# Travel Time Reliability Reference Guide

August 2023

U.S. Department of Transportation
**Federal Highway Administration**

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

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

## APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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| | |
|---|---|
| FHWA | Federal Highway Administration |
| I–5 | Interstate 5 |
| I–94 | Interstate 94 |
| I–95 | Interstate 95 |
| mi | mile |
| min | minute |
| MnDOT | Minnesota Department of Transportation |
| NPMRDS | National Performance Management Research Data Set |
| RRP | reliability reporting period |
| SHRP2 | second Strategic Highway Research Program |
| TMC | traffic management center |
| TTR | travel time reliability |
| TTRMS | travel time reliability monitoring system |
| VC&V | verification, calibration, and validation |
| WisDOT | Wisconsin Department of Transportation |

# CHAPTER 1. INTRODUCTION

Travel time reliability (TTR) is significant for many transportation system users, whether they are vehicle drivers, transit riders, freight shippers, or even air travelers. Personal and business travelers value reliability because it allows them to make better use of their time. Shippers and freight carriers need predictable travel times to remain competitive. Reliability is a valuable service that transportation agencies can provide on privately financed or privately operated highways. Because reliability is so important, transportation planners and decision makers should consider TTR a key performance measure.

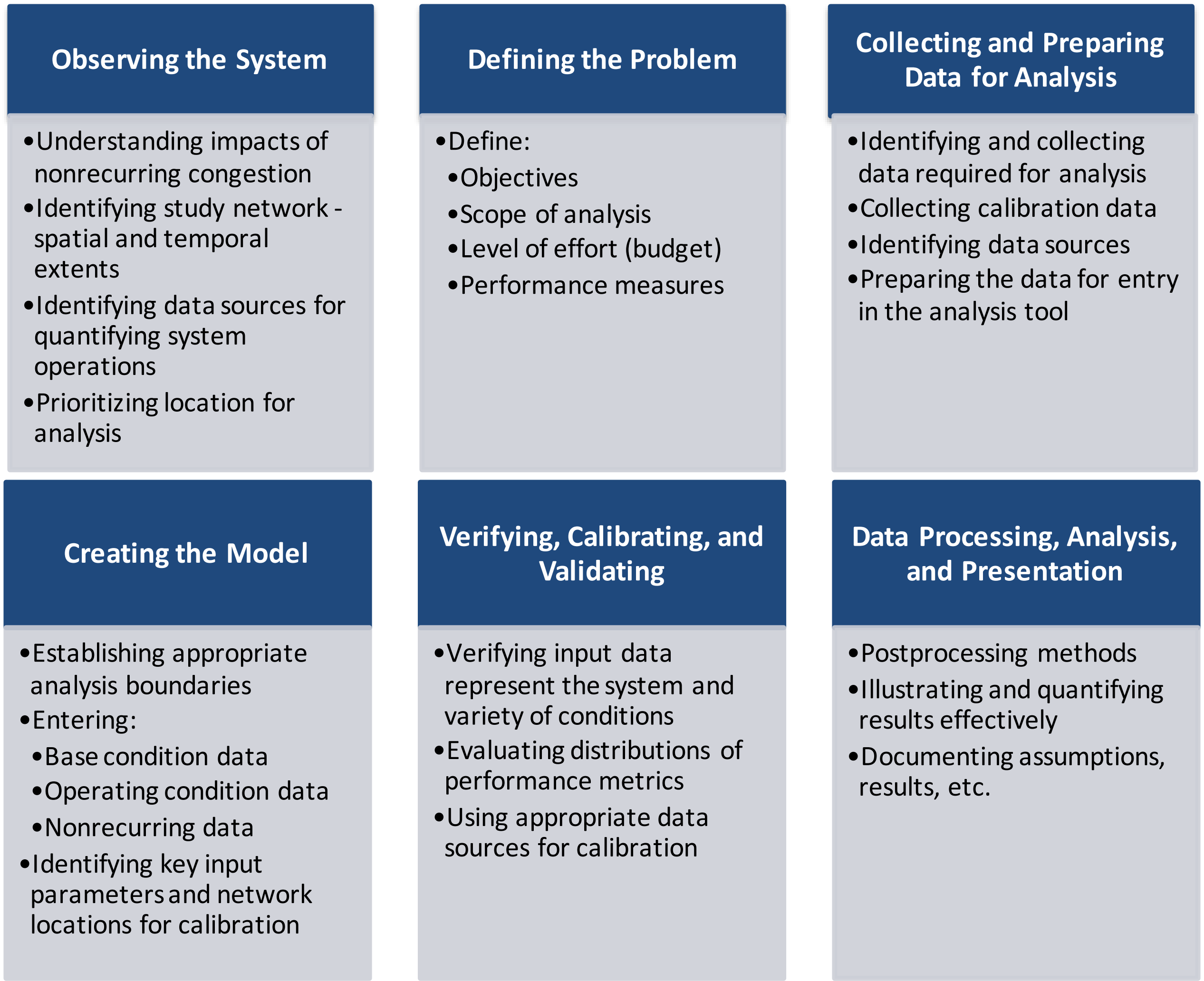
Traffic professionals recognize the importance of TTR because it better quantifies the benefits of traffic management and operation activities than simple averages. For example, a before-and-after study that quantifies the benefits of an incident management or ramp metering program may appear to show a modest improvement in average travel time. However, reliability measures will show a much greater improvement because they demonstrate the effect of improving the worst few days of unexpected delay.

This TTR Reference Guide (Reference Guide) is part of an effort by the U.S. Department of Transportation's Federal Highway Administration (FHWA) to update the FHWA *Traffic Analysis Toolbox* to reflect TTR.

## ORGANIZATION OF THE REFERENCE GUIDE

This Reference Guide is organized around the following six key principles for including TTR evaluation within traffic analysis approaches (see in figure 1):

- Observing the system.
- Defining the problem.
- Collecting and preparing data for analysis.
- Creating the model.
- Verifying, calibrating, and validating.
- Data processing, analysis, and presentation.



**Observing the System**

- Understanding impacts of nonrecurring congestion
- Identifying study network - spatial and temporal extents
- Identifying data sources for quantifying system operations
- Prioritizing location for analysis

**Defining the Problem**

- Define:
  - Objectives
  - Scope of analysis
  - Level of effort (budget)
  - Performance measures

**Collecting and Preparing Data for Analysis**

- Identifying and collecting data required for analysis
- Collecting calibration data
- Identifying data sources
- Preparing the data for entry in the analysis tool

**Creating the Model**

- Establishing appropriate analysis boundaries
- Entering:
  - Base condition data
  - Operating condition data
  - Nonrecurring data
- Identifying key input parameters and network locations for calibration

**Verifying, Calibrating, and Validating**

- Verifying input data represent the system and variety of conditions
- Evaluating distributions of performance metrics
- Using appropriate data sources for calibration

**Data Processing, Analysis, and Presentation**

- Postprocessing methods
- Illustrating and quantifying results effectively
- Documenting assumptions, results, etc.

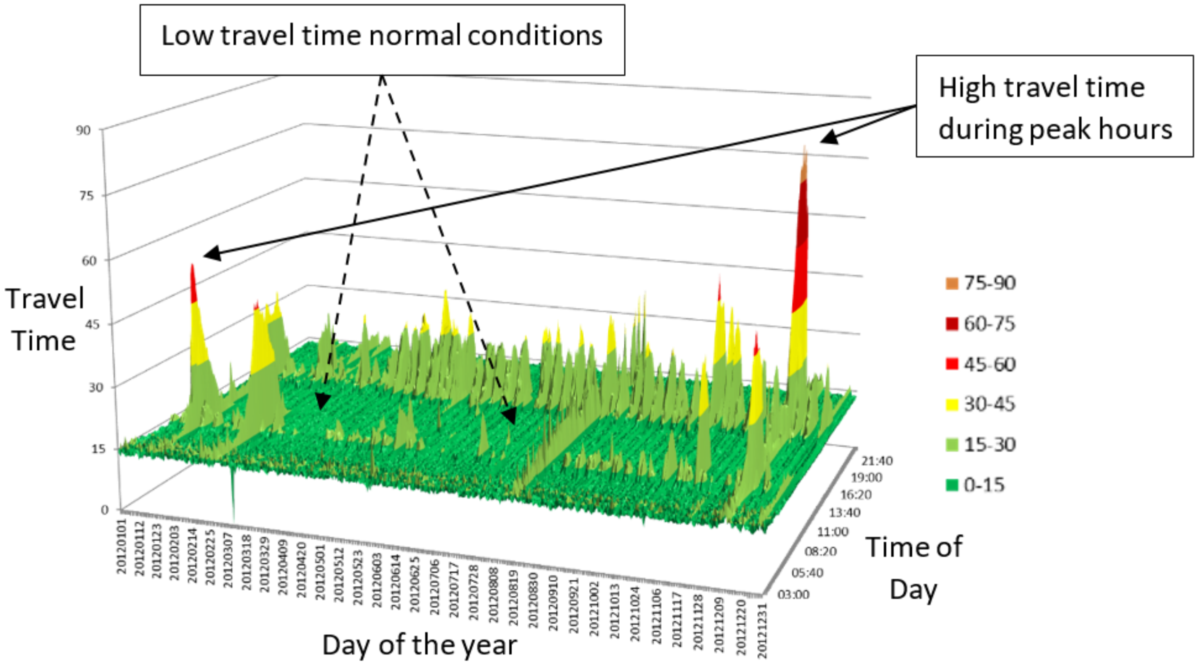
Source: Federal Highway Administration.

**Figure 1. Chart. Reliability analysis components.**

# CHAPTER 2. STEP 1: OBSERVING THE SYSTEM

## WHY RELIABILITY?

All good traffic analyses begin with observing system performance. In a reliability approach, analysts expand their understanding of what influences traffic to include nonrecurring congestion. Figure 2 illustrates an example of this shift to “reliability space,” which adds several dimensions beyond those considered in traditional traffic analyses. This Reference Guide highlights the importance of this mindset and lays out a systematic approach to incorporate it into traffic analysis.



Source: SRF Consulting Group, Inc.

**Figure 2. Graph. Three-dimensional travel time surface plot.**

Traditional traffic analysis methods have often relied on simplifying assumptions (e.g., averaging a sample of observations or controlling data collection to avoid bad weather, crashes, or other incidents). However, this is not the reality of the conditions that travelers and the highway system experience. Indeed, factors causing travel time variability have major impacts on commuters and shippers, and an analysis should align with these issues.

Observing system performance should include understanding the variability in travel times and its underlying causes. To better understand the conditions drivers experienced, analysts can identify distinct regimes of congestion that tend to occur under certain operating conditions. As the industry moves to a more holistic approach to transportation system management and operations, this approach is also important so that officials recognize responsible factors for deficient operations, which may not always be demand versus base capacity.

The emerging reliability paradigm adds new dimensions to traffic operations. With this approach, analysts will consider the frequency of events and their travel time impacts. Events will be characterized by dimensions of severity (i.e., how much travel times increase and duration), length, and extent (i.e., the area affected by congestion). This will enable analysts to characterize the congestion as recurring or nonrecurring.

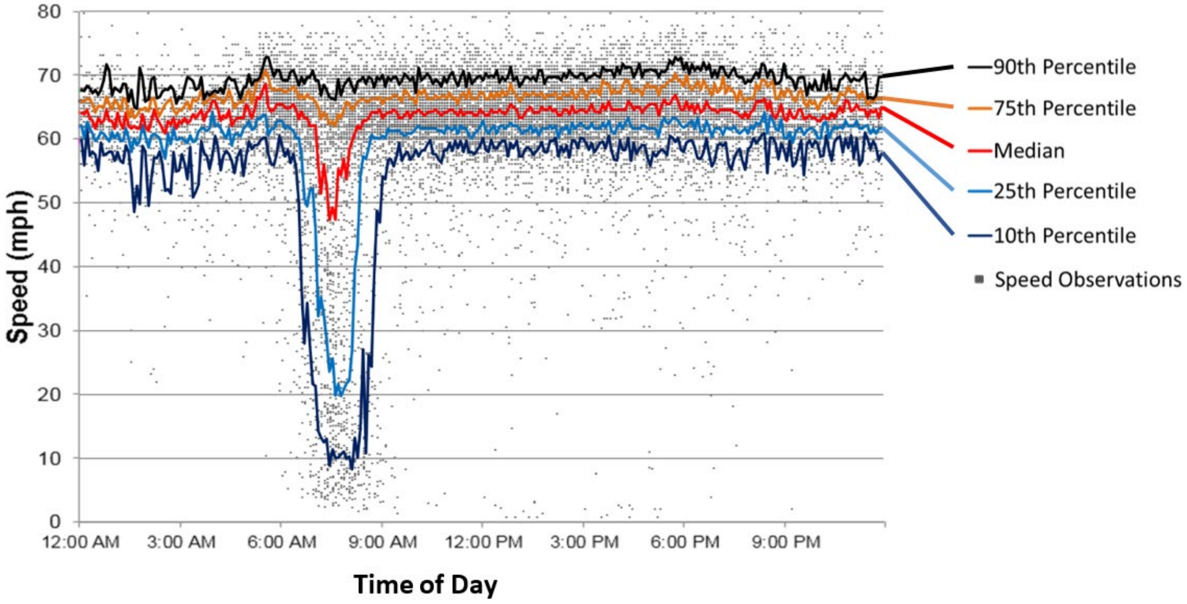
With that information in mind, investigating reliability can introduce additional influence factors that affect traffic conditions. These factors include weather, crashes, incidents, road work, special events, and variations in demand. Depending on local conditions, some factors may be more important than others.

## TOOLS AND EVALUATION

Now that the dimensions of reliability are considered, and there is a sense of the data associated with the evaluation, tools are needed to evaluate and communicate the performance. Compared to traditional methods, using these data with additional dimensions offers more ways to express the information. Because this is still the exploratory stage, it invites the professional to look at the data in the reliability space from several perspectives.

