white paper

MAP-21 Proposed Measures for Congestion, Reliability, and Freight

Step-by-Step Calculation Procedures

prepared for

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1.1 GETTING STARTED

OVERVIEW OF PROCEDURES

This document contains step-by-step procedures for calculating seven of the performance measures outlined in the proposed Part 490 – National Performance Management Measures[1]. As such, this document is intended to be user-friendly draft guidance that contains suggested approaches for data processing and measure calculation. This document is intended to assist members of the public in understanding the proposals in the Part 490 notice of proposed rulemaking (NPRM). Final guidance will be developed for the eventual final rule.

The measures addressed in this document are:

1. Percent of the Interstate System providing for Reliable Travel Times (section 490.507(a)(1))
2. Percent of the non-Interstate NHS providing for Reliable Travel Times (section 490.507(a)(2)).
3. Percent of the Interstate System where Peak Hour Travel Times meet expectations (section 490.507(b)(1))
4. Percent of non-Interstate NHS where Peak Hour Travel Times meet expectations (section 490.507(b)(2))
5. Percent of the Interstate System Mileage providing for Reliable Truck Travel Times (section 490.607(a))
6. Percent of the Interstate System Mileage Uncongested (section 490.607(b))
7. Annual Hours of Excessive Delay Per Capita (section 490.707)

[1] The NPRM was published April 22, 2016.
https://www.regulations.gov/#!documentDetail;D=FHWA_FRDOC_0001-1294

DATA ANALYSIS NEEDS

Calculating the performance measures outlined in the proposed Part 490 would require more than a spreadsheet on a basic desktop computer. Instead, more powerful computer software and hardware would be needed, as well as a technical analyst with intermediate skills in data management, integration, and summary. This section provides an overview of the requirements for software, hardware, and technical skills.

The foundational data for the National Performance Management Measures is the National Performance Management Research Data Set (NPMRDS), which is a comma-delimited text file that can reach 3 gigabytes (for the largest states) for each month when fully uncompressed[2]. To calculate the proposed performance measures, multiple months of travel time data within the NPMRDS would have to be integrated with supplemental data contained in other databases, some of which are likely to be geospatially-referenced within geographic information systems (GIS). After data integration and combining multiple disparate data sources, the resulting data sets could reach 1 terabyte for a large state. Several different data processing steps would then be required before performance measures can be calculated.

Because of the size and complexity of the data integration and processing, the following should be considered:

- **Software:** Relational database management system (e.g., Oracle, SQL Server, etc.) and/or other data management/processing software (e.g., Python, SAS, SPSS, R, etc.) capable of routinely storing and processing at least 5 to 10 terabytes of data. Ideally, it includes a programming/scripting language with pre-defined data processing routines for those that are commonly used. GIS software may also be needed to combine data sets that have different location referencing.
- **Hardware:** Ideally, a server (with appropriate disk redundancy and system backup) dedicated to storing and processing very large data sets and capable of supporting the selected software. In some cases, a powerful desktop computer (paired with the appropriate software) can be used for the performance measure calculations if slower processing time is acceptable.
- **Technical Skills:** Once the suggested computer hardware and software are ready for use (which may require cooperation with your agency's information technology division), a technical analyst with intermediate skills in data management and integration will be needed to implement the performance measure calculations. The technical analyst should be proficient with the selected software, as well as integrating multiple data sets across different software platforms.

[2] Maximum file size at time of NPRM publication.

2.0 Overview of Required Measures and Supporting Data

Table 2.1 summarizes the performance management measures included in the proposed Part 490 regulations. Travel times from the NPMRDS are the foundation for all measures, but several other attributes from different data sources are also required. Table 2.2 summarizes the attributes required for measure calculation, their source and other relevant information.

Table 2.1 Summary of Proposed Part 490 Performance Measures and Required Data Attributes

Measure	Required Attributes for Measure Calculation
Percent of the Interstate System providing for Reliable Travel Times (§490.507)	• Travel time – all vehicles • Reporting Segment length • Posted speed limit • Highway type designation
Percent of the non-Interstate NHS providing for Reliable Travel Times (§490.507)	• Travel time – all vehicles • Reporting Segment length • Posted speed limit • Highway type designation
Percent of the Interstate System where peak hour travel times meet expectations (§490.507)	• Travel time – all vehicles • Desired Peak Period Travel Time • Reporting Segment length • Highway type designation • Urbanized area boundaries[3]
Percent of the non-Interstate NHS where peak hour travel times meet expectations (§490.507)	• Travel time – all vehicles • Desired Peak Period Travel Time • Reporting Segment length • Highway type designation • Urbanized area boundaries[4]
Percent of the Interstate System Mileage providing for Reliable Truck Travel Times (§490.607)	• Travel time – freight vehicles • Travel time – all vehicles • Reporting Segment length

[3] The NPRM proposes the most recent U.S. Decennial Census designated urbanized area boundaries at the start of a performance period or adjusted U.S. Decennial Census boundary approved by FHWA and submitted in HPMS at the start of a performance period.

[4] Ibid.

Measure	Required Attributes for Measure Calculation
	• Posted speed limit • Highway type designation
Percent of the Interstate System Mileage Uncongested (§490.607)	• Travel time – freight vehicles • Travel time – all vehicles • Reporting Segment length • Posted speed limit • Highway type designation
Annual Hours of Excessive Delay Per Capita (§490.707)	• Travel time – all vehicles • Reporting Segment length • Traffic volume • Highway type designation • Urbanized area population[5] • Urbanized area boundaries[6]

Table 2.2 Summary of Data Attributes Used in Proposed Part 490 Performance Measures

Attribute	Source	Purpose in Measure Calculation
Travel time – all vehicles	NPMRDS	Used in several proposed Part 490 measures. Also used to estimate missing travel time values for freight vehicles.
Travel time – freight vehicles	NPMRDS	Used in proposed Part 490 freight movement measures.
Desired Peak Period Travel Time	Defined by State DOT and MPO	Used in proposed Part 490 peak hour travel time measure
Reporting Segment length	NPMRDS	Used to calculate speed values from travel time for outlier data removal; also used to calculate imputed travel time values from posted speed limit.
Posted speed limit	State DOT roadway inventory	Used to impute missing travel time values in NPMRDS for selected metrics.
Traffic volume	State DOT roadway inventory or traffic database	Used to calculate Total Excessive Delay (in vehicle-hours) in the measure of Annual Hours of Excessive Delay Per Capita.
Highway type designation	Inferred from NPMRDS, or State DOT roadway inventory	Used to summarize performance measures into 2 categories: 1) Interstate System; and, 2) non-

[5] Ibid.

[6] Ibid.

Attribute	Source	Purpose in Measure Calculation
		Interstate NHS.
Urbanized area population[7]	U.S. Census	Used to determine requirement to report peak hour travel time measure and excessive delay measure; also used to calculate excessive delay per capita measure
Urbanized area boundaries[8]	U.S. Census or State DOT roadway inventory	Used to determine which travel time segments to include in peak hour travel time measure and excessive delay measure.

[7] Ibid.

[8] Ibid.

3.0 Gathering Data

Before the actual measure calculations can start, the relevant data should be downloaded, assembled/gathered, and prepared. This section outlines the steps for gathering all of the required data (as indicated in Table 2.1 and Table 2.2) for performance measure calculation, whereas the next section outlines the steps for integrating all of the different data sources into a single data set that can then be used directly for performance measure calculation.

This section is organized around the data attributes shown in Table 2.2.

3.1 TRAVEL TIME

Travel times would come from a Travel Time Data Set, which is either the NPMRDS or an equivalent data set (§490.103(e)). The instructions here will refer only to downloading travel times from NPMRDS. Agencies that use an equivalent data set should refer to their data provider's specific instructions, and the proposed requirements for equivalent data set in section 490.103(e).

First, agencies (State DOT or MPO) must request access to the NPMRDS by sending an email to heretraffic.nhsdata@here.com. Be sure to include your agency name and contact information. NPMRDS access can be provided to other entities (e.g., consultants, universities) that are acting on behalf of a State DOT or MPO; however, the State DOT or MPO representative should make the initial request for NPMRDS data access. Once an agency is granted access to NPMRDS, they will be sent instructions on how to access and download the data.

The NPMRDS data will be downloaded as a compressed (*.zip archive) comma-separated value (csv) text file for each month. Users will need to download all 12 monthly data files that are required for the year(s) of interest, as all proposed Part 490 performance measures are based on a full calendar year of travel time data.

It should be noted that the NPMRDS travel time data set includes travel times for 3 different vehicle categories: 1) all vehicles; 2) passenger vehicles; and 3) freight vehicles. The performance measures proposed in Part 490 require the travel time for two separate vehicle categories: all vehicles and freight vehicles.

3.2 DESIRED PEAK PERIOD TRAVEL TIME

As proposed in section 490.103(g), the Desired Peak Period Travel Time is "the desired travel time on a specific reporting segment during the peak period that is defined in coordination between the State DOT and MPO." In most cases, it is anticipated that the State DOT and MPO would define a desired travel speed for multiple reporting segments and then would use the Travel Time Segment

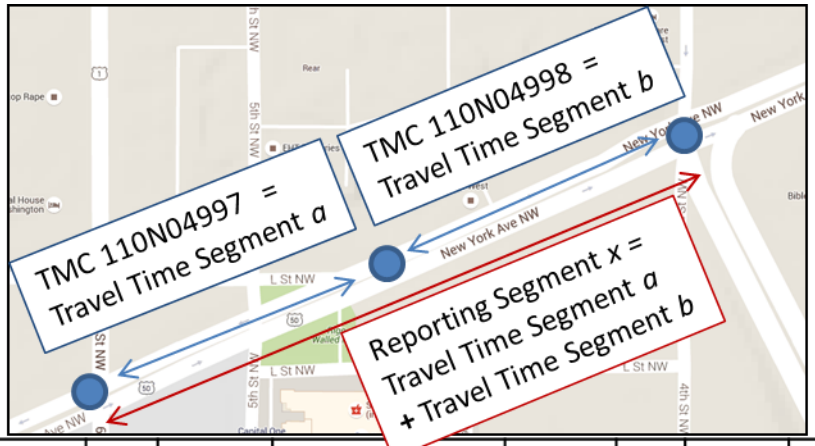
length to calculate the Desired Peak Period Travel time for individual reporting segments using this equation:

$$\frac{Desired\ Peak\ Period}{Travel\ Time\ (seconds)} = \frac{Travel\ Time\ Segment\ Length\ (miles)}{Desired\ Travel\ Speed\ (miles/hour)} \times \frac{3{,}600\ seconds}{1\ hour}$$

3.3 REPORTING SEGMENT LENGTH

In Section 490.101, the proposed definition of a Reporting Segment is "the length of roadway that the State DOT and MPOs define for metric calculation and reporting and is comprised of one or more Travel Time Segments". Section 490.101 proposes to define Travel Time Segment as "a contiguous stretch of the NHS for which average travel time data are summarized in the Travel Time Data Set." Therefore, the Travel Time Segment would be equivalent to the TMC paths that are uniquely identified in the NPMRDS travel time data set. Further, Section 490.103(f) provides the option to combine one or more contiguous Travel Time Segments into a Reporting Segment provided that the length does not exceed ½ mile in urbanized areas or 10 miles in non-urbanized areas, unless an individual Travel Time Segment is longer (see Figure 3.1). In most cases, however, it is likely that a Reporting Segment would be the same as a Travel Time Segment, which would be a single unique directional TMC path.

Figure 3.1 Relationship between Travel Time Segments and Reporting Segments



TMC	Admin Level 1	Admin Level 2	Admin Level 3	Distance	Road Number	Road Name	Latitude	Longitude
110N04997	USA	District of Columbia	Washington DC	0.10858	US-50		38.90358	-77.01991
110N04998	USA	District of Columbia	Washington DC	0.11158	US-50		38.90422	-77.01807

Note that combining more than one *Travel Time Segment* into a *Reporting Segment is* not required, just an option

Within NPMRDS, the Travel Time Segment length is provided separately from the travel time data file, in a file referred to as a "Static File." This NPMRDS Static File accompanies each monthly travel time data file, and includes other Travel Time Segment attributes (e.g., road name and number, travel direction, location, etc.). The Static File is updated periodically, so users should ensure that they use the version of the Static File that corresponds to the month of travel time data they are processing.

NPMRDS does provide more detailed data specifications for attributes contained in the Static File. Agencies that use an equivalent data set should refer to their data provider's specific instructions for how to obtain Travel Time Segment length.

3.4 POSTED SPEED LIMIT

Posted speed limit data are most often included in the statewide roadway inventory maintained by each State DOT[9].The posted speed limit data can be stored in a variety of different file formats using different location referencing methods. The emerging practice, though, is the use of linear referencing within GIS, which facilitates data integration across different data sources.

Posted speed limits can change over time, and when they do, these changes may happen at any time throughout the year. Because all of the proposed Part 490 performance measures are based on a full calendar year, it will be important to know the year represented by the posted speed limit data. Ideally, the year represented in the posted speed limit data would be the same as the year of the corresponding travel time data.

Regardless of the file format and location referencing used to store posted speed limits, the posted speed limit data should be gathered for further processing and integration described in the next section.

