated Traffic	The trip generation summary table lists each type of land use showing : Land use ITE code,Description,Trip generation rates (Average Rate or Regression Line per guideline), Unit Type (size, dwelling units,etc.) AM and PM peak generated Traffic. Copy of Applicable ITE pages in Appendix.		
2	Trip Distribution	Provide the estimates of percentage distribution of trips by turning movements to and from the proposed development by site access location (provide table and figure).		
3	Trip Assignment	Provide the direction of approach and departure of site traffic via the area's roadway system (provide figure by site entrance and boundary street).		
4	Non-Site Traffic	Projected traffic volumes (provide figure) for A.M. street peak hour site traffic (including turning movements). Projected traffic volumes (provide figure) for P.M. street peak hour site traffic (including turning movements).		
5	Total Traffic	Projected traffic volumes (provide figure) for A.M. street peak hour total traffic including site generated traffic and projected traffic (including turning movements). Projected traffic volumes (provide figure) for P.M. street peak hour total traffic including site generated traffic and projected traffic (including turning movements). Projected traffic volumes (provide figure) during special situations where peak traffic typically occurs at non-traditional times, e.g., major sporting venues, large specialty Christmas stores, etc., any otherpeak hour necessary for complete analysis (including turning movements).		
Traffic and Improvement Analysis				
1	Site Access	Access Mangement Manual		
2	Auxiliary Lane Analysis			
3	Sight Distance analysis			
4	Capacity Analysis	Capacity analysis will follow the principles established in the latest edition of the Transportation Research Board's Highway Capacity Manual (HCM). Capacity will be reported in quantitative terms as expressed in the HCM and in terms of traffic level of service based on control delay by movement or lane group. A capacity analysis is required for non-boundary streets within the study area for existing conditions, intermediate and final phase.Capacity analysis will include traffic queuing estimates for all critical applications where the length of queues is a design parameter, e.g., auxiliary turn lanes, and at traffic gates.		
5	Level of Service Analysis	For all Signlized and Unsignlized intersections within study limit.		
6	Roadway Improvements			
7	Driveway Operational Analysis			
8	Alternate Modes	Generated vehicular trip estimates may be discounted in recognition of other reasonable and applicable modes, e.g., transit, pedestrian, bicycles. Furthermore, trip generation estimates may also be discounted through the recognition of pass by trips and internal site trip satisfaction.		
9	Mitigation	If the proposed development and its generated traffic cause a reduction in the level of service for any roadway or intersection within the impact area ,the proposed development will be denied unless the levels of service for all roadways and intersections within the traffic impact analysis study are adequate to accommodate the impacts of such development. Typically LOS D or better can be used for the threshold.		
10	Traffic Control Needs			
11	Traffic Signal Needs			

Safety Analysis				
1	Safety and Crash analysis based on 5-year crash history within the study area			
2	Crash Rate calculations and comparison			
3	Safety considerations for all key intersections and key road segments			
4	Reviewing the location of access points on site plan in relation to existing nearby access points and intersections for safety considerations			
5	Site Plan examination to ensure that design of the external access points account for bicycle and pedestrian safety			
6	Mitigation measure affects (include crash			
Conclusions				
Recommendations				
Appendices				
1	Project Site Plan			
2	TIA determination worksheet/ Code of Ordinances			
3	TIA scoping document			
4	Collected Traffic Counts			
5	Crash Data			
6	Sample Calculations (Growth Rate, Distribution percentages)			
7	Cost Estimates/Proportional Share			
8	ITE Trip Gen Pages			
9	Trip Distribution Calculations			
10	Traffic Analysis output Reports (Synchro, HCS ,....)			
11	Signal Timing plans for signalized intersections (Existing)			
12	Site Visit Documentation			
13	Signal Warrants and documentation			
14	Referenced to municipalities Improvement documents/exhibits			
15	TDM Plans			

Section 2 – TIA Report Outline

A technical memorandum or report should be compiled detailing the analysis completed and stating all findings and recommendations. The memorandum or report should include the following sections:

1. **Introduction and Executive Summary**
    a. Study goals and purpose
    b. Executive Summary
    c. Figure 1: This figure shows site location and vicinity map
2. **Proposed Development**
    a. Site development
        i. Site location and project descriptions
        ii. Land Use
        iii. Interim and Horizon years
        iv. Influence Area
        v. Radius of Traffic Impact
        vi. Background developments within study area
        vii. Figure 2: This Figure shows Site location within radius of Traffic Impact
    b. Site Plan
        i. Site Access
        ii. Figure 3: This figure shows project site plan
3. **Existing Conditions**
    a. Site location and its surrounding network
    b. Study Intersections
    c. Study Roadways
    d. Traffic counts
        i. Count Date
        ii. Count Data for other transportation modes including bikes, pedestrians, transit, etc.
        iii. Count Periods
        iv. Source of Data
        v. Reference to raw data
        vi. Figure 4: This figure shows existing traffic volumes for all study intersections and roadways within Influence area
4. **Projected Traffic**
    a. Future Background Growth
        i. Traffic volume growth rate beyond the analysis area
            1. Interim and Horizon years
            2. Reference to calculations
            3. Reference to confirmation and correspondence
        ii. Background Traffic
            1. Traffic volumes generated by other approved developments within radius of impact
            2. Coordination with municipalities for surrounding approved developments
            3. Interim year background traffic volumes

4. Horizon year background traffic volumes

iii. Future Roadway and Intersection Improvements

iv. Total Background Traffic Volumes

1. Traffic background volumes should account for all approved developments in the analysis area as well as area growth beyond the analysis area without considering the generated traffic by the proposed development.
2. Interim and horizon years
3. Figure 5: This figure shows total future background traffic volumes for all study intersections and roadways within Influence area

b. On-Site and Off-Site Development Traffic Forecasting

i. Trip Generation

ii. Modal Split

iii. Determination of Pass-By Trips and Internal Capture reduction rates

iv. Trip Distribution

1. Figure 6: This figure shows external and internal trip distribution percentages within influence area.

v. Trip Assignment

1. Figure 7: This figure shows estimated volumes solely generated by the project site and assigned to all study intersections and roadways within Influence area

c. Build and Total Traffic Volumes

i. Figure 8: This figure shows future build traffic volumes by adding site generated traffic to background traffic

5. Traffic Operation Analysis

a. Methodology

i. HCM LOS Threshold Tables

ii. Applied Software (version)

b. Existing Conditions Analysis

c. Future Background Analysis

i. Interim and horizon years

d. Future Build Analysis

i. Interim and Horizon Years

ii. Queuing Analysis

6. Traffic Safety Analysis

a. Safety considerations for all key intersections and key road segments

b. Reviewing the location of access points on site plan in relation to existing nearby access points and intersections for safety considerations

c. Site Plan examination to ensure that design of the external access points account for bicycle and pedestrian safety

d. Safety and Crash analysis based on 5-year crash history withing the study area

e. Crash Rate calculations and comparison with sitewide /municipalities acceptable rates

f. Mitigation measure affects (include CRF as applicable)

7. Site Visit

a. Geometry verification

b. Traffic Pattern verification

c. Reference to findings

8. **Site Driveway Analysis**
    a. Access connection Spacing Analysis
    b. Auxiliary Lane Analysis
    c. Sight, Stop, and decision Distance analysis
    d. Signal Warrant analysis
9. **Transportation Improvements Analysis**
    a. Description and justification of needed improvements
    b. Mitigation measures
    c. Mitigation Analysis
    d. Multimodal Considerations
10. **Conclusions and recommendations**
    a. Conclusions
    b. Recommendations
11. **Design Considerations**
    a. New access and their locations
    b. ROW
    c. New Lanes
    d. Storage lengths
    e. Medians
    f. Bridges
    g. Ramp Storage
    h. Bicycle and Pedestrian accommodations
12. **Appendices**
    a. Project Site Plan
    b. TIA determination worksheet/ Code of Ordinances
    c. TIA scoping document
    d. Collected Traffic Counts
    e. Sample Calculations (Growth Rate, Distribution percentages, etc.)
    f. Cost Estimates/Proportional Share
    g. ITE Trip Gen Pages
    h. Trip Distribution Calculations
    i. Traffic Analysis output Reports (Synchro, HCS, etc.)
    j. Signal Timing plans for signalized intersections (Existing)
    k. Site Visit Documentation
    l. Signal Warrants and documentation
    m. Referenced to municipalities Improvement documents/exhibits
    n. TDM Plans

Section 3 – TIA Example Problems

Trip Generation

Site-generated traffic estimates are determined through a process known as trip generation. Rates and equations are applied to the proposed land use to estimate traffic generated by the development during a specific time interval. The acknowledged source for trip generation data is the 11th edition of *Trip Generation Manual* published by the Institute of Transportation Engineers (ITE). ITE has established trip data in nationwide studies of similar land uses. The following example poses a case study for calculating trip generation at a proposed site.

Assume you are dealing with a development that contains 300 dwelling units of single family detached housing. Trip generation must be calculated using either the average rates or equations provided on the data plots in the latest edition of the ITE *Trip Generation Manual*.

The ITE *Trip Generation Handbook* considers the following criteria for calculating trip generation based on either the equation or the rate.

1. The number of data points available
2. Whether the size of the land use is within the provided data extremes
3. Whether the fitted curve equation is provided on the data plots
4. The R^2 value of the data
5. The standard deviation of the data.

In this case, because the data plots for single family detached housing have a fitted curve equation provided, and because each study scenario has over 20 data points available, the fitted curve equation is used for trip generation calculations. Further information on deciding between average rate and the fitted curve equation is available in Section 16.3.3 Analysis Assumptions or in the ITE *Trip Generation Handbook* Chapter 4, "Trip Generation Manual Data".

The following equation represents the number of weekday one-way vehicle trips for a single-family detached housing land use.

$$Ln(T) = 0.92\ Ln(X) + 2.68$$

X represents the number of dwelling units of the proposed development, while T represents the number of vehicle trip ends generated by the development.

After inputting the number of dwelling units (300) and solving for T, it is calculated that the development generates approximately 2,772 daily one-way trips.

Similarly, the following equation represents the number of trips ends during the AM peak hour of adjacent street traffic.

Ln(T) = 0.91 Ln(X) + 0.12.

Once again, after inputting the number of dwelling units (300) and solving for T, this scenario yields 202 total AM peak hour trips.

The number of inbound and outbound vehicle trips can then be determined by applying the directional distribution percentages, which are also provided by ITE. In this case 25% of vehicles enter, and 75% of vehicles exit the development during the AM Peak hour of adjacent street traffic.

Inbound vehicles = 202 * (0.25) = 51

Outbound vehicles = 202 – 51 = 151

This same process is repeated for the PM peak hour of adjacent street traffic. The weekday daily, AM peak hour, and PM peak hour one-way vehicle trips are summarized in Table Q-1.

Table Q-1. Trip Generation Example

Land Uses	Amount	Units	ITE Code	Daily	AM Peak Hour One-Way Trips			PM Peak Hour One-Way Trips		
					IN	OUT	TOTAL	IN	OUT	TOTAL
Single Family Detached Housing	300	DU	210	2,772	51	151	202	176	103	279

Trip Generation rates based on *ITE's Trip Generation Manual*, 11th Edition.

Because the maximum peak hour trip generation in this case is 279 veh/hr, this would classify as a category 1 TIA as shown in section 16.2.1 TIA Categories, Table 16-1.

Estimating Mixed-Use Trip Generation / Internal Capture Reduction

In cases when a development contains two or more complementary land uses, there is potential for interaction among those uses. This is referred to as "Internal Capture Trips", where a reduction in the total generation of external trips is accounted for due to trips within the same development that do not touch the off-site street system. Additional information on Internal Capture is found in the ITE *Trip Generation Handbook*, Chapter 6 "Trip Generation for Mixed-Use Development".

Assume you are dealing with a development that contains 250 dwelling units of low-rise multifamily housing, 250,000 SF of office space, and 50,000 SF of retail space. Individual trip generation calculations for each land use are shown in Table Q-2.