A simple way to begin is with single summary statistics. For reliability, these include planning time index, buffer index, and several additional measures. These statistics are comparable to traditional level-of-service measures, in that they can be quickly stated and used in a simple table or for comparison of corridors or conditions. However, data in the reliability space can tell a much richer story about the range of experiences on a system or facility.

The adage “a picture is worth a thousand words” applies to reliability evaluation. Numerous techniques have come into use, including cumulative density plots, spatial and temporal heat maps, pie charts, bar charts, and thermometers. Similarly, a spread of statistical measures will illustrate the range of condition more meaningfully (e.g., distribution of 10th, 25th, 50th, 75th, and 90th percentile travel times in figure 3 helps show where concentrations and break points exist in the data).



Source: SRF Consulting Group, Inc.

**Figure 3. Graph. Travel speed percentiles by time of day.**

## IDENTIFYING THE STUDY NETWORK

Once analysts understand how to observe reliability performance, they can evaluate solutions for problematic local areas. For these areas, analysts can define the spatial and temporal extents that capture the observed reliability issues.

Analysts may begin by identifying reasonable limits upstream and downstream of the primary point of concern, where reliability performance falls below a desired threshold. Then, they can approach the temporal question by capturing critical times of day that include the formation, duration, and dissipation of the congestion that causes unreliable travel times. Finally, analysts can select a data collection time period that contains historical data from one or more periods known to include causal factors that had led to the reliability problem.

## DETERMINE THE DATA SOURCES NEEDED

The next step in the scoping process is to consider the necessary data sources to conduct the evaluation. First and foremost, speed or travel time information is needed. These types of observations are now available from an increasing number of sources. Traditional sources that include loop detectors or continuous monitoring sites are suitable for reliability evaluation. Practitioners are increasingly turning to probe data providing a sample of vehicle speeds. This category includes global positioning system-based probe data and roadside via wireless technology. More sources are expected to emerge with mobile communications and connected vehicles.

Obtaining volume data can be more challenging, depending on which source of travel time data was used. While traditional sources typically provide volume and speed data, probe data are typically just a sample of trips, which introduces uncertainty into the number of vehicles on the road. If volume is unavailable throughout the study area, estimation methods can extrapolate smaller samples. Spatially, this might be done by scaling a single volume collection point to average daily traffic volumes at nearby locations on a facility. Temporally, a short-duration count could be repeated across similar days and times. These methods may limit the veracity of some performance measures, such as aggregate delay, but may still prove beneficial compared to no data at all. Finally, analysts can also be sensitive to the location where volume data were collected, to understand whether it represents flow versus demand.

Of course, the components that add richness to the reliability space are the nonrecurring factors. Again, these are observed conditions that influence travel time reliability (TTR). Typical sources for nonrecurring factors can include the following:

- **Weather** history can be obtained through road weather information systems, the National Oceanic and Atmospheric Administration, or similar weather forecast websites and services.
- **Crash** records are typically compiled by State law enforcement agencies and provided to transportation agencies to use in their planning processes.
- **Incident** logs may be available through the traffic management center (TMC), depending on their level of management. Other viable sources may include emergency call dispatch logs, variable message sign logs, and similar records of traffic incident management activity.
- **Special events** times should be applied by reviewing schedules for nearby event facilities.
- **Road work** records should be accessible through the department of transportation's construction administration. These should also be cross-referenced with incident logs in instances where traffic management activities had been undertaken in conjunction with road work.
- **Other sources** may be desired in the analysis, depending on conditions that had influenced reliability performance. For example, signal or other operational management data may be incorporated into the process. This could include managed lane operations, ramp meters, and traffic signals phasing and timing.

## PRIORITIZING LOCATIONS FOR ANALYSIS

With the scale and scope of the analysis in mind, the analyst can set up the evaluation network to capture the causes and symptoms of congestion. Beyond the physical extents of the network, this stage should consider the appropriate level of detail to reflect the analysis goals (i.e., time intervals and segment length). Integral to this is deciding which specific analysis methodology to use for the evaluation. This analysis methodology could incorporate a spectrum of tools, from sketch planning to highway capacity methods to microsimulation modeling.

## REFERENCE MATERIALS

Additional resources for observing the system include:

- List, G. F., B. Williams, N. Rouphail, R. Hranac, T. Barkley, E. Mai, A. Ciccarelli et al. "*SHRP 2 Report S2-L02-RR-1: Establishing Monitoring Programs for Travel Time Reliability*." Transportation Research Board of the National Academies, Washington, DC (2014).
- TTRMS user guides developed through SHRP2 Project L02.

## CASE STUDY: INTERSTATE 94 CORRIDOR OF COMMERCE

### Project Description

Interstate 94 (I–94) connects Minneapolis, Minnesota to regions northwest of the Twin Cities metropolitan area. It is a major route for freight movement to Minnesota, North Dakota, and beyond. It is also a significant commuter route for exurban communities into urban core, and it is heavily used for recreational travel from metropolitan areas to Minnesota's lake country.

### Reliability Objectives

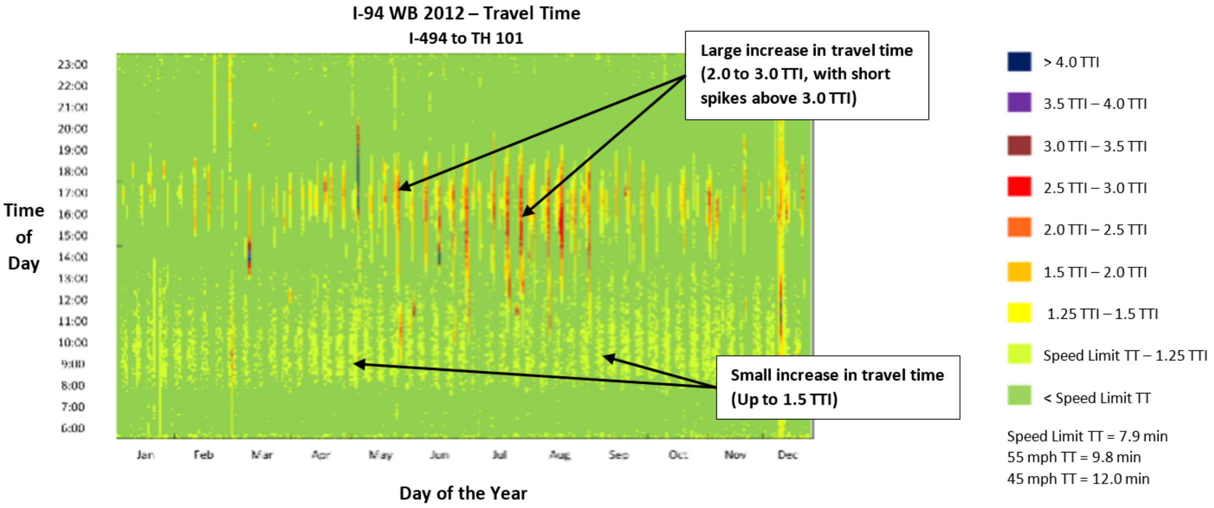
Local Minnesota stakeholders and the Minnesota State legislature had targeted I–94 for investment, based on a shared sense that it had experienced traffic issues. While they shared a concern about traffic, they lacked consensus about specific deficiencies, scope of issues, and where to go next. Some of the disagreement had been fueled by mostly anecdotal reference to frequent, heavy congestion, but with little documentation available to support this.

### Analysis Summary

The Minnesota Department of Transportation (MnDOT) project team turned to reliability analysis to take a broader look at the issues. Continuous traffic data were collected for several years leading up to the study. This included volumes and travel times in 5-minute intervals. These traffic data were combined with observations of weather, crashes, and road work. The summarized results were reviewed both statistically and graphically.

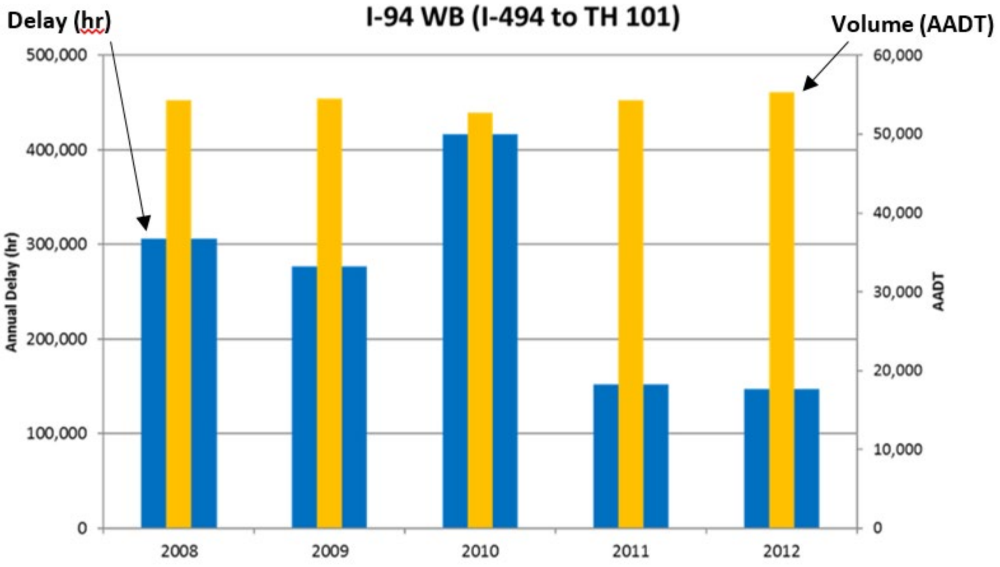
The analysis findings (summarized in figure 4) provided great clarity to the issues present on the roadway. First, demand was observed to be very consistent through the afternoon peak period year-round. During summer months, demand levels started to peak earlier in the day, particularly on Fridays. Travel times, interestingly, did not show recurring congestion every day of the week. What emerged was that congestion was most prevalent on Fridays in the summer, and often significant delays began much earlier in the day than the typical afternoon rush. Reliability was also observed to be impacted by weather events during winter months.

Looking farther back in time, the project team also evaluated the impact of a mobility improvement. About 4 years prior, MnDOT had added a flyover and auxiliary lane to serve a congested movement of the system interchange on the downstream end of the corridor. Looking at the aggregate demand and delay for each year, a 5-year period clearly isolated the influence of the project. The first 2 years represent the before condition, the third year was during construction, and the final 2 years were after project completion. Figure 5 shows that demand was fairly consistent before and after the project, with just a slight dip during construction. However, delay significantly increased during construction, despite the lower demand. The final 2 years show lower overall delay compared to the first 2 years, even while serving the same demand. This shows the mobility improvement did have a measurable impact on the overall delay corridor users experienced.



Source: SRF Consulting Group, Inc.

**Figure 4. Graph. Surface plots of travel times on Interstate 94.**



Source: SRF Consulting Group, Inc.

**Figure 5. Graph. Vehicle delay and average annual daily traffic volume on Interstate 94.**

# CHAPTER 3. STEP 2: DEFINING THE PROBLEM

## OBJECTIVES

This stage involves laying out goals and objectives for the outcomes of the evaluation. Analysts and stakeholders can ask the following questions to help clarify the desired outcomes:

- What do we want to answer with the analysis?
- Are we trying to explore an issue, analyze the issue in detail, develop performance measures, or make an investment to improve conditions?
- Who will be the audience for the results? Are they highly technical or less familiar with transportation performance measures?

With these questions in mind, project leaders can establish the study objectives. An example of a goal statement might sound like this:

> The analysis should identify the overall size of the reliability issues on the corridor, in terms of the severity and frequency of congestion events. Major causal factor(s) for these congestion events should be exposed along with their relative contribution to the overall problem. From that point, the reliability performance evaluation should be used to identify a range of potential mitigation measures, and in turn, appropriate analysis tools to evaluate them.

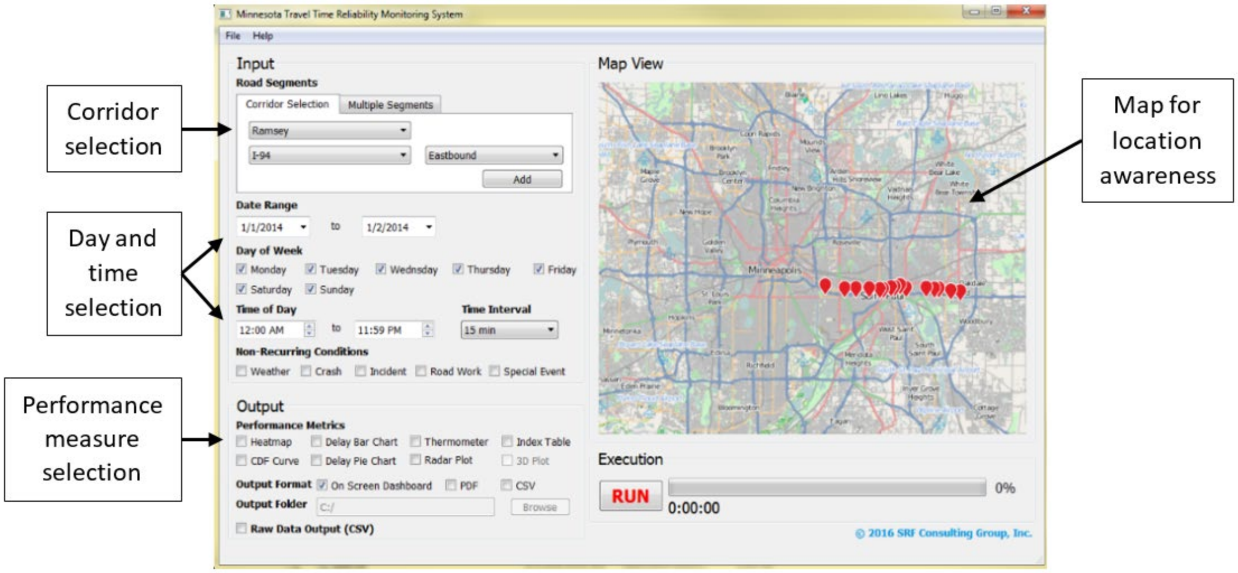
## SCOPE OF ANALYSIS

Several important considerations factor into selecting an analysis method. First, consider the audience for the results of the analysis. What is their level of interest in the details of the work? Are they seeking basic direction or detailed instructions? Second, factor in the scale of evaluation, both temporally and spatially. Larger coverage areas and longer timespans will typically trend toward less-detailed analysis. Applying detailed methods to large areas and timescale is possible, albeit with additional computational time and resources. The next consideration is the planning stage in which the analysis is being applied. For example, in the early planning stages, it is appropriate to use sketch-level evaluation tools, whereas a project entering more detailed design should be evaluated using microsimulation.