3.5 TRAFFIC VOLUME

Traffic volume data are most often included in the statewide roadway inventory maintained by each State DOT[10]. The most common traffic volume attribute in a statewide roadway inventory is annual average daily traffic (AADT), which is a single average count value for each calendar year. More detailed traffic count data are available from permanent continuous count stations, but these detailed counts are not available for the entire roadway network, only a limited number of locations.

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[9] Ibid.

[10] Ibid.

The proposed calculation procedures for Excessive Delay (§490.711(e)) require hourly traffic volumes for each day of the calendar year. Therefore, §490.709 offers 2 possible approaches: 1) use hourly traffic counts from continuous count stations and apply to multiple reporting segments; or, 2) estimate hourly traffic counts for each day using AADT values and an approved method.

Regardless of the approach used, it is likely that both AADT and hourly count data would be necessary, so these data for the current reporting year should be gathered. Further details on each of these two approaches are contained in Section 4.

3.6 HIGHWAY TYPE DESIGNATION

In this context, highway type designation has 2 possible values: 1) Interstate highways; 2) non-Interstate highways on the National Highway System (NHS). These 2 types are used to report separate performance measures for reliability as well as peak hour travel time.

There are at least 2 possible sources for this highway type designation. The first source is each State DOT's roadway inventory, which typically has attributes related to both NHS classification (i.e., On-NHS, Off-NHS) and functional classification (i.e., Interstate highways, Other freeways and expressways, etc.). Combining these 2 attributes allows one to designate Interstate NHS and non-Interstate NHS highways.

The second source for highway type designation is indirect and based on the NPMRDS Static File. For each Travel Time Segment in the NPMRDS Static File, there is an associated Road Name attribute. In nearly all cases, the Road Name attribute uses the I-XX designation for Interstate highways. Therefore, if the first 2 characters of Road Name is "I-," then that Travel Time Segment is an Interstate highway. Since the NPMRDS Static File includes only NHS highways, then it follows that all of the remaining Travel Time Segments (i.e., those for which the first 2 characters of Road Name do not equal "I-") are non-Interstate NHS highways.

Note that if a State DOT roadway inventory is used to determine highway type, there will be a need to conflate this designation to the NPMRDS-based Travel Time Segments. This data conflation process is discussed in Section 4, as it applies to other attributes besides just highway type designation.

3.7 URBANIZED AREA POPULATION

The urbanized area population is used for 2 purposes: 1) to determine the requirement to report the peak hour travel time measure and excessive delay measure; and, 2) to calculate the excessive delay per capita measure. Sections 490.509(c) and 490.709(d) indicate that "Populations of urbanized areas shall be as identified based on the most recent U.S. Decennial Census available at the time when the State DOT Baseline Performance Period Report is due to FHWA."

The urbanized area populations for the 2010 U.S. Decennial Census can be found at https://www.census.gov/geo/reference/ua/urban-rural-2010.html.

3.8 URBANIZED AREA BOUNDARIES

There are 2 possible sources for urbanized area boundaries (see §490.103(b)): 1) the most recent U.S. Decennial Census; or 2) FHWA-approved urbanized area boundaries submitted to HPMS.

For the first source, the U.S. Census Bureau provides a 2010 urbanized area boundary data in GIS format at https://www.census.gov/geo/reference/ua/urban-rural-2010.html. A GIS shapefile for the entire U.S. is provided and should be downloaded. Section 4 describes the procedures to overlay and conflate these urbanized area boundaries with the other data attributes in a GIS environment.

For the second source, a State DOT may submit (through HPMS) urbanized area boundaries that have been adjusted from the U.S. Census-designated boundaries. These adjusted urban area boundaries are typically encoded as a roadway link attribute (e.g., urbanized, non-urbanized) in the State DOT roadway inventory.

With either source, the urbanized area boundary data will need to be conflated with the Travel Time Segment, such that one can determine which Travel Time Segments should be included in the calculation of performance metrics. Section 4 describes the procedures to overlay and conflate these urbanized area boundaries with the other data attributes in a GIS environment.

4.0 Data Preparation

At this point, you should have several different data sets (those described in Section 3) gathered and stored in a single place. It is likely that these data sets are stored in different software applications, using different formats and different location referencing. This section provides an overview of how to integrate all of these different data sets together into a single, consolidated data set. Once this single consolidated data set has been created, the specific performance measure calculations can be performed (detailed in Section 5).

It should be noted that the proposed Part 490 includes two measure-specific data processes that could be implemented here (data preparation stage) or later (measure calculation stage): 1) removal of outlier speed values; and 2) imputing missing travel time values using posted speed limits. Because these processes apply to certain measures only, we have chosen to include them later in the measure calculation stage (Section 5). However, others may choose to include these two processes earlier in the data preparation stage (Section 4).

4.1 MATCHING NPMRDS STATIC FILE (I.E., SEGMENT CONFIGURATION) TO TRAVEL TIME DATA

The first step in developing a single consolidated data set is to join/merge the NPMRDS Static File with the Travel Time Data Set. The Static File contains several attributes that can be used in later calculations:

- Travel Time Segment length (DISTANCE)
- State and County name for each *Travel Time Segment* (ADMIN_LEVEL2 and ADMIN_LEVEL3)
- Highway Type Designation (can be inferred from ROAD_NUMBER)

The join/merge is a standard data operation in most data software and programming languages, but implementation details may vary slightly. Regardless, the key join/merge variable will be the attribute TMC, which is the unique identifier for each Travel Time Segment within the Travel Time File. The NPMRDS Quick Access Guide (part of the documentation provided on the NPMRDS download site) shows an example of this join operation in Microsoft Access.

An Important Note: This join/merge should be performed for each individual monthly Travel Time File and the corresponding Static File that was provided with that monthly Travel Time File. The Static File is updated a few times each year, but the recommended practice is to use the monthly Static File that is provided with the monthly Travel Time File. This ensures that the correct Travel Time Segment information is used with the corresponding Travel Time Data Set.

For states in which all urbanized areas are located within that State:

Prior to performing the join/merge of the Static File and the Travel Time File, you should filter the Static File to include only those Travel Time Segments that are located within your state (as determined by the ADMIN_LEVEL2 attribute). When joining/merging these 2 data sets, you should specify that the database/software keep only those results for which the TMC is in both the filtered Static File and the Travel Time File. This ensures that you keep only those travel time data within your state that are relevant for your calculations, which speeds subsequent measure calculation.

For states in which one or more urbanized areas extend across multiple bordering states:

In this case, the Static File should be filtered for the primary state (using ADMIN_LEVEL2), with the addition of those counties outside the primary state (using ADMIN_LEVEL2 and ADMIN_LEVEL3) that contain the urbanized area of interest. When joining/merging these 2 data sets, you should specify that the database/software keep only those results for which the TMC is in both the filtered Static File and the Travel Time File. This ensures that you keep only those travel time data within your state and urbanized areas that are relevant for your calculations, which speeds subsequent measure calculation.

When this step is complete, you will have a single data set that has all the attributes contained within the Travel Time File as well as the Static File (see Figure 4.1). Additionally, only those Travel Time Segments within your state and urbanized area(s) of interest should be included in this data set.

Figure 4.1 Data Set after Combining Travel Time File and Static File

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	TMC	DATE	EPOCH	Travel_TIME ALL_VEHICLES	Travel_TIME PASSENGER_VEHICLES	Travel_TIME FREIGHT_TRUCKS	ADMIN LEVEL_1	ADMIN LEVEL_2	ADMIN LEVEL_3	DISTANCE	ROAD NUMBER	ROAD NAME	LATITUDE	LONGITUDE	ROAD DIRECTION
2	101N04098	11012015	10	102		102	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
3	101N04098	11012015	65	119		119	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
4	101N04098	11012015	120	91	89	110	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
5	101N04098	11012015	175	104	101	110	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
6	101N04098	11012015	230	291	288	349	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
7	101N04098	11012015	285	93	93		USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
8	101N04098	11022015	9	108	104	109	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
9	101N04098	11022015	64	111	104	112	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
10	101N04098	11022015	119	124	123	127	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
11	101N04098	11022015	174	472	455	554	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
12	101N04098	11022015	229	100	98	111	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
13	101N04098	11022015	284	107	107	107	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
14	101N04098	11032015	8	100	99	110	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
15	101N04098	11032015	63	106	106	105	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
16	101N04098	11032015	118	109	109	109	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
17	101N04098	11032015	173	115	112	120	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
18	101N04098	11032015	228	193	201	186	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
19	101N04098	11032015	283	356	353	357	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound
20	101N04098	11042015	7	110	121	108	USA	Georgia	Henry	1.78955	I-75		33.4774	-84.2158	Southbound

4.2 COMBINING TRAVEL TIME SEGMENTS INTO REPORTING SEGMENTS (IF DESIRED)

Section 490.103(f) provides the option to combine one or more contiguous Travel Time Segments into a Reporting Segment provided that the length does not exceed ½ mile in urbanized areas or 10 miles in non-urbanized areas, unless an individual Travel Time Segment is longer. If combining more than one Travel

Time Segment into a single Reporting Segment is desired and permissible, then this is the appropriate time to perform the calculations.

The length of a Reporting Segment is the sum of the lengths of all included Travel Time Segments. Each 5-minute travel time for a Reporting Segment is the sum of all corresponding Travel Time Segment 5-minute travel times. If one of the Travel Time Segment travel times is missing, then the corresponding Reporting Segment travel time should also be marked as missing.

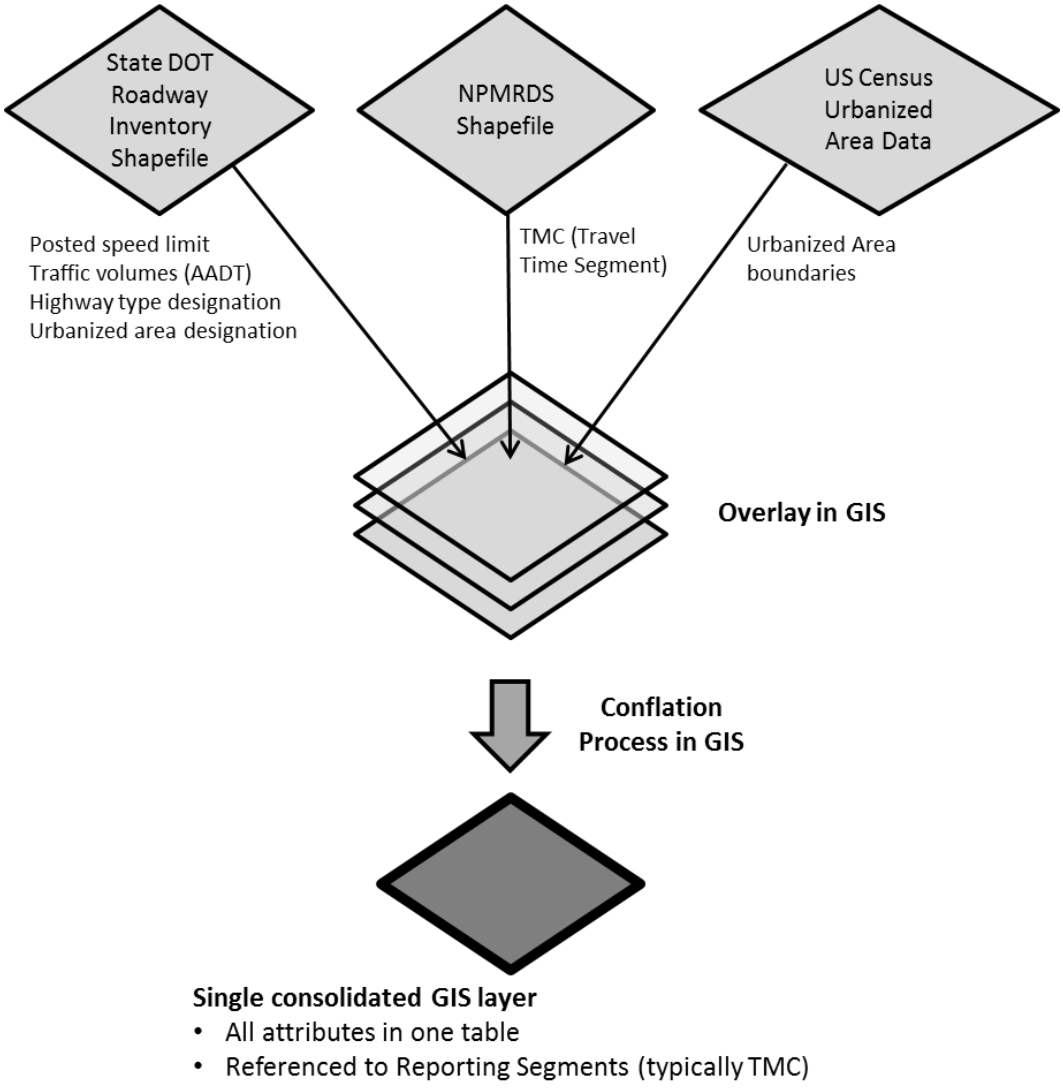
4.3 CONFLATION WITHIN GIS

The next step (after combining each monthly Static File and Travel Time Data Set) is conflation and data integration, which essentially "glues" together the different data sets described in Section 3. In most cases, the best way to accomplish this data integration is within GIS.

