Appendix A
Methodology for the 2012 Urban Mobility Report

The procedures used in the 2012 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 2012 Urban Mobility Report. This methodology incorporates private sector traffic speed data from INRIX for calendar year 2011 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 2012 UMR

There are several changes to the UMR methodology for the 2012 report. The largest changes have to do with estimates of CO₂ emissions for the first time, updated methods for computing wasted fuel based upon the CO₂ emissions, the addition of the Planning Time Index reliability measure, and INRIX data being reported in 15-minute time intervals. These changes are documented in more detail in the following sections of the Methodology. Here are brief summaries of what has changed:

- Additional carbon dioxide (CO₂) greenhouse gas emissions due to congestion are included for the first time. The procedure is based on the Environmental Protection Agency’s Motor Vehicle Emission Simulator (MOVES) modeling procedure.
- Wasted fuel is estimated using the additional carbon dioxide greenhouse gas emissions due to congestion for each urban area. For the first time, this method allows for consideration of urban area climate in emissions and fuel consumption calculations.
- A measure of the variation in travel time from day-to-day is introduced. The Planning Time Index (PTI) is based on the idea that travelers would want to be on-time for an important trip 19 out of 20 times; so one would be late only one day per month (on-time for 19 out of 20 work days each month). A PTI value of 3.00 indicates that a traveler should allow 60 minutes to make an important trip that takes 20 minutes in uncongested traffic. In essence,
the 19th worst commute is affected by crashes, weather, special events, and other causes of unreliable travel and can be improved by a range of transportation improvement strategies.

- Speeds supplied by INRIX are collected every 15-minutes from a variety of sources every day of the year on most major roads.

**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 are necessary to accomplish this.

Calculation procedures use a dataset of traffic speeds from INRIX, a private company that provides travel time information to a variety of customers. INRIX’s 2011 data is an annual average of traffic speed for each section of road for every 15 minutes of each day for a total of 672 day/time period cells (24 hours x 7 days x 4 periods per hour).

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 2011 private sector traffic speed data provide a better data source for the first two inputs, actual and free-flow travel time. The UMR analysis requires 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 were 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.

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2012 Urban Mobility Report Methodology
http://mobility.tamu.edu/ums/congestion-data/
### Exhibit A-1. Day of Week Volume Conversion Factors

<table>
<thead>
<tr>
<th>Day of Week</th>
<th>Adjustment Factor (to convert average annual volume into day of week volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday to Thursday</td>
<td>+5%</td>
</tr>
<tr>
<td>Friday</td>
<td>+10%</td>
</tr>
<tr>
<td>Saturday</td>
<td>-10%</td>
</tr>
<tr>
<td>Sunday</td>
<td>-20%</td>
</tr>
</tbody>
</table>

**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)

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• 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

![Weekend Traffic Distribution Profile Graph](http://mobility.tamu.edu/ums/congestion-data/)

- **Freeway Weekend**
- **Non-Freeway Weekend**
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.

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

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 2011 UMR. The percentage of arterial streets that had INRIX speed data is approximately 65 percent across the U.S. while the freeway match percentage is approximately 90 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 were then aggregated such that it was treated like one large traffic count for freeways and another for street sections.

The unmatched speed data were separated by county also. All of the speed data and freeflow speed data were 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 were 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) Total Peak Period Travel Time
   6) Travel Time Index
   7) Commuter Stress Index
   8) Planning Time Index
   9) Carbon Dioxide (CO₂) Production and Wasted Fuel
   10) Total Congestion Cost and Truck Congestion Cost
   11) Truck Commodity Value
   12) Roadway Congestion Index
   13) Number of Rush Hours
   14) Percent of Daily and Peak Travel in Congested Conditions
   15) 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.