Another element to consider is the level of effort suitable for the evaluation. The range of available analysis methods will entail different levels of effort. This is affected by factors including the granularity of data collection and sophistication of the traffic model. In practice, this can relate to the approach to considering individual nonrecurring events versus rates (e.g., annual crash rates or frequency of special events).

## PERFORMANCE MEASURES AND OUTPUTS

The final step in defining the approach to the reliability analysis is how to communicate the results. There are many means of communicating highway performance from a reliability analysis. These include graphical methods that can illustrate trends and proportions and statistical descriptors that allow for easy comparison among facilities or alternatives. Figure 6 provides an example of how to select and define such outputs.



Minnesota Travel Time Reliability Monitoring System

Input

Road Segments

Ramsey

I-94 Eastbound

Date Range

1/1/2014 to 1/2/2014

Day of Week

☑ Monday ☑ Tuesday ☑ Wednsday ☑ Thursday ☑ Friday
☑ Saturday ☑ Sunday

Time of Day

12:00 AM to 11:59 PM

Time Interval

15 min

Non-Recurring Conditions

☐ Weather ☐ Crash ☐ Incident ☐ Road Work ☐ Special Event

Output

Performance Metrics

☐ Heatmap ☐ Delay Bar Chart ☐ Thermometer ☐ Index Table
☐ CDF Curve ☐ Delay Pie Chart ☐ Radar Plot ☐ 3D Plot

Output Format ☑ On Screen Dashboard ☐ PDF ☐ CSV

Output Folder C:/

☐ Raw Data Output (CSV)

0%

0:00:00

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Source: SRF Consulting Group, Inc.

**Figure 6. Screenshot. Interface of travel time reliability monitoring system.**

The main characteristic important in the analysis is that measures address the dimensions of reliability space that are important to the evaluation. Several commonly used performance measures help answer a specific question the audience will want to know about the corridor:

- What is the frequency of events meeting a desired travel time threshold?
- What percent of the time does the corridor operate above a threshold or within a range of travel times?
- Will there be a comparison of performance under different conditions?

## REFERENCE MATERIALS

Additional resources for defining the problem include:

- Wunderlich, Karl E., Vassili Alexiadis, and Peiwei Wang. *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses*. No. FHWA-HOP-16-072. United States. Federal Highway Administration. Office of Operations, 2017.
- Jeannotte, Krista, Andre Chandra, Vassili Alexiadis, and Alexander Skabardonis. *Traffic analysis toolbox Volume II: Decision support methodology for selecting traffic analysis tools*. No. FHWA-HRT-04-039. 2004.

# CHAPTER 4. STEP 3: DATA FOR ANALYSIS

The third step in the reliability analysis process is obtaining necessary data for the intended traffic analysis effort. One procedure that separates reliability analyses from traditional peak-hour evaluations is including nonrecurring factors. Analysts can use traditional roadway geometric and traffic demand characteristics along with nonrecurring data elements (see table 1) to produce a comprehensive evaluation that reflects transportation facility conditions over time. Table 2 summarizes typical nonrecurring data components for traffic analysis.

**Table 1. Traffic analysis data requirements.**

| Base Analysis | Nonrecurring Components |
|---|---|
| • Geometry<br>• Base Demand | • Demand patterns<br>• Traffic incidents<br>• Inclement weather<br>• Work zones |

Source: Federal Highway Administration.

**Table 2. Nonrecurring data components.**

| Nonrecurring Data Component | Description |
|---|---|
| **Traffic demand variability** | Varies by time of day, day of month, month of year; demand can sharply increase due to special events |
| **Traffic incidents** | Includes crash and non-crash breakdowns of different severity (e.g., shoulder closure, one-lane closure) |
| **Inclement weather** | Includes snow, rain, cold, visibility, etc. |
| **Work zones** | Impacts capacity and demand patterns; can vary by severity and time effective throughout analysis period |

## LEVEL OF DETAIL

The level of detail and types of data required vary with the selected analysis type. For instance, more robust analyses, such as those that use microsimulation, involve a wider selection of data than sketch-level evaluations. The Transportation Research Board's second Strategic Highway Research Program (SHRP2) projects offers useful guides on data requirements for various traffic analysis types. Examples of SHRP2 guides are as follows:

- SHRP2 Project L04: *Incorporating Reliability Performance Measures into Operations and Planning Modeling Tools* (mesoscopic and microscopic).[1]

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[1] National Academies of Sciences, Engineering, and Medicine, *Incorporating Reliability Performance Measures into Operations and Planning Modeling Tools*, report S2-L04-RR-1 (Washington, DC: The National Academies Press, 2014), https://doi.org/10.17226/22388.

- SHRP2 Project L08: *Incorporating Travel Time Reliability into the Highway Capacity Manual* (macroscopic).[2]

For data-poor analyses, traffic analysis tools that provide default values or automate entry of data may be most practical. SHRP2 Projects L07 and L08 offer built-in functionality to generate a range of data elements, including weather distributions by city (see figure 7), demand profiles by area type, and incident frequencies by severity.

Although referring to default data values can reduce the level of effort required for an analysis, it can have an adverse effect on accuracy of results. Thus, the authors recommend applying local data for the analysis whenever possible. Several of the nonrecurring conditions mentioned in this section also call for the analyst to identify corresponding impacts to traffic. For example, inclement weather conditions tend to have negative impacts on facility capacity. Similarly, with traffic incidents and work zones, the severity of closures associated with each event will have a corresponding effect on vehicle throughput. Analysts can estimate nonrecurring event impacts by collecting field measurements while the conditions of interest are present. Common types of calibration measurements may include travel time, vehicle speed, vehicle throughput, and queue length.

## CALIBRATION DATA

It is helpful to consider potential outputs of the traffic analysis when determining appropriate calibration measures to collect. Planning-level tools may only produce statistical outputs from the reliability analysis period (e.g., planning time index), whereas microscopic evaluations may produce performance measures associated with individual analysis scenarios. The chosen calibration parameters may have a strong impact on data collection and level of effort.

Probe data and loop detector data are common resources to collect calibration data. A key difference is that probe data collect physical travel times between two points, whereas detector data collect speeds and volumes at certain locations. Thus, additional effort is needed to impute travel times when using detector data. Probe data are available through the National Performance Management Research Data Set (NPMRDS) and INRIX®. Instrumented data may be available through local traffic management centers (TMC). SHRP2 L03: *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies* provides guidance for processing both forms of data to produce performance measures.[3] Many SHRP2 project reports (L08, L04, L03, and L07) discuss data sources for the various nonrecurring components and calibration measures. Table 3 summarizes example data sources for each data type.

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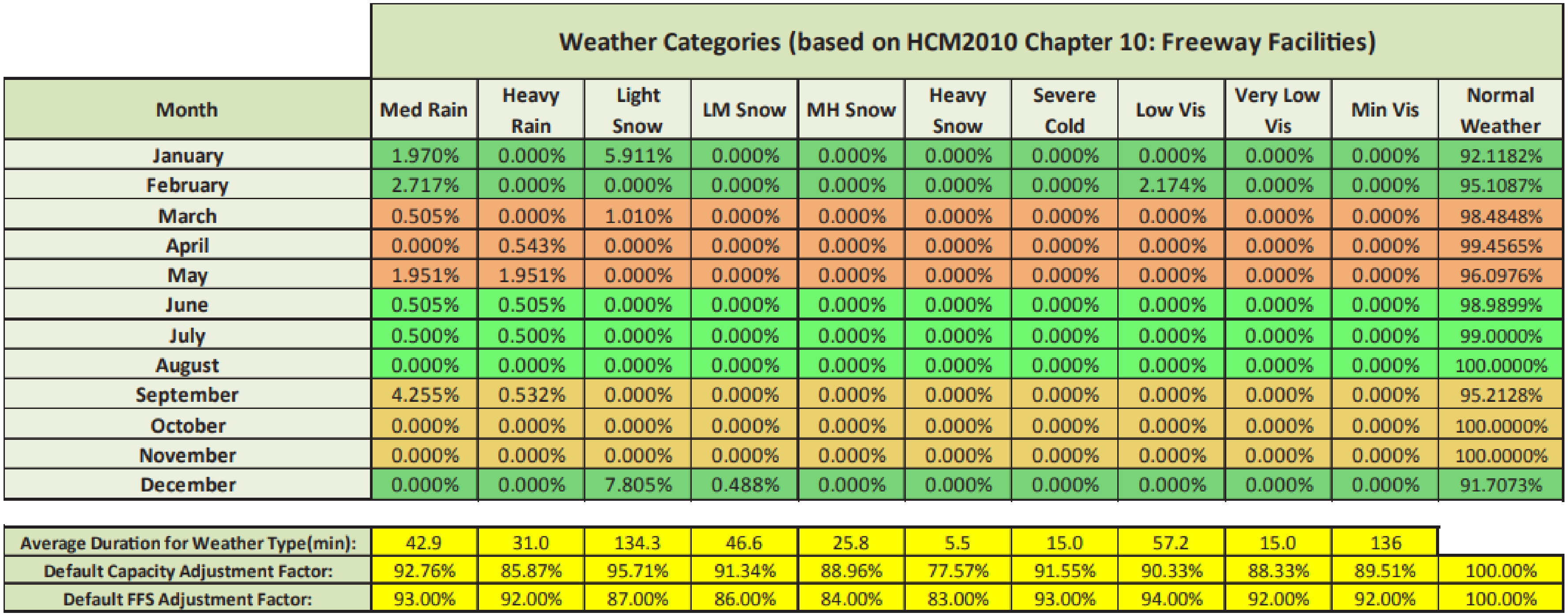
[2] National Academies of Sciences, Engineering, and Medicine, *Incorporating Travel Time Reliability into the Highway Capacity Manual*, report S2-L08-RW-1 (Washington, DC: The National Academies Press, 2014), https://doi.org/10.17226/22487.

[3] National Academies of Sciences, Engineering, and Medicine, *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*, report S2-L03-RR-1 (Washington, DC: The National Academies Press, 2012), https://doi.org/10.17226/22806.



| | Weather Categories (based on HCM2010 Chapter 10: Freeway Facilities) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Med Rain | Heavy Rain | Light Snow | LM Snow | MH Snow | Heavy Snow | Severe Cold | Low Vis | Very Low Vis | Min Vis | Normal Weather |
| January | 1.970% | 0.000% | 5.911% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 92.1182% |
| February | 2.717% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 2.174% | 0.000% | 0.000% | 95.1087% |
| March | 0.505% | 0.000% | 1.010% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 98.4848% |
| April | 0.000% | 0.543% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 99.4565% |
| May | 1.951% | 1.951% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 96.0976% |
| June | 0.505% | 0.505% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 98.9899% |
| July | 0.500% | 0.500% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 99.0000% |
| August | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 100.0000% |
| September | 4.255% | 0.532% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 95.2128% |
| October | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 100.0000% |
| November | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 100.0000% |
| December | 0.000% | 0.000% | 7.805% | 0.488% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 91.7073% |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Duration for Weather Type(min): | 42.9 | 31.0 | 134.3 | 46.6 | 25.8 | 5.5 | 15.0 | 57.2 | 15.0 | 136 | |
| Default Capacity Adjustment Factor: | 92.76% | 85.87% | 95.71% | 91.34% | 88.96% | 77.57% | 91.55% | 90.33% | 88.33% | 89.51% | 100.00% |
| Default FFS Adjustment Factor: | 93.00% | 92.00% | 87.00% | 86.00% | 84.00% | 83.00% | 93.00% | 94.00% | 92.00% | 92.00% | 100.00% |

Source: Kittleson, W., and M. Vandehey, 2014. Second Strategic Highway Research Program report S2-L08-RW-1. Transportation Research Board.

**Figure 7. Screenshot. Second Strategic Highway Research Program L08-generated weather input interface.**

**Table 3. Data sources for travel time reliability analysis.**

| Data Type | Source |
|---|---|
| **Demand** | Traffic management centers (TMC), INRIX®, National Performance Management Research Data Set, and manual counts. |
| **Incidents** | Incident logs (from TMCs, police reports, etc.) and Highway Economic Requirements System or *Highway Safety Manual* predictions. |
| **Weather** | National Climatic Data Center, National Weather Service, Clarus initiative, and private-sector weather websites. |
| **Work zones** | TMCs and local agencies. |
| **Travel times or vehicle speeds** | TMCs, INRIX, and NPMRDS |

Literature related to probe data sites (e.g., NPMRDS, INRIX, etc.) could also help in determining appropriate data inputs for the intended analysis type and preparing data for further analysis.

## CASE STUDY: INTERSTATE 94 VALUE OF A SHOULDER

### Project Description

The Wisconsin Department of Transportation (WisDOT) had been considering alternatives for reconstructing Interstate (I–94) from 70th Street to 16th Street in the Milwaukee. A segment of concern between Hawley Road and Mitchell Boulevard passes through a cemetery, severely limiting the available right of way. WisDOT had identified two alternatives for reconstructing I–94 through this segment:

- An eight-lane, at-grade alternative with 11-foot lanes and 2-foot shoulders.
- A double-deck alternative with 10 lanes and standard-width shoulders.