GIS software is used to capture, manage, analyze and display all forms of geographically referenced data—that is, data that is referenced to a specific location. In this situation, the geographically-referenced data is most likely contained in at least 2 different sets or layers (Figure 4.1):

- **NPMRDS Shapefile –** Each monthly Static File has an accompanying Shapefile, which is a GIS-compatible data set. This GIS data set contains the *Travel Time Segment* identifier (TMC), which links to several other required attributes (e.g., travel time – all vehicles, travel time – freight vehicles, *Travel Time Segment* length) in the combined Static File and Travel Time Data Set. However, all that is needed during conflation is the *Travel Time Segment* identifier. Note that, in the NPMRDS Shapefile, a table join will be necessary to bring the TMC identifier from a Lookup Table into the primary mapping layer. This GIS table join is described on page 21 (titled "Joining Shapefiles") of the NPMRDS Quick Access Guide.
- **State DOT Roadway Inventory Shapefile –** Typically, the roadway inventory shapefile contains these attributes:
  - State DOT roadway segment identifier
  - Posted speed limit
  - Traffic volume (typically AADT)
  - Highway type designation
  - Urbanized area designation (if applicable)
- **U.S. Census Urbanized Area Boundaries –** If a state DOT has not adjusted the U.S. Census urbanized area boundaries, this U.S. Census-provided shapefile contains these boundaries as polygons.

Figure 4.2 Conceptual Illustration of Conflation within GIS



Before the conflation process is started within GIS, several preparatory steps should be taken to improve process efficiency and accuracy:

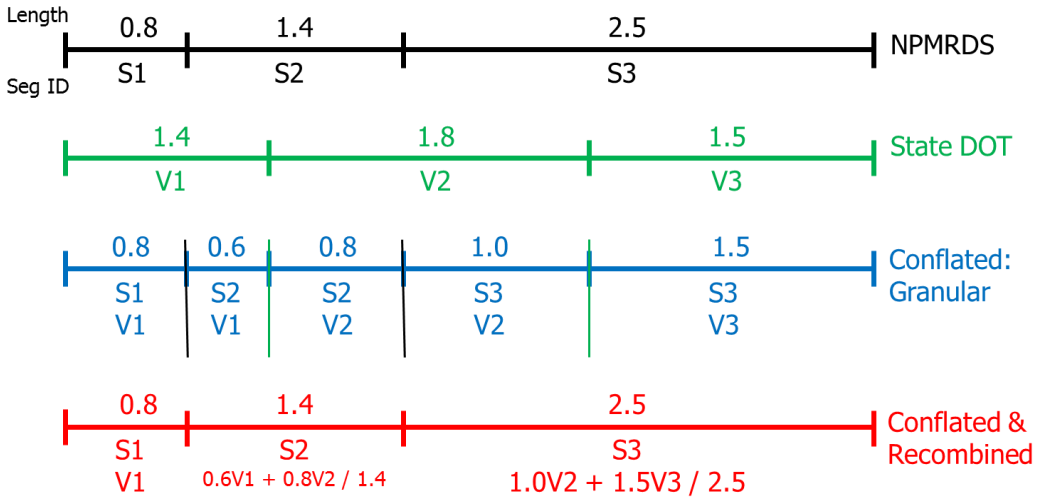
- **Clip All GIS Shapefiles to the Relevant Geography –** For example, the NPMRDS shapefile includes all 50 states and should be clipped to the relevant state(s). If an urbanized area over 1,000,000 in population falls within multiple states, then those states should also be included in the final clipped NPMRDS shapefile. The roadway inventory shapefile is typically produced for an entire state and likely will not need to be clipped. However, roadway inventory data for those portions of the urbanized areas falling outside will need to be obtained from the neighboring State DOT and added to the primary roadway inventory shapefile.
- **Remove All Unnecessary Roadway Features and Attributes –** For example, the State DOT roadway inventory includes all roadway functional classes,

but only roadways with NHS designation are needed. Therefore, these non-NHS roadways should be selected and removed to improve conflation efficiency and accuracy. Similarly, unneeded attributes in the roadway inventory shapefile (e.g., pavement condition, etc.) can be removed to speed the conflation processing.

- **Project All Shapefile Layers to the Same Coordinate System –** This will ensure consistency among the location referencing during the conflation process.

Conceptually, Figure 4.3 illustrates how segments with dissimilar lengths (i.e., DOT-defined segments and Travel Time Segments/TMC paths) are combined during the GIS conflation process.

Figure 4.3 Illustration of Combining Dissimilar Segment Lengths during Conflation



The conflation process within GIS is outlined as follows:

- Convert the State DOT layer into a point layer showing the starting and ending point of each link (Figure 4.4).
- Create a buffer around each point (Figure 4.5).
- Consolidate and eliminate any points that overlap or are adjacent (Figure 4.6).
- Break the NPMRDS segments into shorter segments using the State DOT points as breakpoints.
- Create a spatial buffer around each State DOT segment in order to join the appropriate State DOT segment with each split NPMRDS segment (Figure 4.7).
- Join the State DOT segments to the NPMRDS segments.

Figure 4.4 Example of a Point Layer with Starting and Ending Points

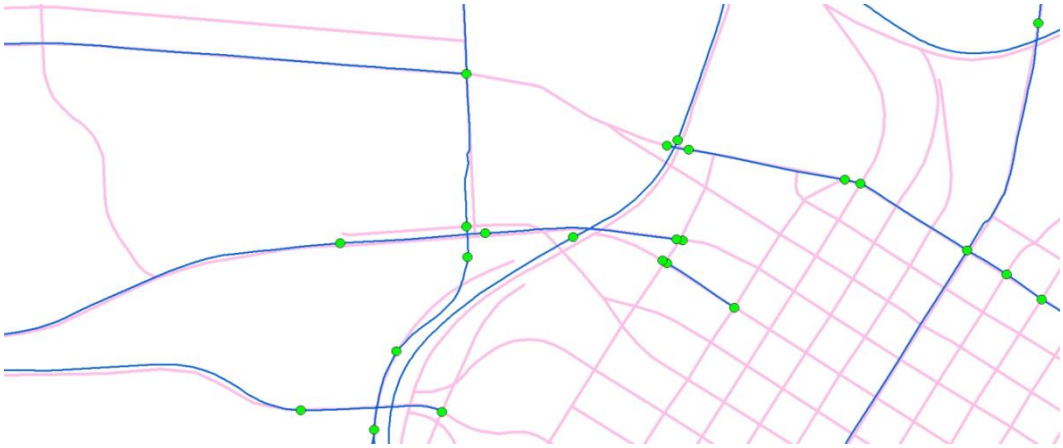


Figure 4.5 Create Buffers Around the State DOT Segment Endpoints

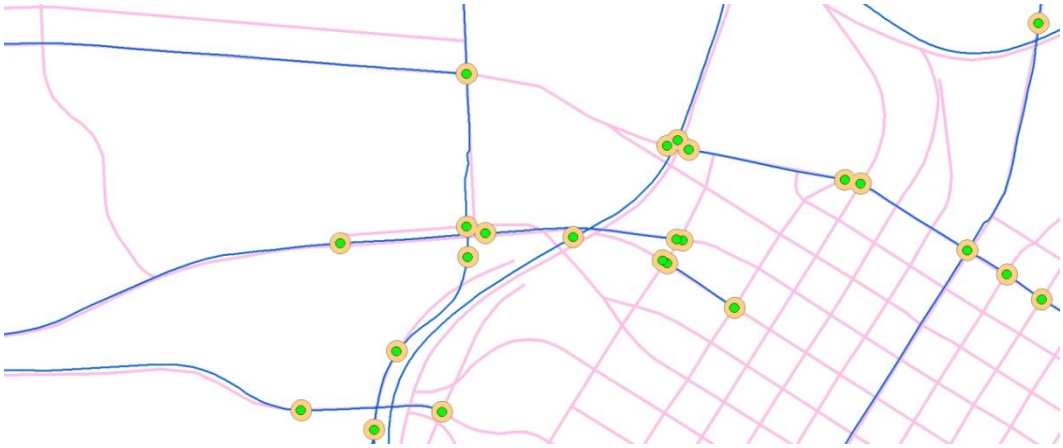


Figure 4.6 Break the NPMRDS Segments at these State DOT Segment Endpoints

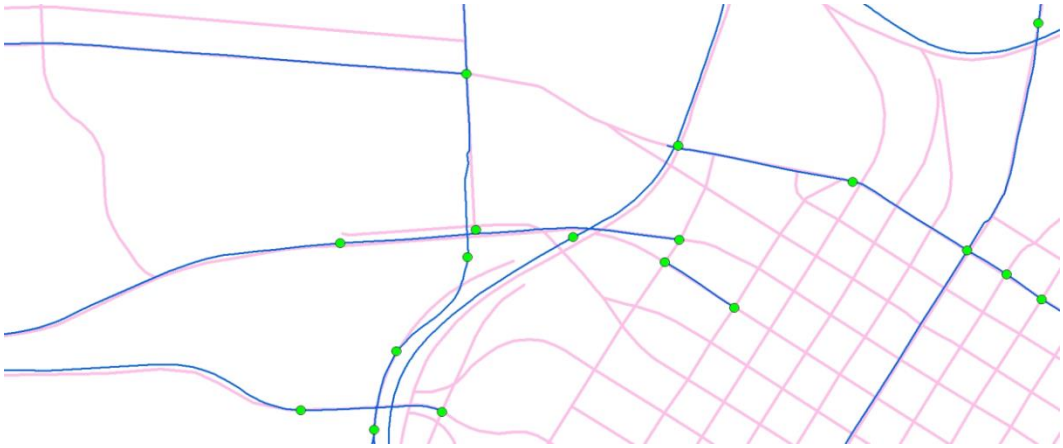


Figure 4.7 Create Spatial Buffers on State DOT Segments

After the above steps are complete, quality assurance steps should be undertaken. For example, there may be segments that did not get matched so this process may need to be repeated on unmatched segments to determine if there is a match that did not fit the parameters used for matching in the first iteration. The quality assurance is crucial to ensure that the analysis will produce the desired results. Data errors may exist in any database and could have been present in either of the datasets prior to conflation. However, some errors can result directly from the conflation process. Because of the potential for data errors created due to conflation, it is necessary to spend some manual quality control time to ensure the overall accuracy. Some examples of issues that can arise during quality control include:

- NPMRDS segments that should have been conflated with corresponding State DOT segments but were left unprocessed. This could result from very poor or inconsistent mapping along a stretch of roadway
- NPMRDS segments that should not have been conflated with any State DOT segments but were matched due to their proximity to other State DOT segments.
- NPMRDS segments that were conflated with inappropriate State DOT segments. This happens in areas with HOV lanes, freeway frontage roads, and at some complex interchanges.

4.4 ESTIMATING HOURLY TRAFFIC VOLUMES

Hourly traffic volumes are required only for the calculation of Total Excessive Delay. Agencies that are not required to calculate this metric can disregard this section.

Once the GIS conflation process is complete, each Reporting Segment should have a traffic volume assigned to it from the State DOT roadway inventory. In

most cases, this traffic volume will be an AADT value for one or more calendar years being analyzed. This section describes how to estimate hourly traffic volumes from each AADT value by applying several adjustment factors. These adjustment factors can be derived from continuous counters located on NHS roadways within your state, or in some cases, default national values are provided in this section.

First, monthly adjustment factors should be applied to the AADT value to calculate 12 monthly ADT values. National default values for monthly adjustment factors are not readily available due to differing effects of seasonality throughout the U.S. Therefore, monthly adjustment factors should be derived from continuous counters within your state.

Second, day-of-week adjustment factors should be applied to the 12 monthly ADT values, resulting in 84 monthly average day-of-week ADT values. National default values for day-of-week adjustment factors are shown in Table 4.1; alternatively, you can use day-of-week adjustment factors derived from continuous counters within your state.

Table 4.1 National Default Values for Day-of-Week Adjustment Factors

Day of Week	Adjustment Factor
Monday to Thursday	105%
Friday	110%
Saturday	90%
Sunday	80%

Source: 2015 Urban Mobility Scorecard, http://mobility.tamu.edu/ums/

Finally, time-of-day and directional adjustment factors should be applied to estimate the hourly traffic volumes that are required for each Travel Time Segment. Like the previous 2 adjustment factors, these adjustment factors can be derived from continuous counters within your state. Alternatively, default national values have been developed and the process for applying these to each Travel Time Segment is described in the following paragraphs.

Previous analytical efforts, [11,12] have developed typical time-of-day traffic profiles at an hourly level. These traffic distribution profiles were developed for the following different scenarios (resulting in 16 unique time-of-day traffic profiles):

---

[11] *Roadway Usage Patterns: Urban Case Studies.* Prepared for Volpe National Transportation Systems Center and Federal Highway Administration, July 22, 1994.

[12] *Development of Diurnal Traffic Distribution and Daily, Peak and Off-peak Vehicle Speed Estimation Procedures for Air Quality Planning.* Final Report, Work Order B-94-06, Prepared for Federal Highway Administration, April 1996.

- **Functional Class:** Freeway and non-freeway
- **Day Type:** Weekday and weekend
- **Traffic Congestion Level:** Percentage reduction in speed from free-flow (varies for freeways and streets)
- **Directionality:** Peak traffic in the morning (AM), peak traffic in the evening (PM), approximately equal traffic in each peak

The 16 traffic distribution profiles shown in Figure 4.8 through Figure 4.12 are considered to be very comprehensive, as they were developed from 713 continuous traffic monitoring locations in urban areas of 37 states.

