

Appendix A

Methodology for the 2011 Urban Mobility Report

The procedures used in the 2011 Urban Mobility Report have been developed by the Texas Transportation Institute over several years and several research projects. The congestion estimates for all study years are recalculated every time the methodology is altered to provide a consistent data trend. The estimates and methodology from this report should be used in place of any other previous measures. All the measures and many of the input variables for each year and every city are provided in a spreadsheet that can be downloaded at http://mobility.tamu.edu/ums/congestion_data/.

This memo documents the analysis conducted for the methodology utilized in preparing the 2011 Urban Mobility Report. This methodology incorporates private sector traffic speed data from INRIX for calendar year 2010 into the calculation of the mobility performance measures presented in the initial calculations. The roadway inventory data source for most of the calculations is the Highway Performance Monitoring System from the Federal Highway Administration (1). A detailed description of that dataset can be found at: <http://www.fhwa.dot.gov/policy/ohpi/hpms/index.htm>.

Methodology Changes to the 2011 UMR

There are several changes to the UMR methodology for the 2011 report. The largest changes have to do with how wasted fuel is calculated and how commercial vehicle operating costs are calculated. These changes are documented in more detail in the following sections of the Methodology. Here are brief summaries of what has changed:

- New fuel efficiency equations have been incorporated that are based on the more fuel efficient fleets that we operate in the U.S. as compared with 10 and 20 years ago. The previous fuel efficiency equation used in the UMR was based on 1980's data. Separate fuel efficiency equations for passenger cars and commercial vehicles are now being used in calculating the UMR statistics. In the past, one efficiency equation was used for all vehicle types.
- Diesel costs are now being utilized to calculate commercial vehicle operating costs. In the past, the fuel costs were rolled into the hourly operating costs of commercial vehicles. Now the fuel costs are separated out for commercial vehicles just like passenger vehicles and the diesel prices are applied to the commercial vehicle wasted fuel. The commercial vehicle hourly operating costs in the 2011 UMR only reflect such items as wasted time and operating/maintenance costs; fuel is no longer a component.

Summary

The Urban Mobility Report (UMR) procedures provide estimates of mobility at the areawide level. The approach that is used describes congestion in consistent ways allowing for comparisons across urban areas or groups of urban areas. As with the last several editions of the UMR, this report includes the effect of several operational treatments and to public transportation. The goal is to include all improvements, but good data is necessary to accomplish this.

The previous UMR methodology used a set of estimation procedures and data provided by state DOT's and regional planning agencies to develop a set of mobility measures. This memo describes the congestion calculation procedure that uses a dataset of traffic speeds from INRIX, a private company that provides travel time information to a variety of customers. INRIX's 2010 data is an annual average of traffic speed for each section of road for every hour of each day for a total of 168 day/time period cells (24 hours x 7 days).

The travel speed data addresses the biggest shortcoming of previous editions of the UMR – the speed estimation process. INRIX's speed data improves the freeway and arterial street congestion measures in the following ways:

- “Real” rush hour speeds used to estimate a range of congestion measures; *speeds are measured not estimated.*
- Overnight speeds were used to identify the free-flow speeds that are used as a comparison standard; *low-volume speeds on each road section were used as the comparison standard.*
- The volume and roadway inventory data from FHWA's Highway Performance Monitoring System (HPMS) files were used with the speeds to calculate travel delay statistics; *the best speed data is combined with the best volume information to produce high-quality congestion measures.*

The Congestion Measure Calculation with Speed and Volume Datasets

The following steps were used to calculate the congestion performance measures for each urban roadway section.

1. Obtain HPMS traffic volume data by road section
2. Match the HPMS road network sections with the traffic speed dataset road sections
3. Estimate traffic volumes for each hour time interval from the daily volume data
4. Calculate average travel speed and total delay for each hour interval

5. Establish free-flow (i.e., low volume) travel speed
6. Calculate congestion performance measures
7. Additional steps when volume data had no speed data match

The mobility measures require four data inputs:

- Actual travel speed
- Free-flow travel speed
- Vehicle volume
- Vehicle occupancy (persons per vehicle) to calculate person-hours of travel delay

The 2010 private sector traffic speed data provided a better data source for the first two inputs, actual and free-flow travel time. The UMR analysis required vehicle and person volume estimates for the delay calculations; these were obtained from FHWA's HPMS dataset. The geographic referencing systems are different for the speed and volume datasets, a geographic matching process was performed to assign traffic speed data to each HPMS road section for the purposes of calculating the performance measures. When INRIX traffic speed data was not available for sections of road or times of day in urban areas, the speeds were estimated. This estimation process is described in more detail in Step 7.

Step 1. Identify Traffic Volume Data

The HPMS dataset from FHWA provided the source for traffic volume data, although the geographic designations in the HPMS dataset are not identical to the private sector speed data. The daily traffic volume data must be divided into the same time interval as the traffic speed data (hour intervals). While there are some detailed traffic counts on major roads, the most widespread and consistent traffic counts available are average daily traffic (ADT) counts. The hourly traffic volumes for each section, therefore, were estimated from these ADT counts using typical time-of-day traffic volume profiles developed from continuous count locations or other data sources. The section "Estimation of Hourly Traffic Volumes" shows the average hourly volume profiles used in the measure calculations.

Volume estimates for each day of the week (to match the speed database) were created from the average volume data using the factors in Exhibit A-1. Automated traffic recorders from around the country were reviewed and the factors in Exhibit A-1 are a "best-fit" average for both freeways and major streets. Creating an hourly volume to be used with the traffic speed values, then, is a process of multiplying the annual average by the daily factor and by the hourly factor.

Exhibit A-1. Day of Week Volume Conversion Factors

Day of Week	Adjustment Factor (to convert average annual volume into day of week volume)
Monday to Thursday	+5%
Friday	+10%
Saturday	-10%
Sunday	-20%

Step 2. Combine the Road Networks for Traffic Volume and Speed Data

The second step was to combine the road networks for the traffic volume and speed data sources, such that an estimate of traffic speed and traffic volume was available for each roadway segment in each urban area. The combination (also known as conflation) of the traffic volume and traffic speed networks was accomplished using Geographic Information Systems (GIS) tools. The INRIX speed network was chosen as the base network; an ADT count from the HPMS network was applied to each segment of roadway in the speed network. The traffic count and speed data for each roadway segment were then combined into areawide performance measures.

Step 3. Estimate Traffic Volumes for Shorter Time Intervals

The third step was to estimate traffic volumes for one-hour time intervals for each day of the week. Typical time-of-day traffic distribution profiles are needed to estimate hourly traffic flows from average daily traffic volumes. Previous analytical efforts^{1,2} have developed typical traffic profiles at the hourly level (the roadway traffic and inventory databases are used for a variety of traffic and economic studies). These traffic distribution profiles were developed for the following different scenarios (resulting in 16 unique profiles):

- 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)

¹ *Roadway Usage Patterns: Urban Case Studies*. Prepared for Volpe National Transportation Systems Center and Federal Highway Administration, July 22, 1994.

² *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.

- 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 Exhibits A-2 through A-6 are considered to be very comprehensive, as they were developed based upon 713 continuous traffic monitoring locations in urban areas of 37 states.