<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Occupancy</td>
<td>1.25 persons per vehicle</td>
</tr>
<tr>
<td>Average Cost of Time ($2011)*</td>
<td>$16.79 per person hour(^1)</td>
</tr>
<tr>
<td>Commercial Vehicle Operating Cost ($2011)</td>
<td>$86.81 per vehicle hour(^{1,2})</td>
</tr>
<tr>
<td>Total Travel Days (7x52)</td>
<td>364 days</td>
</tr>
</tbody>
</table>

\(^1\) 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 52 work weeks to annualize the delay. 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 $16.79 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 $86.81 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 were 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.

*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.

\[
\text{Daily Vehicle-Hours of Delay} = \left( \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Speed}} \right) - \left( \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Free-Flow Speed}} \right) \tag{Eq. A-2}
\]
### Exhibit A-8. 2010 Traffic Speed Data

<table>
<thead>
<tr>
<th>Urban Area</th>
<th>Freeway</th>
<th>Arterial Streets</th>
<th></th>
<th>Freeway</th>
<th>Arterial Streets</th>
<th></th>
<th>Freeway</th>
<th>Arterial Streets</th>
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<tbody>
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<td>Freeflow Speed</td>
<td>Peak</td>
<td>Freeflow Speed</td>
<td>Urban Area</td>
<td></td>
<td>Peak</td>
<td>Freeflow Speed</td>
<td>Peak</td>
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<td>Speed</td>
<td>Speed</td>
<td>Speed</td>
<td>Large Areas</td>
<td></td>
<td>Speed</td>
<td>Speed</td>
<td>Speed</td>
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<td>Atlanta GA</td>
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<td>64.7</td>
<td>36.3</td>
<td>44.1</td>
<td>Minneapolis-St. Paul MN</td>
<td>54.3</td>
<td>63.8</td>
<td>39.6</td>
<td>43.1</td>
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<tr>
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<td>Nashville-Davidson TN</td>
<td>57.2</td>
<td>64.1</td>
<td>34.2</td>
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<td>Chicago IL-IN</td>
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<td>New Orleans LA</td>
<td>54.9</td>
<td>63.2</td>
<td>39.6</td>
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<td>Dallas-Fort Worth-Arlington TX</td>
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<td>33.9</td>
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<td>39.2</td>
<td>Raleigh-Durham NC</td>
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<td>64.7</td>
<td>37.5</td>
<td>43.1</td>
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<td>63.6</td>
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## Exhibit A-8. 2010 Traffic Speed Data, continued

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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 52 weeks per year (Equation A-3).

\[
\text{Annual Persons-Hours of Delay} = \frac{\text{Daily Vehicle-Hours of Delay on Frwys and Arterial Streets}}{52 \text{ Weeks} \times 1.25 \text{ Persons per Vehicle}} \quad (\text{Eq. A-3})
\]

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.

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

Total Peak Period Travel Time
This and future reports will expand on the use of total peak period travel time as a performance measure using supplemental information. In this report, travel time is reported during the peak period by commuters in minutes.

Total travel time is the sum of travel delay and free-flow travel time. Beginning in the 2012 Urban Mobility Report, both quantities are calculated for freeways, arterial, collector, and local streets. Previously, peak period travel time excluded collector and local streets because data were largely unavailable and incomplete. Though still sparse, these data elements have been included this year, offering a refinement to previous efforts. As data become more available, so will the measure’s refinement.

For this report, the four roadway classifications have been grouped into two primary categories: primary roads (freeways and arterials) and minor roads (collectors and local streets).