Table Q-2. Mixed-Use Trip Generation

Land Uses	Amount	Units	ITE Code	Daily One-Way Trips	AM Peak Hour One-Way Trips			PM Peak Hour One-Way Trips		
					IN	OUT	TOTAL	IN	OUT	TOTAL
Multifamily Housing (Low-Rise)	250	DU	210	1,678	24	76	100	81	47	128
General Office Building	250,000	SF	710	2,575	324	44	368	60	295	355
Retail / Shopping Plaza (40-150k)	50,000	SF	821	4,725	109	67	177	241	261	502

Trip Generation rates based on *ITE's Trip Generation Manual*, 11th Edition.

The following steps for calculating internal capture are provided in the ITE *Trip Generation Handbook*, Chapter 6.

Step 1: Determine whether methodology is appropriate for study site.
Step 2: Estimate person trip generation for individual on-site land uses.
Step 3: Estimate proximity between on-site land use pairs.
Step 4: Estimate unconstrained internal person trip capture rates with proximity adjustment.
Step 5: Estimate unconstrained demand between on-site land use pairs.
Step 6: Estimate balanced demand between on-site land use pairs.
Step 7: Estimate total internal person trips between on-site land use pairs.
Step 8: Estimate total external person trips for each land use.
Step 9: Calculate overall internal capture and total external vehicle trip generation.

Steps 1 & 2 have already been completed above. Step 3, proximity adjustment, was not done in this problem since no distinction was made between vehicle and non-vehicle trips. However, this should not impact the distinction between internal trips and external trips.

Steps 4-9 are automatically calculated with the internal capture spreadsheet tool provided on the ITE website: https://www.ite.org/technical-resources/topics/trip-and-parking-generation/other-resources/

Using this tool, you plug in the trip generation values for each land use into Table 1-A and Table 1-P. The resulting computations summary table (Table 5-A and Table 5-P) shows the new external vehicle trips after the internal capture reduction has been applied. The AM and PM peak hour trips for the mixed-use development after internal capture has been applied are shown in Table Q-3.

Table Q-3. Internal Capture

Land Uses	Amount	Units	ITE Code	AM Peak Hour One-Way Trips			PM Peak Hour One-Way Trips		
				IN	OUT	TOTAL	IN	OUT	TOTAL
Multifamily Housing (Low-Rise)	250	DU	210	24	76	100	81	47	128
General Office Building	250,000	SF	710	324	44	368	60	295	355
Retail / Shopping Plaza (40-150k)	50,000	SF	821	109	67	177	241	261	502
Development Totals									
Raw Trip Generation Total:				457	187	645	383	603	986
Internal Capture Total:				28	28	56	86	86	172
Total Net New External Vehicle Trips:				429	159	589	297	517	814

Trip Generation rates based on *ITE's Trip Generation Manual*, 11th Edition.
Internal Capture procedure from *ITE Trip Generation Handbook*, 3rd Edition (2017).

Because the maximum peak hour trip generation in this case is 814 veh/hr, this would classify as a category 2 TIA as shown in section 16.2.1 TIA Categories, Table 16-1.

Additional detail on each step of the internal capture estimation process is available in the ITE *Trip Generation Handbook*, Section 6.5 "Process for Estimating Mixed-Use Trip Generation".

Trip Distribution and Assignment

Trip Distribution

Trip distribution refers to the origins and destinations of site-generated trips from the proposed development.

Assume you are dealing with a multifamily development. After evaluation of the existing counts, traffic percentages entering and exiting the study area can be calculated by dividing the number of traffic to/from each direction with the total traffic at all approaches along the edges of the study area.

Based on existing traffic counts, the following traffic distribution percentages are shown:

1) 45% of existing traffic travels in or out from the south (Road 3 and Main Steet)
2) 55% of existing traffic travels in or out from the north (Road 1, Road 2, and Main Street)

The distribution percentages are displayed in Figure Q-1.

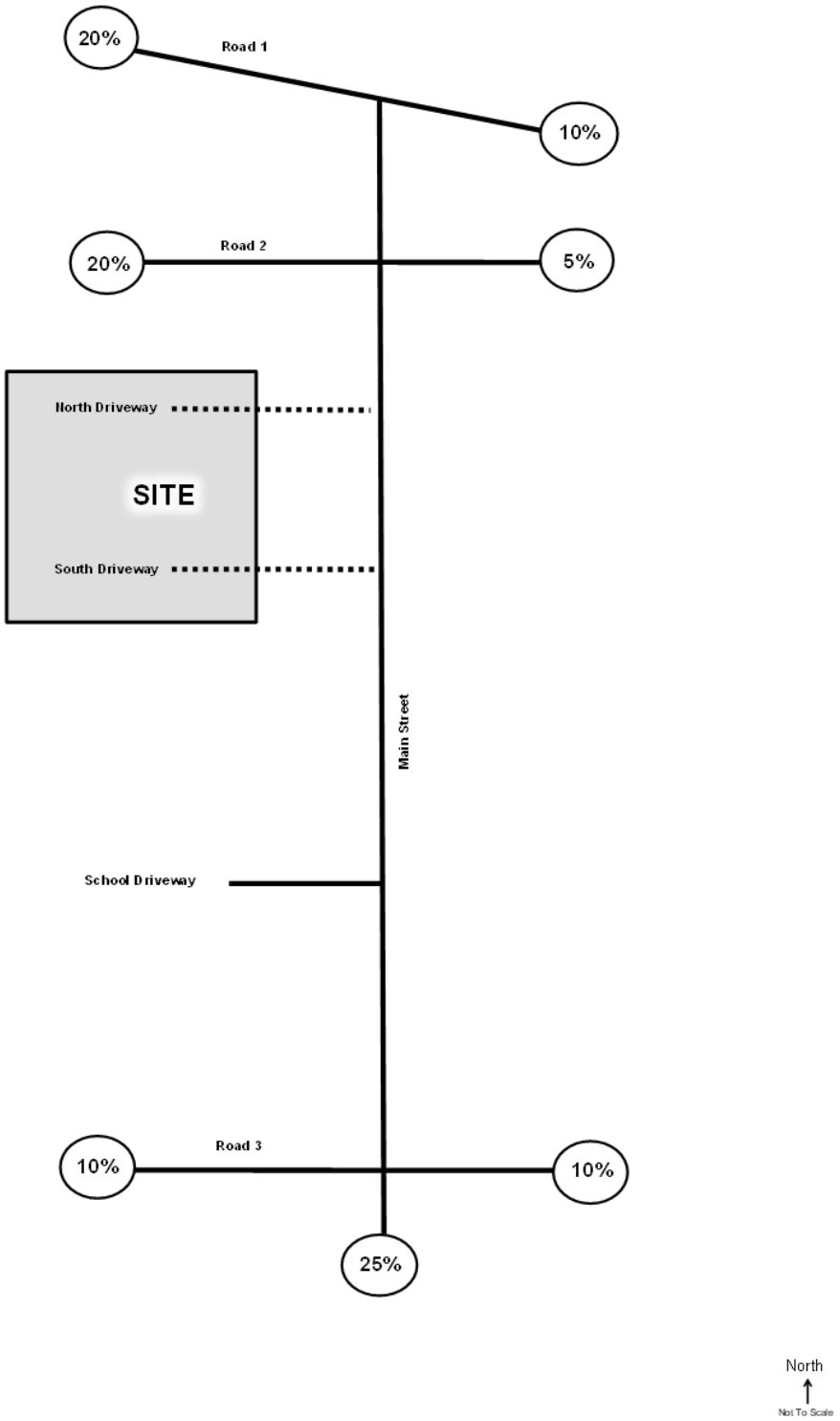


Figure Q-1. Existing Trip Distribution

Existing traffic patterns should be used as a starting point for determining trip distribution percentages. However, the existing traffic pattern percentages should be altered based on engineering judgement and context dependent characteristics. These characteristics may include:

1) The land use of the development
2) The street system characteristics
3) Nearby central business districts or employment centers

In this case, let's say Road 1 and Road 2 connect to rural highways to the north while Main Street and Road 3 connect to employment centers and denser development to the south. It would make more sense for the majority of users of the multifamily development to travel south towards employment centers rather than to the rural highway to the north. Additionally, Road 1 and Road 2 intersect at a point approximately 3,000 feet east of the study area. This would mean that vehicles are more likely to travel along Road 2 when coming from the east rather than on Road 1, since it provides a more direct route to the development.

The adjusted trip distribution percentages based on the provided context are shown in Figure Q-2. As always, engineering judgement should be exercised when developing distribution percentages according to the context of your development scenario. Distribution results are typically reviewed and approved by TxDOT or the applicable city/county.

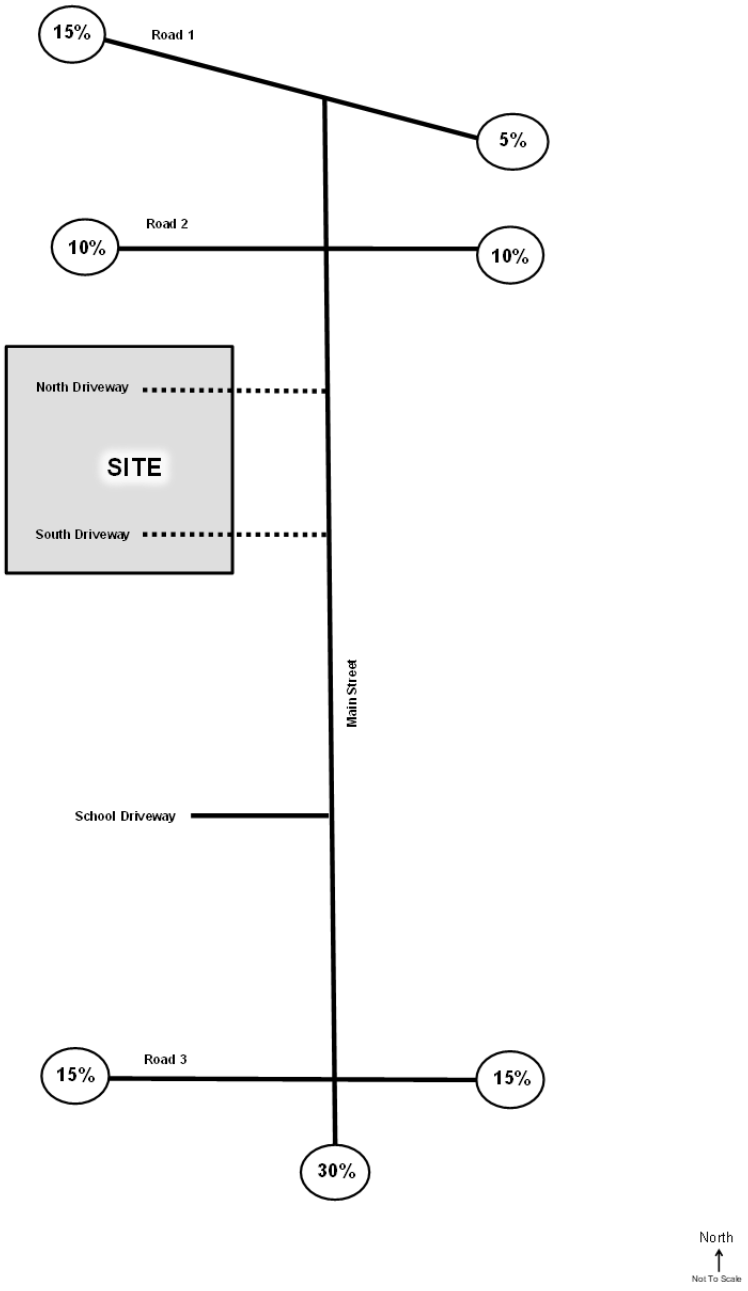


Figure Q-2. Adjusted Trip Distribution

Traffic Assignment

Whereas trip distribution refers to the origins and destination of site generated trips, traffic assignment refers to the specific routes that the trips will take along the roadway network and into the site driveways. In this case, the following assumptions are made:

1) Drivers will tend to use the first available driveway when reaching the development.
2) No northbound left or eastbound left turns are made at the position of North Driveway, due to there being no median opening at this access point.
3) More drivers will use South Driveway to exit the development, due to a median opening on Main Street allowing outbound vehicles to turn left towards the north. Additionally, it is also the closest driveway to the south which is where the majority of vehicles are traveling from.