Figure 4.8 Weekday Traffic Distribution Profile for No to Low Congestion

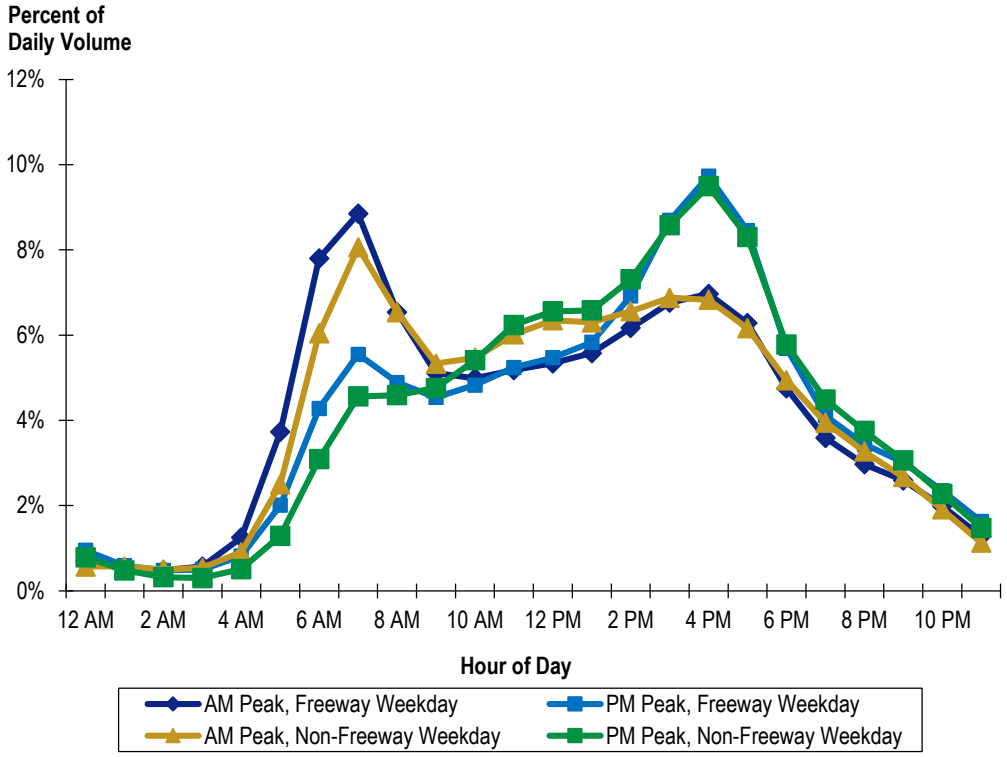


Figure 4.9 Weekday Traffic Distribution Profile for Moderate Congestion

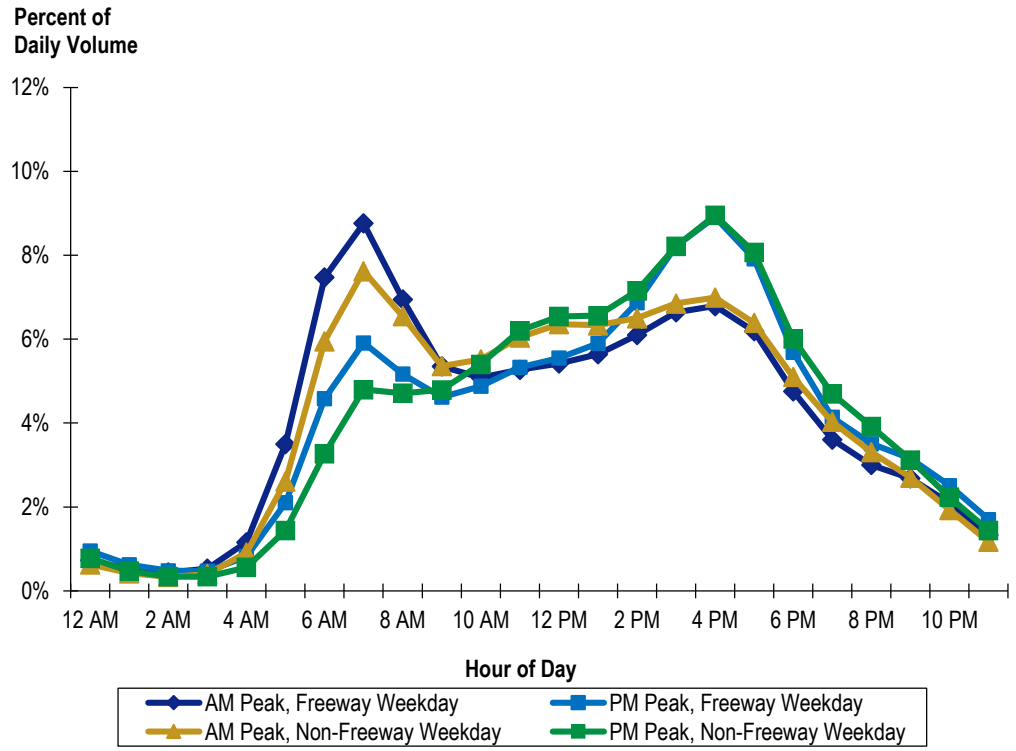


Figure 4.10 Weekday Traffic Distribution Profile for Severe Congestion

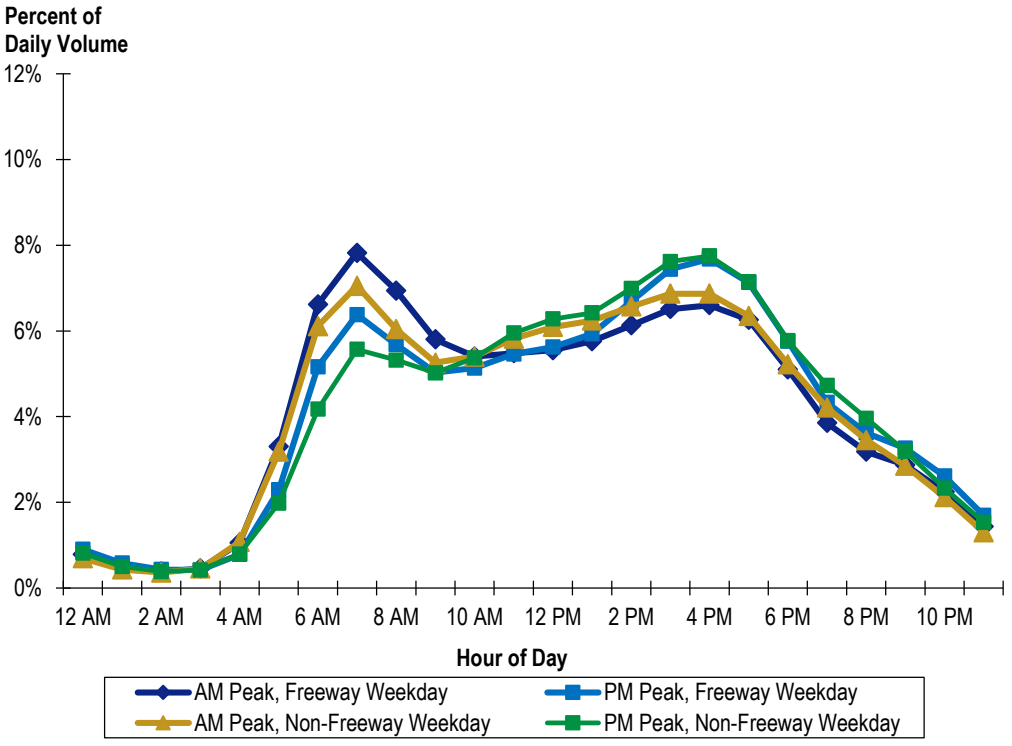


Figure 4.11 Weekend Traffic Distribution

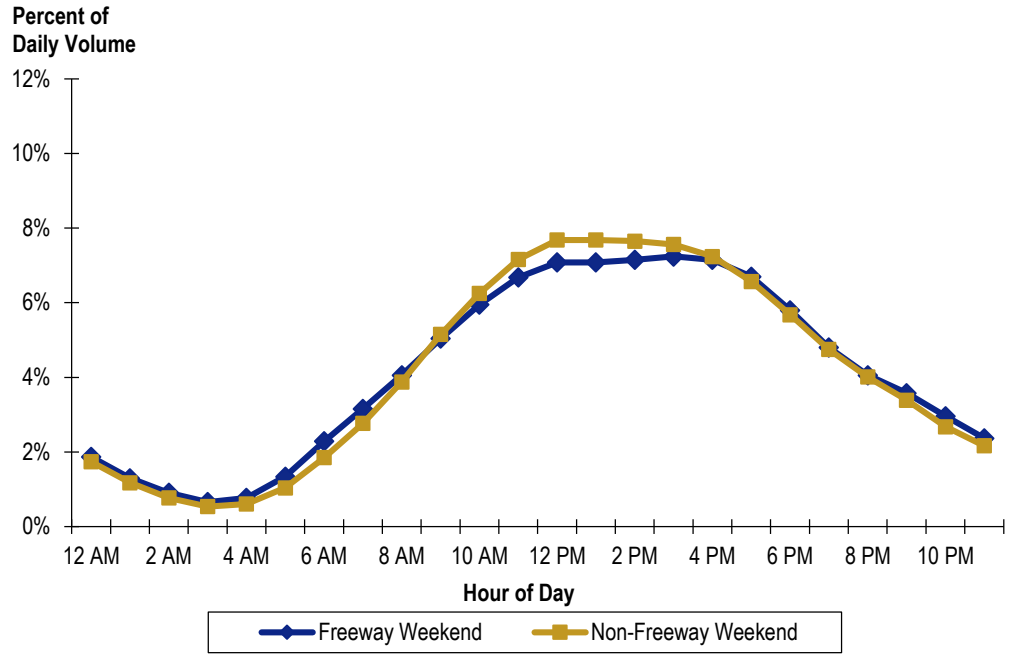
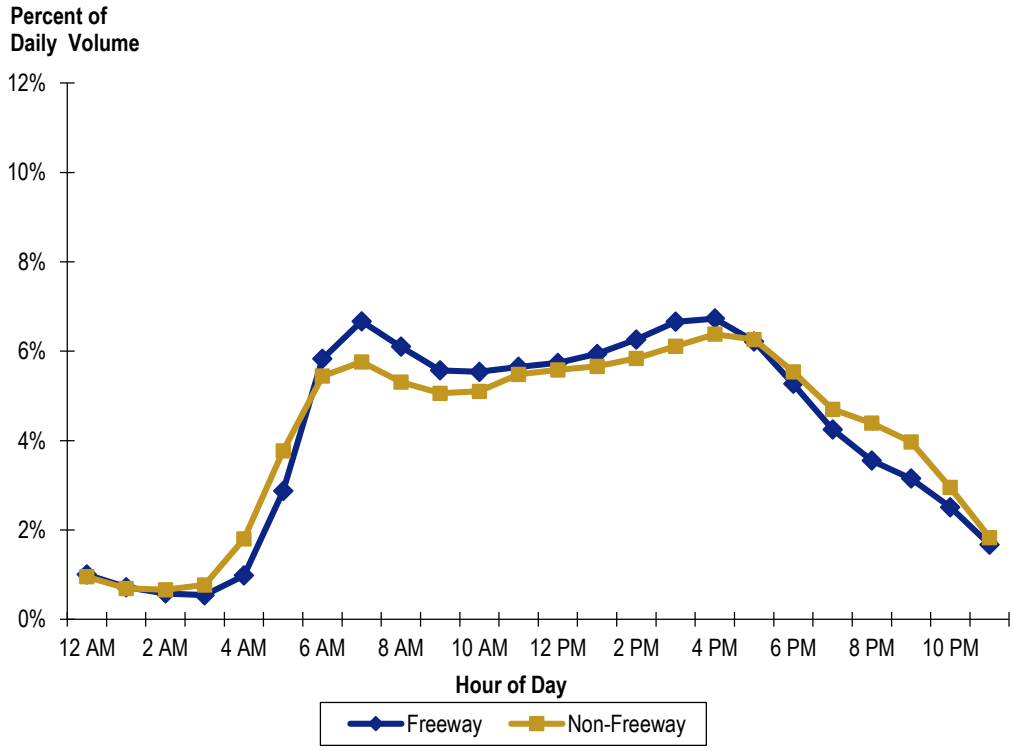


Figure 4.12 Weekly Distribution Profile for Severe Congestion and Similar Speeds in Each Peak Period



The next step in the factor adjustment process is to determine which of the 16 traffic distribution profiles should be assigned to each Reporting Segment. The assignment should be as follows:

- **Functional Class:** assign based on HPMS functional road class
  - **Freeway –** access-controlled highways
  - **Non-Freeway –** all other major roads and streets
- **Day Type:** assign volume profile based on each day
  - Weekday (Monday through Friday)
  - Weekend (Saturday and Sunday)
- **Traffic Congestion Level:** Assign based on the peak period speed reduction percentage calculated from the private sector speed data. The peak period speed reduction is calculated as follows:
  1. Calculate a simple average peak period speed (add up all the morning and evening peak period speeds and divide the total by the 8 periods in the eight peak hours) for each Reporting Segment using speed data from 6 a.m. to 10 a.m. (morning peak period) and 3 p.m. to 7 p.m. (evening peak period).
  2. Calculate a free-flow speed during the light traffic hours (e.g., 10 p.m. to 5 a.m.) to be used as the baseline for congestion calculations.
  3. Calculate the peak period speed reduction by dividing the average combined peak period speed by the free-flow speed.

$$\underset{Reduction\ Factor}{Speed} = \frac{\underset{Period\ Speed}{Average\ Peak}}{\underset{(10\ pm\ to\ 5\ am)}{Free-Flow\ Speed}}$$

- **For Freeways:**
  - speed reduction factor ranging from 90% to 100% (no to low congestion)
  - speed reduction factor ranging from 75% to 90% (moderate congestion)
  - speed reduction factor less than 75% (severe congestion)
- **For Non-Freeways:**
  - speed reduction factor ranging from 80% to 100% (no to low congestion)
  - speed reduction factor ranging from 65% to 80% (moderate congestion)
  - speed reduction factor less than 65% (severe congestion)
- **Directionality:** Assign this factor based on peak period speed differentials in the private sector speed dataset. The peak period speed differential is calculated as follows:

1. Calculate the average morning peak period speed (6 a.m. to 10 a.m.) and the average evening peak period speed (3 p.m. to 7 p.m.)
2. Assign the peak period volume curve based on the speed differential. The lowest speed determines the peak direction. Any section where the difference in the morning and evening peak period speeds is 6 mph or less will be assigned the even volume distribution.