Total peak period daily delay is the amount of extra time spent traveling during the morning peak hours of 6:00 a.m. and 10:00 a.m. and the evening peak hours of 3:00 p.m. and 7:00 p.m. due to congestion. Equation A-5 is modeled after Equation A-2 but includes factors to convert daily delay into peak period delay and vehicle-hours into a person hours.

\[
\text{Peak Period Daily Delay (Person-Hours)} = \left( \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Speed}} \right) - \left[ \frac{\text{Daily Vehicle-Miles of Travel}}{\text{Free-Flow Speed}} \right] \times \text{Percent of Vehicle Miles of Travel During the Peak} \times 1.25 \text{ Persons per Vehicle} \quad (\text{Eq. A-5})
\]

Total peak period 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) during the day’s peak hours (Equation A-6). Equation A-6 converts vehicle hours to person hours.

\[
\text{Peak Free-Flow Travel Time (Person-Hours)} = \frac{1}{\text{Free-Flow Travel Speed}} \times \text{Daily Vehicle-Miles of Travel} \times \text{Percent of Vehicle Miles of Travel During the Peak} \times 1.25 \text{ Persons per Vehicle} \quad (\text{Eq. A-6})
\]

Peak period travel time is the sum of peak period delay and free-flow travel time for each roadway type (both primary and minor roads) (Equation A-7). The metric considers commuters rather than the total population to reflect actual travel time for those experiencing the worst congestion.
\[
\text{Total Daily Peak Period Travel Time (Minutes per Commuter)} = \left( \frac{\text{Primary Road Peak Delay} + \text{Minor Road Peak Delay}}{\text{Auto Commuters}} + \frac{\text{Primary Road Peak Free-Flow Travel Time} + \text{Minor Road Peak Free-Flow Travel Time}}{60 \text{ Minutes}} \right) \times 60 \text{ Minutes} \quad \text{(Eq. A-7)}
\]
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 A85 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-8 and A-9).

\[
\text{Travel Time Index} = \frac{\text{Peak Travel Time}}{\text{Free-Flow Travel Time}} \quad \text{(Eq. A-8)}
\]

\[
\text{Travel Time Index} = \frac{\text{Delay Time} + \text{Free-Flow Travel Time}}{\text{Free-Flow Travel Time}} \quad \text{(Eq. A-9)}
\]

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.

Planning Time Index (Freeway Only)

The Planning Time Index (PTI) is new to the 2012 Urban Mobility Report. Results are shown in Table 3. The PTI values in Table 3 are for freeways only. On pages 7 and 10 of the report, researchers discuss unreliable travel in more detail. Appendix B also has discussion of the PTI and unreliable travel.

The PTI is computed as the 95\(^{th}\) percentile travel time relative to the free-flow travel time as shown in Equation A-10. The PTI\(_{80}\) shown in Equation A-11 is computed as the 80\(^{th}\) percentile travel time relative to the free-flow travel time. Both the PTI and PTI\(_{80}\) computations are performed with the 15-minute data and aggregated up to the urban area by weighting by passenger-miles of travel (PMT).
The PTI value represents the “worst trip of the month” and the PTI₈₀ value represents the “worst trip of the week.” The authors of the UMR present both because the PTI is the preferred measure for individual commuters or truck drivers delivering goods – they need to allow more times for urgent trips. However, the PTI₈₀ value is also presented because bad weather is often the cause for the longest travel times, and it really is not fair to measure an agency on these situations they have no impact upon.

Therefore, the PTI₈₀ measure is introduced, and transportation improvements can impact this measure.

Exhibit A-9 shows an illustration of a distribution of travel times for a morning commute. It illustrates over a calendar year how travel times can vary and their typical causes in extreme cases. It also quantifies and illustrates the relationship between the free-flow travel time, average travel time, 80th percentile travel time, and 95th percentile travel time.
Exhibit A-9. Example of Morning Commute Travel Time Distribution

Is Your Morning Commute Time the Same Each Day? – **No, It Varies!**

- **20 minutes** is your free-flow travel time (commute time when few other cars are on the road).
- **30 minutes** is your average travel time (of all 250 morning workday trips in the year).
- **38 minutes** is the worst day of the week. Allow this much time to only be late for work one day a week (sometimes called the **95th percentile travel time**).

You have to leave home by 7 a.m. to be sure that you are at your job by 8 a.m. (sometimes called the **95th percentile travel time**), allowing this much time ensures you plan for the worst day of the month. Note that this is 3 times your free-flow travel time.