Exhibit A-2. Weekday Traffic Distribution Profile for No to Low Congestion

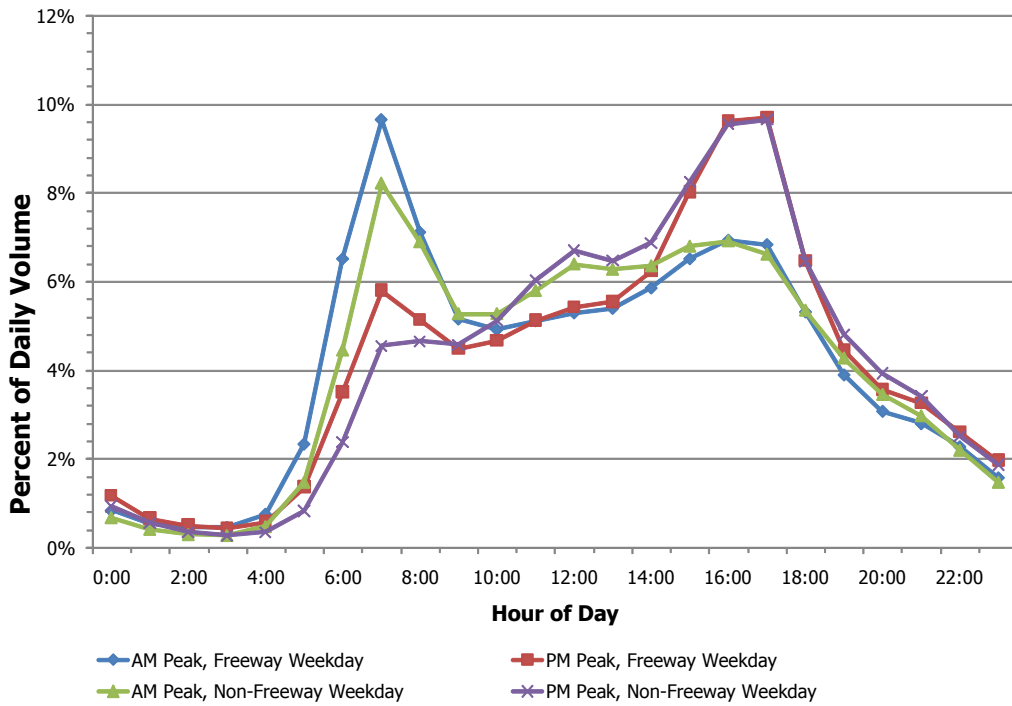


Exhibit A-3. Weekday Traffic Distribution Profile for Moderate Congestion

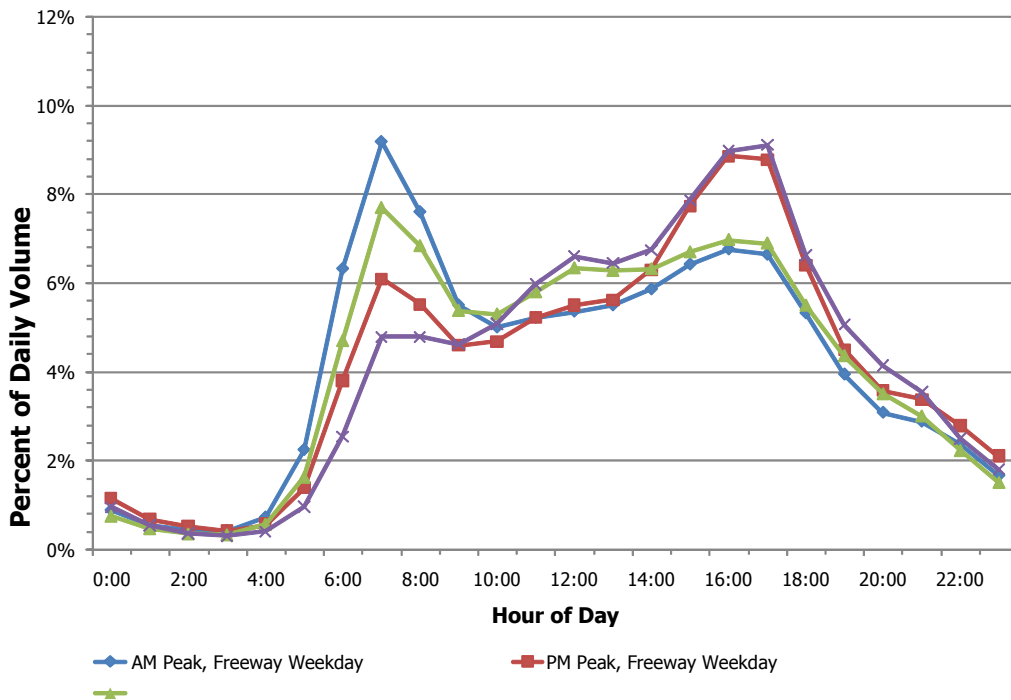


Exhibit A-4. Weekday Traffic Distribution Profile for Severe Congestion

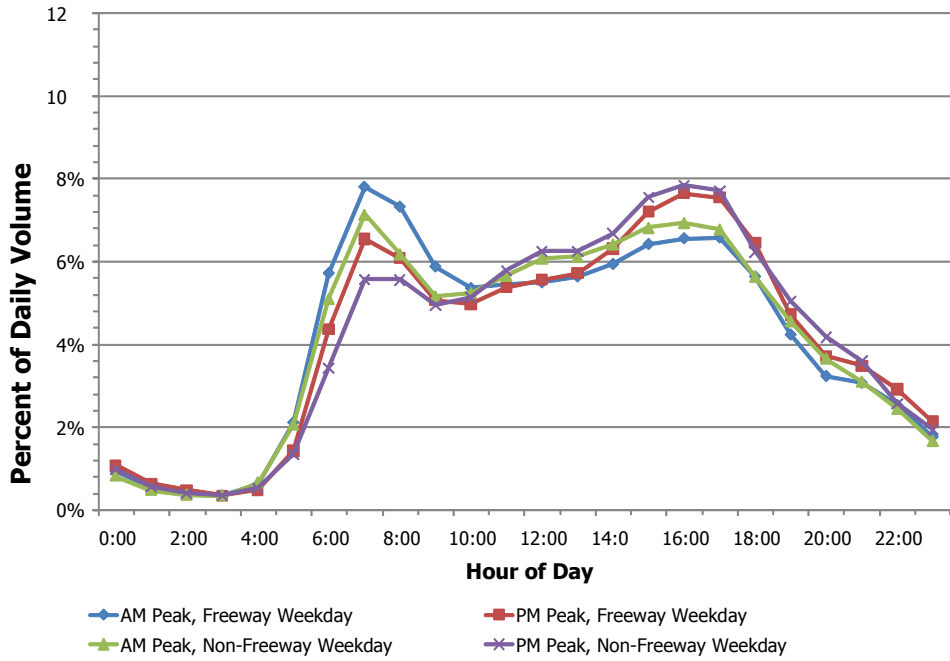


Exhibit A-5. Weekend Traffic Distribution Profile

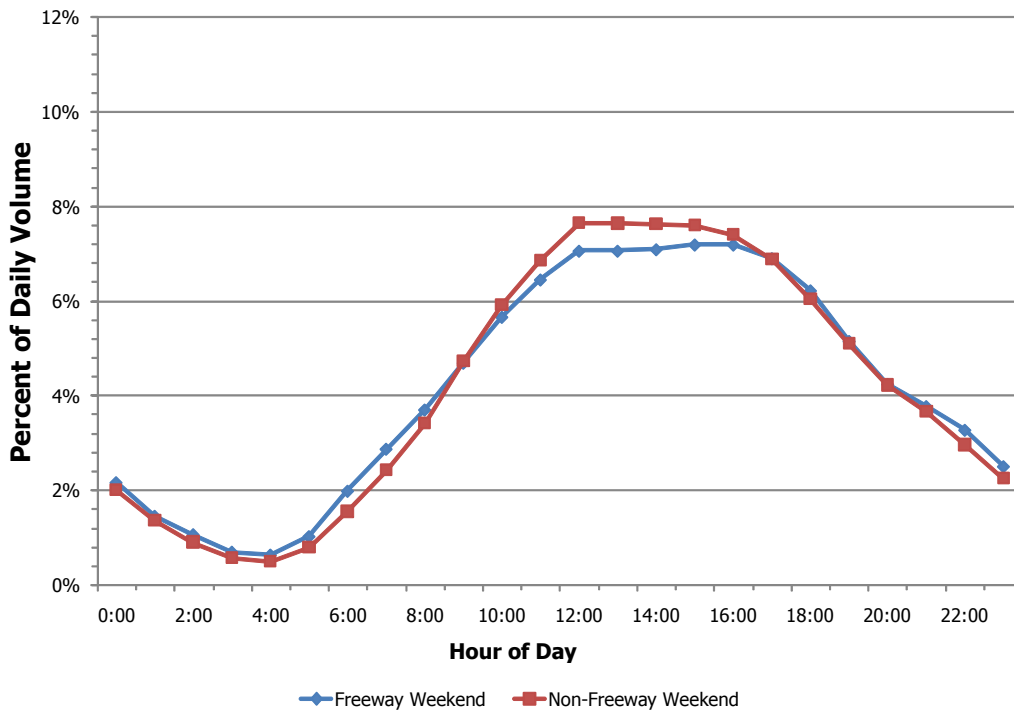
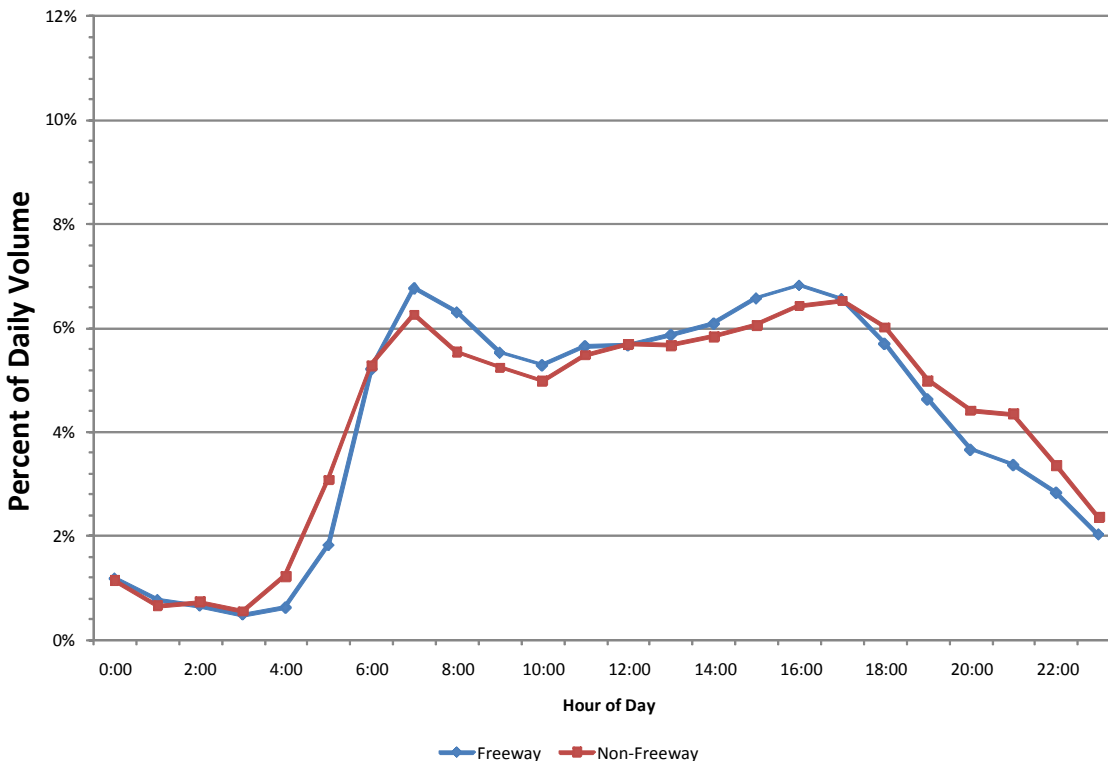


Exhibit A-6. Weekday Traffic Distribution Profile for Severe Congestion and Similar Speeds in Each Peak Period



The next step in the traffic flow assignment process is to determine which of the 16 traffic distribution profiles should be assigned to each Traffic Message Channel (TMC) path (the “geography” used by the private sector data providers), such that the hourly traffic flows can be calculated from traffic count data supplied by HPMS. 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 TMC path

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.

$$\text{Speed Reduction Factor} = \frac{\text{Average Peak Period Speed}}{\text{Free-Flow Speed (10 p. m. to 5 a. m.)}} \quad (\text{Eq. A-1})$$

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.

Step 4. Calculate Travel and Time

The hourly speed and volume data was combined to calculate the total travel time for each one hour time period. The one hour volume for each segment was multiplied by the corresponding travel time to get a quantity of vehicle-hours; these were summed across the entire urban area.

Step 5. Establish Free-Flow Travel Speed and Time

The calculation of congestion measures required establishing a congestion threshold, such that delay was accumulated for any time period once the speeds are lower than the congestion threshold. There has been considerable debate about the appropriate congestion thresholds, but for the purpose of the UMR methodology, the data was used to identify the speed at low volume conditions (for example, 10 p.m. to 5 a.m.). This speed is relatively high, but varies according to the roadway design characteristics. An upper limit of 65 mph was placed on the freeway free-flow speed to maintain a reasonable estimate of delay; no limit was placed on the arterial street free-flow speeds.

Step 6. Calculate Congestion Performance Measures

The mobility performance measures were calculated using the equations shown in the next section of this methodology once the one-hour dataset of actual speeds, free-flow travel speeds and traffic volumes was prepared.