The corresponding inbound and outbound traffic assignment is shown in Figure Q-3. Once again, engineering judgement should be exercised to appropriately assign the traffic according to site specific characteristics of the development.

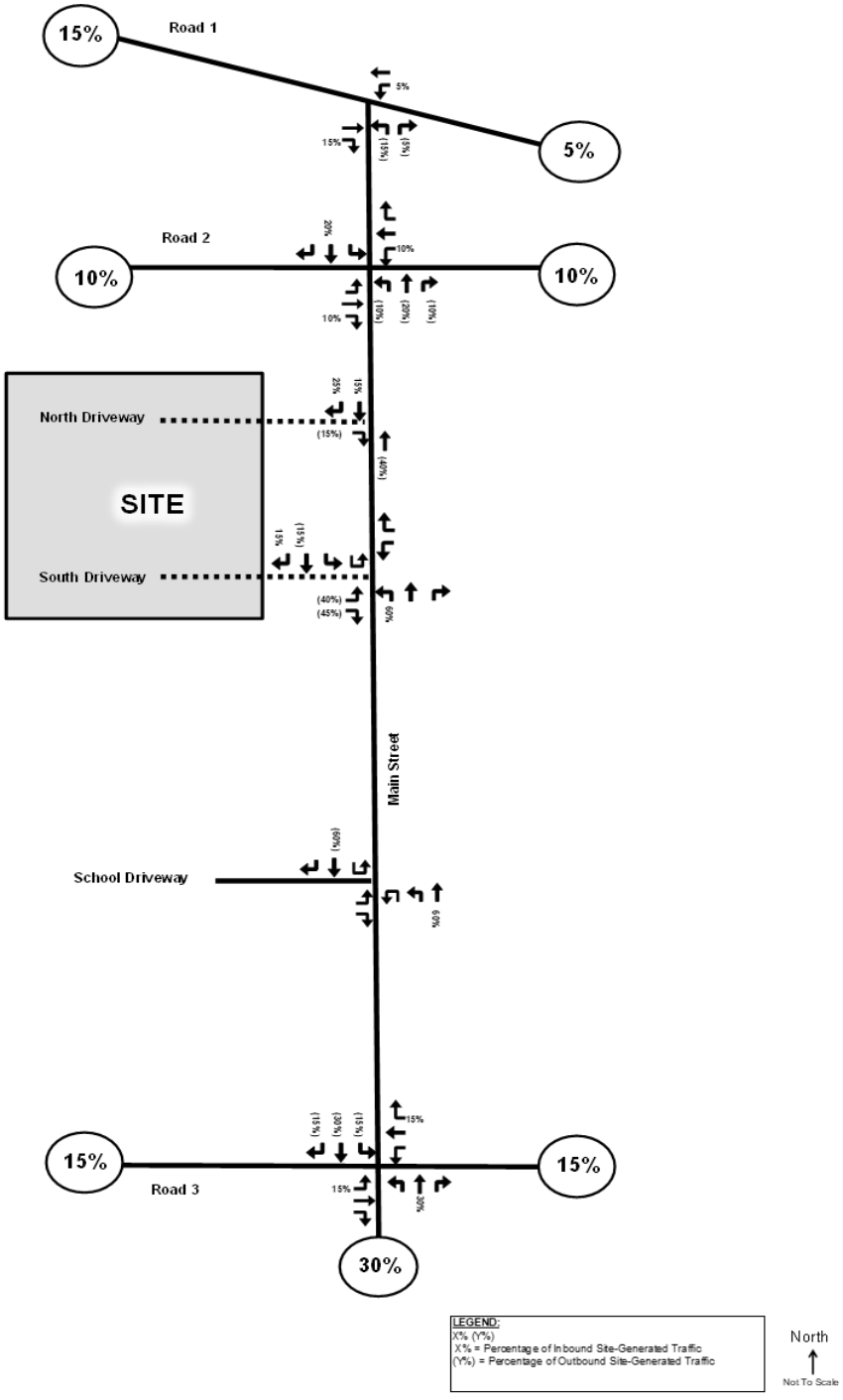


Figure Q-3. Traffic Assignment

Background Site Traffic Assignment

In some cases, future developments near the study area are slated to open during the period of analysis. These sites need to be included in the traffic analyses. As a result of this, traffic assignment for the corresponding background development must also be added to the surrounding roadway network. If a TIA has been completed for the site, the traffic assignment reported in that TIA should be used, when a TIA is not available traffic assignment should be completed in a similar methodology as site trip distribution and traffic assignment.

Take the case shown above, but now with an additional background development directly east of the site, across Main Street. The background development contains an additional right-in, right-out, driveway on its northern side that is not within the boundaries of the studied intersections of the original development. This driveway from the background development is not studied and not shown on the figure. However, it will be necessary to assign traffic that will travel through the studied roadway network, as well as to the background driveway that is directly east of South Driveway.

The corresponding traffic assignment for the background development is shown in Figure Q-4.

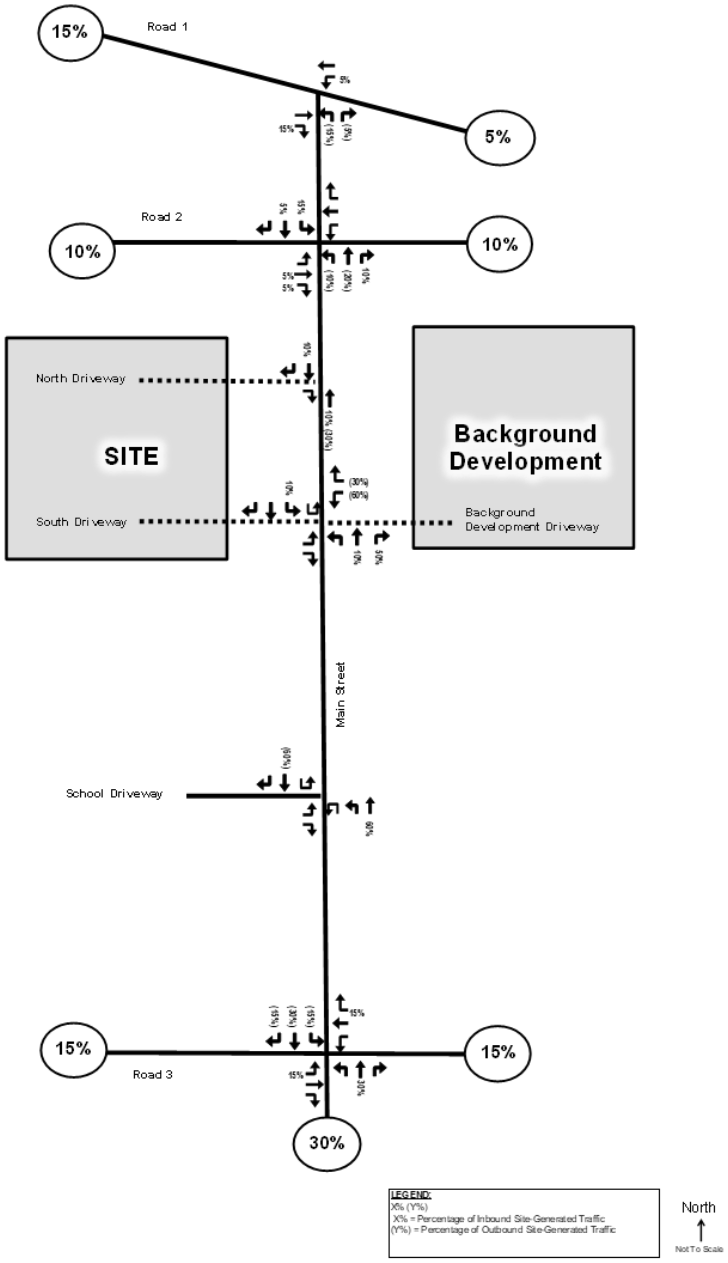


Figure Q-4. Background Site Traffic Assignment

Likewise, any additional background developments must also have their own corresponding traffic assignment along the surrounding roadway network.

Projected Traffic

Determining Background Growth Rates

When analyzing future conditions, existing traffic is grown using compound growth rates extended to the future study years specified in the scope.

The annual growth rate may be available from the city or MPO. When available, the annual growth rate can also be based on historical AADT information, where historical AADT data within the road network is averaged for at least the last five years of data. Historical AADT data may be available from the TxDOT Traffic Count Database System linked in Appendix Q, Section 4 – External References (Reference 1).

Table Q-4 shows a historical example data from the Traffic Count Database System, where the 24-hour volume column represents the AADT data for each year.

Table Q-4. Average Annual Growth Rate

Goliad Street [Location ID: 199T5]						
Record	**Year**	**Link Start**	**Link End**	**Source**	**24-Hour Volume**	**Annual Growth Rate**
1	2018	Ross Street	Boydstun Avenue	TxDOT	39,633	-
2	2019	Ross Street	Boydstun Avenue	TxDOT	41,055	3.6%
3	2020	Ross Street	Boydstun Avenue	TxDOT	38410	-6.4%
4	2021	Ross Street	Boydstun Avenue	TxDOT	42,950	11.8%
5	2022	Ross Street	Boydstun Avenue	TxDOT	40,189	-6.4%
				Average Growth 2018 - 2022:		0.7%

The annual growth rate is calculated by applying the following compound annual growth rate formula.

$$Compound\ Annual\ Growth\ Rate = \left(\frac{V_{Final}}{V_{Begin}}\right)^{\frac{1}{t}} - 1$$

Where V_{Final} and V_{Begin} represent the AADT data for each year, and t represents the number of years between each AADT data point. From 2018 to 2019, the compound annual growth rate is calculated as follows:

$$Compound\ Annual\ Growth\ Rate = \left(\frac{41{,}055}{39{,}633}\right)^{\left(\frac{1}{(2019-2018)}\right)} - 1 = 0.0358$$

Represented as a percentage, 0.0358 can be expressed as approximately 3.6%. This process is repeated for each of the five years of available data and an average is taken, in this case, the average growth rate was 0.7%.

In cases where 5 consecutive years of AADT data are not available, engineering judgement should be used to estimate the annual growth rate from the best available data points.

Future Background Growth

As mentioned earlier in this section, the calculated annual growth rate is used for future background traffic analysis, where existing traffic is grown according to the future study years specified in the scope. Take the existing intersection traffic counts shown in Table Q-5.

Table Q-5. Existing Traffic Counts

Intersection		EXISTING (2023)	
		AM	PM
Road 1 & Road 2	EBL	13	9
	EBT	919	906
	EBR	1,177	967
	EBU	0	1
	WBL	82	68
	WBT	894	924
	WBR	7	4
	WBU	0	3
	NBL	560	847
	NBT	14	22
	NBR	92	84
	NBU	0	0
	SBL	21	21
	SBT	44	16
	SBR	8	6
	SBU	0	0

The traffic counts for each movement are grown by the compound growth rate using the following formula.

$$Future\ Traffic = P\left(1 + \frac{r}{100}\right)^{t}$$

Where P represents the existing traffic, r represents the rate, and t represents the number of years that the traffic will be grown to. Let's say you want to grow the AM traffic counts at the EBT movement at a rate of 2% for 5 years. After plugging in each value, the estimated future traffic is rounded to 1015.

Similarly, the same equation is applied to each traffic movement and displayed in Table Q-6.