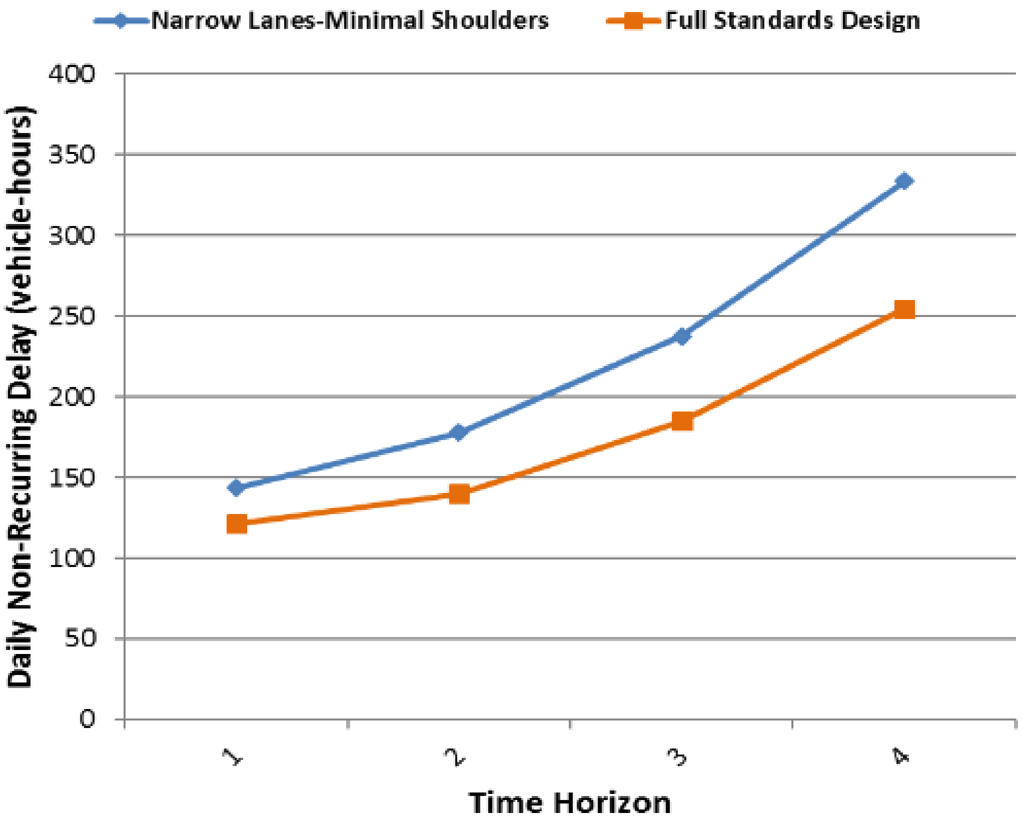
To assist in evaluating the two alternatives, nonrecurring delay (shown in figure 8) was analyzed for the I–94 east/west corridor in Milwaukee.

### Reliability Objectives

While traditional traffic analysis methods include evaluating predictable peak-period recurring delay, nonrecurring analysis methods consider elements such as inclement weather, incidents, and event traffic demands. To evaluate nonrecurring delay for the two alternatives, the analysis team used the Project L07 tool developed as part of the SHRP2 reliability focus area. This is a sketch-planning evaluation tool that considers the influences of nonrecurring conditions on travel times and delays.

### Analysis Summary

The Project L07 tool relies on several data inputs to estimate the travel time impacts of nonrecurring congestion factors. These inputs include geometry, demand, incidents, weather, events, and work zones. The study team referenced geometric layouts from the WisDOT design team for geometric inputs, L07 guidance and automated traffic recorder data for demand inputs, Enhanced Interchange Safety Analyses Tool crash computations, traffic volume information for Milwaukee Brewers game days, and L07 defaults for weather and incident inputs. The team also tested two forecast growth scenarios to determine the sensitivity of each design under higher traffic volume conditions. The study team used readily available data inputs and programmed default values to effectively evaluate the trade-offs of each design.



Source: SRF Consulting Group, Inc.

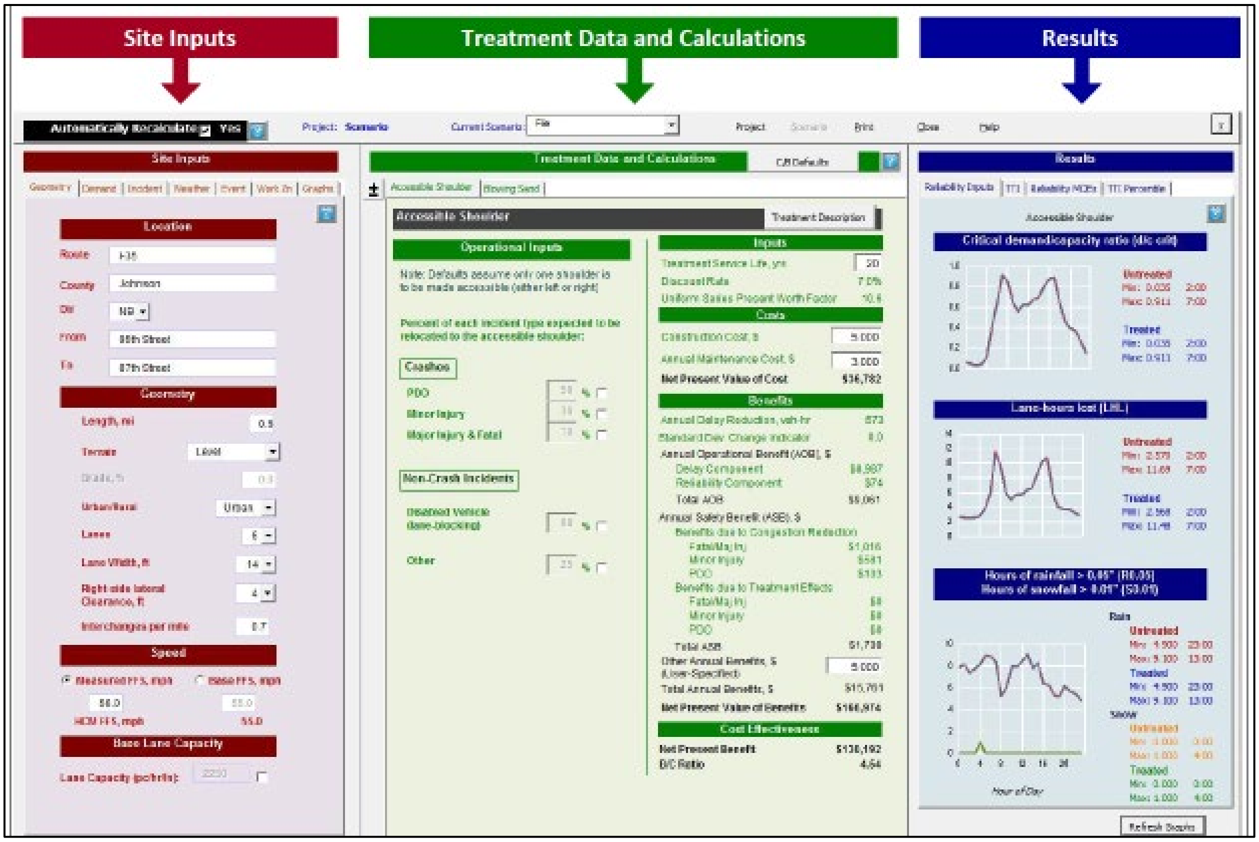
Figure 8. Graph. Nonrecurring delay hours on Interstate 94.

# CHAPTER 5. STEP 4: CREATING THE MODEL

The fourth step in the reliability analysis process involves creating the model (i.e., software data entry). Analysts may need to revisit these steps before the analysis process reaches a stable convergence. The step of creating the model may reveal previously unknown information that warrants revisiting previous steps. Examples may include:

- Discovering that the model requires data that are currently unavailable.
- Observing unexpected traffic flow behavior.
- Observing unexpected congestion levels requiring wider spatiotemporal boundaries.
- Discovering the software tool does not contain certain reliability analysis features.

Unexpected traffic flow behavior or congestion levels could potentially be resolved during step 5. However, other issues would need to be resolved by additional observation of the system, redefining the problem, and obtaining additional data for analysis. The analyst can use judgment to determine which step should come next, although the final iteration should generally involve a straight step 1–6 sequence. Data entry for creating a model may be applicable to data-poor sketch-planning models, various types of deterministic models, and various simulation models. These models are capable of predicting future conditions and/or comparative alternatives analysis. However, step 4 is generally not applicable to data analytics tools, platforms, or travel time reliability (TTR) monitoring systems (TTRMS). The level of effort involved in creating the model is often proportional to the input data requirements. For example, sketch-planning tools may involve filling out one form (see figure 9), or a single worksheet within a spreadsheet. However, many traffic analysis tools with significant input data requirements also contain features that automate certain portions of the data entry process.



Automatically Recalculate: Yes

Project: Scenario

Current Scenario: File

Route: I-35

County: Johnson

Dir: NB

From: 85th Street

To: 87th Street

Length, mi: 0.5

Terrain: Level

Grade, %: 0.3

Urban/Rural: Urban

Lanes: 6

Lane Width, ft: 14

Right-side lateral Clearance, ft: 4

Interchanges per mile: 0.7

● Measured FFS, mph: 58.0 ○ Base FFS, mph: 55.0

HCM FFS, mph: 55.0

Lane Capacity (pc/hr/ln): 2250 ☐

Note: Defaults assume only one shoulder is to be made accessible (either left or right)

Percent of each incident type expected to be relocated to the accessible shoulder:

Crashes

PDO: [illegible] % ☐

Minor Injury: [illegible] % ☐

Major Injury & Fatal: [illegible] % ☐

Non-Crash Incidents

Disabled Vehicle (lane-blocking): [illegible] % ☐

Other: [illegible] % ☐

| | |
|---|---|
| Treatment Service Life, yrs | 20 |
| Discount Rate | 7.0% |
| Uniform Series Present Worth Factor | 10.6 |
| **Costs** | |
| Construction Cost, $ | 5,000 |
| Annual Maintenance Cost, $ | 3,000 |
| **Net Present Value of Cost** | **$36,782** |
| **Benefits** | |
| Annual Delay Reduction, veh-hr | 573 |
| Standard Dev. Change Indicator | 0.0 |
| Annual Operational Benefit (AOB), $ | |
| Delay Component | $8,987 |
| Reliability Component | $74 |
| Total AOB | $9,061 |
| Annual Safety Benefit (ASB), $ | |
| Benefits due to Congestion Reduction | |
| Fatal/Maj Inj | $1,016 |
| Minor Injury | $581 |
| PDO | $133 |
| Benefits due to Treatment Effects | |
| Fatal/Maj Inj | $0 |
| Minor Injury | $0 |
| PDO | $0 |
| Total ASB | $1,730 |
| Other Annual Benefits, $ (User-Specified) | 5,000 |
| Total Annual Benefits, $ | $15,791 |
| **Net Present Value of Benefits** | **$166,974** |
| **Cost Effectiveness** | |
| **Net Present Benefit** | **$130,192** |
| B/C Ratio | 4.54 |

Critical demand/capacity ratio (d/c crit)

Untreated Min: 0.026 2:00 Max: 0.911 7:00

Treated Min: 0.026 2:00 Max: 0.911 7:00

Lane-hours lost (LHL)

Untreated Min: 2.578 2:00 Max: 11.69 7:00

Treated Min: 2.568 2:00 Max: 11.48 7:00

Rain

Untreated Min: 4.900 23:00 Max: 9.100 13:00

Treated Min: 4.900 23:00 Max: 9.100 13:00

Snow

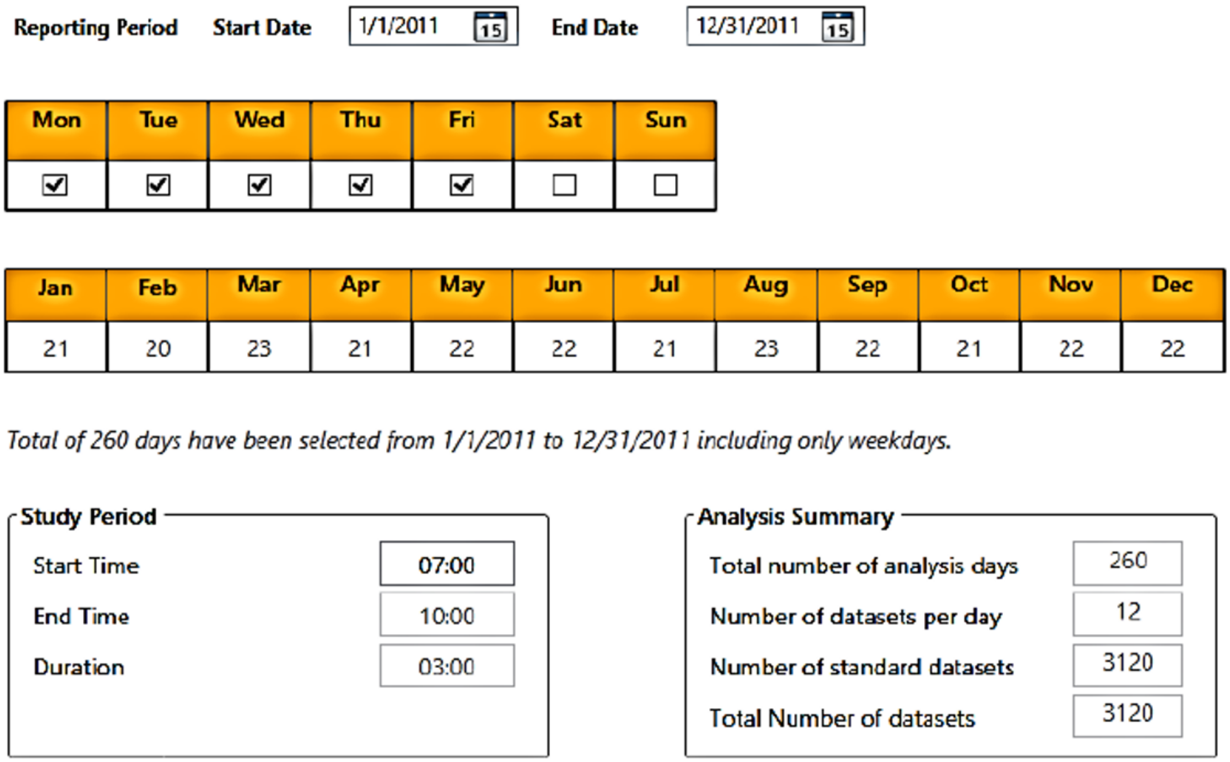
Untreated Min: 1.000 0:00 Max: 1.000 4:00

Treated Min: 1.000 0:00 Max: 1.000 4:00

Source: Potts, Ingrid, 2008. Second Strategic Highway Research Program report S2-L07-RR-1. Transportation Research Board.