4.5 FINAL ANALYSIS DATASET STRUCTURE

At this stage in the process, you should have a single expanded data set that will serve as the basis for all performance measure calculations. This data set will include the attributes shown in Table 4.2.

As mentioned previously in Section 4, there are two measure-specific data processes that will be applied during the measure calculation stage (Section 5) rather than the data preparation stage (Section 4): 1) removal of outlier speed values; and 2) imputing missing travel time values using posted speed limits.

Table 4.2 Attributes Included in a Single Expanded Data Set for Measure Calculation

Attribute	Description
Reporting Segment	Unique identifier for Reporting Segment. In most cases, this will be the TMC identifier contained in the Travel Time Data Set and Static File.
Reporting Segment length	Length of Reporting Segment (miles, to the nearest hundredth mile)
Date	Date value from Travel Time Data Set. At this stage, some Date values may not be present due to missing data. Imputation for specific measures is covered in Section 4.
Epoch	Time value from Travel Time Data Set. The integer-based Epoch values can be converted to an actual time value if desired. At this stage, some Epoch values may not be present due to missing data. Imputation for specific measures is covered in Section 5.
Travel time – all vehicles	5-minute average travel time value for all vehicles from the Travel Time Data Set (seconds, to nearest second)
Travel time – freight vehicles	5-minute average travel time value for freight vehicles from the Travel Time Data Set (seconds, to nearest second)
Desired Peak Period Travel Time	Desired peak period travel time for each reporting segment (seconds). Defined by State DOT and MPOs. **Required only for calculation of peak hour travel time metric.**
Posted speed limit	Posted speed limit for Reporting Segment (miles per hour). Required for imputation of missing travel time values for these 3 metrics: level of travel

Attribute	Description
	time reliability, truck travel time reliability, and average truck speed.
Highway type designation	Highway type designation for Reporting Segment. Required to summarize performance measures into 2 categories: 1) Interstate System; and, 2) non-Interstate NHS.
Urbanized area designation	Urbanized area designation (i.e., urbanized, non-urbanized) for Reporting Segment. Required to select appropriate Reporting Segments for the Peak Hour Travel Time measure and the Excessive Delay metric.
Traffic volume	Estimated hourly traffic count for this Reporting Segment, Date, and Epoch/time. **Required only for Excessive Delay metric.**

5.0 Performance Measures

5.1 Percent of the Interstate System Providing for Reliable Travel Times and Percent of the Non-Interstate NHS Providing for Reliable Travel Times

Measure Definition

This measure is meant to capture the annual reliability of travel separately for Interstates and Non-Interstate NHS highways, for four different time periods:

1. Weekdays between of 6:00 a.m. and 10:00 p.m.;
2. Weekdays between 10:00 a.m. and 4:00 p.m.;
3. Weekdays between 4:00 p.m. and 8:00 p.m.; and
4. Weekend days between 6:00 a.m. and 8:00 p.m.

Data Preparation

Data Structure

Travel Time Data

Data to compute this measure shall be based (as proposed in 490.509) on actual travel time measurements in seconds reported for epochs that are no longer than 5-minutes in duration and for the FHWA-approved reporting segments. The travel time measurements used in the calculation are for all vehicles combined (e.g., passenger cars plus trucks). If the reporting epoch is smaller than 5-minutes in duration, the data should be aggregated to the 5-minute level by computing the arithmetic travel time mean.

Additional Necessary Data

The following data elements are also necessary:

- Length of each reporting segment
- Posted speed limit for each reporting segment
- Highway type for the reporting segment: Interstate vs. Non-Interstate NHS Roadway

MISSING DATA PROCESSING

Any travel time for reporting segments contained within a reporting segment that are "0" or null shall be replaced (as proposed in section 490.511(b)(1)(v)) with the calculated travel time for that segment, based on the segment length and posted speed limit (TT@PSL), rounded to the nearest second.

$$TT@PSL = \frac{SegmentLength}{Posted\ SpeedLimit} \times 3600$$

Where: *SegmentLength* is in miles

PostedSpeedLimit is in miles per hour

3600 is the conversion factor for hours to seconds

Sometimes the dataset on hand does not actually contain "0" or null values of travel time, but rather the entire record is missing; this is the case with the NPMRDS. One algorithm for creating the appropriate data set is as follows.

1. Create a template that is a complete enumeration of all reporting segments, dates, and 5-minute intervals that are present in the original data set. For example, if there are 4,000 reporting segments, 365 days in a year, and 288 5-minute intervals in a day, the total number of records in the template is 420,480,000.
2. Join/merge the template with the smaller travel time data set reporting segment. Be sure the software used will accept observations from both data sets. In the example above, the new data set will have 420,480,000 records. For records where the template contributed but not the travel time dataset, the travel time fields should be null.
3. Create a file that has posted speed limit assigned to each reporting segment in the data. This may be done manually or created from an agency's roadway characteristics inventory.
4. Join/merge the posted speed limit data set with the data set created in #2. Where travel time is null, assign it the value of the posted speed limit.

GEOGRAPHIC AGGREGATION METHOD

See "Measure Calculation Details."

TIME AGGREGATION METHOD

See "Measure Calculation Details."

THRESHOLD VALUE

Not applicable.

THRESHOLD CALCULATION

Not applicable.

MEASURE CALCULATION: EQUATIONS

The calculation of the reliability measures is based on computing metrics for each reporting segment for each of the four time periods specified in Measure Definition above. These metrics are the Level of Travel Time Reliability (LOTTR), defined below. First, LOTTR values are computed for each time period (see Measure Definition above) and for each reporting segment as:

$$LOTTR_i = \frac{80th\ Percentile\ Travel\ Time_i}{50th\ Percentile\ Travel\ Time_i}$$

Where: i is one of the four time periods.

The following step is used to accomplish this. For each of the time periods, a distribution of travel times is created for each reporting segment. From this distribution, the 80th and 50th percentile travel times are computed.

The second stage is to compute the systemwide measures from the four-time period LOTTRs for the individual reporting segments. The systemwide measures are computed separately for the two highway types: Interstates vs. Non-interstate NHS roadways.

$$SystemLOTTR_h = \frac{\sum_{r=1}^{R} SL_{h,r}}{\sum_{t=1}^{T} SL_{h,t}}$$

Where: $SystemLOTTR_h$ is the systemwide measure for highway type h (the Percent of the Interstate System or other NHS roadways providing for Reliable Travel Times).

$SL_{h,r}$ is the length of a reporting segment to the nearest hundredth mile where all of the $LOTTR_i$ values are less than 1.50 for highway type h.

$SL_{h,t}$ is the length of a reporting segment t that reports a $LOTTR_i$ value for highway type h, to the nearest hundredth mile.

R is the total number of reporting segments where all of the $LOTTR_i$ values are less than 1.50 for highway type h, to the nearest hundredth mile.

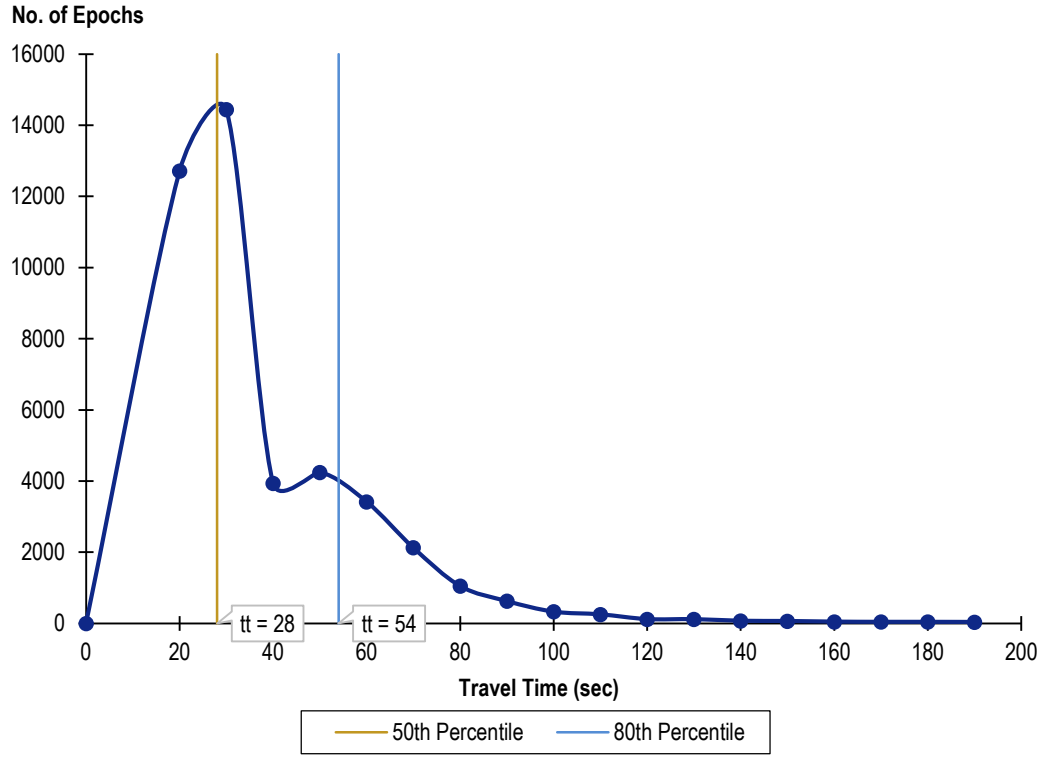
T is the total number of reporting segments that report a $LOTTR_i$ value for highway type h, to the nearest hundredth mile.

MEASURE CALCULATION: DETAILS

The following discussion is based on using the NPMRDS to develop the LOTTR measures.

1. As discussed above, data in addition to the travel time measurements are required to compute the LOTTR measures. The NPMRDS has the reporting segment length data in the so-called "Static File" (TMC configuration file). The analysis dataset for this measure should contain:
   a. Travel times
   b. Lengths of reporting segments
   c. Highway type
   d. Formats or new data elements created from the epoch start times to identify each of the four time periods for the LOTTR measure.
2. Travel time distributions are created for each of the four time periods and for each of the reporting segments individually (TMCs in the NPMRDS case). Figure 5.1 shows the distribution of travel times for a TMC located on an urban freeway.

Figure 5.1 Distribution of Travel Times on an Urban Freeway TMC (Weekdays, 6:00 am to 8:00 p.m.)