Table Q-6. 2028 Background Traffic Counts

Intersection		EXISTING (2023)		Background Traffic (2028)	
		AM	PM	AM	PM
Road 1 & Road 2	EBL	13	9	14	10
	EBT	919	906	1,015	1,000
	EBR	1,177	967	1,300	1,068
	EBU	0	1	0	1
	WBL	82	68	91	75
	WBT	894	924	987	1,020
	WBR	7	4	8	4
	WBU	0	3	0	3
	NBL	560	847	618	935
	NBT	14	22	15	24
	NBR	92	84	102	93
	NBU	0	0	0	0
	SBL	21	21	23	23
	SBT	44	16	49	18
	SBR	8	6	9	7
	SBU	0	0	0	0

This process is repeated for any other traffic counts that you wish to grow for any number of future study years.

Traffic Operations Analysis

Intersection Analysis Methodology

This section provides one example using HCM methodology for delay and Level of Service (LOS) to measure intersection operations. The level of detail required for intersection operations analysis may vary from project to project, may vary due to the TxDOT project manager, or due to applicable city / county requirements. This example is not meant to be exhaustive. The required intersection analysis for each project should be consulted with the appropriate authorities prior to beginning the study.

Table Q-7 shows the definition of LOS for signalized and unsignalized intersections.

Table Q-7. Level of Service Definitions

Level of Service	Signalized Intersection Average Total Delay (sec/veh)	Unsignalized Intersection Average Total Delay (sec/veh)
A	≤10	≤10
B	>10 and ≤20	>10 and ≤15
C	>20 and ≤35	>15 and ≤25
D	>35 and ≤55	>25 and ≤35
E	>55 and ≤80	>35 and ≤50
F	>80	>50

Definitions provided from the HCM, Special Report 209, Transportation Research Board, 2010

The synchro software was used to analyze the following two signalized intersections during the AM peak hour. Average delay and LOS are reported for each approach during existing, background, and buildout scenarios. The results are shown in Table Q-8. In this case, background traffic consists of existing traffic with added compound growth rates grown to 2030 and 2035, while build out traffic consists of background traffic combined with site generated traffic.

Table Q-8. Traffic Operational Results

INTERSECTION	APPROACH	2023 Existing Traffic		2030 Background Traffic		2030 Build Traffic		2035 Background Traffic		2035 Build Traffic	
		AM PEAK HOUR		AM PEAK HOUR		AM PEAK HOUR		AM PEAK HOUR		AM PEAK HOUR	
		DELAY (SEC/VEH)	LOS	DELAY (SEC/VEH)	LOS	DELAY (SEC/VEH)	LOS	DELAY (SEC/VEH)	LOS	DELAY (SEC/VEH)	LOS
Signalized Intersection											
Road 1 @ Road 2	EB	47.7	D	48	D	48.1	D	48.5	D	48.5	D
	WB	33.8	C	34	C	31.9	C	34	C	32.1	C
	NB	12.9	B	13.5	B	15.2	B	14	B	15.9	B
	SB	21.3	C	24	C	24.2	C	26.9	C	27.3	C
	Overall	**20**	**B**	**22**	**C**	**21.9**	**C**	**23.5**	**C**	**23.8**	**C**
Road 3 @ Road 4	WB	28.3	C	30	C	30.6	C	31.5	C	31.8	C
	NB	13.4	B	19	B	54.7	D	34.8	C	64	E
	SB	5.7	A	7.4	A	9.9	A	9.3	A	12.7	B
	Overall	**10.5**	**B**	**14**	**B**	**31.6**	**C**	**21.6**	**C**	**37.1**	**D**

Build Versus No-Build Analysis

Intersection operations are analyzed for the following scenarios.

1) Existing conditions
2) Background (no-build)
3) Build

Existing conditions are used as a baseline to compare the impact a development has on traffic operations during future conditions. Background (no-build) consists of existing traffic volumes grown with compound growth rates to the future study years. In this case, the future study years consisted of 2030 and 2035, therefore, traffic volumes were grown for seven and twelve years respectively. In cases where additional background developments are near the study area, site generated traffic from the proposed developments must also be added to the background traffic.

Build scenarios consist of the previously mentioned background traffic combined with site-generated traffic from the proposed development.

As shown in the table above, LOS E was reported in the northbound direction of Road 3 and Road 4 during the 2035 build scenario. The addition of site generated traffic caused the northbound delay at the intersection to increase from 34.8 sec/veh to 64.0 sec/veh, which caused the LOS to worsen from LOS C to LOS E. Assuming the threshold at this jurisdiction is to not have any approach drop below LOS D, a mitigation would be required at this intersection.

Other than the approach identified above, all other approaches register LOS D or better. Site generated traffic has little impact on delay, with all other approaches operating with acceptable delay times.

Mitigation

Where necessary, recommendations are required to mitigate impacts from the additional traffic generated by the development. Recommendations can include altering lane configurations and geometries of the intersection, optimizing signal timings, modifications to the traffic control at the intersection, or reducing the projects density. These changes are documented as mitigations, which are evaluated to improve intersection operations to an acceptable threshold set by varying project specific, TxDOT District, or city/county requirements.

In this case, due to the large delay present at the northbound approach on Road 3 and Road 4, mitigation will be required to improve the LOS at this intersection to an acceptable threshold. Because it is already signalized, traffic signal timing adjustments were recommended. Table Q-9 lists Road 3 and Road 4 before and after traffic signal timing adjustments have been made.

Table Q-9. Traffic Operational Results with Mitigation

INTERSECTION	APPROACH	2035 Build Traffic		2035 Build Traffic Mitigation	
		AM PEAK HOUR		AM PEAK HOUR	
		DELAY (SEC/VEH)	LOS	DELAY (SEC/VEH)	LOS
Signalized Intersection					
Road 3 @ Road 4	WB	31.8	C	32.5	C
	NB	64	E	40.3	D
	SB	12.7	B	20.3	C
	Overall	**37.1**	**D**	**30.2**	**C**

As shown, northbound delay at the intersection decreases from 64 sec/veh to 40.3 sec/veh, improving from LOS E to LOS D. Assuming that the acceptable LOS threshold is LOS D this approach now satisfies the necessary criteria after implementing the mitigation.

Site Driveway Analysis

Access Connection Spacing

Access management guidelines for driveway spacing can be found in the TxDOT *Access Management Manual* (Appendix Q, Section 4 – External References 'Reference 4'). As per the *Access Management Manual*, these standards are designed to enable the highway to function efficiently while at the same time providing reasonable access to development.

Distance between access connections is measured along the edge of the traveled way from the closest edge of pavement to closest edge of pavement. Refer to Figure 2-1 *Access Connection Spacing Diagram* on the TxDOT *Access Management Manual* for more information.

Take the following development and corresponding access connections shown in Figure Q-5 . Assume that Main Street in this case has a speed limit of 35 MPH.

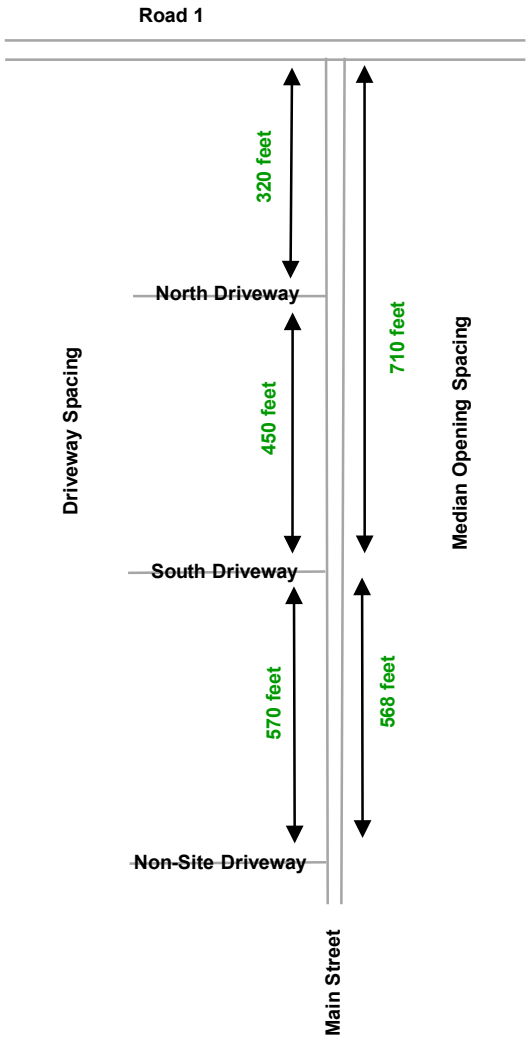


Figure Q-5. Access Spacing Diagram

Minimum connection spacing criteria for State highways can be found on Table 2-2 of the TxDOT *Access Management Manual*. Access spacing at the development and corresponding TxDOT criteria is shown on Table Q-10 below.

Table Q-10. Driveway Spacing

Main Roadway	Intersecting Roadways	TxDOT Criteria	Spacing Length
Main Street	Road 1 to North Driveway	250 feet	320 feet
Main Street	North Driveway to South Driveway	250 feet	450 feet
Main Street	South Driveway to Non-Site Driveway	250 feet	570 feet

As shown, the development satisfies the required TxDOT driveway spacing criteria.

Other driveway spacing criteria along frontage roads is shown on Table 2-1 of the *Access Management Manual*. Engineering judgement should be exercised when deciding on the appropriate spacing criteria to use for your specific project.

Additionally, Figure Q-5 shows median opening spacing on the proposed development. There is no official median opening spacing requirement per the TxDOT *Access Management Manual*. However, median opening spacing is the minimum for normal TxDOT design left-turn lanes on both ends. The following table shows the median spacing of the proposed development along with the functional median opening spacing.

Table Q-11. Median Opening Spacing

Main Roadway	Intersecting Roadways	Functional Median Opening Spacing	Spacing Length
Main Street	Road 1 to South Driveway	530 feet	710 feet
Main Street	South Driveway to Non-Site Driveway	530 feet	568 feet

Engineering judgement should be exercised when the development does not satisfy TxDOT access connection criteria. Additionally, a variance may be requested per the process shown in Chapter 2 of the TxDOT *Access Management Manual*.

Auxiliary Lane Analysis

Where justified, the addition of right-turn deceleration lanes can help inbound turning vehicles separate from the through traffic, avoiding conflicts and smoothing traffic flow. TxDOT has identified right-turning volume thresholds where right-turn lanes are justified. Assume the following peak hour right turn volumes into the development in Figure Q-6.