Step 7. Estimate Speed Data Where Volume Data Had No Matched Speed Data

The UMR methodology analyzes travel on all freeways and arterial streets in each urban area. In many cases, the arterial streets are not maintained by the state DOT's so they are not included in the roadway network GIS shapefile that is reported in HPMS (all roadway classes will be added to the GIS roadway shapefiles within the next few years by the state DOTs as mandated by FHWA). A technique for handling the unmatched sections of roadway was developed for the 2010 UMR. The percentage of arterial streets that had INRIX speed data match ranged from about 20 to 40 percent across the U.S. while the freeway match percentages ranged from about 80 to 100 percent.

After the original conflation of the volume and speed networks in each urban area was completed, there were unmatched volume sections of roadway and unmatched INRIX speed sections of roadway. After reviewing how much speed data was unmatched in each urban area, it was decided that unmatched data would be handled differently in urban areas over under one million in population versus areas over one million in population.

Areas Under One Million Population

The HPMS volume data for each urban area that was unmatched was separated into freeway and arterial street sections. The HPMS sections of road were divided by each county in which the urban area was located. If an urban area was located in two counties, the unmatched traffic volume data from each county would be analyzed separately. The volume data was then aggregated such that it was treated like one large traffic count for freeways and another for street sections.

The unmatched speed data was separated by county also. All of the speed data and freeflow speed data was then averaged together to create a speed profile to represent the unmatched freeway sections and unmatched street sections.

The volume data and the speed data were combined and Steps 1 through 6 were repeated for the unmatched data in these smaller urban areas.

Areas Over One Million Population

In urban areas with populations over one million, the unmatched data was handled in one or two steps depending on the area. The core counties of these urban areas (these include the counties with at least 15 to 20 percent of the entire urban area's VMT) were treated differently because they tended to have more unmatched speed data available than some of the more suburban counties.