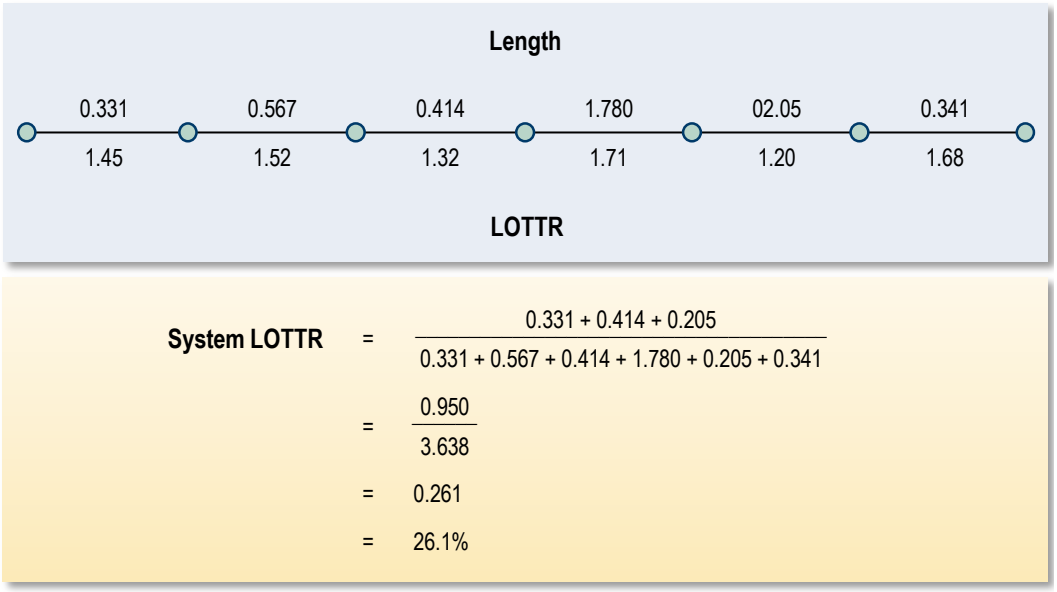
3. From these distributions, the 80th and 50th percentile travel times are extracted. The $LOTTR_i$ metric is computed as shown in Measure Calculation: Equations. Statistically-based software packages will compute the percentiles automatically. To compute the percentiles without special software:

a. Sort the data from lowest to highest. Note the total number of observations.

b. The 50th percentile is the travel time value for the observation number that is half of the total number of observations. The 80th percentile is travel time value for the observation that is 80 percent of the total number of observations. *Example: The total number of observations for a LOTTR calculation is 43,848. The 50th percentile is the travel time for the 21,924th observation and the 80th percentile is the travel time value for the 35,078th observation.*

4. The sum of the length of all reporting segments by highway type is computed (denominator in the *SystemLOTTR*$_h$ equation). The sum of the length of all reporting segments, by highway type, where LOTTR$_i$ is less than 1.50 is computed (numerator in the *SystemLOTTR*$_h$ equation). Figure 5.2 shows an example calculation using a facility comprised of six reporting segments.

Figure 5.2 Example LOTTR Calculation



5. *SystemLOTTR*$_h$ (the Percent of the Interstate System or other NHS roadways providing for Reliable Travel Times) is computed for each of the four time periods and two highway type combinations.

5.2 PERCENT OF THE INTERSTATE SYSTEM WHERE PEAK HOUR TRAVEL TIMES MEET EXPECTATIONS AND PERCENT OF THE NON-INTERSTATE NHS WHERE PEAK HOUR TRAVEL TIMES MEET EXPECTATIONS

MEASURE DEFINITION

This measure is meant to capture the annual peak period congestion conditions for urbanized areas with a population over 1,000,000. All reporting segments inside of the urbanized area boundaries are used to compute the peak hour travel time measures. Reporting is done separately for Interstates and non-Interstate NHS roadways.

DATA PREPARATION

Data Structure

TRAVEL TIME DATA

Data to compute this measure shall be based (as proposed in section 490.509) on actual travel time measurements in seconds reported for epochs that are no longer than 5-minutes in duration and for reporting segments that are no longer in length than traffic message channels, unless otherwise approved by FHWA. The travel time measurements used in the calculation are for all vehicles combined (e.g., passenger cars plus trucks). If the reporting epoch is smaller than 5-minutes in duration, the data should be aggregated to the 5-minute epoch level by computing the arithmetic travel time mean.

ADDITIONAL NECESSARY DATA

The following data element is necessary: highway type for the reporting segment: Interstate vs. Non-Interstate NHS Roadway.

OUTLIER PROCESSING

All travel times that are less than 2 mph or greater than 100 mph shall not be used (as proposed in section 490.511(c)(2)) in the calculation of the PHTTR. This can be achieved by either creating a subset of the full dataset or, if the software allows, excluding these observations from the analysis with a "WHERE" or similar clause.

GEOGRAPHIC AGGREGATION METHOD

See "Measure Calculation Details."

TIME AGGREGATION METHOD

See "Measure Calculation Details."

THRESHOLD VALUE

Desired Peak Period Travel Time – defined by the agency for every reporting segment separately for morning and afternoon peak periods. (The same value may be used for both periods.) This is the travel time above which the agency feels is unacceptable from a congestion perspective.

THRESHOLD CALCULATION

Agency-specific procedures are to be used.

MEASURE CALCULATION: EQUATIONS

The peak hour travel time measures are based on first computing the Peak Hour Travel Time Ratio (PHTTR) for each reporting segment. Then, a three-stage process is used to develop the peak hour travel time measures. First, an annual average travel time for each of six hours of the day for non-Federal holiday weekdays are computed; an entire year of data is used in this calculation. The six hours for which average travel times are computed individually are:

- 6:00 – 7:00 a.m.;
- 7:00 – 8:00 a.m.;
- 8:00 – 9:00 a.m.,
- 4:00 – 5:00 p.m.;
- 5:00 – 6:00 p.m.; and
- 6:00 – 7:00 p.m.

The second stage computes the average annual travel time as the simple arithmetic average of all 5-minute time intervals present for each hour for the entire year. The result is six average annual travel times for each reporting segment. From these six values, the highest travel time value is selected, and whether it occurs in the morning or afternoon is noted. The PHTTR metric is then computed for each reporting segment as:

$$PHTTR_t = \frac{HHTT_t}{DPPTT_t}$$

Where: $PHTTR_t$ is the Peak Hour Travel Time Ratio for reporting segment t

$HHTT_t$ is the highest average annual hour travel time for the six peak period hours for reporting segment t

$DPPTT_t$ is the Desired Peak Period Travel Time for reporting segment *s* for the peak period (a.m. or p.m.) in which the $HHTT_t$ occurs.

The third stage is to compute the PHTTR systemwide measures from the individual reporting segments. The systemwide measures are computed separately for the two highway types: Interstates vs. Non-interstate NHS roadways:

$$SystemPHTTR_h = \frac{\sum_{r=1}^{R} SL_{h,r}}{\sum_{t=1}^{T} SL_{h,t}}$$

Where: $SystemPHTTR_h$ is the systemwide measure for highway type *h* (the Percent of the Interstate System or Other NHS roadways where peak hour travel times meet expectations)

$SL_{h,r}$ is the length of a reporting segment to the nearest hundredth mile where the PHTTR value is less than 1.50 for highway type *h*

$SL_{h,t}$ is the length of a reporting segment that report a PHTTR value for highway type *h*, to the nearest hundredth mile

R is the total number of reporting segments where the PHTTR value is less than 1.50 for highway type *h*

T is the total number of reporting segments that report a PHTTR value for highway type *h*, to the nearest hundredth mile

MEASURE CALCULATION: DETAILS

The following discussion is based on using the NPMRDS to develop the PHTTR measures.

1. As discussed above, data in addition to the travel time measurements are required to compute the PHTTR measures. The NPMRDS has the reporting segment length data in the so-called "Static File" (TMC configuration file). The analysis dataset for this measure should contain for each reporting segment:
   a. Travel times
   b. Lengths of reporting segments
   c. Highway type
   d. Formats or new data elements created from the epoch start times to identify each of the four time periods for the LOTTR measure.
2. A dataset is created with observations that have the following attributes:
   a. Six peak hours for non-Federal holiday weekdays;
   b. Speeds between 2 and 100 mph.

If the software in use allows, this process can be handled with a subsetting "WHERE" clause in the analysis code.

3. Using the data set created in #2, the average annual travel times are computed for each hour for each reporting segment.
4. For each reporting segment, the highest travel time value for the six peak hours is selected. The PHTTR is computed for this hour. Table 5.1 shows an example of the results to this point. For each segment, the highest annual average travel time is chosen from the six possible peak hours and the PHTTR is calculated for this hour.
5. SystemPHTTR$_h$ (the Percent of the Interstate System or Other NHS roadways where peak hour travel times meet expectations) is computed for each of two highway types. Using the example data in Table 5.1:

$$SystemPHTTR_h = \frac{0.562}{0.920 + 0.562 + 0.286 + 0.667}$$
$$= 23.1\%$$

Table 5.1 Example Annual Average Hourly Travel Times by Reporting Segment

Reporting Segment	Length	Hour	Free Flow Travel Time	Annual Average Travel Time	PHTTR
A	0.920	6	52	63.76	
A	0.920	7	52	66.83	
A	0.920	8	52	77.11	
A	0.920	16	52	113.20	
A	0.920	17	52	159.53	3.07
A	0.920	18	52	137.91	
B	0.562	6	31	33.05	
B	0.562	7	31	38.57	
B	0.562	8	31	41.45	
B	0.562	16	31	39.68	
B	0.562	17	31	42.87	1.38
B	0.562	18	31	34.79	
C	0.286	6	17	20.92	
C	0.286	7	17	21.23	
C	0.286	8	17	29.22	
C	0.286	16	17	23.88	
C	0.286	17	17	30.17	1.77

Reporting Segment	Length	Hour	Free Flow Travel Time	Annual Average Travel Time	PHTTR
C	0.286	18	17	27.87	
D	0.667	6	38	46.65	
D	0.667	7	38	51.59	
D	0.667	8	38	82.20	2.16
D	0.667	16	38	55.19	
D	0.667	17	38	75.28	
D	0.667	18	38	71.41	

5.3 PERCENT OF THE INTERSTATE SYSTEM MILEAGE PROVIDING FOR RELIABLE TRUCK TRAVEL TIMES

MEASURE DEFINITION

This measure is meant to capture the annual reliability of truck travel for Interstates only.

DATA PREPARATION

Data Structure

TRAVEL TIME DATA

Data to compute this measure shall be based (as proposed in section 490.609) on actual travel time measurements in seconds reported for epochs that are no longer than 5-minutes in duration and for the FHWA-approved reporting segments. The travel time measurements used in the calculation are for trucks only. If the reporting epoch is smaller than 5-minutes in duration, the data should be aggregated to the 5-minute epoch level by computing the arithmetic travel time mean.

ADDITIONAL NECESSARY DATA

The following data elements are also necessary:

- Length of each reporting segment
- Posted speed limit for each reporting segment
- Travel time for all vehicles combined (passenger cars + trucks, to be used in Missing Data Processing below)
- Data necessary to identify reporting segments on the Interstate system

MISSING DATA PROCESSING

Any travel time for reporting segments contained within a reporting segment that are "0" or null shall be replaced (as proposed in section 490.611(b)(1)(ii)) using the following procedure:

1. If a travel time value for all vehicles combined exists for a 5-minute interval and it is less than the posted speed limit, the "0" or null for truck travel time is replaced with it.
2. If the conditions of a) are not satisfied, "0" or null truck travel time is replaced with the truck travel time at the posted speed limit, based on the segment length and posted speed limit rounded to the nearest second.

$$TTT@PSL = \frac{SegmentLength}{Posted\ SpeedLimit} \times 3600$$

Where: *TTT@PSL* is the truck travel time at the posted speed limit

SegmentLength is in miles

PostedSpeedLimit is in miles per hour

3600 is the conversion factor for hours to seconds

Sometimes the dataset on hand does not actually contain "0" or null values of travel time but rather the entire record is missing; this is the case with the NPMRDS. One algorithm for creating the appropriate data set is as follows.

1. Create a template that is a complete enumeration of all reporting segments, dates, and 5-minute intervals that are present in the original data set. For example, if there are 4,000 reporting segments, 365 days in a year, and 288 5-minute intervals in a day, the total number of records in the template is 420,480,000.
2. Join/merge the template with the smaller travel time data set by reporting segment. Be sure the software used will accept observations from both data sets. In the example above, the new data set will have 420,480,000 records. For records where the template contributed but not the travel time dataset, the travel time fields should be null.
3. Create a file that has posted speed limit assigned to each reporting segment in the data.
4. Join/merge the posted speed limit data set with the data set created in #2. Where truck travel time is null, assign it the value of the posted speed limit.

GEOGRAPHIC AGGREGATION METHOD

See "Measure Calculation Details."

TIME AGGREGATION METHOD

See "Measure Calculation Details."

THRESHOLD VALUE

Not applicable.

THRESHOLD CALCULATION

Not applicable.

MEASURE CALCULATION: EQUATIONS

A two-stage process is used to develop the "Percent of the Interstate System Mileage providing for Reliable Truck Travel Times" metric. First, the Truck Travel Time Reliability (TTTR) value is calculated for each Interstate reporting segment as:

$$TTTR = \frac{95th\ Percentile\ Truck\ Travel\ Time}{50th\ Percentile\ Truck\ Travel\ Time}$$

Where: *TTTR* is the Truck Travel Time Reliability value

To create the TTTR, a distribution of travel times is developed for each Interstate reporting segment. From this distribution, the 95th and 50th percentile travel times are computed. This step is similar to the development of the LOTTR except that the numerator here is the 95th percentile travel time.

The second stage is to compute the Interstate systemwide measure from the TTTRs for the individual reporting segments:

$$InterstateTTTR = \frac{\sum_{a=1}^{R} SL_a}{\sum_{t=1}^{T} SL_t}$$

Where: *InterstateTTTR* is the Interstate systemwide truck travel time reliability measure

SL_a is the length of an Interstate reporting segment a to the nearest hundredth mile where the TTTR value is less than 1.50

SL_t is the length of an Interstate reporting segment t that reports a TTTR value, to the nearest hundredth mile

R is the total number of Interstate reporting segments where the TTTR value is less than 1.50, to the nearest hundredth mile

T is the total number of Interstate reporting segments that report a TTTR value, to the nearest hundredth mile.

MEASURE CALCULATION: DETAILS

The following discussion is based on using the NPMRDS to develop the TTTR metric.