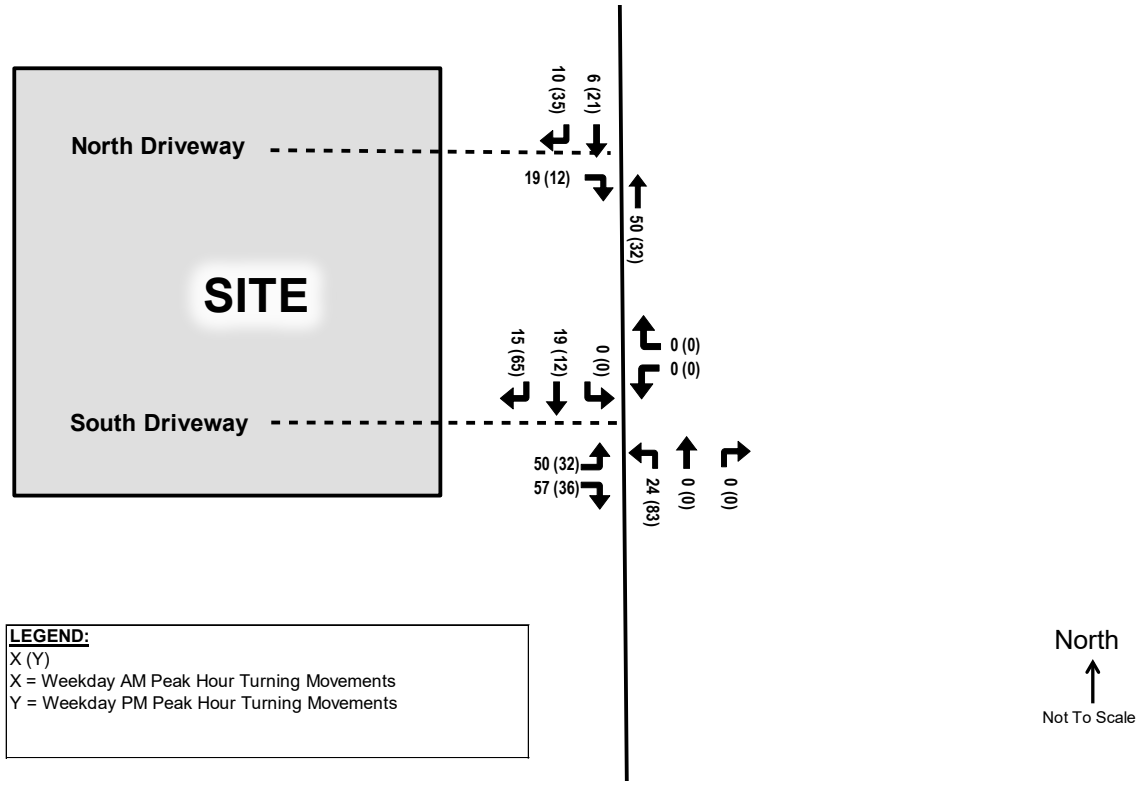


Figure Q-6. Peak Hour Volumes

Table Q-12 shows the driveway locations with right-turn driveway access to the site, and how they compare with the TxDOT right turn volume threshold per the *Access Management Manual*.

Table Q-12. Right-Turn Peak Hour Thresholds

Right-Turn Location	Peak Hour Right-Turn Volume (vph)	TxDOT Threshold Access Management Manual, Table 2-3)	Right-Turn Lane Recommended?
North Driveway from Main Street	35	60 vph	No
South Driveway from Main Street	65	60 vph	Yes

In this case, a right turn lane is not recommended at North Driveway, while it would be recommended at South Driveway.

Per TxDOT *Access Management Manual* (Table 2-3), Left turn deceleration lanes are justified at median openings that provide direct access to the proposed development wherever left turns are permitted. Therefore, in this case, a left turn deceleration lane is recommended at the median opening at South Driveway.

As always, engineering judgement must be exercised when recommending turn lanes at developments.

Section 4 – External References

The websites below were last accessed on May 31, 2024

1. **Traffic Count Database System**

   https://txdot.public.ms2soft.com/tcds/tsearch.asp?loc=Txdot&mod=TCDS

   - The Traffic Count Database System provides information regarding traffic data across the State

2. **Texas Department of Transportation: Statewide Planning Map**

   https://www.txdot.gov/apps/statewide_mapping/StatewidePlanningMap.html

   - The statewide planning map offers tracking data regarding timelines ranging from preliminary to construction in a 10+ years span.

3. **Texas Department of Transportation: Unified Transportation Program**

   https://www.txdot.gov/inside-txdot/division/transportation-planning/utp.html

   - The UTP is TxDOT's 10-year plan that guides the development of transportation work across the State.

4. **Texas Department of Transportation: Access Management Manual**

   http://onlinemanuals.txdot.gov/txdotmanuals/acm/acm.pdf

   - The Access Management Manual provides access management assist in protecting the public investment in transportation by preserving roadway efficiency and increasing safety.

5. **Roadway Design Manual**

   http://onlinemanuals.txdot.gov/txdotmanuals/rdw/manual_notice.htm

   - The Roadway Design Manual has been updated in roadway policy within FHWA guidelines and comments from DES Division and additional Divisions.

6. **Incorporating Data-Driven Safety Analysis in Traffic Impact Analyses: A How-To Guide**

   https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa19026.pdf

   - Data-Driven Safety Analysis approach to safety analysis. Provides evidence-based models that provide State and local agencies with the means to quantify safety impacts similar to the way they do other impacts.

7. **Essential Components of Incorporating Safety in Transportation Impact Analysis**

   https://www.ite.org/pub/?id=94372DF6-BAB5-AE00-E6D5-471ED4F338CE

   - Advocates for the prioritization of multimodal safety in transportation analysis and decision-making.

Chapter 17 - Appendix R – Reports & Documentation

- **Section 1** – Traffic Analysis Report
- **Section 2** – Safety Analysis Report
- **Section 3** – Traffic Tool Outputs
- **Section 4** – External References

Section 1 – Traffic Analysis Report

A suggested Traffic Analysis Report outline is as follows:

1. **Title Page**
2. **Table of Contents**
    a. List of Chapters and Sections
    b. List of Figures
    c. List of Tables
3. **Executive Summary**
4. **Introduction**
    a. Description of the proposed project
    b. Analysis objective and project scope
    c. Project location map
5. **Data Requirements**
    a. Data requirements and data sources
    b. Data collection methodology
    c. Summary of data collection and field observations
6. **Analysis Methodology**
    a. Analysis methodology and assumptions
        i. Multimodal considerations if any
    b. Analysis (geographical and time duration) boundary limits
    c. Analysis tool(s)
7. **Performance Measures**
    a. Measures of Effectiveness
8. **Evaluation of Alternatives**
    a. Existing conditions
    b. No-Build alternatives
        i. Future year traffic projections
        ii. No-Build analysis
    c. Preliminary alternatives
        i. Development of project concepts
        ii. Screening of concepts
    d. Build alternatives
        i. Alternatives considered
        ii. Traffic projections, trip pattern/circulation routes and assumptions
        iii. Design considerations
        iv. Model development (microsimulation approach only)
        v. Operational analysis

e. Alternative evaluation matrix and description of success/failure of alternatives

9. Conclusions and Recommendations

10. References

11. Appendices:

a. Raw Traffic Data (Counts, Travel Times, Historical Data)

b. Traffic Projections

c. Calibration Memo (microsimulation approach only)

d. Traffic Analysis Outputs

e. Alternatives Analysis

Section 2 – Safety Analysis Report

A suggested Safety Analysis Report outline is as follows:

1. **Title Page**
2. **Table of Contents**
    a. List of Chapters and Sections
    b. List of Figures
    c. List of Tables
3. **Executive Summary**
4. **Introduction**
    a. Description of the proposed project
    b. Analysis objective and project scope
    c. Project location map
5. **Data Requirements**
    a. Crash data sources
    b. Summary of crash data collection and field observations
6. **Safety Analysis Methodology**
    a. Safety analysis methodology and assumptions
        i. Safety analysis based on crash data and Highway Safety Manual procedures as appropriate
    b. Safety analysis (geographical and time duration) boundary limits
    c. Safety analysis tool(s)
7. **Safety Performance Measures**
8. **Evaluation of Alternatives**
    a. Existing conditions
    b. No-Build alternatives
        i. No-Build safety analysis
    c. Preliminary alternatives
        i. Development of project concepts
        ii. Screening of concepts based on safety
    d. Build alternatives
        i. Alternatives considered
        ii. Design considerations
        iii. Safety analysis
    e. Alternative evaluation matrix and safety evaluation
9. **Conclusions and Recommendations**
10. **References**

11. Appendices

a. Crash Data

b. Crash Analysis Outputs

c. Alternatives Analysis

Section 3 – Traffic Tool Outputs

Capacity Analysis for Planning of Junctions

Detailed Results Worksheet

		Estimated Volume-to-Capacity Ratio			
Project Name:	*First Street at Main Street*	Number of Configurations			
Project Number:	*0001-01-1111*	< 0.750	0.750 - 0.875	0.875 - 1.00	≥ 1.00
Location	*Austin, Texas*	45	1	0	4
Date	January 30, 2024				

Results for Non-roundabout Intersections

TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Traffic Signal	FULL									781	0.46	0.46	Good	Excellent
Conventional Shared RT LN	CSRL									618	0.36	0.36	Excellent	Excellent
Two-Way Stop Control	N-S									--	####	15.85	Fair	Good
	E-W									--	1.26	1.26	Fair	Good
All-Way Stop Control	FULL									1572	1.31	1.31	Good	Excellent
Continuous Green T	W									242	0.14	0.14	Good	Excellent
	N									167	0.10	0.10	Good	Excellent
	E									320	0.18	0.18	Good	Excellent
	S									242	0.14	0.14	Good	Excellent
Quadrant Roadway	S-W			390	0.22			242	0.14	373	0.21	0.22	Good	Excellent
	N-E	352	0.20			291	0.17			459	0.26	0.26	Good	Excellent
	S-E			392	0.22	379	0.22			408	0.23	0.23	Good	Excellent
	N-W	313	0.18					282	0.16	424	0.24	0.24	Good	Excellent
Partial Displaced Left Turn	N-S	574	0.32	342	0.19					645	0.37	0.37	Good	Excellent
	E-W					268	0.15	339	0.19	492	0.28	0.28	Good	Excellent
Displaced Left Turn	FULL	303	0.17	225	0.12	150	0.08	186	0.10	357	0.20	0.20	Good	Excellent
Signalized Restricted Crossing U-Turn	N-S	437	0.24	702	0.39	816	0.45	636	0.35			0.45	Good	Excellent
	E-W	636	0.35	1260	0.70	908	0.50	437	0.24			0.70	Good	Excellent
Unsignalized Restricted Crossing U-Turn	N-S	286	0.22	816	0.35	541	0.59	235	0.37			0.59	Good	Excellent
	E-W	306	0.41	235	1.06	286	0.57	286	0.22			1.06	Good	Excellent
Median U-Turn	N-S	309	0.17	486	0.27					408	0.23	0.27	Good	Excellent
	E-W					309	0.17	221	0.12	478	0.27	0.27	Good	Excellent
Partial Median U-Turn	N-S	271	0.15	447	0.25					441	0.25	0.25	Good	Excellent
	E-W					182	0.10	182	0.10	405	0.23	0.23	Good	Excellent
Bowtie	N-S					286	0.24	286	0.22	847	0.48	0.48	Good	Excellent
	E-W	286	0.24	816	0.63					847	0.48	0.63	Good	Excellent
Split Intersection	N-S					778	0.44	510	0.29			0.44	Good	Excellent
	E-W	745	0.43	849	0.49							0.49	Good	Excellent

Results for Grade Separated Intersections

TYPE OF INTERSECTION	Sheet	Zone 1 (North)		Zone 2 (South)		Zone 3 (East)		Zone 4 (West)		Zone 5 (Center)		Zone 6 (Raised)		Overall v/c Ratio	Ped	Bike
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Echelon	N-S									204	0.11	357	0.20	0.20	Good	Good
	E-W									204	0.11	357	0.20	0.20	Good	Good
Center Turn Overpass	FULL									357	0.20	140	0.08	0.20	Good	Excellent

Capacity Analysis for Planning of Junctions

Detailed Results Worksheet

Results for Roundabouts

TYPE OF ROUNDABOUT	Zone 1 (North)			Zone 3 (East)			Zone 2 (South)			Zone 4 (West)			Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3			
50 ICD	0.42			0.39			1.06			0.80			1.06	Excellent	Good
75 ICD	0.40			0.38			1.03			0.67			1.03	Excellent	Good
1 X 1	0.29			0.27			0.78			0.40			0.78	Excellent	Excellent
1NS X 2EW	0.27			0.13	0.13		0.72			0.18	0.18		0.72	Good	Excellent
2NS X 1EW	0.14	0.14		0.25			0.36	0.38		0.35			0.38	Good	Excellent
2 X 2	0.14	0.14		0.18	0.18		0.36	0.38		0.13	0.13		0.38	Good	Excellent
3 X 3	0.09	0.09	0.10	0.12	0.12	0.13	0.25	0.25	0.26	0.09	0.09	0.09	0.26	Fair	Excellent