In the suburban counties (non-core), where less than 15 or 20 percent of the area's VMT was in a particular county, the volume and speed data from those counties were treated the same as the data in smaller urban areas with populations below one million discussed earlier. Steps 1 through 6 were repeated for the non-core counties of these urban areas.

In each of the core counties, all of the unmatched HPMS sections were gathered and ranked in order of highest traffic density (VMT per lane-mile) down to lowest for both freeways and arterial streets. These sections of roadway were divided into three groups. The top 25 percent of the lane-miles, with highest traffic density, were grouped together into the first set. The next 25 percent were grouped into a second set and the remaining lane-miles were grouped into a third set.

Similar groupings were made with the unmatched speed data for each core county for both functional classes of roadway. The roadway sections of unmatched speed data were ordered from most congested

to least congested based on their Travel Time Index value. Since the lane-miles of roadway for these sections were not available with the INRIX speed data, the listing was divided into the same splits as the traffic volume data (25/25/50 percent). (The Travel Time Index was used instead of speed because the TTI includes both free-flow and actual speed).

The volume data from each of the 3 groups was matched with the corresponding group of speed data and steps 1 through 6 were repeated for the unmatched data in the core counties.

Calculation of the Congestion Measures

This section summarizes the methodology utilized to calculate many of the statistics shown in the Urban Mobility Report and is divided into three main sections containing information on the constant values, variables and calculation steps of the main performance measures of the mobility database.

- 1. National Constants**
- 2. Urban Area Constants and Inventory Values**
- 3. Variable and Performance Measure Calculation Descriptions**
 - 1) Travel Speed
 - 2) Travel Delay
 - 3) Annual Person Delay
 - 4) Annual Delay per Auto Commuter
 - 5) Annual Peak Period Travel Time
 - 6) Travel Time Index
 - 7) Commuter Stress Index
 - 8) Wasted Fuel
 - 9) Total Congestion Cost and Truck Congestion Cost
 - 10) Truck Commodity Value
 - 11) Roadway Congestion Index
 - 12) Number of Rush Hours
 - 13) Percent of Daily and Peak Travel in Congested Conditions
 - 14) Percent of Congested Travel

Generally, the sections are listed in the order that they will be needed to complete all calculations.

National Constants

The congestion calculations utilize the values in Exhibit A-7 as national constants—values used in all urban areas to estimate the effect of congestion.

Exhibit A-7. National Congestion Constants for 2011 Urban Mobility Report

Constant	Value
Vehicle Occupancy	1.25 persons per vehicle
Average Cost of Time (\$2010)*	\$16.30 per person hour ¹
Commercial Vehicle Operating Cost (\$2010)	\$88.12 per vehicle hour ^{1,2}
Working Days (5x50)	250 days
Total Travel Days (7x52)	364 days

¹ Adjusted annually using the Consumer Price Index.

² Adjusted periodically using industry cost and logistics data.

*Source: (Reference 7,8)

Vehicle Occupancy

The average number of persons in each vehicle during peak period travel is 1.25.

Working Days and Weeks

With the addition of the INRIX speed data in the 2011 UMR, the calculations are based on a full year of data that includes all days of the week rather than just the working days. The delay from each day of the week is multiplied by 50 work weeks to annualize the delay. The weekend days are multiplied by 57 to help account for the lighter traffic days on holidays. Total delay for the year is based on 364 total travel days in the year.

Average Cost of Time

The 2010 value of person time used in the report is \$16.30 per hour based on the value of time, rather than the average or prevailing wage rate (7).

Commercial Vehicle Operating Cost

Truck travel time and operating costs (excluding diesel costs) are valued at \$88.12 per hour (8).

Urban Area Variables

In addition to the national constants, four urbanized area or state specific values were identified and used in the congestion cost estimate calculations.

Daily Vehicle-Miles of Travel

The daily vehicle-miles of travel (DVMT) is the average daily traffic (ADT) of a section of roadway multiplied by the length (in miles) of that section of roadway. This allows the daily volume of all urban facilities to be presented in terms that can be utilized in cost calculations. DVMT was estimated for the freeways and principal arterial streets located in each urbanized study area. These estimates originate from the HPMS database and other local transportation data sources.

Population, Peak Travelers and Commuters

Population data were obtained from a combination of U.S. Census Bureau estimates and the Federal Highway Administration's Highway Performance Monitoring System (HPMS) (1,9). Estimates of peak period travelers are derived from the National Household Travel Survey (NHTS) (10) data on the time of day when trips begin. Any resident who begins a trip, by any mode, between 6 a.m. and 10 a.m. or 3 p.m. and 7 p.m. is counted as a peak-period traveler. Data are available for many of the major urban areas and a few of the smaller areas. Averages for areas of similar size are used in cities with no specific data. The traveler estimate for some regions, specifically high tourism areas, may not represent all of the transportation users on an average day. These same data from NHTS was also used to calculate an estimate of commuters who were traveling during the peak periods by private vehicle—a subset of the peak period travelers.

Fuel Costs

Statewide average fuel cost estimates were obtained from daily fuel price data published by the American Automobile Association (AAA) (11). Values for gasoline and diesel are reported separately.

Truck Percentage

The percentage of passenger cars and trucks for each urban area was estimated from the Highway Performance Monitoring System dataset (1). The values are used to estimate congestion costs and are not used to adjust the roadway capacity.

Variable and Performance Measure Calculation Descriptions

The major calculation products are described in this section. In some cases the process requires the use of variables described elsewhere in this methodology.

Travel Speed

The peak period average travel speeds from INRIX are shown in Exhibit A-8 for the freeways and arterial streets. Also shown are the freeflow travel speeds used to calculate the delay-based measures in the report. These speeds are based on the “matched” traffic volume/speeds datasets as well as the “unmatched” traffic volume/speed datasets described in Step 7 of the “Process” description.

Exhibit A-8. 2010 Traffic Speed Data

Urban Area	Freeway		Arterial Streets		Urban Area	Freeway		Arterial Streets	
	Peak Speed	Freeflow Speed	Peak Speed	Freeflow Speed		Peak Speed	Freeflow Speed	Peak Speed	Freeflow Speed
Very Large Areas					Large Areas				
Atlanta GA	56.0	63.3	34.5	42.4	Minneapolis-St. Paul MN	51.4	60.1	35.1	42.1
Boston MA-NH-RI	55.3	62.5	29.8	35.9	Nashville-Davidson TN	57.2	62.1	39.6	46.0
Chicago IL-IN	49.4	58.2	29.0	35.5	New Orleans LA	51.5	60.8	31.1	38.2
Dallas-Fort Worth-Arlington TX	53.0	61.3	31.3	37.4	Orlando FL	57.3	62.5	33.7	40.8
Detroit MI	56.7	61.7	31.4	37.4	Pittsburgh PA	53.5	58.8	41.3	46.6
Houston TX	51.8	61.9	34.7	42.8	Portland OR-WA	48.6	56.5	36.2	42.0
Los Angeles-Long Beach-Santa Ana CA	47.3	60.3	29.9	37.1	Providence RI-MA	56.7	60.8	34.7	38.9
Miami FL	58.3	62.9	32.5	37.8	Raleigh-Durham NC	59.1	63.3	41.0	46.9
New York-Newark NY-NJ-CT	52.3	60.6	32.5	40.8	Riverside-San Bernardino CA	53.8	59.8	34.2	39.8
Philadelphia PA-NJ-DE-MD	55.3	61.5	34.0	40.6	Sacramento CA	53.2	59.6	32.2	38.7
Phoenix AZ	58.1	62.2	37.2	42.6	San Antonio TX	56.3	62.5	37.5	44.5
San Diego CA	55.9	62.3	34.0	40.5	Salt Lake UT	59.2	62.5	50.6	55.1
San Francisco-Oakland CA	51.8	60.5	29.8	36.4	San Jose CA	52.9	61.4	37.3	42.7
Seattle WA	49.1	58.9	30.6	37.0	San Juan PR	55.0	61.7	35.8	39.1
Washington DC-VA-MD	48.2	60.8	33.4	41.5	St. Louis MO-IL	57.4	60.0	35.1	40.3
					Tampa-St. Petersburg FL	60.4	63.8	36.0	42.5
Large Areas					Virginia Beach VA	54.6	60.0	36.9	43.2
Austin TX	48.4	61.2	39.2	49.5					
Baltimore MD	54.0	61.2	34.0	40.9					
Buffalo NY	55.4	58.9	36.4	41.1					
Charlotte NC-SC	56.8	62.2	35.8	42.5					
Cincinnati OH-KY-IN	56.7	59.9	38.8	42.7					
Cleveland OH	56.1	59.3	38.8	42.7					
Columbus OH	58.1	60.5	43.1	48.2					
Denver-Aurora CO	51.1	60.4	31.1	37.3					
Indianapolis IN	41.8	52.7	35.4	39.6					
Jacksonville FL	59.1	61.9	40.4	45.3					
Kansas City MO-KS	57.1	61.4	36.0	40.5					
Las Vegas NV	56.0	61.0	34.7	40.0					
Louisville KY-IN	57.5	60.3	36.0	41.6					
Memphis TN-MS-AR	55.5	59.5	39.8	44.1					
Milwaukee WI	54.1	60.4	39.7	43.2					