1. As discussed above, data in addition to the travel time measurements are required to compute the TTTR metric. The NPMRDS has the reporting

segment length data in the so-called "Static File" (TMC configuration file). The analysis dataset for this measure should contain:

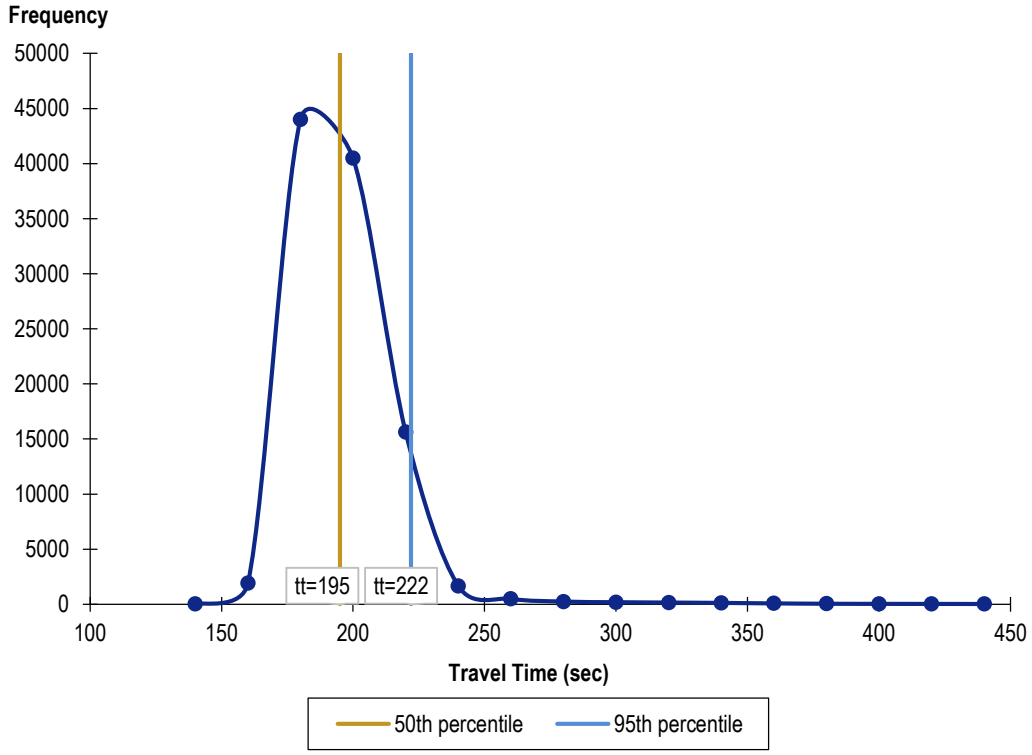
a. Travel times

b. Lengths of reporting segments

c. Highway type (Interstate routes only)

2. Travel time distributions are created for each of the Interstate reporting segments individually (TMCs in the NPMRDS case). Data for every 5-minute interval during the entire year are used. Figure 5.3 shows the distribution of travel times for a TMC located on an rural Interstate.

Figure 5.3 Travel Time Distribution for a Rural Interstate TMC



3. From these distributions, the 95th and 50th percentile travel times are extracted. The TTTR metric is computed as shown in Measure Calculation: Equations above. Statistically-based software packages will compute the percentiles automatically. To compute the percentiles without special software:

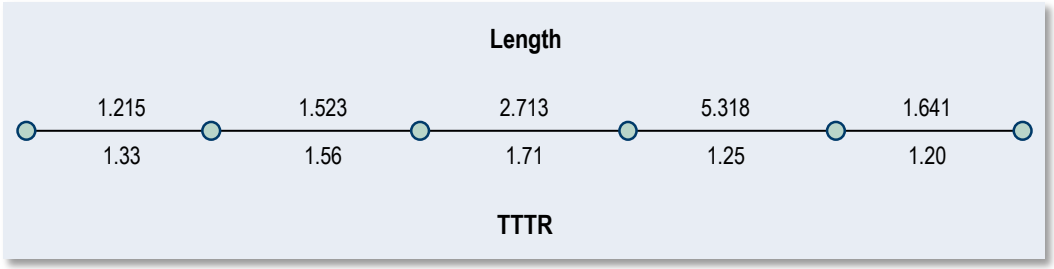
a. Sort the data from lowest to highest. Note the total number of observations.

b. The 50th percentile is the travel time value for the observation number that is half of the total number of observations. The 95th percentile is the travel time value for the observation that is 95 percent of the total number

of observations. *Example: The total number of observations for a TTTR calculation is 43,848. The 50th percentile is the travel time for the 21,924th observation and the 95th percentile is the travel time value for the 41,656th observation.*

c. The sum of the length of all reporting segments by highway type is computed (denominator in the *InterstateTTTR* equation). The sum of the length of all Interstate reporting segments ***where TTTR is less than 1.50*** is computed (numerator in the *InterstateTTTR* equation). Figure 5.4 shows an example calculation using a facility comprised of six reporting segments.

Figure 5.4 Example TTTR Calculation



$$\text{Interstate TTTR} = \frac{1.215 + 5.318 + 1.641}{1.215 + 1.523 + 2.713 + 5.318 + 1.641} = \frac{8.174}{12.410} = 0.659 = 65.9\%$$

d. Interstate TTTR is computed using the equation in Measure Calculation: Equations above.

5.4 PERCENT OF THE INTERSTATE SYSTEM MILEAGE UNCONGESTED

MEASURE DEFINITION

This measure is meant to capture the annual performance of truck travel for Interstates only, where performance is defined as uncongested conditions subject to the terms below.

DATA PREPARATION

Data Structure

TRAVEL TIME DATA

Data to compute this measure shall be based (as proposed in section 490.609) on actual travel time measurements in seconds reported for time intervals that are no longer than 5-minutes in duration and for the FHWA-approved reporting segments. The travel time measurements used in the calculation are for trucks only. If the reporting time interval is smaller than 5-minutes in duration, the data should be aggregated to the 5-minute level by computing the arithmetic travel time mean.

ADDITIONAL NECESSARY DATA

The following data elements are also necessary:

- Length of each reporting segment
- Posted speed limit for each reporting segment
- Travel time for all vehicles combined (passenger cars + trucks, to be used in Missing Data Processing below)
- Data necessary to identify reporting segments on the Interstate system

MISSING DATA PROCESSING

Any travel time for reporting segments contained within a reporting segment that are "0" or null shall be replaced (as proposed in section 490.611(b)(1)(ii)) using the following procedure:

1. If a travel time value for all vehicles combined exists for a 5 minute interval and it is less than the posted speed limit, the "0" or null for truck travel time is replaced with it.
2. If the conditions of #1 are not satisfied, "0" or null truck travel time is replaced with the truck travel time at the posted speed limit, based on the segment length and posted speed limit rounded to the nearest second.

$$TTT@PSL = \frac{SegmentLength}{Posted\ SpeedLimit} \times 3600$$

Where: *TTT@PSL* is the truck travel time at the posted speed limit

SegmentLength is in miles

PostedSpeedLimit is in miles per hour

3600 is the conversion factor for hours to seconds

Sometimes the dataset on hand does not actually contain "0" or null values of travel time but rather the entire record is missing; this is the case with the NPMRDS. One algorithm for creating the appropriate data set is as follows.

1. Create a template that is a complete enumeration of all reporting segments, dates, and 5-minute intervals that are present in the original data set. For example, if there are 4,000 reporting segments, 365 days in a year, and 288 5-minute intervals in a day, the total number of records in the template is 420,480,000.
2. Join the template with the smaller travel time data set by reporting segment. Be sure the software used will accept observations from both data sets. In the example above, the new data set will have 420,480,000 records. For records where the template contributed but not the travel time dataset, the travel time fields should be null.
3. Create a file that has posted speed limit assigned to each reporting segment in the data.
4. Join the posted speed limit data set with the data set created in #2. Where truck travel time is null, assign it the value of the posted speed limit.

GEOGRAPHIC AGGREGATION METHOD

See "Measure Calculation Details."

TIME AGGREGATION METHOD

See "Measure Calculation Details."

THRESHOLD VALUE

The threshold value used in calculating the metric is 50.00 mph.

THRESHOLD CALCULATION

Not applicable; it is fixed.

MEASURE CALCULATION: EQUATIONS

A two-stage process is used to develop the Percent of the Interstate System Mileage Uncongested metric. First, Average Truck Speed is calculated for each Interstate reporting segment over the course of a year as:

$$AverageTruckSpeed_s = \left[\sum_{b=1}^{T} \frac{SegmentLength_s}{TruckTravelTime_b}\right] \Big/ T \times 3{,}600$$

Where: b = a 5-minute time interval of a travel time reporting segment s;

s = a travel time reporting segment;

T = total number of time intervals in everyday in a full calendar year;

$SegmentLength_s$ = length of reporting segment s, to the nearest one tenth of a mile;

$TruckTravelTime_b$ = travel time of trucks, for time interval b in the Travel Time Data Set, to the nearest second;

3,*600* = number of seconds in an hour; and

AverageTruckSpeeds = average annual speed of trucks traveling through the reporting segment s, to the nearest hundredth mile per hour.

The second stage is to compute the Interstate systemwide measure from the Average Truck Speeds developed for the individual reporting segments:

$$PercentInterstateSystemMileageUncongested = 100 \times \frac{\sum_{g=1}^{U} SL_g}{\sum_{i=1}^{T} SL_i}$$

Where: g is an uncongested Interstate System reporting segment, defined as a segment that has an average truck speed greater than 50.00 mph;

SL_g = segment length, to the nearest hundredth of a mile, of an Interstate System reporting segment that has an average truck speed greater than 50.00 mph;

U = total number of uncongested Interstate System reporting segments;

i is an Interstate System reporting segment; and

T = total number of Interstate System reporting segments.

MEASURE CALCULATION: DETAILS

The following discussion is based on using the NPMRDS to develop the "Percent of the Interstate System Mileage Uncongested" metric.

1. As discussed above, data in addition to the travel time measurements are required to compute the "Percent of the Interstate System Mileage Uncongested" metric. The NPMRDS has the reporting segment length data in the so-called "Static File" (TMC configuration file). The analysis dataset for this measure should contain:
   a. Travel times
   b. Lengths of reporting segments
   c. Highway type (Interstate routes only)
2. Average Truck Speed for each Interstate reporting segment is computed. Table 5.2 shows an example of how the computations are made on a very small sample of truck travel times.

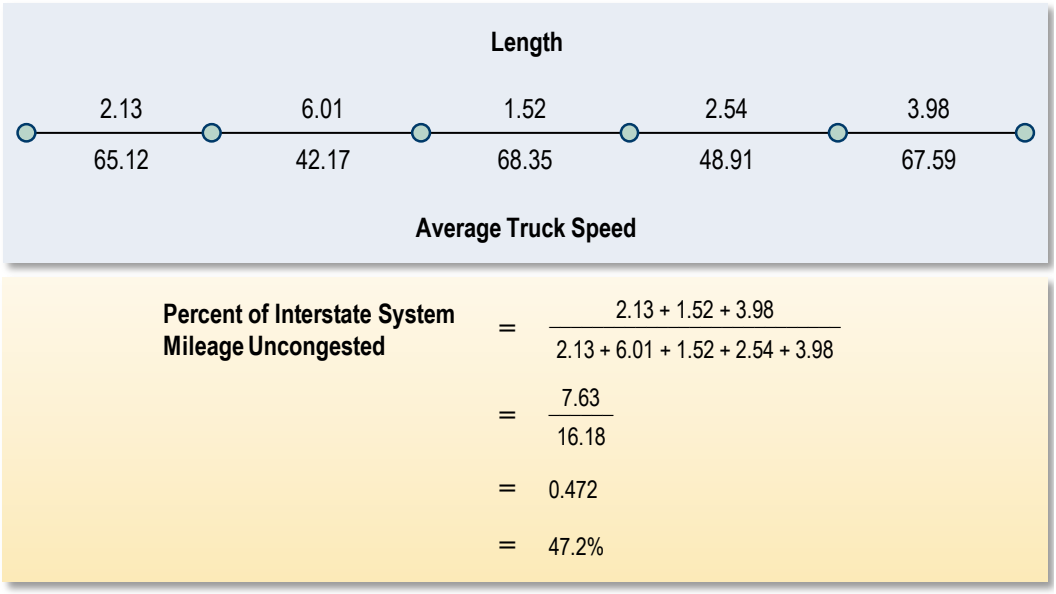
Table 5.2 Example Computations for Average Truck Speed

TMC	Start Time	TMC Length	Truck Travel Time (sec)	Truck Speed (mph)
102N05623	12:00 PM	8.3	444	67.25
102N05623	12:05 PM	8.3	418	71.44
102N05623	12:10 PM	8.3	418	71.44
102N05623	12:15 PM	8.3	418	71.44
102N05623	12:20 PM	8.3	418	71.44
102N05623	12:25 PM	8.3	418	71.44
102N05623	12:30 PM	8.3	384	77.76
102N05623	12:35 PM	8.3	394	75.79
102N05623	12:40 PM	8.3	418	71.44
102N05623	12:45 PM	8.3	418	71.44
102N05623	12:50 PM	8.3	418	71.44
102N05623	12:55 PM	8.3	466	64.08
102N05623	1:00 AM	8.3	471	63.40
102N05623	1:05 AM	8.3	420	71.10
102N05623	1:10 AM	8.3	418	71.44
102N05623	1:15 AM	8.3	418	71.44
102N05623	1:20 AM	8.3	418	71.44
102N05623	1:25 AM	8.3	411	72.65
102N05623	1:30 AM	8.3	411	72.65
102N05623	1:35 AM	8.3	495	60.33
102N05623	1:40 AM	8.3	480	62.21
102N05623	1:45 AM	8.3	418	71.44
102N05623	1:50 AM	8.3	418	71.44
102N05623	1:55 AM	8.3	418	71.44
			SUM	**1687.36**
AVERAGE TRUCK SPEED				**70.31 mph**

3. The sum of the length of all Interstate reporting segments computed (denominator in the Measure Calculation: Equations equation). The sum of the length of all Interstate reporting segments ***where the Average Truck Speed is greater than 50.00 mph*** is computed (numerator in the Measure Calculation: Equations equation).