Federal Holiday – you speed to work in 22 minutes because traffic is light!

Several of your trips from April to August were delayed by construction.

Last year, before the construction – life was better then.

2 lanes were closed by a multi-vehicle crash on December 8th.

Unexpected downpour on July 12th!

Who can forget that Jan 17th blizzard?
Carbon Dioxide (CO₂) Production and Wasted Fuel

This methodology uses data from the United States Environmental Protection Agency’s (EPA) MOtor Vehicle Emission Simulator (MOVES) model. MOVES is a model developed by the EPA to estimate emissions from mobile sources. Researchers primarily used MOVES to obtain vehicle emission rates, climate data, and vehicle fleet composition data.

The methodology uses data from three primary data sources: 1) the FHWA’s HPMS, 2) INRIX traffic speed data, and 3) EPA’s MOVES model. Five steps are implemented in the methodology:

1. Group Similar Urban Areas – considers seasonal variations and the percentage of travel that occurs with the air conditioner “on,” which impacts CO₂ production.
2. Obtain CO₂ Emission Rates for Urban Area Group – emission rates (in grams per mile) were created for each of the 14 groups from Step #1.
3. Fit Curves to CO₂ Emission Rates – curves were created relating speed and emission rates from Step #2.
4. Calculate CO₂ Emissions and Fuel Consumption During Congested Conditions – combine speed, volume and emission rates to calculate emissions during congested conditions. Estimate fuel consumption using factors that relate the amount of gas (or diesel for trucks) produced for the CO₂ emissions produced.
5. Estimate the CO₂ Emissions and Fuel Consumption During Free-flow Conditions, and Estimate Wasted Fuel and CO₂ Due to Congestion – repeat the calculations from Step #4 using the free-flow speeds when few cars are on the road. Free-flow results are subtracted from congested-conditions results to obtain CO₂ emissions and fuel wasted due to congestion.

Step 1. Group Similar Urban Areas

For some pollutants, the influence of weather conditions causes vehicle tail-pipe emissions to vary considerably by location. Tail-pipe CO₂ emissions, however, are not directly influenced by weather conditions, although they still vary by location because they are influenced by air conditioning use. Traveling with the air conditioner turned “on” lowers fuel efficiency and increases CO₂ emission rates.
Thus, locations with warmer climates typically have higher emission rates because more travel occurs with the air conditioner turned “on.”

It was not feasible to use emission rates for every county in the United States, so researchers instead created representative climate-type groups to account for the impact of climate on CO₂ emission rates. To create these groups, TTI researchers grouped the UMR urban areas based on similar seasonal “AConFraction” (ACF) values—a term used in MOVES to indicate the fraction of travel that occurs with the air conditioner turned “on.” For example, a vehicle traveling 100 miles with an ACF of 11 percent would travel 11 of those 100 miles with the air conditioner turned “on.”

Because ACF is a factor of temperature and relative humidity, researchers collected hourly temperature and relative humidity data for a county within each urban area included in TTI’s UMR from the MOVES database. Researchers collected the climate data by county, rather than urban area (or city), because the MOVES database only has climate data available by county.

For simplicity, one county per urban area (or city) was selected because the climate differences between adjacent counties were not significant.

TTI researchers used methods similar to those used in MOVES to calculate the seasonal “AConFraction” (ACF) for each county. Researchers developed seasonal ACFs based on hourly temperature and relative humidity data from MOVES. They used this hourly data to calculate hourly ACFs, which they then weighted by hourly traffic volume data from MOVES and averaged for each month. To produce the weighted seasonal ACFs, researchers averaged these weighted monthly ACFs over three-month periods for the seasons defined by MOVES.