**Figure 9. Screenshot. Second Strategic Highway Research Program L07 tool for analyzing geometric design effects on reliability.**

The most comprehensive tools (usually simulation models) may explicitly support all of these options. Other tools contain limitations and assumptions, such that they would only support a subset of these options. In most tools that extend beyond sketch planning, analysis of TTR would involve some amount of data entry to specify the reliability reporting period (RRP). One example of a data entry form for defining the RRP is shown in figure 10.



**Reporting Period** **Start Date** 1/1/2011 **End Date** 12/31/2011

| Mon | Tue | Wed | Thu | Fri | Sat | Sun |
|---|---|---|---|---|---|---|
| ☑ | ☑ | ☑ | ☑ | ☑ | ☐ | ☐ |

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 20 | 23 | 21 | 22 | 22 | 21 | 23 | 22 | 21 | 22 | 22 |

*Total of 260 days have been selected from 1/1/2011 to 12/31/2011 including only weekdays.*

**Study Period**

| | |
|---|---|
| Start Time | 07:00 |
| End Time | 10:00 |
| Duration | 03:00 |

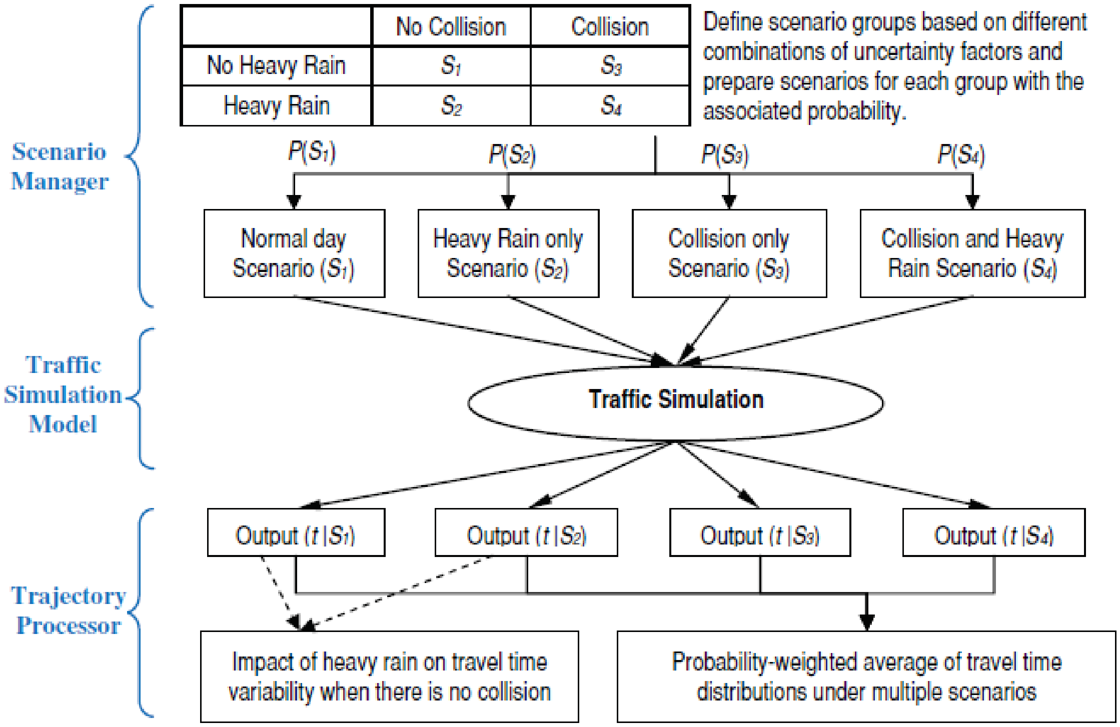
**Analysis Summary**

| | |
|---|---|
| Total number of analysis days | 260 |
| Number of datasets per day | 12 |
| Number of standard datasets | 3120 |
| Total Number of datasets | 3120 |

Source: Highway Capacity Software$^{\text{TM}}$.

**Figure 10. Screenshot. Specification of reliability reporting period.**

Many of the tools that extend beyond sketch planning provide a scenario-based modeling approach. Under this approach, the analyst performs discrete scenario evaluations to capture the effects of varying operating conditions (e.g., demand variability, incidents, weather, visibility, work zones, and special events). Figure 11 illustrates defining several scenarios to capture weather and incident effects. The core model then evaluates these scenarios toward generating a distribution of possible outcomes. In figure 11, the model generates a probability-weighted average of travel time distributions. Many output performance measures and visualizations are possible, as discussed later in step 6.



Source: Mahmassani, H., J. Kim, Y. Chen, Y. Stogios, A. Brijmohan, and P. Vovsha, 2015. Second Strategic Highway Research Program report S2-L04-RR-1. Transportation Research Board.

**Figure 11. Flowchart. Simulation of different incident and weather scenarios.**

In some cases, the tools generate individual scenario data sets. Each data set would be a copy of the original master data set, but with subtle modifications to the input data to reflect the operating condition. Dozens, or hundreds, of scenario data sets may be automatically generated as a function of seed inputs from the user (e.g., seasonal rain probability, weekly demand variability, incident probability, etc.). Monte Carlo calculations may be applied to “assign” demand, weather, and incident levels to any given data set. The Federal Highway Administration, Addendum to Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software (2019 Update), describes an alternative manual method of creating scenario data sets.

## REFERENCE MATERIALS

Other relevant resources in this area include:

- Second Strategic Highway Research Program (SHRP2) L04 workshop materials.
- The simulation Scenario Generator tool from L04.

## CASE STUDY: SHRP2 L04 – PHOENIX, AZ PILOT

The Federal Highway Administration (FHWA) report *Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools (February 2022, FHWA-HOP-20-042)* describes a SHRP2 L04 pilot test in Phoenix, Arizona for supplying scenario manager and trajectory processor tools in a real-world environment.

The SHRP2 L04 project explored how to address reliability using micro- and mesosimulation models. Sources of unreliability in the analysis included incidents, weather changes, and volume changes. The SHRP2 L04 team conducted a whole-year analysis, which generated travel time distribution profiles for four corridors ranging in length from approximately 6 miles (mi) to approximately 15 mi. The team then contrasted the simulation results with actual travel time distribution profiles observed under base-year conditions and found them to be comparable. Regarding the definition of RRP, the team defined the whole-year analysis in terms that are likely typical for most urban areas:

- Only non-holiday weekdays were included (i.e., 253 days out of a 365-day year).
- Only the afternoon/evening peak period was investigated. The evening peak usually occurs between 4 and 6 p.m. in Phoenix, Arizona. However, bottleneck queues can sometimes develop and dissipate outside of this time window. Therefore, pilot tests were based on a 4-hour weekday time window that began at 3 p.m. and ended at 7 p.m.
- All data were aggregated into 5-minute (min) time intervals so that, for each weekday, 48 separate 5-min time intervals were recorded and analyzed. A 5-min time interval was used because it is short enough to capture many of the significant sources of unreliability that can affect travel time, but also long enough to avoid overwhelming the effects from recognized sources of unreliability with the high flow rate variabilities that often occur within very short time spans.

When possible, a TTR analysis report should provide details about network data development, geometric data, traffic data, and control data as well. Table 4 shows an example of Scenario Manager incident data requirements, but the report also addressed demand and weather data inputs. The L04 Phoenix pilot report also provided a limited discussion of verification, calibration, and validation (VC&V) issues. Chapter 6 further discusses these VC&V issues.

**Table 4. Incident data input requirements for the Scenario Manager tool.**

| Attribute | Description | Source of Availability at Pilot Test Sites |
|---|---|---|
| **Start Time & End Time** | Date-time information on the onset of the event and either the termination of the event or its duration | Incident logs |
| **Latitude & Longitude** | Latitude and longitude coordinates of the event location | Incident logs and crash reports |
| **Number of Lanes Blocked** | Number of lanes blocked | Incident logs |
| **Which road side?** | The road side (left or right) of the incident | Incident logs and crash reports |

# CHAPTER 6. STEP 5: VC&V

The VC&V stage may reveal previously unknown information that warrants revisiting the previous steps. Examples may include:

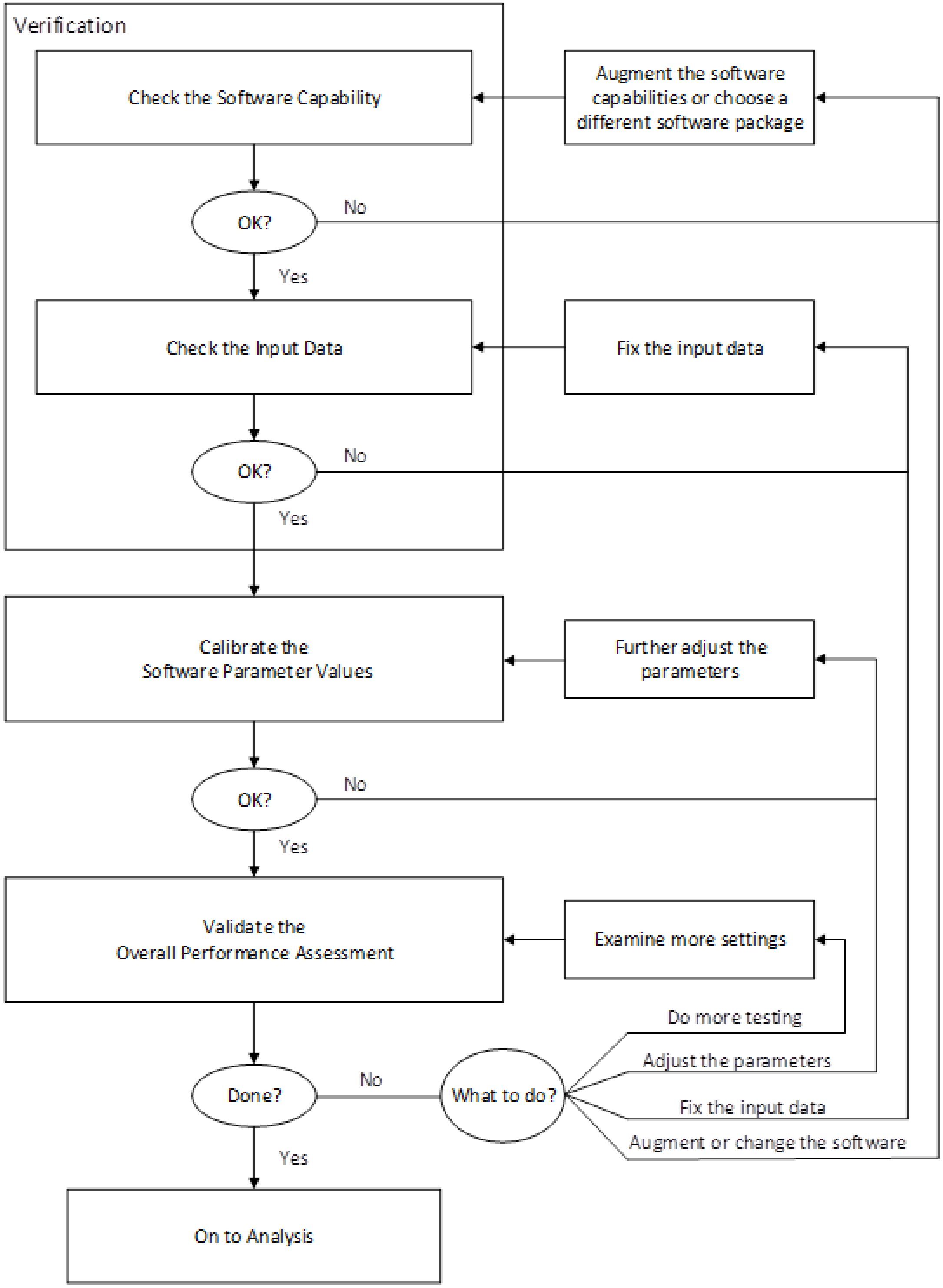
- Discovering that one or more input data values were not properly coded (e.g., a typo).
- Discovering that the software tool incorrectly models certain conditions or behaviors.
- Scrutinizing certain aspects of traffic flow more thoroughly in the field.
- Obtaining certain visualizations to confirm the VC&V process was successful.

## VC&V PROCEDURE

VC&V tasks are generally accepted to have four integrative, sequential, and iterative steps: (1a) checking that the software package can analyze the settings of interest, (1b) ensuring that the input data correctly describe those settings, (2) adjusting the model parameters so they have the best values for producing outputs consistent with field observations, and (3) checking that the model produces overall results that are defensible for the settings of interest. The first two steps pertain to verification, the third step pertains to calibration, and the fourth pertains to validation (see figure 12).