Exhibit A-8. 2010 Traffic Speed Data, continued

Urban Area	Freeway		Arterial Streets		Urban Area	Freeway		Arterial Streets	
	Peak Speed	Freeflow Speed	Peak Speed	Freeflow Speed		Peak Speed	Freeflow Speed	Peak Speed	Freeflow Speed
Medium Areas					Medium Areas				
Akron OH	58.4	59.2	36.7	40.3	Toledo OH-MI	59.2	60.1	37.5	41.6
Albany-Schenectady NY	59.8	62.0	33.1	38.4	Tucson AZ	60.7	60.0	35.8	41.3
Albuquerque NM	59.5	61.0	42.4	47.5	Tulsa OK	58.4	62.0	50.7	52.7
Allentown-Bethlehem PA-NJ	60.6	61.5	41.4	46.0	Wichita KS	58.3	60.4	45.1	51.3
Bakersfield CA	57.0	58.6	32.8	39.6					
Baton Rouge LA	53.5	61.7	39.5	47.2	Small Areas				
Birmingham AL	58.5	62.3	35.3	43.1	Anchorage AK	59.7	62.9	32.9	39.1
Bridgeport-Stamford CT-NY	51.9	62.0	28.9	34.7	Beaumont TX	60.4	63.5	45.7	50.0
Charleston-North Charleston SC	57.0	61.4	38.8	45.6	Boise ID	58.4	60.4	35.5	41.8
Colorado Springs CO	55.3	59.5	34.4	39.8	Boulder CO	47.1	55.0	31.9	37.6
Dayton OH	59.6	59.9	46.4	48.8	Brownsville TX	61.7	63.5	36.7	43.3
El Paso TX-NM	54.1	60.2	55.0	56.3	Cape Coral FL	67.4	65.0	40.1	46.3
Fresno CA	58.0	58.3	37.0	41.4	Columbia SC	60.9	63.1	32.8	38.3
Grand Rapids MI	60.4	61.0	41.2	46.9	Corpus Christi TX	62.7	64.0	63.0	63.9
Hartford CT	57.3	62.3	38.5	43.8	Eugene OR	54.6	56.8	43.1	46.9
Honolulu HI	0.0	0.0	34.1	41.9	Greensboro NC	59.5	61.5	35.6	41.8
Indio-Cathedral City-Palm Springs CA	58.5	59.5	35.9	38.9	Jackson MS	62.3	63.8	46.8	52.4
Knoxville TN	58.2	59.9	43.7	48.0	Laredo TX	58.1	60.8	32.6	38.6
Lancaster-Palmdale CA	59.7	60.5	43.6	47.9	Little Rock AR	59.8	63.1	33.8	38.4
McAllen TX	59.4	63.4	44.7	48.1	Madison WI	60.5	62.7	44.8	49.2
New Haven CT	59.1	63.0	40.3	47.2	Pensacola FL-AL	63.6	63.3	37.9	43.4
Oklahoma City OK	58.3	61.5	39.3	45.2	Provo UT	58.9	64.2	33.7	38.4
Omaha NE-IA	57.5	59.8	32.5	37.5	Salem OR	55.3	57.1	38.0	41.2
Oxnard-Ventura CA	56.4	60.6	46.3	49.5	Spokane WA	57.6	59.2	29.4	33.2
Poughkeepsie-Newburgh NY	61.5	62.3	42.6	46.8	Stockton CA	58.2	58.6	49.6	51.4
Richmond VA	61.1	62.5	37.1	42.3	Winston-Salem NC	59.4	61.5	38.4	43.7
Rochester NY	58.8	60.9	32.9	39.0	Worcester MA	61.2	62.7	37.5	41.8
Sarasota-Bradenton FL	67.8	65.0	39.0	44.2					
Springfield MA-CT	60.9	62.6	34.6	38.9					

Travel Delay

Most of the basic performance measures presented in the Urban Mobility Report are developed in the process of calculating travel delay—the amount of extra time spent traveling due to congestion. The travel delay calculations have been greatly simplified with the addition of the INRIX speed data. This speed data reflects the effects of both recurring delay (or usual) and incident delay (crashes, vehicle breakdowns, etc.). The delay calculations are performed at the individual roadway section level and for each hour of the week. Depending on the application, the delay can be aggregated into summaries such as weekday peak period, weekend, weekday off-peak period, etc.

$$\text{Daily Vehicle-Hours of Delay} = \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Speed}} - \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Free-Flow Speed}} \quad (\text{Eq. A-2})$$

Annual Person Delay

This calculation is performed to expand the daily vehicle-hours of delay estimates for freeways and arterial streets to a yearly estimate in each study area. To calculate the annual person-hours of delay, multiply each day-of-the-week delay estimate by the average vehicle occupancy (1.25 persons per vehicle) and by 50 working weeks per year (Equation A-3).

$$\text{Annual Persons-Hours of Delay} = \frac{\text{Daily Vehicle-Hours of Delay on Frwys and Arterial Streets}}{\text{Annual Conversion Factor}} \times \frac{1.25 \text{ Persons}}{\text{per Vehicle}} \quad (\text{Eq. A-3})$$

Annual Delay per Auto Commuter

Annual delay per auto commuter is a measure of the extra travel time endured throughout the year by auto commuters who make trips during the peak period. The procedure used in the Urban Mobility Report applies estimates of the number of people and trip departure times during the morning and evening peak periods from the National Household Travel Survey (10) to the urban area population estimate to derive the average number of auto commuters and number of travelers during the peak periods (15).