To group the counties (or urban areas) based on similar seasonal climates, researchers used temperature and relative humidity scatter plots to visually identify which counties had similar climates. To refine the tentative groups, researchers previewed each group’s average seasonal ACF values and removed any counties that differed from the group averages. The standard to which researchers allowed a county to vary from the average was approximately 5 to 10 percent or less. Researchers determined this margin for error during the grouping process based on the need to create a manageable number of groups without sacrificing accuracy. Several counties did not share similar seasonal ACF values with any group, so they retained their original values and would be calculated individually.

Exhibit A-10 shows the groupings of urban areas.

2012 Urban Mobility Report Methodology
http://mobility.tamu.edu/ums/congestion-data/
Step 2. Obtain CO₂ Emission Rates for Urban Area Group

TTI researchers used MOVES to produce emission rates for different vehicle types and locations. Researchers used these emission rates by combining them with volume and speed data to incorporate CO₂ emissions as described in Step 4. Researchers produced emission rates for every ACF value assigned to the groups in Step 1. For each ACF value, researchers produced emission rates for each vehicle type, fuel type, and road type used in the UMR.

MOVES has many different vehicle classifications, but TTI’s UMR has just three broad categories: light-duty vehicles, medium-duty trucks, and heavy-duty trucks. To obtain emission rates, researchers selected MOVES vehicle types that were most similar to the vehicle types of the UMR.
Multiple “SourceType”s from MOVES meet the description of each vehicle type used in TTI’s UMR (light-duty vehicles, medium-duty trucks, and heavy-duty trucks). For example, both the combination short-haul and combination long-haul trucks qualify as heavy-duty trucks. Rather than weighting the emission rates of every “SourceType,” researchers selected a single “SourceType” to supply emission rates for each UMR vehicle type because many “SourceType”s have similar emission rates (light-duty vehicles are an exception, however). To determine which “SourceType” would supply the emission rates for a vehicle type, researchers chose the “SourceType” with the highest percentage of vehicle-miles of travel (VMT) within each UMR vehicle type.

TTI researchers used a different method for light-duty vehicles because not all “SourceType”s within this classification have similar emission rates. The light-duty vehicle classification consists of passenger cars, passenger trucks, and light commercial trucks. Passenger trucks and light commercial trucks have similar emission rates, but passenger car emission rates are substantially different. To create one set of emission rates for this vehicle type (light-duty vehicles), researchers combined and weighted the emission rates of two different “SourceType”s – passenger cars (59%) and passenger trucks (41%). Researchers used only the passenger truck “SourceType” to supply the emission rates for both passenger trucks and light commercial trucks because they have similar emission rates, and because passenger trucks account for more VMT.

Emission rates also differ for specific fuel types, and TTI researchers selected a fuel type for each vehicle type based on fuel usage data in MOVES. Given that light commercial trucks account for a small portion of the light-duty vehicle population, researchers used the gasoline emission rates to represent all fuel usage for light-duty vehicles when calculating emissions. Researchers used the diesel emission rates to represent all fuel usage for medium-duty trucks and heavy-duty trucks.

TTI researchers ran MOVES for the appropriate vehicle types, fuel types, and road types to obtain emission rates in grams per mile.

**Step 3. Fit Curves to CO2 Emission Rates**

TTI researchers developed curves to calculate emission rates for a given speed. Researchers later used the equations for each curve to calculate emissions.

MOVES produces emission rates for speeds of 2.5 to 75 mph in increments of five (except for 2.5 mph). Using Microsoft Excel®, researchers initially constructed speed-dependent emission factor curves by...
focusing one to three polynomial curves (spline) to the emission rate data from MOVES (see Exhibit A-11 example). Researchers compared emission rates generated with the polynomial spline to the underlying MOVES-generated emission rates.