Results for Interchanges

TYPE OF INTERCHANGE	Sheet	Zone 1 (Rt Mrg)		Zone 2 (Lt Mrg)		Zone 3 (Ctr. 1)		Zone 4 (Ctr. 2)		Zone 5 (Lt Mrg)		Zone 6 (Rt Mrg)		Overall v/c Ratio	Pedestrian Accommodations	Bicycle Accommodations
		CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C	CLV	V/C			
Diamond	N-S					411	0.23	446	0.25					0.25	Good	Fair
	E-W					493	0.28	293	0.17					0.28	Good	Fair
Partial Cloverleaf A	N-S					150	0.08	339	0.19					0.19	Good	Excellent
	E-W					150	0.08	225	0.12					0.12	Good	Excellent
Partial Cloverleaf B	N-S					225	0.12	339	0.19					0.19	Good	Excellent
	E-W					166	0.09	150	0.08					0.09	Good	Excellent
Displaced Left Turn	N-S	324	0.18			516	0.29	501	0.28			225	0.12	0.29	Good	Excellent
	E-W	207	0.11			186	0.10	735	0.41			332	0.18	0.41	Good	Excellent
Contraflow Left Interchange	N-S					331	0.19	348	0.20					0.20	Good	Excellent
	E-W					213	0.12	375	0.21					0.21	Good	Excellent
Diverging Diamond Interchange	N-S	324	0.18	150	0.08	388	0.22	424	0.24	339	0.19	171	0.10	0.24	Good	Excellent
	E-W	213	0.12	271	0.15	150	0.08	225	0.12	235	0.13	358	0.20	0.20	Good	Excellent
Single Point	N-S	331	0.18			395	0.23					178	0.10	0.23	Good	Excellent
	E-W	213	0.12			242	0.14					358	0.20	0.20	Good	Excellent
Single Point with Roundabout	N-S		0.19		0.46						0.06		0.05	0.46	Good	Excellent
	E-W		0.08		0.29						0.24		0.22	0.29	Good	Excellent

CORSIM Outputs

FREEWAY AND HIGHWAY ANALYSIS - CORSIM RUN: 2020PM_Ex.out

FRESIM RESULTS ASSUME SIMULATION WAS FOR ONE HOUR

Link #	A Node	B Node	Facility	Type of Analys	Description	# of Full Lanes	Ramp Auxil Lanes (ft)	% Trck	Et	Input Vol	CORSM Vol	% Vol Served	Delay (s/v)	Ave Speed (m/h)	Initial Link Density (v/m/l)	Final Adjusted Density (pc/m/l)	LOS
1,	42-	51	MAINLINE	BASIC	NB South of 1st St	2	0	11%	1.5	4500	4438	98.6%	1.9	66.28	33.7	35.32	E
2,	43-	44	MAINLINE	RAMP	NB Off-Ramp to 1st St	2	10	11%	1.5	4500	4431	98.5%	1.2	64.62	34.3	36.07	F
3,	48-	84	MAINLINE	RAMP	NB On-Ramp from 1st St	2	400	11%	1.5	3825	3783	98.9%	2.3	60.47	27.6	29.09	D
4,	49-	52	MAINLINE	BASIC	NB North of 1st St	2	0	11%	1.5	3825	3783	98.9%	1.0	63.51	29.8	31.42	D
5,	53-	54	MAINLINE	BASIC	SB North of 1st St	2	0	11%	1.5	2932	2935	100.1%	1.2	67.26	21.9	23.02	C
6,	56-	57	MAINLINE	RAMP	SB Off-Ramp to 1st St	2	10	11%	1.5	2932	2932	100.0%	1.1	65.03	22.5	23.68	C
7,	60-	61	MAINLINE	RAMP	SB On-Ramp from 1st st	2	275	11%	1.5	2840	2805	98.8%	2.4	59.95	21.4	22.58	C
8,	62-	63	MAINLINE	BASIC	SB South of 1st St	2	0	11%	1.5	2840	2792	98.3%	2.6	64.42	21.7	22.86	C

Program completed.

HCS Outputs

HCS7 Multilane Highway Segments Text Report

MULTILANE HIGHWAY SEGMENT ANALYSIS

File Name:	2045_Build_Multilane_FirstSt.xuf
Analyst:	ABC
Agency:	Kimley-Horn
Jurisdiction:	TXDOT
Date:	5/23/2021
Analysis Year:	2045
Time Period Analyzed:	PM Peak Period
Project Description:	First St
Units:	U.S. Customary

Direction 1: NB

LOS and Performance Measures

Flow rate, v_p	1295	pc/h/ln
Capacity, C	3678	pc/h/ln
Speed, S	37.8	mi/h
Density, D	17.1	pc/mi/ln
Level of Service, LOS	B	

Step 1: Input Data

Number of Lanes, N	2	ln
Lane Width	12	ft
Segment length	-	ft
Terrain Type	Level	
Percent Grade	-	%
Grade Length	-	mi
Right-Side Lateral Clearance, LCR	6	ft
Left-Side Lateral Clearance, LCL	6	ft
Median Type	TWLTL	
Access Point Density	25.0	access points/mi
Demand Volume, V	1076	veh/h
Peak Hour Factor, PHF	0.91	
Percent Total Trucks	9.50	%
Percent Single-Unit Trucks, SUT	-	%
Percent Tractor-Trailers, TT	-	%

Step 2: Estimate and Adjust FFS

Estimating FFS		
Measured or Base FFS	Base	
Base Free-Flow Speed, BFFS	45.0	mi/h
Lane width	12	ft
Lane Width Adjustment, fLW	0.0	mi/h
Right-Side Lateral Clearance, LCR	6	ft
Left-Side Lateral Clearance, LCL	6	ft
Total Lateral Clearance, TLC	12.00	ft
Total Lateral Clearance Adjustment, fTLC	0.0	mi/h
Median Type	TWLTL	
Median Type Adjustment, fM	0.0	mi/h
Access Point Density	25.0	access points/mi
Access Point Density Adjustment, fA	6.3	mi/h
Free-Flow Speed, FFS	38.8	mi/h
Speed Adjustments		
Driver Population	Mostly Familiar	
Speed Adjustment Factor, SAF	0.975	
Adjusted Free-Flow Speed, FFSadj	37.8	mi/h

Step 3: Estimate and Adjust Capacity

Adjusted Free-flow Speed, FFSadj	37.8	mi/h
Capacity, c	1900	pc/h/ln
Capacity Adjustments		
Driver Population	Mostly Familiar	
Capacity Adjustment Factor, CAF	0.968	
Adjusted Capacity, cadj	1839	pc/h/ln

Step 4: Adjust Demand Volume

Demand Volume, V	1076	veh/h
Peak Hour Factor, PHF	0.91	
Number of lanes, N	2	ln
Terrain type	Level	
Percent Grade	-	%
Grade Length	-	mi
Percent Total Trucks	9.50	%
Percent Single-Unit Trucks, SUT	-	%
Percent Tractor-Trailers, TT	-	%
Proportion of Total Trucks, PT	0.10	
Heavy Vehicle PCE, ET	2.000	
Heavy vehicle adjustment, f_{hv} :	0.913	
Demand Adjustment Factor, DAF	1.000	
Demand Flow Rate, v_p	648	pc/h/ln

Steps 5 and 6: Estimate Speed and Density and Determine LOS

Demand Flow Rate, v_p	648	pc/h/ln
Free-Flow Speed, FFS	45.0	mi/h
Capacity, c	1839	pc/h/ln
Breakpoint, BP	1400	pc/h/ln
Density at Capacity, Dc	45	pc/mi/ln
Mean Speed under Base Conditions, S	37.8	mi/h
Density, D	17.1	pc/mi/ln
Level of service, LOS	B	

This Multilane Highway Segment text report was created on 5/23/2021 15:38:57

SIDRA Outputs

LANE SUMMARY

Site: 101 [First Street at Main Street]

2040 Conditions - AM Peak Hour
Single-Lane Roundabout
Site Category: (None)
Roundabout

Lane Use and Performance

	DEMAND FLOWS [Total veh/h	HV] %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Aver. Delay sec	Level of Service	95% BACK OF QUEUE [Veh	Dist] ft	Lane Config	Lane Length ft	Cap. Adj. %	Prob. Block. %
South: First Street													
Lane 1[d]	112	3.0	558	0.200	100	9.1	LOS A	0.8	19.9	Full	1600	0.0	0.0
Approach	112	3.0		0.200		9.1	LOS A	0.8	19.9				
East: Main Street													
Lane 1[d]	729	3.0	1291	0.564	100	9.2	LOS A	4.8	124.1	Full	1600	0.0	0.0
Approach	729	3.0		0.564		9.2	LOS A	4.8	124.1				
North: First Street													
Lane 1[d]	78	3.0	603	0.129	100	7.5	LOS A	0.5	12.6	Full	1600	0.0	0.0
Approach	78	3.0		0.129		7.5	LOS A	0.5	12.6				
West: Main Street													
Lane 1[d]	826	3.0	1236	0.668	100	11.9	LOS B	6.7	171.4	Full	1600	0.0	0.0
Approach	826	3.0		0.668		11.9	LOS B	6.7	171.4				
Intersection	1744	3.0		0.668		10.4	LOS B	6.7	171.4				

Site Level of Service (LOS) Method: Delay & v/c (HCM 6). Site LOS Method is specified in the Parameter Settings dialog (Site tab).
Roundabout LOS Method: Same as Sign Control.
Lane LOS values are based on average delay and v/c ratio (degree of saturation) per lane.
LOS F will result if v/c > 1 irrespective of lane delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all lanes (v/c not used as specified in HCM 6).
Roundabout Capacity Model: US HCM 6.
Delay Model: HCM Delay Formula (Geometric Delay is not included).
Queue Model: HCM Queue Formula.
Gap-Acceptance Capacity: Traditional M1.
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.

d Dominant lane on roundabout approach

Approach Lane Flows (veh/h)

South: First Street

Mov. From S To Exit:	L2 W	T1 N	R2 E	Total	%HV	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Prob. SL Ov. %	Ov. Lane No.
Lane 1	33	1	78	112	3.0	558	0.200	100	NA	NA
Approach	33	1	78	112	3.0		0.200			

East: Main Street

Mov. From E To Exit:	L2 S	T1 W	R2 N	Total	%HV		Deg. Satn v/c	Lane Util. %	Prob. SL Ov. %	Ov. Lane No.
Lane 1	21	706	1	729	3.0	1291	0.564	100	NA	NA

Approach	21	706	1	729	3.0		0.564			
North: First Street										
Mov. From N To Exit:	L2 E	T1 S	R2 W	Total	%HV	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Prob. SL Ov. %	Ov. Lane No.
Lane 1	28	28	22	78	3.0	603	0.129	100	NA	NA
Approach	28	28	22	78	3.0		0.129			
West: Main Street										
Mov. From W To Exit:	L2 N	T1 E	R2 S	Total	%HV		Deg. Satn v/c	Lane Util. %	Prob. SL Ov. %	Ov. Lane No.
Lane 1	1	805	19	826	3.0	1236	0.668	100	NA	NA
Approach	1	805	19	826	3.0		0.668			
	Total	%HV	Deg.Satn (v/c)							
Intersection	1744	3.0		0.668						

Lane flow rates given in this report are based on the arrival flow rates subject to upstream capacity constraint where applicable.

Merge Analysis

	Exit Lane Number	Short Lane Length ft	Percent Opng in Lane %	Opposing Flow Rate veh/h	Critical Gap pcu/h	Follow-up Headway sec	Lane Flow Rate veh/h	Capacity veh/h	Deg. Satn v/c	Min. Delay sec	Merge Delay sec
South Exit: First Street Merge Type: **Not Applied**											
Full Length Lane	1	Merge Analysis not applied.									
East Exit: Main Street Merge Type: **Not Applied**											
Full Length Lane	1	Merge Analysis not applied.									
North Exit: First Street Merge Type: **Not Applied**											
Full Length Lane	1	Merge Analysis not applied.									
West Exit: Main Street Merge Type: **Not Applied**											
Full Length Lane	1	Merge Analysis not applied.									