4. The "Percent of the Interstate System Mileage Uncongested" metric is computed using the equation in Measure Calculation: Equations above. Figure 5.5 shows an example calculation using a facility comprised of five reporting segments.

Figure 5.5 Percent of the Interstate System Mileage Uncongested



5.5 ANNUAL HOURS OF EXCESSIVE DELAY PER CAPITA

METRIC DEFINITION

This performance measure is used to assess traffic congestion in urbanized areas over 1,000,000 in population, for the purpose of carrying out the CMAQ program**.** All reporting segments inside of the urbanized area boundaries are used to compute the Annual Hours of Excessive Delay per Capita metric.

DATA PREPARATION

Data Structure

TRAVEL TIME DATA

Data to compute this measure shall be based (as proposed in section 490.709) on actual travel time measurements in seconds reported for epochs that are no longer than 5-minutes in duration and for the FHWA-approved reporting segments. The travel time measurements used in the calculation are for all vehicles combined (e.g., passenger cars plus trucks). If the reporting epoch is

smaller than 5-minutes in duration, the data should be aggregated to the 5-minute level by computing the arithmetic travel time mean.

ADDITIONAL NECESSARY DATA

The following data elements are also necessary:

- Length of each reporting segment
- Hourly traffic volumes for each reporting segment
- Functional classification for each reporting segment, in accordance with the scheme used by FHWA's Highway Performance Monitoring System (HPMS)[13]
- NHS designation for each reporting segment

GEOGRAPHIC AGGREGATION METHOD

See "Measure Calculation Details."

TIME AGGREGATION METHOD

See "Measure Calculation Details."

THRESHOLD VALUE

- Functional Classes 1 (Interstates) and 2 (Freeways and Expressways): speed threshold is set to 35 mph.
- All other Functional Classes that are on the NHS: speed threshold is set to 15 mph.

THRESHOLD CALCULATION

Not applicable; fixed values used.

MEASURE CALCULATION: EQUATIONS

The calculation of the Annual Hours of Excessive Delay Per Capita is a multiple step process.

1. Excessive Delay Threshold Travel Time is computed for each reporting segment as:

[13] *Highway Functional Classification Concepts, Criteria and Procedures*: http://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/fcauab.pdf.

$$Excessive\ Delay\ Threshold\ Travel\ Time\ (s) = \left(\frac{Travel\ Time\ Segment\ Length\ (s)}{Threshold\ Speed\ (s)}\right) \times 3{,}600$$

Where:

- $Excessive\ Delay\ Threshold\ Travel\ Time(s)$ = The time of travel, to the nearest whole second, to traverse the Travel Time Segment at which any longer measured travel times would result in excessive delay for the travel time segment *s*;

- $Travel\ Time\ Segment\ Length\ (s)$ = Total length of travel time segment to the nearest hundredth of a mile for travel time reporting segment *s*; and

- $Threshold\ Speed\ (s)$ = The speed of travel at which any slower measured speeds would result in excessive delay for travel time reporting segment *s*.

$$Threshold\ Speed\ (s) = \begin{cases} 35 \text{ mph for Interstates/freeways/expressways} \\ 15 \text{ mph for all other principal arterials} \end{cases}$$

2. The travel segment delay (RSD) is calculated to the nearest whole second as follow:

$$RSD(s)_b = Travel\ time(s)_b - Excessive\ Delay\ Treshold\ Travel\ Time(s)$$
$$\text{and } RSD(s)_b \leq 300\ seconds$$

Where:

- $RSD(s)_b$ = travel segment delay, calculated to the nearest whole second, for a five minute bin b of travel time reporting segment s for in a day in a calendar year. $RSD(s)_b$ not to exceed 300 seconds;

- $Travel\ time(s)_b$ = a measured travel time, to the nearest second, for 5-minute time bin b recorded for travel time reporting segment *s*;

- $Excessive\ Delay\ Threshold\ Travel\ Time(s)$ = The maximum amount of time, to the nearest second, for a vehicle to traverse through travel time segment *s* before excessive delay would occur;

- b = a five minute bin of a travel time reporting segment s; and

- s = a travel time reporting segment.

3. Excessive delay, the additional amount of time to traverse a travel time segment in a five minute bin as compared to the time needed to traverse the travel time segment when traveling at the excessive delay travel speed threshold, is calculated to the nearest thousandths of an hour as follows:

$$Excessive\ Delay(s)_b = \begin{cases} \frac{RSD(s)_b}{3{,}600}\ when\ RDS(s)_b \geq 0 \\ or \\ 0\ when\ RDS(s)_b < 0 \end{cases}$$

Where:

- Excessive Delay$(s)_b$ = Excessive delay, calculated to the nearest thousandths of an hour, for five minute bin b of travel time reporting segment s;
- $RSD(s)_b$ = the calculated travel time reporting segment delay for five minute bin b of a travel time reporting segment s;
- b = a five minute bin of a travel time reporting segment s; and
- s = a travel time reporting segment.

4. Total Excessive Delay (vehicles-hours) is calculated for each reporting segment as follows:

$$Total\ Excessive\ Delay(s) = \sum_{d=1}^{TD}\left\{\sum_{h=1}^{TH}\left[\sum_{b=1}^{TB}\left([Excessive\ Delay(s)_{b,h,d} \times \left(\frac{hourly\ volume(s)}{12}\right)_{h,d}\right)_b\right]_h\right\}_d$$

Where:

- *Total Excessive Delay (in vehicle-hours)* = the sum of the excessive delay, to the nearest thousandths, for all traffic traveling through single travel time reporting segment s on NHS within an urbanized area;
- *s* = a travel time reporting segment;
- *d* = a day of the reporting year;
- *TD*= total number of days in the reporting year;
- *h* = single hour interval of the day where the first hour interval is 12:00 a.m. to 12:59 a.m.;
- *TH* = total number of hour intervals in day *h*;
- *b* = 5-minute bin for hour interval *h*;

- *TB* = total number of 5-minute bins where travel times are recorded in the travel time data set for hour interval *h*;

- $Excessive\ Delay(s)_{b,h,d}$ = calculated excessive travel time, in thousandths of an hour, for 5 minute bin (b), hour interval (h), day (d), and travel time segment (s); and

- $\left(\frac{\text{hourly volume(s)}}{12}\right)_{\text{h,d,s}}$ = hourly traffic volume, to the nearest tenth, for hour interval *h* and day *d* that corresponds to 5-minute bin *b* and travel time reporting segment *s* divided by 12. For example, the 9:05 a.m. to 9:10 a.m. minute bin would be assigned one twelfth of the hourly traffic volume for the 9:00 a.m. to 9:59 a.m. hour on the roadway in which travel time segment is included.

5. The Annual Hours of Excessive Delay Per Capita performance measure for CMAQ Traffic Congestion is calculated as follows:

$$Annual\ Hours\ of\ Excessive\ Delay\ per\ Capita = \frac{\sum_{s=1}^{T} Total\ Excessive\ Delay(s)}{Total\ Population}$$

Where:

- *Annual Hours of Excessive Delay per Capita* = the cumulative hours of excessive delay, to the nearest tenth, experienced by all traffic traveling through all reporting segments in the applicable urbanized area for the full reporting calendar year;

- s = travel time reporting segment within an urbanized area;

- T = total number of travel time reporting segments in the applicable urbanized area;

- $Total\ Excessive\ Delay(s)$ = total hours of excessive delay for all traffic traveling through travel time reporting segment *s* during the reporting year;

- *Total Population* = the total population in the applicable urbanized area as reported by the most recent U.S. Decennial Census.

MEASURE CALCULATION: DETAILS

The following discussion is based on using the NPMRDS to develop the Annual Hours of Excessive Delay per Capita measure.

1. As discussed above, data in addition to the travel time measurements are required to compute the measure. The NPMRDS has the reporting segment length data in the so-called "Static File" (TMC configuration file). In addition,

traffic volume and functional classification data must be merged into the travel time data set through conflation or other means. The analysis dataset at the reporting segment level for this measure should contain:

a. Travel times;

b. Lengths of reporting segments;

c. FHWA functional class – used to assign the threshold speed; and

d. Hourly traffic volume.

2. Four new data elements are computed at the reporting segment level for every 5-minute time interval, i.e., they are computed for every record in the analysis data set. These data elements are computed in sequence following the procedures in Measure Calculation: Equations above:

   a. Excessive Delay Threshold Travel Time (EDTTT);

   b. Travel segment delay (RSD);

   c. Excessive delay (ED); and:

   d. Total Excessive Delay (TED).

Table 5.3 shows how the calculations are made using the 5-minute/reporting segment level data set (see notes at the bottom of the table). The Annual Hours of Excessive Delay per Capita measure is calculated by simply summing up all of the 5-minute/reporting segment level Total Excessive Delay values for those segments within the urbanized area boundary, then dividing by the urbanized area population; this calculation is not shown in Table 5.3 because it is only for a very small sample of data.

Table 5.3 Example Calculations at the Reporting Segment Level for the Annual Hours of Excessive Delay per Capita Measure

Original Data Set							Calculated Data Elements			
TMC	Date	Start Time	Speed Threshold (mph)	TMC Length (mi)	Travel Time (all vehs, sec)	Hourly Volume	Ex. Delay Thresh. Travel Time, EDTTT (sec)	Travel Segment Delay, RSD (sec)	Excessive Delay, ED (hrs)	Total Excessive Delay, TED (veh-hrs)
130N09999	03/15/13	7:00	35	0.52	30	3850	53	0	0.000	0.000
130N09999	03/15/13	7:05	35	0.52	30	3850	53	0	0.000	0.000
130N09999	03/15/13	7:10	35	0.52	29	3850	53	0	0.000	0.000
130N09999	03/15/13	7:15	35	0.52	28	3850	53	0	0.000	0.000
130N09999	03/15/13	7:20	35	0.52	31	3850	53	0	0.000	0.000
130N09999	03/15/13	7:25	35	0.52	34	3850	53	0	0.000	0.000
130N09999	03/15/13	7:30	35	0.52	42	3850	53	0	0.000	0.000
130N09999	03/15/13	7:35	35	0.52	55	3850	53	2	0.000	0.140
130N09999	03/15/13	7:40	35	0.52	49	3850	53	0	0.000	0.000
130N09999	03/15/13	7:45	35	0.52	62	3850	53	9	0.002	0.794
130N09999	03/15/13	7:50	35	0.52	60	3850	53	7	0.002	0.615
130N09999	03/15/13	7:55	35	0.52	65	3850	53	11	0.003	0.986
130N09999	03/15/13	8:00	35	0.52	67	4125	53	13	0.004	1.277
130N09999	03/15/13	8:05	35	0.52	75	4125	53	21	0.006	2.043
130N09999	03/15/13	8:10	35	0.52	67	4125	53	40	0.011	3.830
130N09999	03/15/13	8:15	35	0.52	62	4125	53	51	0.014	4.823
130N09999	03/15/13	8:20	35	0.52	65	4125	53	36	0.010	3.405
130N09999	03/15/13	8:25	35	0.52	75	4125	53	21	0.006	2.043
130N09999	03/15/13	8:30	35	0.52	53	4125	53	0	0.000	0.000

Original Data Set							Calculated Data Elements			
TMC	Date	Start Time	Speed Threshold (mph)	TMC Length (mi)	Travel Time (all vehs, sec)	Hourly Volume	Ex. Delay Thresh. Travel Time, EDTTT (sec)	Travel Segment Delay, RSD (sec)	Excessive Delay, ED (hrs)	Total Excessive Delay, TED (veh-hrs)
130N09999	03/15/13	8:35	35	0.52	45	4125	53	0	0.000	0.000
130N09999	03/15/13	8:40	35	0.52	38	4125	53	0	0.000	0.000
130N09999	03/15/13	8:45	35	0.52	34	4125	53	0	0.000	0.000
130N09999	03/15/13	8:50	35	0.52	31	4125	53	0	0.000	0.000
130N09999	03/15/13	8:55	35	0.52	29	4125	53	0	0.000	0.000
									TOTAL	**19.957**

EDTTT = (TMCLength/ThresholdSpeed) * 3,600

RSD = MAX[0,(TravelTime – EDTTT)]

ED = RSD/3,600

TED = ED * (HourlyVolume/12)