![Exhibit A-11. Example Light-duty Vehicle Emission Rate Curve-set Showing Three Emission Rate Curves](image)

The polynomial spline that was deemed sufficiently accurate by researchers was a two-segment spline using one $6^\text{th}$-order polynomial for the $0 – 30$ mph segment and another $6^\text{th}$-order polynomial for the $30 – 60$ mph segment. Speeds over 60 used the emission rates of the $30 – 60$ mph polynomial at 60 mph. Note that these speeds are averages, and variability with speed (slope) is negligible for speeds greater than 60 mph. Lower average speeds have higher speed fluctuations (or more stop-and-go), which causes higher emission rates. From a CO$_2$ perspective, these slower speeds are of great concern. Because there are fewer speed fluctuations at higher speeds, which results in a more efficient system operation, it is desirable for urban areas to operate during the relatively free-flow conditions as much as possible. Thus, the authors capped emissions generation at approximately 60 mph.

**Step 4. Calculate CO$_2$ Emissions and Fuel Consumption During Congested Conditions**

To calculate emissions, researchers combined the emission rates with hourly speed data supplied by INRIX and hourly volume data supplied by Highway Performance Monitoring System (HPMS).
Researchers used SAS® to automate the process of calculating emissions. This process involves selecting the appropriate emission rate equations (or curves), using the speed data to calculate emission rates, and combining the volume data with the emission rates to calculate emissions.

The volume and speed data are structured for each 15-minutes for each day of the week. This means there will be a separate speed and volume value for light-duty vehicles, medium-duty trucks, and heavy-duty trucks for each 15-minutes of each day of the week. To account for the seasonal climate changes, researchers calculated a separate emission rate for each season.

After calculating the emission rates, researchers combined these emission rates with the volume data to calculate emissions for each season. Lastly, researchers sum the emissions of each season, vehicle type, and day of the week to produce the annual emission estimates.

Researchers produced the annual emission estimates for congested conditions, which includes free-flow. Researchers used factors that relate CO₂ emissions from a gallon of gasoline (8,887 grams CO₂/gallon) and diesel (10,180 grams CO₂/gallon), in relation with the vehicle types and associated fuel type used, to estimate fuel consumption during congestion conditions, which includes free-flow.

**Step 5. Estimate the CO₂ Emissions and Fuel Consumption During Free-flow Conditions and Estimate Wasted Fuel and CO₂ Due to Congestion**

Researchers repeated the calculations in Step #4 using the free-flow speeds when few cars are on the road to estimate free-flow emissions and fuel consumption. To estimate the CO₂ emissions Due to congestion, researchers subtracted the free-flow conditions emissions estimates from the congested-conditions emissions estimate from Step #4. This is shown in Equation A-12. To estimate wasted fuel due to congestion, researchers subtracted the fuel consumed during free-flow from the fuel used during congested conditions (Equation A-13).
A word about Assumptions in the CO₂ and Fuel Methodology

Table 4 of the main report presents the results of the steps above. Table 4 reports the total millions of pounds of CO₂ emissions that occur during free-flow in each urban area, which is a result of Step 5. The additional results of Step 5 (additional emissions because of congestion) are reported in Table 4 in pounds per auto commuter and millions of pounds for each urban area. As shown in Table 4, the emissions produced during congestion are only about 3 percent (from all 498 urban areas) of emissions produced during free-flow.

A number of national-level assumptions are used as model inputs (e.g., volume, speed, vehicle composition, fuel types). This analysis also only includes freeways and principal arterial streets. The assumptions allow for a relatively simple and replicable methodology for 498 urban areas. More detailed and localized inputs and analyses are conducted by local or state agencies; those are better estimates of CO₂ production.

The analysis is based upon the urban area boundaries which are a function of state and local agency updates. Localized CO₂ inventory analyses will likely include other/all roadways (including collectors and local streets) and will likely have a different area boundary (e.g., often based upon metropolitan statistical area).