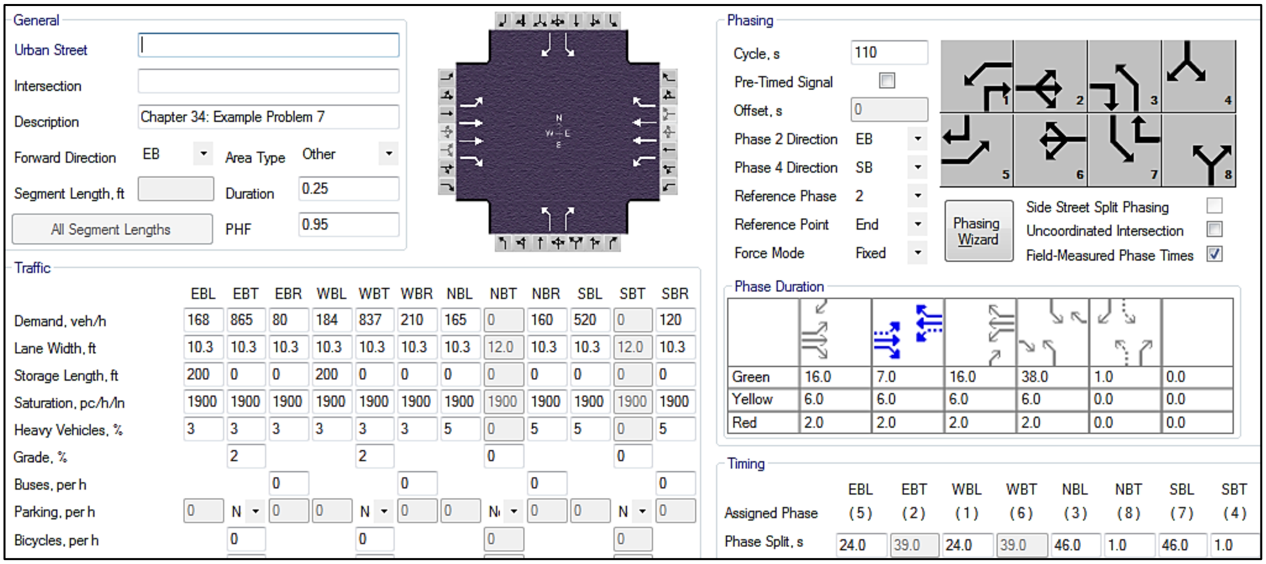
Analysts could potentially obtain necessary visualizations during step 6. However, they could resolve other issues by additional observation of the system, redefining the problem, data for analysis, and data entry to create the model. Analysts can use judgment to determine which step should come next, although the final process should generally involve a straight step 1–6 sequence.

VC&V may be applicable to data-poor sketch-planning models, deterministic models, and simulation models. These models are capable of predicting future conditions and/or comparative alternatives analysis. However, step 5 is generally not applicable to data analytics tools, platforms, or travel time reliability (TTR) monitoring systems (TTRMS). The level of effort involved in VC&V is often proportional to the input data requirements. For example, the most simple analysis tools may only offer one or two input parameters that could be considered eligible for calibration. Figure 13 illustrates this, in the sense that volume demands, signal timings, and lane configurations are inputs that are subject to verification and validation, but only the saturation flow rate would count as a calibration parameter. Beyond this, the user may have verified that the software in figure 13 can analyze a "complementary" right turn, which moves during the same signal phase as a protected left turn. In addition, the analyst could validate the Phase Duration outputs, shown below, against field data to confirm that they entered the Phase Split inputs correctly.



Source: Federal Highway Administration.

Figure 12. Flowchart. The process of VC&V.



Urban Street
Intersection
Description: Chapter 34: Example Problem 7
Forward Direction: EB
Area Type: Other
Segment Length, ft
Duration: 0.25
PHF: 0.95

| | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand, veh/h | 168 | 865 | 80 | 184 | 837 | 210 | 165 | 0 | 160 | 520 | 0 | 120 |
| Lane Width, ft | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 12.0 | 10.3 | 10.3 | 12.0 | 10.3 |
| Storage Length, ft | 200 | 0 | 0 | 200 | 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, % | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 0 | 5 | 5 | 0 | 5 |
| Grade, % | | 2 | | | 2 | | | 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 | |

Cycle, s: 110
Pre-Timed Signal ☐
Offset, s: 0
Phase 2 Direction: EB
Phase 4 Direction: SB
Reference Phase: 2
Reference Point: End
Force Mode: Fixed
Side Street Split Phasing ☐
Uncoordinated Intersection ☐
Field-Measured Phase Times ☑

| | | | | | | |
|---|---|---|---|---|---|---|
| Green | 16.0 | 7.0 | 16.0 | 38.0 | 1.0 | 0.0 |
| Yellow | 6.0 | 6.0 | 6.0 | 6.0 | 0.0 | 0.0 |
| Red | 2.0 | 2.0 | 2.0 | 2.0 | 0.0 | 0.0 |

| | EBL | EBT | WBL | WBT | NBL | NBT | SBL | SBT |
|---|---|---|---|---|---|---|---|---|
| Assigned Phase | (5) | (2) | (1) | (6) | (3) | (8) | (7) | (4) |
| Phase Split, s | 24.0 | 39.0 | 24.0 | 39.0 | 46.0 | 1.0 | 46.0 | 1.0 |

Source: Highway Capacity Software$^{TM}$.

**Figure 13. Screenshot. Analysis of signalized intersection operations.**

Beyond the relatively simple tools, a more rigorous VC&V process may be appropriate. Toledo et al. suggest four steps for the calibration effort: (1) driving behavior parameters; (2) route choice parameters; (3) traffic demands;[1] and (4) overall fine-tuning.[2] Chu et al.[3] suggest a similar sequence. Using sequence is urged here as well. Effectively, the parameters focused on facility-level phenomena are calibrated first, like those dealing with car following, lane changing, queue discharge, etc.; then route choice, like the parameters in probabilistic path choice models; then the traffic demands, i.e., the spatial and temporal variations in the origin-destination flows, to ensure that performance metrics such as delays, queue lengths, and travel times can be predicted based on the input flows; and then an overall fine-tuning. This helps ensure that analysts resolve lower-level issues before addressing system-level problems.[4] The model will then be able to predict appropriate cause-and-effect relationships at the facility level (e.g., at individual freeway bottlenecks or signalized intersections). And system-scale issues will not occur due to lower-scale miscalculations.[5]

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[1] Specifically, the temporal and spatial nature of the origin-destination flows.

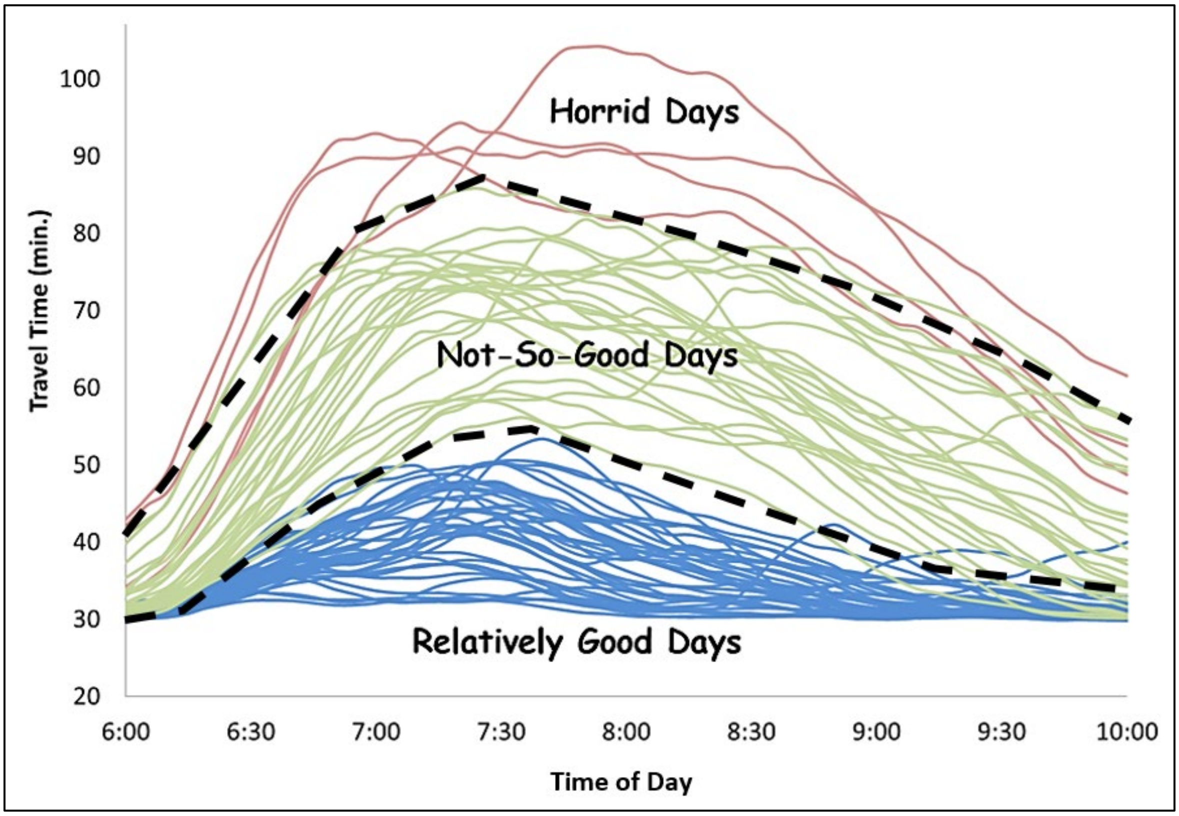
[2] Tomer Toledo, Haris Koutsopolous, Angus Davol, Moshe Ben-Akiva, Wilco Burghout, Ingmar Andréasson, Tobias Johansson, and Christen Lundin, “Calibration and Validation of Microscopic Traffic Simulation Tools: Stockholm Case Study,” *Transportation Research Record* 1831 (2003): 65–75.

[3] Lianyu Chu, Henry Liu, Jun-Seok Oh, and Will Recker, *A Calibration Procedure for Microscopic Traffic Simulation*, UCI-ITS-WP-04-2 (University of California, Irvine, 2004).

[4] The cascading effects of facility-to-facility interactions do not confound the calibration effort.

[5] A possibility is that the system-level differences are due to incongruity between the traffic demands and the observed performance metric values. That is, the origin-destination flows being used as input cannot produce the performance values observed.

Beyond the choice of calibration inputs and sequence, many analyses could benefit from a scenario-based calibration. Under this approach, the study team collects extensive field data to identify the effects of varying operating conditions (e.g., demand variability, incidents, weather, visibility, work zones, special events). Figure 14 defines three scenarios to capture these variability effects. FHWA's *Traffic Analysis Toolbox Volume III* provides more detail on the cluster analysis procedure, which can produce robust calibration outcomes.[6]



Source: Noblis.

**Figure 14. Graph. System dynamics affected by operating conditions.**

## CASE STUDY: SHRP2 L04 PORTLAND, OR PILOT

The report *Incorporating Performance Reliability Measures in Operating Planning Modeling Tools (February 2022, FHWA-HOP-20-042)* describes another SHRP2 L04 pilot, this one in Portland, Oregon. Sources of unreliability in the SHRP2 L04 Portland analysis included incidents, weather changes, and volume changes. The L04 team conducted a whole-year analysis, in which travel time distribution profiles were generated for four corridors ranging in length from approximately 6 mi to approximately 15 mi. The team then contrasted the simulation

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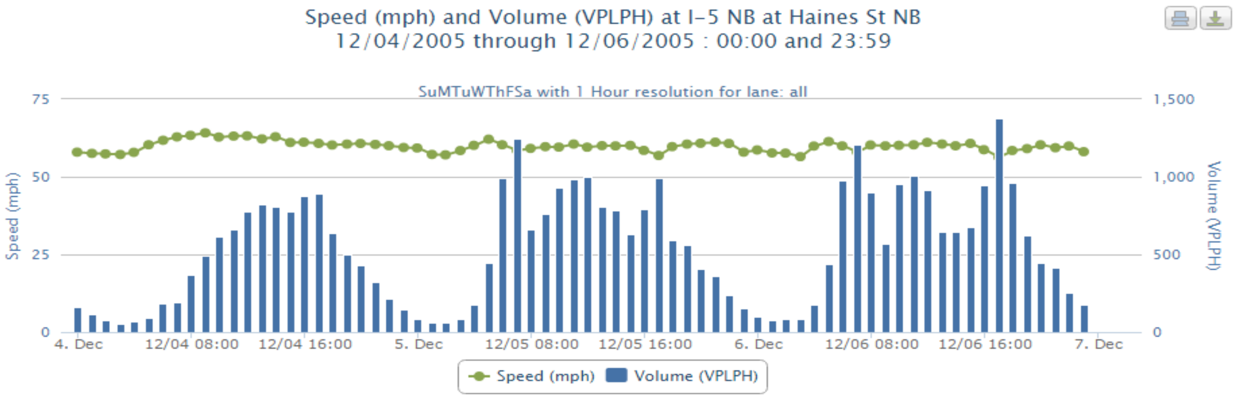
[6] Wunderlich, Karl E., Meenakshy Vasudevan, and Peiwei Wang. *TAT Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software 2019 Update to the 2004 Version*. No. FHWA-HOP-18-036. United States. Federal Highway Administration, 2019.

results with actual travel time distribution profiles observed under base-year conditions and found them to be comparable.

Two data sources were used in the SHRP2 L04 Portland pilot to obtain volume and verification data. The Portland Archival Listing is a unique online database developed, maintained, and housed at Portland State University. Oregon Department of Transportation has also licensed data from Inrix™, which is a third-party vendor of real-time and historical travel time data. Weekday PM peak-hour traffic counts were obtained from the Portland Archival Listing automatic traffic recorder station data archive at locations nearest to the boundaries of the Portland Southwest Corridor sub-regional model. These counts were evaluated to determine average 5-min flow rates over the course of the 4-hr weekday study period between 3 PM and 7 PM. Figure 15 provides an example of the available Portland State University Count Station traffic volume data.

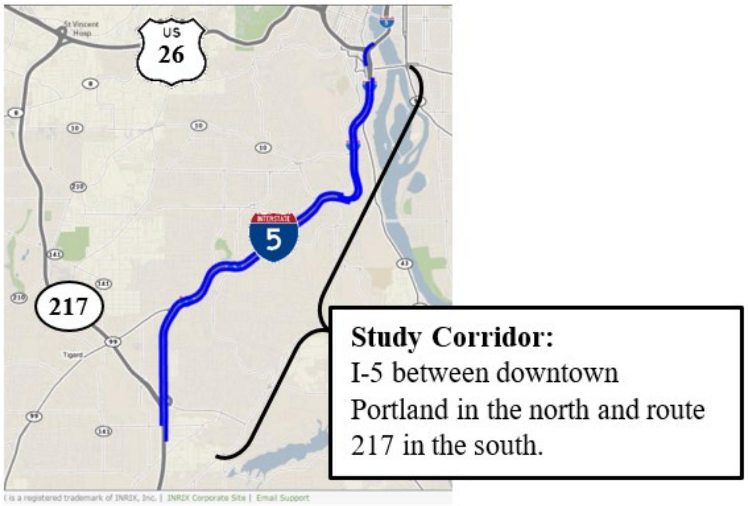


Source: Mahmassani, H., J. Kim, Y. Chen, Y. Stogios, A. Brijmohan, and P. Vovsha, 2015. Second Strategic Highway Research Program Report S2-L04-RR-1. Transportation Research Board.