The delay calculated for each commuter comes from delay during peak commute times and delay that occurs during other times of the day. All of the delay that occurs during the peak hours of the day (6:00

a.m. to 10:00 a.m. and 3:00 p.m. to 7:00 p.m.) is assigned to the pool of commuters. In addition to this, the delay that occurs outside of the peak period is assigned to the entire population of the urban area. Equation A-4 shows how the delay per auto commuter is calculated. The reason that the off-peak delay is also assigned to the commuters is that their trips are not limited to just peak driving times but they also contribute to the delay that occurs during other times of the weekdays and the weekends.

$$\text{Delay per Auto Commuter} = \frac{\text{Peak Period Delay}}{\text{Auto Commuters}} + \frac{\text{Remaining Delay}}{\text{Population}} \quad (\text{Eq. A-4})$$

Annual Peak Period Major Road Travel Time

Total travel time can be used as both a performance measure and as a component in other calculations. The 2010 Urban Mobility Report used travel time as a component; future reports will incorporate other information and expand on the use of total travel time as a performance measure.

Total travel time is the sum of travel delay and free-flow travel time. Both of the quantities are only calculated for freeways and arterial streets. Free-flow travel time is the amount of time needed to travel the roadway section length at the free-flow speeds (provided by INRIX for each roadway section) (Equation A-5).

$$\text{Annual Free-Flow Travel Time (Vehicle-Hours)} = \frac{1}{\text{Free-Flow Travel Speed}} \times \text{Daily Vehicle-Miles of Travel} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-5})$$

$$\text{Annual Travel Time} = \text{Freeway Delay} + \text{Arterial Street Delay} + \text{Freeway Free-Flow Travel Time} + \text{Arterial Free-Flow Travel Time} \quad (\text{Eq. A-6})$$

Travel Time Index

The Travel Time Index (TTI) compares peak period travel time to free-flow travel time. The Travel Time Index includes both recurring and incident conditions and is, therefore, an estimate of the conditions faced by urban travelers. Equation A-5 illustrates the ratio used to calculate the TTI. The ratio has units of time divided by time and the Index, therefore, has no units. This “unitless” feature allows the Index

to be used to compare trips of different lengths to estimate the travel time in excess of that experienced in free-flow conditions.

The free-flow travel time for each functional class is subtracted from the average travel time to estimate delay. The Travel Time Index is calculated by comparing total travel time to the free-flow travel time (Equations A-7 and A-8).

$$\text{Travel Time Index} = \frac{\text{Peak Travel Time}}{\text{Free-Flow Travel Time}} \quad (\text{Eq. A-7})$$

$$\text{Travel Time Index} = \frac{\text{Delay Time} + \text{Free-Flow Travel Time}}{\text{Free-Flow Travel Time}} \quad (\text{Eq. A-8})$$

Commuter Stress Index

The Commuter Stress Index (CSI) is the same as the TTI except that it includes only the travel in the peak directions during the peak periods; the TTI includes travel in all directions during the peak period. Thus, the CSI is more indicative of the work trip experienced by each commuter on a daily basis.

Wasted Fuel

The average fuel economy calculation is used to estimate the difference in fuel consumption of the vehicles operating in congested and uncongested conditions. Equations A-9 and A-10 are the regression equations resulting from fuel efficiency data from EPA/FHWA's MOVES model (16).

$$\text{Passenger Car Fuel Economy} = 0.0066 \times (\text{speed})^2 + 0.823 \times (\text{speed}) + 6.1577 \quad (\text{Eq. A-9})$$

$$\text{Truck Fuel Economy} = 1.4898 \times \ln \text{ speed} - 0.2554 \quad (\text{Eq. A-10})$$

The Urban Mobility Report calculates the wasted fuel due to vehicles moving at speeds slower than free-flow throughout the day. Equation A-11 calculates the fuel wasted in delay conditions from Equation A-3, the average hourly speed, and the average fuel economy associated with the hourly speed (Equation A-9 and A-10).

$$\text{Annual Fuel Wasted} = \frac{\text{Travel Time}}{\text{Eq. A-5}} \times \frac{\text{Average Hourly Speed}}{\text{Eq. A-2}} \div \frac{\text{Average Fuel Economy}}{\text{Eq. A-9,10}} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-11})$$

Equation A-12 incorporates the same factors to calculate fuel that would be consumed in free-flow conditions. The fuel that is deemed “wasted due to congestion” is the difference between the amount consumed at peak speeds and free-flow speeds (Equation A-11).

$$\text{Annual Fuel Consumed in Free-Flow Conditions} = \frac{\text{Travel Time}}{\text{Eq. A-5}} \times \frac{\text{Free-Flow Speed from INRIX Data}}{\text{Free-Flow Speeds}} \div \frac{\text{Average Fuel Economy for Free-Flow Speeds}}{\text{Free-Flow Speeds}} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-12})$$

$$\text{Annual Fuel Wasted in Congestion} = \frac{\text{Annual Fuel Consumed in Congestion}}{\text{Congestion}} - \frac{\text{Annual Fuel That Would be Consumed in Free-flow Conditions}}{\text{in Free-flow Conditions}} \quad (\text{Eq. A-13})$$

Total Congestion Cost and Truck Congestion Cost

Two cost components are associated with congestion: delay cost and fuel cost. These values are directly related to the travel speed calculations. The following sections and Equations A-14 through A-16 show how to calculate the cost of delay and fuel effects of congestion.

Passenger Vehicle Delay Cost. The delay cost is an estimate of the value of lost time in passenger vehicles in congestion. Equation A-14 shows how to calculate the passenger vehicle delay costs that result from lost time.

$$\text{Annual Psgr-Veh Delay Cost} = \frac{\text{Daily Psgr Vehicle Hours of Delay}}{\text{Eq. A-4}} \times \frac{\text{Value of Person Time}}{\text{($ / hour)}} \times \frac{\text{Vehicle Occupancy}}{\text{(pers vehicle)}} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-14})$$

Passenger Vehicle Fuel Cost. Fuel cost due to congestion is calculated for passenger vehicles in Equation A-15. This is done by associating the wasted fuel, the percentage of the vehicle mix that is passenger, and the fuel costs.

$$\text{Annual Fuel Cost} = \frac{\text{Daily Fuel Wasted}}{\text{(Eq. A-13)}} \times \frac{\text{Percent of Passenger Vehicles}}{\text{Vehicles}} \times \text{Gasoline Cost} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-15})$$

Truck or Commercial Vehicle Delay Cost. The delay cost is an estimate of the value of lost time in commercial vehicles and the increased operating costs of commercial vehicles in congestion. Equation A-16 shows how to calculate the passenger vehicle delay costs that result from lost time.

$$\text{Annual Comm-Veh Delay Cost} = \frac{\text{Daily Comm Vehicle Hours of Delay}}{\text{(Eq. A-4)}} \times \frac{\text{Value of Comm Vehicle Time}}{\text{(\$ / hour)}} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-16})$$

Truck or Commercial Vehicle Fuel Cost. Fuel cost due to congestion is calculated for commercial vehicles in Equation A-16. This is done by associating the wasted fuel, the percentage of the vehicle mix that is commercial, and the fuel costs.

$$\text{Annual Fuel Cost} = \frac{\text{Daily Fuel Wasted}}{\text{(Eq. A-13)}} \times \frac{\text{Percent of Commercial Vehicles}}{\text{Vehicles}} \times \text{Diesel Cost} \times \text{Annual Conversion Factor} \quad (\text{Eq. A-17})$$

Total Congestion Cost. Equation A-18 combines the cost due to travel delay and wasted fuel to determine the annual cost due to congestion resulting from incident and recurring delay.

$$\text{Annual Cost Due to Congestion} = \frac{\text{Annual Passenger Vehicle Delay Cost}}{\text{Eq. A-14}} + \frac{\text{Annual Passenger Fuel Cost}}{\text{Eq. A-15}} + \frac{\text{Annual Comm Veh Delay Cost}}{\text{Eq. A-16}} + \frac{\text{Annual Comm Veh Fuel Cost}}{\text{(Eq A-17)}} \quad (\text{Eq. A-18})$$

Truck Commodity Value

The data for this performance measure came from the Freight Analysis Framework (FAF) and the Highway Performance Monitoring System (HPMS) from the Federal Highway Administration. The basis of this measure is the integration of the commodity value supplied by FAF and the truck vehicle-miles of travel (VMT) calculated from the HPMS roadway inventory database.