Finally, Step 5 uses the difference between actual congested-condition CO₂ emissions and free-flow CO₂ emissions and fuel consumption. According to the methodology, this difference is the “wasted” fuel and "additional" CO₂ produced due to congestion. Some may note that if the congestion were not present, speeds would be higher, throughput would increase, and this would generally result in lower fuel consumption and CO₂ emissions – thus the methodology could be seen as overestimating the wasted fuel and additional CO₂ produced due to congestion. Similarly, if there is substantial induced demand due to the lack of congestion, it is possible that more CO₂ could be present than during congested conditions because of more cars traveling at free-flow. While these are notable considerations and may be true for specific corridors, the UMR analysis is at the areawide level for all principal arterials and freeways and the assumption is that overestimating and underestimating will approximately balance out over the urban area. Therefore, the methodology provides a credible method for consistent and replicable analysis across 498 urban areas.
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.

\[
\text{Annual \text{Passenger-Veh\ Delay Cost}} = \text{Daily \text{Passenger-Veh\ Hours of Delay}} \times \text{Value of Person Time} \times \text{Vehicle Occupancy} \times \text{Conversion Factor} \quad (\text{Eq. A-14})
\]

**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.

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

**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.

\[
\text{Annual Comm-Veh\ Delay Cost} = \text{Daily Comm-Veh\ Hours of Delay} \times \text{Value of Comm-Veh\ Time} \times \text{Conversion Factor} \quad (\text{Eq. A-16})
\]

**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.

2012 Urban Mobility Report Methodology
http://mobility.tamu.edu/ums/congestion-data/
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.

\[
\text{Annual Cost Due to Congestion} = \left( \frac{\text{Annual Passenger Vehicle Delay Cost}}{\text{Eq. A-14}} \right) \times \left( \frac{\text{Annual Passenger Fuel Cost}}{\text{Eq. A-15}} \right) + \left( \frac{\text{Annual Comm Veh Delay Cost}}{\text{Eq. A-16}} \right) + \left( \frac{\text{Annual Comm Veh Fuel Cost}}{\text{Eq. A-17}} \right)
\]

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 2012.
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.

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

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.

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

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

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).

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

**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.

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

\[
\text{Final Commodity Value for Urban Area} = \left( \frac{\text{Urban Area VMT-Based Commodity Value}}{\text{VMT-Based Commodity Value}} + \frac{\text{Urban Area O/D-Based Commodity Value}}{\text{O/D-Based Commodity Value}} \right) + 2
\]  

(Rootway 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, 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.

\[
\text{Roadway Congestion Index} = \frac{\text{Freeway VMT/Ln.Mi} \times \frac{\text{Prin Art Str VMT}}{\text{Prin Art Str VMT/Ln.Mi}}}{14,000 \times \frac{\text{Freeway VMT}}{\text{Prin Art Str VMT/Ln.Mi}}} + \frac{5,000 \times \frac{\text{Prin Art Str VMT}}{\text{Prin Art Str VMT/Ln.Mi}}}{14,000}
\]  

(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-12. 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.

<table>
<thead>
<tr>
<th>Population Group</th>
<th>TTI Range</th>
<th>Number of Hours of Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Large</td>
<td>Over 1.22</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.17-1.22</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>1.12-1.17</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Under 1.12</td>
<td>0.00</td>
</tr>
<tr>
<td>Large</td>
<td>Over 1.20</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.15-1.20</td>
<td>0.50</td>
</tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Under 1.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Medium/Small</td>
<td>Over 1.17</td>
<td>1.00</td>
</tr>
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<td></td>
<td>1.12-1.17</td>
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</tr>
<tr>
<td></td>
<td>Under 1.07</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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 2012 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-13 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-13 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-13. 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.

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

\[
\text{Percent Congested Peak Period Travel} = \frac{\text{Percent Congested Daily Travel} + 50 \text{ percent}}{\text{(Eq. A-33)}}
\]
\[
\text{Percent Congested Daily Travel} = \frac{\text{Freeway Congested Travel}}{\text{Daily Travel}} + \frac{\text{Arterial Congested Travel}}{\text{Daily Travel}} \quad (\text{Eq. A-34})
\]