**Figure 15. Graph. Portland Archival Listing count station traffic volumes, Dec. 4-6, 2014.**

For verification purposes, INRIX data sets were available to determine corridor-level speeds and travel times. Portland Metro has access to INRIX data for multiple years, by month and day of the week (e.g., Monday, Tuesday, Wednesday, Thursday, and Friday). All data are reported at the traffic management center (TMC)-level, which provides excellent resolution for freeways. Specifically, INRIX has split TMCs so that they break at each decision point (i.e., access and egress points) along limited-access roadways. On arterials, the resolution is coarser, with TMCs often representing multiple miles along an arterial and quite possibly many intersections. While the coarse arterial resolution can make it difficult to pinpoint exact points of congestion along the TMC, prior analysis has found that the INRIX-derived average travel times through arterial corridors are reasonable.

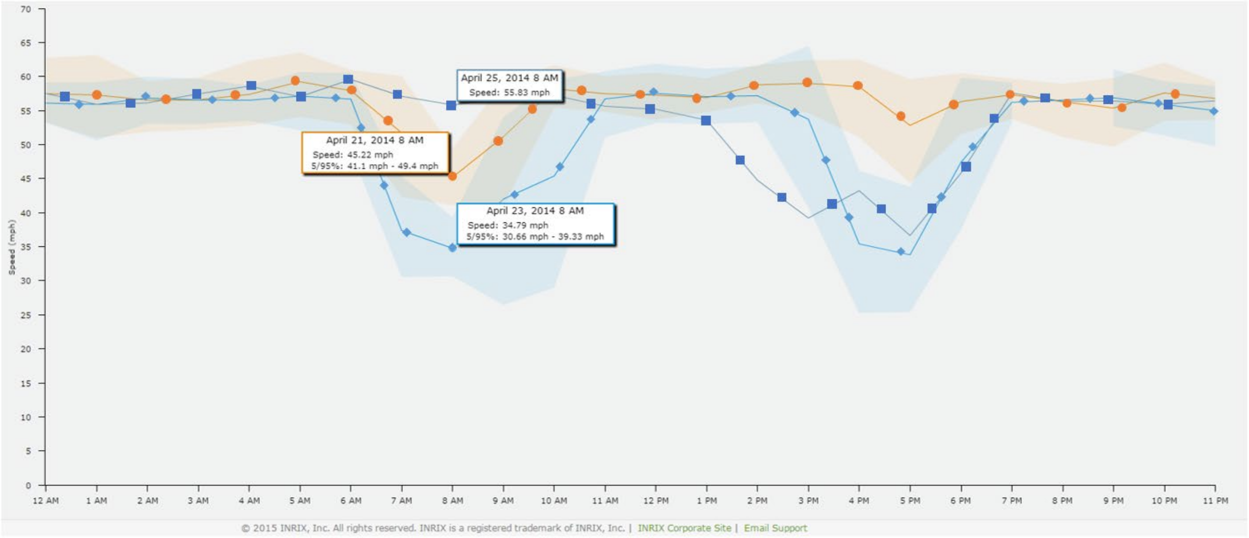
INRIX data contain a rich set of statistical attributes, such as averages, standard deviations, and percentile breakdowns (10th, 20th … 80th, 90th, etc.). This enables one to determine ranges of travel times through a corridor (i.e., travel time variability). Figure 16 illustrates the INRIX coverage area in the project area along Interstate 5 (I–5), and figure 17 shows example INRIX travel time calculations along I–5 in the southwest corridor project area.



**Study Corridor:**
I-5 between downtown Portland in the north and route 217 in the south.

Source: Mahmassani, H., J. Kim, Y. Chen, Y. Stogios, A. Brijmohan, and P. Vovsha, 2015. Second Strategic Highway Research Program report S2-L04-RR-1. Transportation Research Board.

**Figure 16. Map. Example INRIX® data set coverage segments.**



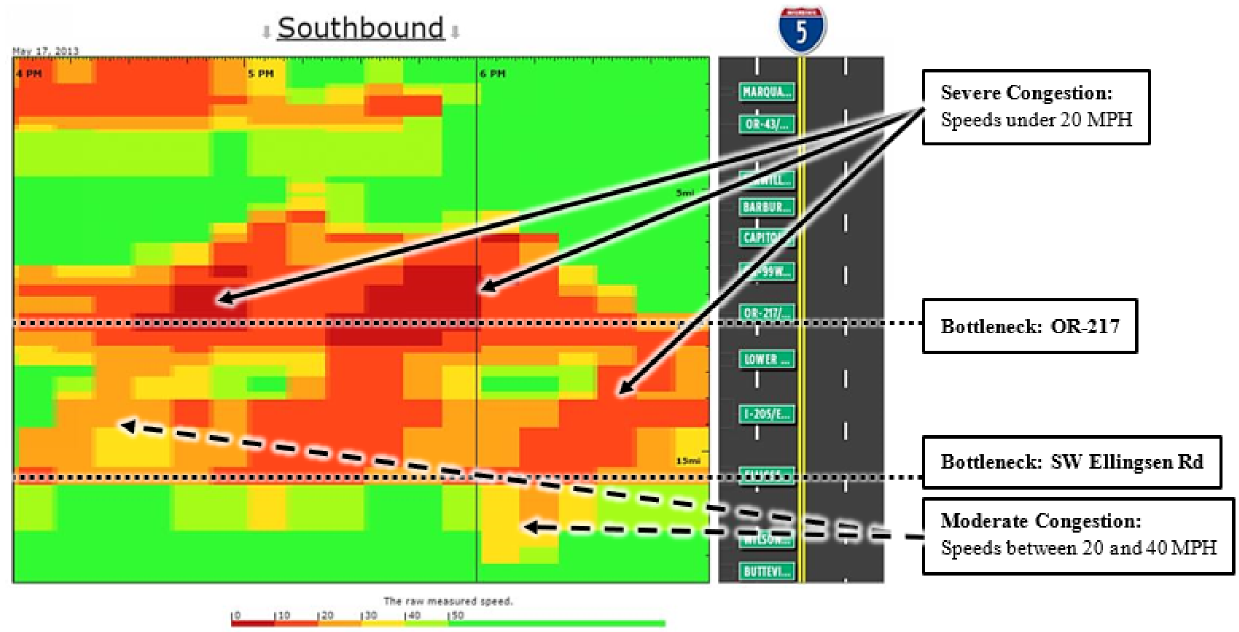
Source: Mahmassani, H., J. Kim, Y. Chen, Y. Stogios, A. Brijmohan, and P. Vovsha, 2015. Second Strategic Highway Research Program report S2-L04-RR-1. Transportation Research Board.

**Figure 17. Graph. Example INRIX® running speed for average, 5th, and 95th percentile conditions, April 21, 23, and 25, 2014.**

Finally, INRIX can produce congestion heat maps, as figure 18 shows. During this pilot test, these maps proved useful in identifying the origin, duration, and extent of congestion within a corridor.

An important finding from this project is that TTR within a corridor must be determined through a regional or large area analysis, and not through a subarea study with boundaries narrowly drawn around the subject corridor. This is because in nearly all urban areas today, corridor traffic volumes and travel time characteristics are frequently affected by congestion and incidents in other parts of the region that can be far-removed from the corridor itself. These effects come from not only queue backups, but also vehicle path diversions affecting volume and speed in the subject corridor.

In Portland's southwest corridor pilot test site, observed congestion and reduced travel times within the corridor were frequently found to be caused by incidents and bottlenecks located well outside the corridor's boundaries. This can be seen in figure 18, where it is clear that congestion and queueing experienced inside the corridor had been initiated south of the corridor's southern boundary, which is approximately at the Oregon Route 217 interchange.



**Severe Congestion:** Speeds under 20 MPH

**Bottleneck: OR-217**

**Bottleneck: SW Ellingsen Rd**

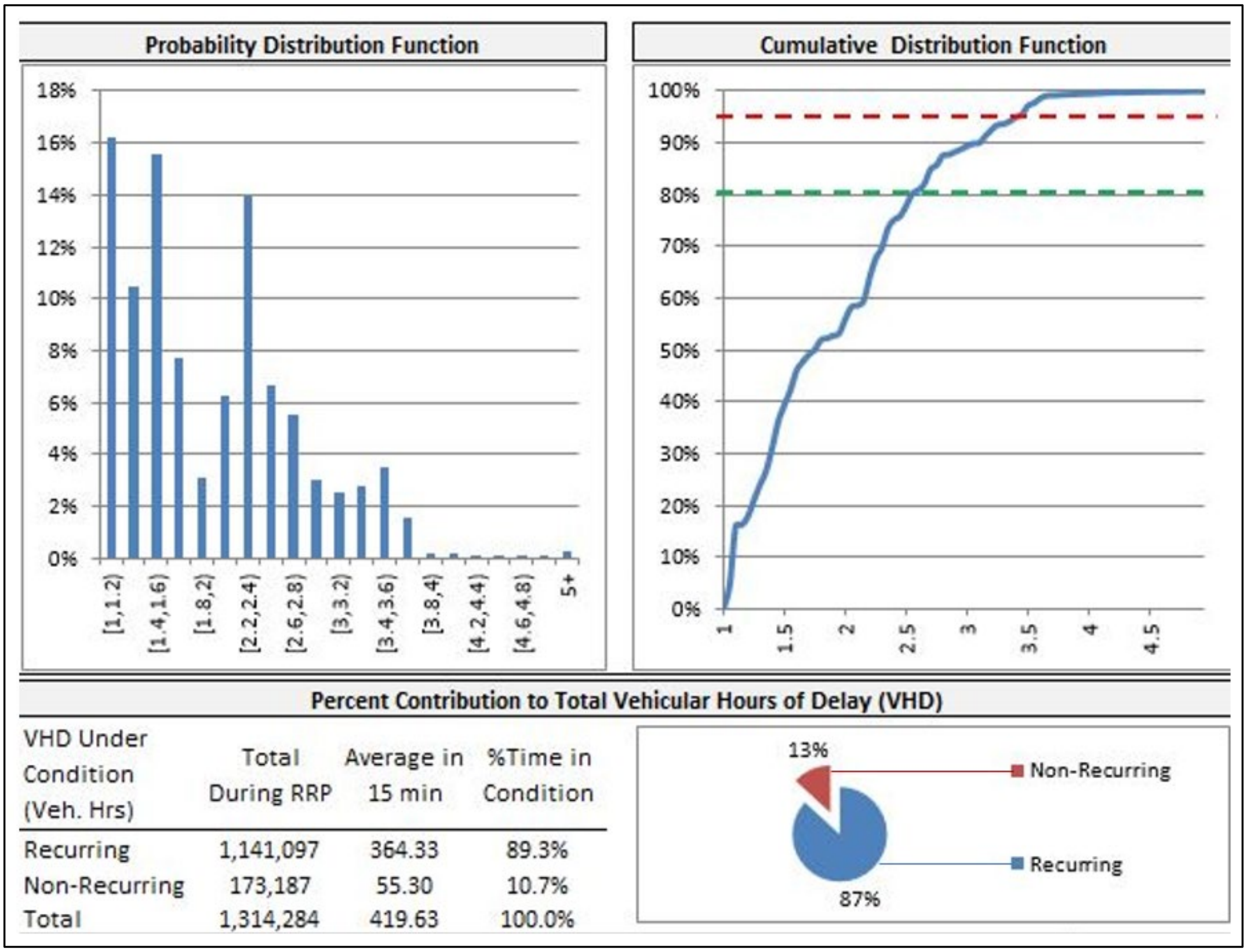
**Moderate Congestion:** Speeds between 20 and 40 MPH

Source: Mahmassani, H., J. Kim, Y. Chen, Y. Stogios, A. Brijmohan, and P. Vovsha, 2015. Second Strategic Highway Research Program report S2-L04-RR-1. Transportation Research Board.

**Figure 18. Screenshot. Travel time heat map for Interstate 5 southbound, 4–7 p.m., weekday.**

# CHAPTER 7. STEP 6: DATA PROCESSING, ANALYSIS, AND PRESENTATION

The final step in the reliability analysis is using the outputs from preceding steps to develop useful study results. The effort needed to derive reliability results from analysis outputs can vary based on the analysis type and tool used. For example, the second Strategic Highway Research Program (SHRP2) Project L04 guidance describes how analysts can use the Trajectory Processor tool to automatically process simulation outputs and develop illustrative results. Additionally, SHRP2 Project L08 produces tables and figures that highlight key results (see figure 19), and exports raw analysis data for users to produce their own visualizations.



Percent Contribution to Total Vehicular Hours of Delay (VHD)

| VHD Under Condition (Veh. Hrs) | Total During RRP | Average in 15 min | %Time in Condition |
|---|---|---|---|
| Recurring | 1,141,097 | 364.33 | 89.3% |
| Non-Recurring | 173,187 | 55.30 | 10.7% |
| Total | 1,314,284 | 419.63 | 100.0% |

Source: Kittelson, W., and M. Vandehey, 2014. Second Strategic Highway Research Program report S2-L08-RW-1. Transportation Research Board.