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Synchro Outputs

Timings — 2020 No-Build AM Peak

1001: First St at Main Street — 11/14/2021

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	1	712	74	235	385	2	33	1	118	2	1	1
Future Volume (vph)	1	712	74	235	385	2	33	1	118	2	1	1
Satd. Flow (prot)	1770	1863	1583	1770	1863	1583	0	1777	1583	0	1803	1583
Flt Permitted	0.950			0.950				0.730			0.851	
Satd. Flow (perm)	1770	1863	1583	1770	1863	1583	0	1360	1583	0	1585	1583
Satd. Flow (RTOR)			68			55			128			95
Lane Group Flow (vph)	1	774	80	255	418	2	0	37	128	0	3	1
Turn Type	Prot	NA	Perm	Prot	NA	Perm	Perm	NA	Perm	Perm	NA	Perm
Protected Phases	5	2		1	6			8			4	
Permitted Phases			2			6	8		8	4		4
Detector Phase	5	2	2	1	6	6	8	8	8	4	4	4
Switch Phase												
Minimum Initial (s)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Minimum Split (s)	9.5	22.5	22.5	9.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5
Total Split (s)	10.0	64.0	64.0	30.0	84.0	84.0	26.0	26.0	26.0	26.0	26.0	26.0
Total Split (%)	8.3%	53.3%	53.3%	25.0%	70.0%	70.0%	21.7%	21.7%	21.7%	21.7%	21.7%	21.7%
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0		0.0	0.0
Total Lost Time (s)	4.5	4.5	4.5	4.5	4.5	4.5		4.5	4.5		4.5	4.5
Lead/Lag	Lead	Lead	Lead	Lag	Lag	Lag						
Lead-Lag Optimize?	Yes	Yes	Yes	Yes	Yes	Yes						
Recall Mode	None	C-Max	C-Max	None	C-Max	C-Max	None	None	None	None	None	None
Act Effct Green (s)	5.6	72.4	72.4	25.5	100.3	100.3		8.6	8.6		8.6	8.6
Actuated g/C Ratio	0.05	0.60	0.60	0.21	0.84	0.84		0.07	0.07		0.07	0.07
v/c Ratio 1	0.01	0.69	0.08	0.68	0.27	0.00		0.38	0.55		0.03	0.00
Control Delay	98.0	3.6	0.1	46.7	0.9	0.0		63.5	18.2		50.3	0.0
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0		0.0	0.0
Total Delay 2	98.0	3.6	0.1	46.7	0.9	0.0		63.5	18.2		50.3	0.0
LOS 3	F	A	A	D	A	A		E	B		D	A
Approach Delay 4		3.4			18.2			28.3			37.8	
Approach LOS 5		A			B			C			D	

Intersection Summary

Cycle Length: 120

Actuated Cycle Length: 120

Offset: 65 (54%), Referenced to phase 2:EBT and 6:WBT, Start of Green

Natural Cycle: 90

Control Type: Actuated-Coordinated

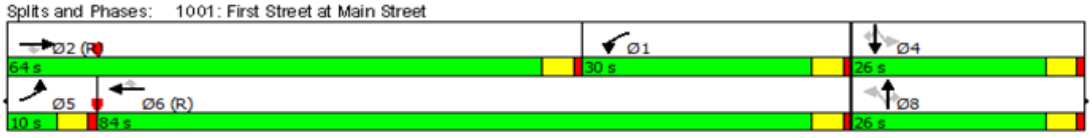
Maximum v/c Ratio: 0.69

Intersection Signal Delay: 11.8 6 — Intersection LOS: B 7

Intersection Capacity Utilization 70.3% — ICU Level of Service C

Analysis Period (min) 15

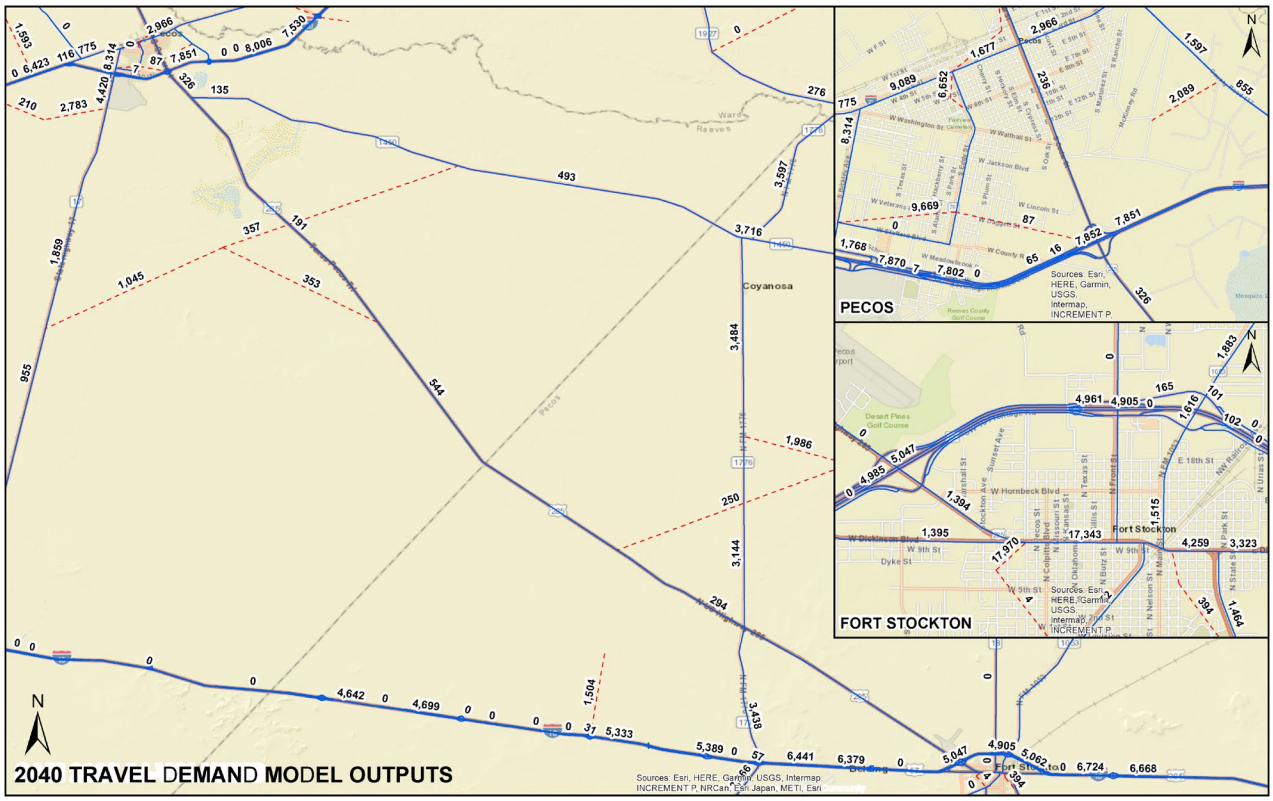
Splits and Phases: 1001: First Street at Main Street



Commonly Used Synchro Outputs

1. **v/c Ratio** – the ratio of the traffic volume on a road to its capacity, indicating the level of congestion or efficiency in the transportation system.
2. **Total Delay (movement)** – the average time that vehicles for a specific movement spend waiting or moving at a slower speed than the optimal speed, accounting for traffic signal timing, congestion, and the overall efficiency of the intersection.
3. **LOS (movement)** – a letter grade (A-F) given to a movement, dependent on it's delay.
4. **Approach Delay** – the average time that vehicles at an approach spend waiting or moving at a slower speed than the optimal speed, accounting for traffic signal timing, congestion, and the overall efficiency of the intersection.
5. **Approach LOS**– a letter grade (A-F) given to the approach, dependent on it's delay.
6. **Intersection Signal Delay** – the average time that vehicles at an intersection spend waiting on or moving at a slower speed than the optimal speed, accounting for traffic signal timing, congestion, and the overall efficiency of the intersection.
7. **Intersection LOS**– a letter grade (A-F) given to the intersection, dependent on it's delay.

Travel Demand Model Outputs



Vissim Outputs
(Freeway Density)

Freeway Density Comparison

PM Network Peak Hour (5:00-6:00 PM)

SOUTHBOUND US 111

Segment	Type	No-Build	Option 1	Option 2	Option 3	Option 4
US 111 SB Start of Corridor	Basic	25	25	21	21	21
Upstream	Diverge	42	43	37	33	33
Off-Ramp to 1st St	Ramp	22	23	23	23	23
Between Ramps	Basic	32	24	24	23	23
On-Ramp from 1st St	Ramp	48	32	32	32	32
Between Ramps	Weave	43	23	23	22	22
Off-Ramp to 2nd St	Ramp	31	34	34	32	32
Between Ramps	Basic	51	22	22	22	22
On-Ramp from 2nd St	Ramp	65	41	42	41	41
Downstream	Merge	53	24	25	24	24
Between 3rd St and 4th St	Basic	91	30	29	28	28
Upstream	Diverge	96	37	28	26	26
Off-Ramp to 5th St	Ramp	25	34	34	31	31
Between Ramps	Basic	121	40	25	25	25
On-Ramp from 5th St	Ramp	28	27	26	27	27
US 111 SB End of Corridor	Basic	91	38	24	24	24

Vissim Outputs
Freeway Throughput

Freeway Throughput Comparison

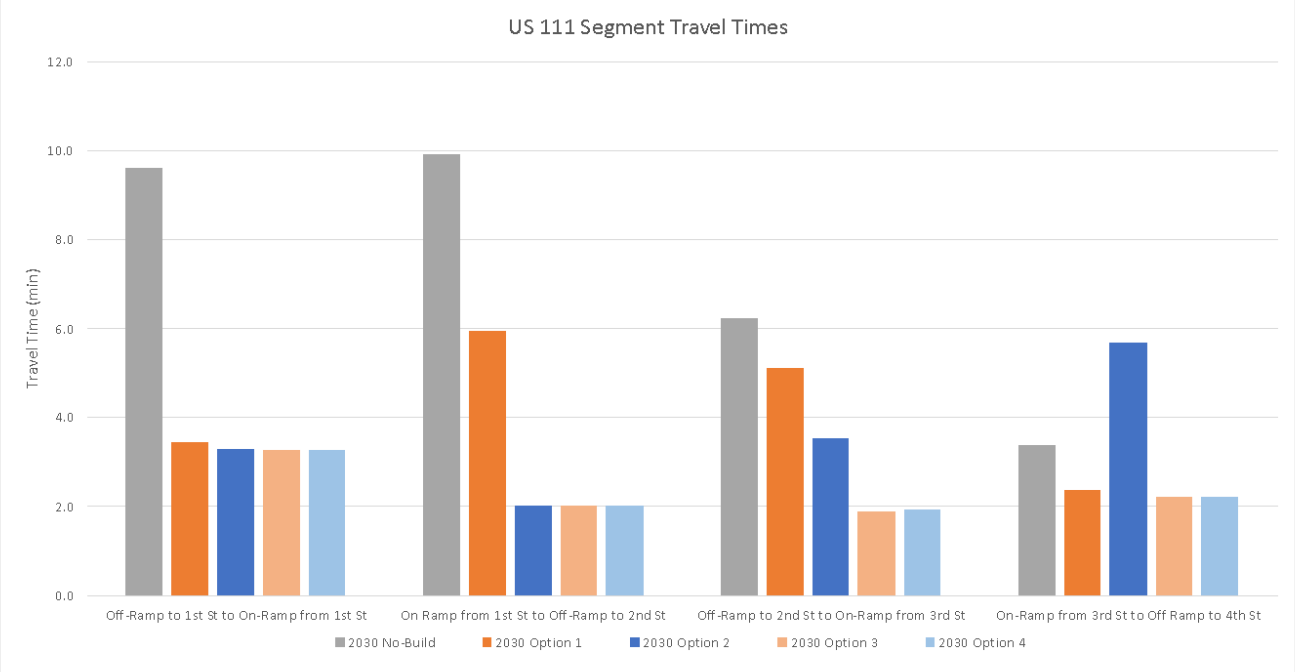
PM Network Peak Hour (5:00-6:00 PM)