There are 5 steps involved in calculating the truck commodity value for each urban area.

1. Calculate the national commodity value for all truck movements
2. Calculate the HPMS truck VMT percentages for states, urban areas and rural roadways

3. Estimate the state and urban commodity values using the HPMS truck VMT percentages
4. Calculate the truck commodity value of origins and destinations for each urban area
5. Average the VMT-based commodity value with the origin/destination-based commodity value for each urban area.

Step 1 - National Truck Commodity Value. The FAF (version 3) database has truck commodity values that originate and end in 131 regions of the U.S. The database contains a 131 by 131 matrix of truck goods movements (tons and dollars) between these regions. Using just the value of the commodities that originate within the 131 regions, the value of the commodities moving within the 131 regions is determined (if the value of the commodities destined for the 131 regions was included also, the commodity values would be double-counted). The FAF database has commodity value estimates for different years. The base year for FAF-3 is 2007 with estimates of commodity values in 2010 through 2040 in 5-year increments. The 2008 and 2009 commodity value was estimated using a constant percentage growth trend between the 2007 and 2010 FAF values.

Step 2 – Truck VMT Percentages. The HPMS state truck VMT percentages are calculated in Equation A-19 using each state’s estimated truck VMT and the national truck VMT. This percentage will be used to approximate total commodity value at the state level.

$$\text{State Truck VMT Percentage} = \frac{\text{State Truck VMT}}{\text{U.S. Truck VMT}} \times 100\% \quad (\text{Eq. A-19})$$

The urban percentages within each state are calculated similarly, but with respect to the state VMT. The equation used for the urban percentage is given in Equation A-20. The rural truck VMT percentage for each state is shown in Equation A-21.

$$\text{State Urban Truck VMT Percentage} = \frac{\text{State Urban Truck VMT}}{\text{State Truck VMT}} \times 100\% \quad (\text{Eq. A-20})$$

$$\text{State Rural Truck VMT Percentage} = 100\% - \text{State Urban Truck VMT Percentage} \quad (\text{Eq. A-21})$$

The urban area truck VMT percentage is used in the final calculation. The truck VMT in each urban area in a given state is divided by all of the urban truck VMT for the state (Equation A-20).

$$\text{Urban Area Truck VMT Percentage} = \frac{\text{Urban Area Truck VMT}}{\text{State Urban Truck VMT}} \quad (\text{Eq. A-22})$$

Step 3 – Estimate State and Urban Area VMT from Truck VMT percentages. The national estimate of truck commodity value from Step 1 is used with the percentages calculated in Step 2 to assign a VMT-based commodity value to the urban and rural roadways within each state and to each urban area.

$$\text{State Urban Truck VMT-Based Commodity Value} = \text{U. S. Truck Commodity Value} \times \text{State Urban Truck Percentage} \quad (\text{Eq. A-23})$$

$$\text{State Rural Truck VMT-Based Commodity Value} = \text{U. S. Truck Commodity Value} \times \text{State Rural Truck Percentage} \quad (\text{Eq. A-24})$$

$$\text{Urban Area Truck VMT-Based Commodity Value} = \frac{\text{State Urban Truck VMT-Based Commodity Value}}{\text{Urban Area Truck VMT Percentage}} \quad (\text{Eq. A-25})$$

Step 4 – Calculate Origin/Destination-Based Commodity Value. The results in Step 3 show the commodity values for the U.S. distributed based on the truck VMT flowing through states in both rural portions and urban areas. The Step 3 results place equal weighting on a truck mile in a rural area and a truck mile in an urban area. Step 4 redistributes the truck commodity values with more emphasis placed on the urban regions where the majority of the truck trips were originating or ending.

The value of commodities with trips that began or ended in each of the 131 FAF regions was calculated and the results were combined to get a total for the U.S. The percentage of the total U.S. origin/destination-based commodity values corresponding to each of the FAF regions, shown in Equations A-26 and A-27, was calculated and these percentages were used to redistribute the national freight commodity value estimated in Step 1 that were based only on the origin-based commodities. Equation A-28 shows that this redistribution was first done at the state level by summing the FAF regions within each state. After the new state commodity values were calculated, the commodity values were assigned to each urban area within each state based on the new percentages calculated from the origin/destination-based commodity data. Urban areas not included in a FAF region were assigned a commodity value based on their truck VMT relative to all the truck VMT which remained unassigned to a FAF region (Equation A-29).

$$\text{FAF Region O/D-Based Commodity Value \%} = \frac{\text{FAF Region O/D-Based Commodity Value}}{\text{U.S. O/D-Based Commodity Value}} \times 100\% \quad (\text{Eq. A-26})$$

$$\text{FAF Region O/D-Based Commodity Value} = \text{FAF Region O/D-Based Commodity Value \%} \times \text{U.S. O/D-Based Commodity Value} \quad (\text{Eq. A-27})$$

$$\text{O/D-Based Commodity Value for State 1} = \text{FAF Region 1 Value from State 1} + \text{FAF Region 2 Value from State 1} \quad (\text{Eq. A-28})$$

$$\text{Non-FAF Region Urban Area O/D-Based Commodity Value from State 1} = \text{Remaining Unassigned State 1 FAF O/D-Based Commodity Value} \times \frac{\text{Non-FAF Urban Area Truck VMT Percentage}}{\text{Remaining Unassigned State 1 Truck VMT Percentage}} \quad (\text{Eq. A-29})$$

Step 5 – Final Commodity Value for Each Urban Area. The VMT-based commodity value and the O/D-based commodity value were averaged for each urban area to create the final commodity value to be presented in the Urban Mobility Report.

$$\text{Final Commodity Value for Urban Area} = \frac{\text{Urban Area VMT-Based Commodity Value} + \text{Urban Area O/D-Based Commodity Value}}{2} \quad (\text{Eq. A-30})$$

Roadway Congestion Index

Early versions of the Urban Mobility Report used the roadway congestion index as a primary measure. While other measures that define congestion in terms of travel time and delay have replaced the RCI, it is still a useful performance measure in some applications. The RCI measures the density of traffic across the urban area using generally available data. Urban area estimates of vehicle-miles of travel (VMT) and lane-miles of roadway (Ln-Mi) are combined in a ratio using the amount of travel on each portion of the system. The combined index measures conditions on the freeway and arterial street systems according to the amount of travel on each type of road (Eq. A-31). This variable weighting factor allows comparisons between areas that carry different percentages of regional vehicle travel on arterial streets and freeways. The resulting ratio indicates an undesirable level of areawide congestion if the index value is greater than or equal to 1.0.