**Figure 19. Screenshot. Second Strategic Highway Research Program L08 FREeway EVALuation (FREEVAL) results.**

When analysts need to produce results from raw output, they can apply frequency weighting factors to scenarios based on known or expected proportions. The resulting distributions can help generate reliability performance measures (e.g., travel time index, 85th percentile day, and buffer index) and accompanying visualizations (e.g., scatterplots, histograms, probability density functions, and cumulative density functions) that reflect the reliability analysis period. More information on this procedure is available in the *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* update.[1]

A common hurdle in travel time reliability (TTR) analysis is producing effective and understandable results from outputs of a highly complex analysis. The Transportation Research Board's SHRP2 L03 Report, *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*, lists the following TTR measures[2]:

- Mean, standard deviation, median, mode, minimum, and percentiles (10th, 80th, 95th, and 99th) for both the travel time and the travel time index.
- Buffer indices (based on mean and median), planning time index, skew statistic, and misery index.
- On-time percentages for thresholds of median plus 10 percent and median plus 25 percent and average speeds of 30, 45, and 50 miles per hour.

Examples of effective methods of measuring TTR are 90th or 95th percentile travel times, buffer index, and planning time index[3] because they directly relate to a typical commuter's travel experiences. In other words, 95th percentile travel time is representative of the worst condition experienced over a monthly commuting period, on average (see figure 20). Analysts have used several statistical measures, such as standard deviation and coefficient of variation, to quantify TTR. However, they are not easy for a nontechnical audience to understand and could be less effective for communicating results. Additional information on definitions, uses, and computation methods for different reliability performance measures is available in the *Traffic Analysis Toolbox Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness* update.[4]

The analyst can ensure the reliability results represent the range of scenarios and corresponding operations they had evaluated. Reducing the output data to a singular performance measure can decrease the inclusiveness of results. Instead, analysts can aspire to present the distribution of data in a few comprehensive visualizations. Figure 21 illustrates how one figure can summarize numerous data points. This annual travel time heat map enables the viewer to draw several

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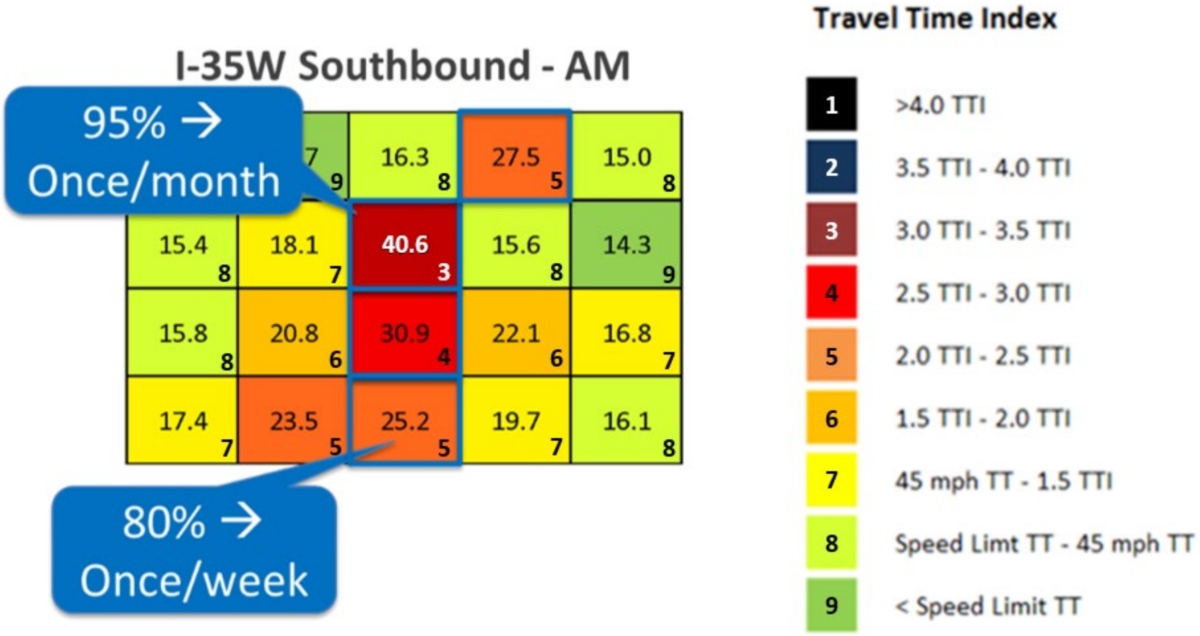
[1] Wunderlich, Karl E., Meenakshy Vasudevan, and Peiwei Wang. *TAT Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software 2019 Update to the 2004 Version*. No. FHWA-HOP-18-036. United States. Federal Highway Administration, 2019.

[2] Margiotta, R., T. Lomax, M. Hallenbeck, R. Dowling, A. Skabardonis, and S. Turner. "SHRP 2 report s2-l03-rr-1: Analytical procedures for determining the impacts of reliability mitigation strategies." *Transportation Research Board of the National Academies, Washington, DC* (2010).

[3] Federal Highway Administration, *Travel Time Reliability: Making it There on Time, All the Time*, FHWA-HOP-06-070, https://ops.fhwa.dot.gov/publications/tt_reliability/brochure/ttr_brochure.pdf.

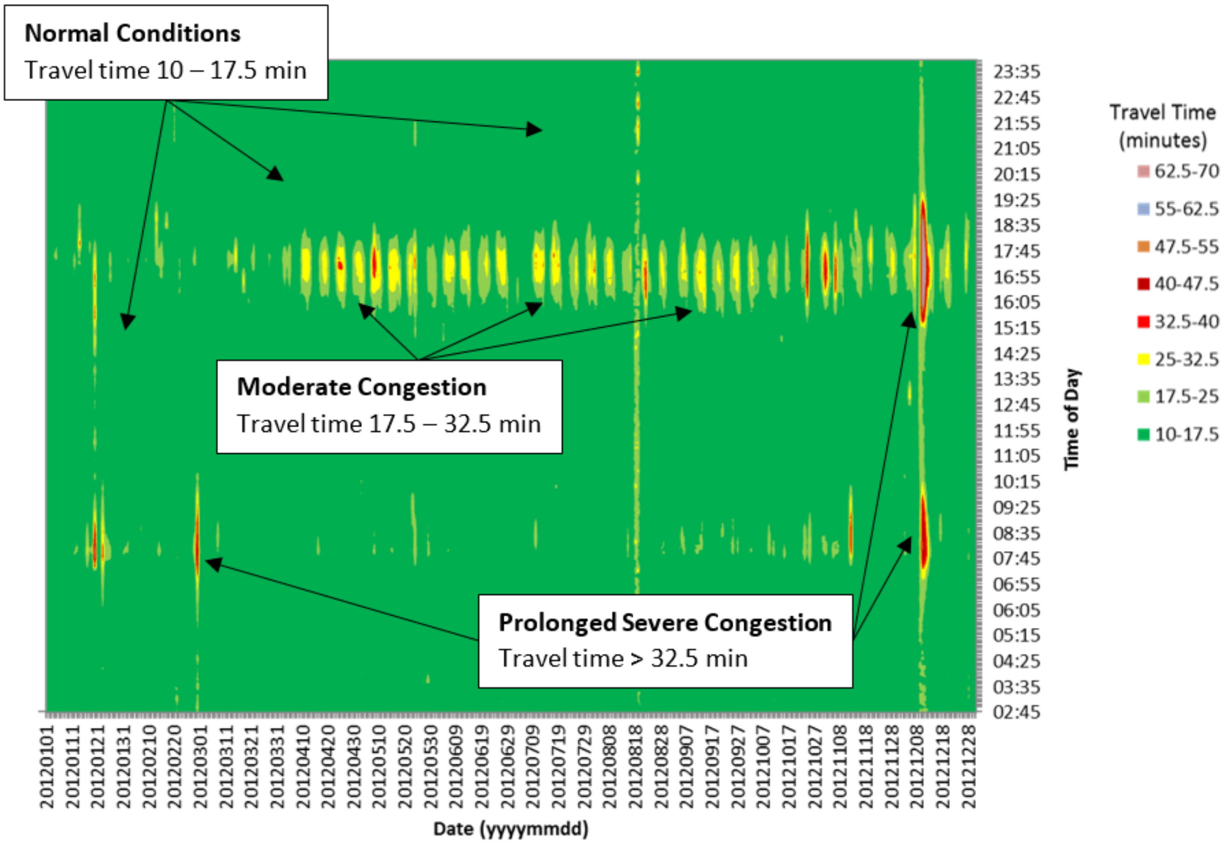
[4] Dowling, R. "Traffic Analysis Toolbox Volume VI: Definition." Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness: Federal Highway Administration Report FHWA-HOP-08-054 (2007).

conclusions on corridor traffic performance (e.g., duration and severity of recurring congestion, frequency, and severity of nonrecurring events, etc.). Although this example used existing loop detector data to develop the annual travel time report, similar methods can illustrate predictive travel time performance when applied to traffic analysis tool output. User guides associated with travel time monitoring provide analysts with methods for producing useful illustrations and performance measures.



Source: SRF Consulting Group, Inc.

**Figure 20. Illustration. Travel time calendar visualization.**



**Normal Conditions**
Travel time 10 – 17.5 min

**Moderate Congestion**
Travel time 17.5 – 32.5 min

**Prolonged Severe Congestion**
Travel time > 32.5 min

Source: SRF Consulting Group, Inc.

**Figure 21. Heat map. Annual travel time.**

## REFERENCE MATERIALS

An additional resource for developing results and visualizations from data is:

- Higgins, Nathan, Ronald Basile, Samuel Van Hecke, Joseph Zissman, and Scott Gilkeson. "*Data visualization methods for transportation agencies*". No. NCHRP Project 08-36, Task 128. 2016.

## CASE STUDY: INTERSTATE 95 IN BROWARD COUNTY

### Project Description

The objective of this project was to examine the use of TTR predictive tools in the Florida Department of Transportation's project development and environmental process studies. An additional goal was to develop a methodology and framework for using TTR measures in alternatives analyses. This project demonstrated how TTR analyses can be performed by post-processing results from microsimulation tools with theoretical extensions developed under

SHRP2 Project L08: *Incorporating Travel Time Reliability into the Highway Capacity Manual.*[5] The key study area was the Interstate 95 (I–95) corridor from north of Oakland Park Boulevard (State Route 816) to south of Glades Road (State Route 808).

### Reliability Objectives

The proposed methodology and framework for using TTR in evaluating project alternatives used microsimulation analysis results to calibrate a stand-alone *Highway Capacity Manual* reliability model. Using the calibrated model, the analysts then applied *Highway Capacity Manual,* 6th ed., methods to predict the TTR for each alternative.

### Analysis Summary

The cumulative distribution functions for each of the three scenarios are illustrated in figure 22. The resulting travel time index distribution for the year 2040 build scenario is similar to that of the existing (2011) scenario. The year 2040 no-build scenario, however, results in a travel time index almost double that of the build scenario. The average vehicle would be expected to experience a travel time approximately four times longer than the free-flow travel time during the PM peak period. The case study demonstrated the successful calibration of a TTR analysis tool. As part of the reliability evaluation effort, useful performance measures and graphics were developed to compare alternatives.

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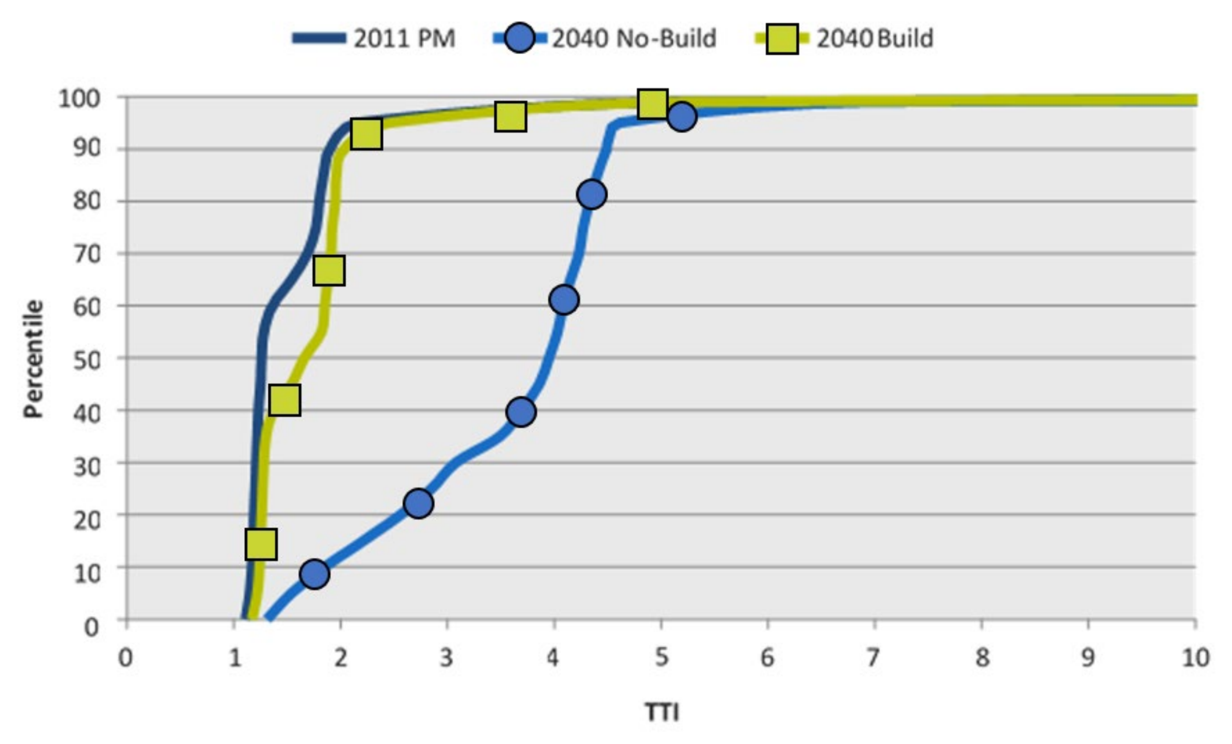
[5] Kittelson, W., and M. Vandehey. "SHRP 2 Project L08: Incorporation of Travel Time Reliability into the HCM." *Transportation Research Board of the National Academies, Washington, DC* (2013).



Source: Kittelson & Associates, Inc.

**Figure 22. Graph. Travel time index cumulative density curve for Interstate 95.**

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