SOUTHBOUND US 111

Segment	Type	No-Build	Option 1	Option 2	Option 3	Option 3
US 111 SB Start of Corridor	Basic	6,229	6,348	6,382	6,284	6,284
Upstream	Diverge	6,165	6,322	6,374	6,277	6,277
Off-Ramp to 1st St	Ramp	1,321	1,370	1,382	1,348	1,348
Between Ramps	Basic	4,829	4,966	5,007	4,942	4,942
On-Ramp from 1st St	Ramp	1,184	1,273	1,274	1,271	1,269
Between Ramps	Weave	5,944	6,231	6,272	6,204	6,203
Off-Ramp to 2nd St	Ramp	797	891	887	847	847
Between Ramps	Basic	5,059	5,329	5,372	5,346	5,345
On-Ramp from 2nd St	Ramp	1,416	1,556	1,562	1,525	1,525
Downstream	Merge	6,370	6,870	6,921	6,857	6,856
Between 3rd St and 4th St	Basic	5,966	6,906	6,965	6,897	6,896
Upstream	Diverge	5,675	6,805	6,950	6,883	6,881
Off-Ramp to 5th St	Ramp	853	1,146	1,167	1,048	1,047
Between Ramps	Basic	4,813	5,648	5,791	5,847	5,846
On-Ramp from 5th St	Ramp	697	677	672	697	697
US 111 SB End of Corridor	Basic	5,493	6,285	6,462	6,540	6,539

Vissim Outputs
Travel Times

Corridor Segment (US 111)	PM Peak Hour Average Travel Time (min)				
	2030 No-Build	2030 Option 1	2030 Option 2	2030 Option 3	2030 Option 4
Off-Ramp to 1st St to On-Ramp from 1st St	9.6	3.4	3.3	3.3	3.3
On Ramp from 1st St to Off-Ramp to 2nd St	9.9	5.9	2.0	2.0	2.0
Off-Ramp to 2nd St to On-Ramp from 3rd St	6.2	5.1	3.5	1.9	1.9
On-Ramp from 3rd St to Off Ramp to 4th St	3.4	2.4	5.7	2.2	2.2
Entire Corridor	**29.1**	**16.8**	**14.5**	**9.3**	**9.4**
Savings (min)		12.3	14.6	19.7	19.7
Savings (%)		42%	50%	68%	68%



Section 4 – External References

The website below was last accessed on May 31, 2024

1. **Texas Department of Transportation Brand Guidelines**

   https://ftp.txdot.gov/pub/txdot-info/cmd/branding/brand-guidelines.pdf

   - This document provides clear guidelines on the use of the TxDOT logo and brand.

Appendix S – Acronym Glossary

- **2R** – resurfacing or restoration
- **3R** – resurfacing, restoration, or rehabilitation
- **4R** - reconstruction
- **AADT** – Annual Average Daily Traffic
- **AASHTO** – American Association of State Highway and Transportation Officials
- **ABM** – activity-based models
- **ADT** – Average daily traffic
- **AFs** – adjustment factors
- **AIIR** – Alternative Intersection/Interchange Informational Report
- **ARCADY** – Assessment of Roundabout Capacity and Delay
- **ATDM** – Active Transportation and Demand Management
- **ATP** – Active Transportation Plan
- **ATR** – automated traffic vendors
- **ATS** – average travel speed
- **AVL** – automatic vehicle location
- **AWSC** – all-way stop controlled
- **B/C** – Benefit/Cost
- **BDAE** – bounded dynamic absolute error
- **BEA** – Bureau of Economic Analysis
- **BLS** – Bureau of Labor Statistics
- **BLTS** – Bicycle Level of Traffic Stress
- **BPCX** – Bicycle and Pedestrian Count Exchange
- **BTS** – Bureau of Transportation Statistics
- **CAFs** – capacity adjustment factors
- **CAP-X** – Capacity Analysis for Planning of Junctions
- **CAVs** – connected and automated vehicles
- **CE** – categorical exclusion
- **CFI** – continuous flow interchange
- **CGT** – continuous green-T
- **CSJ** – control section job
- **CMF** – crash modification factors
- **CORSIM** – Corridor Simulation
- **CR-3** – Texas peace officer's crash reports
- **CRF** – crash reduction factors
- **CRIS** – Crash Records Information System
- **DAFs** – demand adjustment factors
- **DCD** – double crossover diamond

- **DCM** – data collection measurements
- **DCP** – data collection points
- **DDI** –diverging diamond interchange
- **DES** – Design Division
- **DFO –** distance-from-origin
- **DHV** – design Hourly volume
- **DLT** – displaced left turn
- **DSD** – Desired speed decision
- **DTA** – dynamic traffic assignment
- **EA** – environmental assessment
- **EB** – Empirical Bayes
- **EDTT** – extra distance travel time
- **EIS** – Environmental Impact Statement
- **ESAL** – equivalent single axle load
- **ESD** – emergency stop distance
- **ESRI** – Environmental Systems Research Institute
- **ETT** – experienced travel time
- **FAA** – Federal Aviation Administration
- **FAF** – Freight Analysis Framework
- **FCD** – floating car data
- **FEMA** – Federal Emergency Management Agency
- **FHWA** – Federal Highway Administration
- **FREEVAL** –FREeway EVALuation
- **GDP** – gross domestic product
- **GEH** – Geoffrey E. Havers
- **GIS** – geographic information system
- **GPS** – global positioning system
- **HCM** – Highway Capacity Manual
- **HCS** – Highway Capacity Software
- **HOT** – high occupancy toll
- **HOV** – heavy occupancy vehicles
- **HPMS** – Highway Performance Monitoring System
- **HSIP** – Highway Safety Improvement Program
- **HSM** – Highway Safety Manual
- **HSM2** – Highway Safety Manual 2nd edition
- **HSS** – Highway Safety Software
- **IAJR** – interstate access justification report
- **ICE** – Intersection Control Evaluation
- **ICD** – Inscribed circle diameter
- **IHSDM** – Interactive Highway Safety Design Model
- **ISATe** – Enhanced Interchange Safety Analysis Tool

- **ITE** – Institute of Transportation Engineer
- **ITS** – intelligent transportation system
- **KABCO** – K = Killed, A = Incapacitating Injury, B = Non-incapacitating Injury, C = Possible injury, O = Not injured
- **LCD** – lane change distance
- **LOE** – level of effort
- **LOS** – level-of-service
- **MDOV –** maximum deceleration of own vehicle
- **MEV –** million entering vehicles
- **MOE –** Measure of Effectiveness
- **Mph –** miles per hour
- **MPO –** Metropolitan Planning Organization
- **MRM –** Multi-Resolution Modeling
- **MSTR –** MicroStrategy
- **MTI –** Mineta Transportation Institute
- **MTP –** metropolitan transportation plan
- **MUT –** median u-turn
- **MVMT** – million vehicle miles traveled
- **NACTO** – National Association of City Transportation Officials
- **NCHRP** – National Cooperative Highway Research Program
- **NEPA** – National Environmental Policy Act
- **NPMRDS** – National Performance Management Research Data Set
- **NPV** – net present value
- **NSC** – National Safety Council
- **NWS** – National Weather Service
- **OD** – origin-destination
- **OM** – operations and maintenance
- **OPCC** – Opinion of Probable Construction Cost
- **PBPD** – Performance Based Practical Design
- **PCE** – passenger car equivalent/equivalency
- **Pcpmpl** – passenger cars per mile per lane
- **PDS** – Project Development Stage
- **PFFS** – percent of free-flow speed
- **PHB** – pedestrian hybrid beacon
- **PHF** – peak hour factor
- **PHT** – person hours of travel
- **PIP** – Public Involvement Plan
- **PLTS** – Pedestrian level of traffic stress
- **PM** – preventative maintenance
- **PMIS** – Pavement Management Information System
- **PS** – Project Specific

- **PSI** – potential for safety improvement
- **PS&E** – plans, specifications, and estimates
- **PSAP** – pedestrian safety action plan
- **PTSF** – percent time-spent-following
- **PTV** – Planung Transport Verkehr
- **R**– Required
- **RAID** – Roundabouts and Alternative Intersection Designs
- **RBC** – Ring Barrier Controllers
- **RCUT** – restricted crossing u-turn
- **RDM** – Roadway Design Manual
- **RHiNo** – Roadway-Highway Inventory Network
- **RITIS** – Regional Integrated Transportation Information System
- **ROW** – Right-of-Way
- **RRFB** – rectangular rapid-flashing beacon
- **RRP** – reliability reporting period
- **RSA** – Road Safety Assessment
- **RSA** – reduced speed areas
- **RTM** – regression-to-the-mean
- **RTOR**- right-turn-on-red
- **RTP** – Rural Transportation Plan
- **SAM** – Statewide Analysis Model
- **SAFs** – speed adjustment factors
- **SEAs** – Safety Emphasis Areas
- **SHSP** – Strategic Highway Safety Plan
- **SIDRA** – Signalized and Unsignalized Intersection Design and Research Aid
- **SII** – Safety Improvement Index
- **SLRTP** – statewide long range transportation plan
- **SMS** – space-mean-speed
- **SOP** – Standard Operating Procedure
- **SOV** – Single occupancy vehicle
- **SPF** – safety performance functions
- **SPICE** – safety performance of intersection control evaluation
- **SPUI** – single-point urban interchange
- **SST** – Safety Scoring Tool
- **SSWP** – Systemic Safety Widening Program
- **STARS** – Statewide Traffic Analysis and Reporting System
- **SUPLOS** – Shared Use Path Level-of-Service
- **TAHD** – Traffic Analysis for Highway Design
- **TAZ** – Traffic Analysis Zone
- **TCAP** – TxDOT Comprehensive Accessibility Program
- **TCAT** – Truck Congestion Analysis Tool

- **TDC** – Texas Demographic Center
- **TDM** – Travel demand model
- **TIA** – Traffic Impact Analysis
- **TIM** – Traffic incident management
- **TIM-BC** – Traffic Incident Management Benefit-Cost
- **TMC** – turning movement count
- **TMIP** – Travel Model Improvement Portal
- **TMS** – Time-mean-speed
- **TMUTCD** – Texas Manual on Uniform Traffic Control Devices
- **TNRIS**– Texas Natural Resources Information System
- **TOPS-BC** – Tool for Operations Benefit/Cost
- **TPP** – Transportation Planning and Programming (TxDOT Division)
- **TRB** – Transportation Research Board
- **TRC** – Texas Railroad Commission
- **TRF** – Traffic Safety Division
- **TRL** – Transport Research Laboratory
- **TSAP** – Traffic and Safety Analysis Procedures (Manual)
- **TSM** – Transportation System Management
- **TSMO** – Transportation Systems Management and Operations
- **TTI** – Texas A&M Transportation Institute
- **TWSC** – two-way stop-controlled
- **TxDOT** – Texas Department of Transportation
- **USACE** – United States Army Corps of Engineers
- **USFWS** – United States Fish and Wildlife Service
- **UTP** – Unified Transportation Program
- **V/C** – volume-to-capacity (ratio)
- **VHD** – Vehicle hours of Delay
- **VHT** – Vehicle Hours of Travel
- **VPD** – Vehicles per day
- **Vissim** – Verkehr in Staedten Simulation
- **VMT** – Vehicle Miles of Travel
- **Vph** – vehicles per hour
- **Vphpl** – Vehicles per hour per lane
- **Vpmpl** – vehicles per mile per lane
- **VTRIS** – vehicle travel information system
- **WIM** – Weigh-in-motion
- **XDLT** – crossover displaced left-turn

Appendix T – References

- Transportation Research Board. 2022. Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis. Reproduced with permission from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.
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