The traffic density ratio (VMT per lane-mile) is divided by a value that represents congestion for a system with the same mix of freeway and street volume. The RCI is, therefore, a measure of both intensity and duration of congestion. While it may appear that the travel volume factors (e.g., freeway VMT) on the top and bottom of the equation cancel each other, a sample calculation should satisfy the reader that this is not the case.

$$\text{Roadway Congestion Index} = \frac{\text{Freeway VMT Ln. Mi.} \times \text{Freeway VMT} + \text{Prin Art Str VMT Ln. Mi.} \times \text{Prin Art Str VMT}}{14,000 \times \text{Freeway VMT} + 5,000 \times \text{Prin Art Str VMT}} \quad (\text{Eq. A-31})$$

An Illustration of Travel Conditions When an Urban Area RCI Equals 1.0

The congestion index is a macroscopic measure which does not account for local bottlenecks or variations in travel patterns that affect time of travel or origin-destination combinations. It also does not include the effect of improvements such as freeway entrance ramp signals, or treatments designed to give a travel speed advantage to transit and carpool riders. The urban area may see several of the following effects:

- Typical commute time 25% longer than off-peak travel time.
- Slower moving traffic during the peak period on the freeways, but not sustained stop-and-go conditions.
- Moderate congestion for 1 1/2 to 2 hours during each peak-period.
- Wait through one or two red lights at heavily traveled intersections.
- The RCI includes the effect of roadway expansion, demand management, and vehicle travel reduction programs.
- The RCI does not include the effect of operations improvements (e.g., clearing accidents quickly, regional traffic signal coordination), person movement efficiencies (e.g., bus and carpool lanes) or transit improvements (e.g., priority at traffic signals).
- The RCI does not address situations where a traffic bottleneck means much less capacity than demand over a short section of road (e.g., a narrow bridge or tunnel crossing a harbor or river), or missing capacity due to a gap in the system.
- The urban area congestion index averages all the developments within an urban area; there will be locations where congestion is much worse or much better than average.

Number of “Rush Hours”

The length of time each day that the roadway system contains congestion is presented as the number of “rush hours” of traffic. This measure is calculated differently than under previous methodologies. The average Travel Time Index is calculated for each urban area for each hour of the average weekday. The TTI for each hour of the day and the population of the urban area *determine the number of “rush hours”*.

For each hour of the average weekday in each urban area, the TTI values are analyzed with the criteria in Exhibit A-9. For example, if the TTI value meets the highest criteria, the entire hour is considered congested. The TTI values in these calculations are based on areawide statistics. In order to be considered a “rush hour” the amount of congestion has to meet a certain level of congestion to be considered areawide. In the case of Very Large urban areas, the minimum TTI value for a portion of an hour to be considered congested is 1.12.

Exhibit A-9. Estimation of Rush Hours

Population Group	TTI Range	Number of Hours of Congestion
Very Large	Over 1.22	1.00
	1.17-1.22	0.50
	1.12-1.17	0.25
	Under 1.12	0.00
Large	Over 1.20	1.00
	1.15-1.20	0.50
	1.10-1.15	0.25
	Under 1.10	0.00
Medium/Small	Over 1.17	1.00
	1.12-1.17	0.50
	1.07-1.12	0.25
	Under 1.07	0.00

The following two measures are not based on the INRIX speeds and the new methodology. Due to some low match rates in some of the urban areas between the INRIX speed network and the HPMS roadway inventory data and because we currently use hourly speed and volume data instead of 15-minute, these measures are based on the previous methodology with estimated speeds. In the future as the match rate improves, these measures will be based on the new methodology with measured speeds.

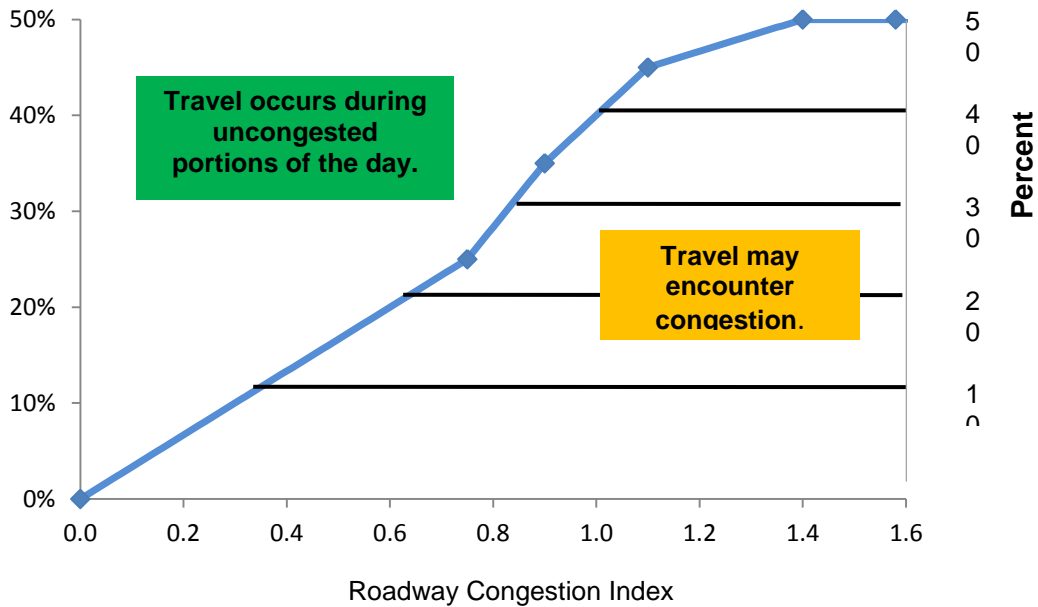
Percent of Daily and Peak Travel in Congested Conditions

Traditional peak travel periods in urban areas are the morning and evening “rush hours” when slow speeds are most likely to occur. The length of the peak period is held constant—essentially the most traveled four hours in the morning and evening—but the amount of the peak period that may suffer congestion is estimated separately. Large urban areas have peak periods that are typically longer than smaller or less congested areas because not all of the demand can be handled by the transportation network during a single hour. The congested times of day have increased since the start of the UMR.

These percentages have been estimated again for the 2010 UMR. The historical measured speed data will make it possible in future reports to calculate the travel that occurs at a speed that is under a certain congestion threshold speed. However, in this report, the travel percentages were estimated using the process described below as changes to the methodology were not incorporated prior to this release.

Exhibit A-10 illustrates the estimation procedure used for all urban areas. The UMR procedure uses the Roadway Congestion Index (RCI)—a ratio of daily traffic volume to the number of lane-miles of arterial street and freeway—to estimate the length of the peak period. In this application, the RCI acts as an indicator of the number of hours of the day that might be affected by congested conditions (a higher RCI value means more traffic during more hours of the day). Exhibit A-10 illustrates the process used to estimate the amount of the day (and the amount of travel) when travelers might encounter congestion. Travel during the peak period, but outside these possibly congested times, is considered uncongested and is assigned a free-flow speed. The maximum percentage of daily travel that can be in congestion is 50 percent which is also the maximum amount of travel that can occur in the peak periods of the day. The percentage of peak period travel that is congested comes from the 50 percent of travel that is assigned to the peak periods.

Exhibit A-10. Percent of Daily Travel in Congested Conditions



Percent of Congested Travel

The percentage of travel in each urban area that is congested both for peak travel and daily travel can be calculated. The equations are very similar with the only difference being the amount of travel in the denominator. For calculations involving only the congested periods (Equations A-32 and A-33), the amount of travel used is half of the daily total since the assumption is made that only 50 percent of daily travel occurs in the peak driving times. For the daily percentage (Equation A-34), the factor in the denominator is the daily miles of travel.

$$\text{Peak Period Congested Travel} = \frac{\text{Percent of Congested Peak Period Travel}}{\text{Peak Period Travel}} \times \text{VMT for Roadway Type} \quad (\text{Eq. A-32})$$

$$\text{Percent Congested Peak Period Travel} = \frac{\text{Percent Congested Daily Travel}}{\text{Daily Travel}} \div 50 \text{ percent} \quad (\text{Eq. A-33})$$

$$\text{Percent Congested Daily Travel} = \frac{\text{Freeway Congested Travel} + \text{Arterial Congested Travel}}{\text{Daily Travel}} \quad (\text{Eq. A-34})$$