

Appendix A

Methodology for the 2015 Urban Mobility Scorecard

The procedures used in the *2015 Urban Mobility Scorecard* have been developed by the Texas A&M 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 appendix documents the analysis conducted for the methodology utilized in preparing the *2015 Urban Mobility Scorecard*. This methodology incorporates private sector traffic speed data from INRIX for calendar year 2014 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 for the 2015 UMS

There are several changes to the *UMS* methodology for the *2015 Urban Mobility Scorecard*. The largest changes have to do with the reliability measure (Planning Time Index), estimates of daily truck volumes, and the ever-increasing INRIX speed data set size. These changes are documented in more detail in the following sections of the Methodology. Here are brief summaries of what has changed:

- Estimates of hourly truck volume were developed and incorporated. In past reports, trucks were assumed to have the same patterns as car travel.
- The measure of the variation in travel time from day-to-day now uses a more representative trip-based process rather than the old dataset that used individual road links. The Planning Time Index (PTI) is based on the ideas that travelers want to be on-time for an important trip 19 out of 20 times; so one would be late to work only one day per month (on-time for 19 out of the 20 work days each month). For example, a PTI value of 1.80 indicates that a traveler should allow 36 minutes to make an important trip that takes 20 minutes in low traffic volumes.
- Speeds supplied by INRIX are collected every 15-minutes from a variety of sources every day of the year on most major roads. Many of the slow speeds formerly considered “too slow to be a valid observation” are now being retained in the INRIX dataset. Experience and increased travel speed sample sizes have increased the confidence in the data.

Summary

The *Urban Mobility Scorecard (UMS)* 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.

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 2014 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 INRIX 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 2014 INRIX traffic speed data provide a better data source for the first two inputs, actual and free-flow travel time. The *UMS* 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 INRIX 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 15-minute time intervals for each day of the week to match with the time aggregation of the speed data.

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)
- 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 from 713 continuous traffic monitoring locations in urban areas of 37 states.

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

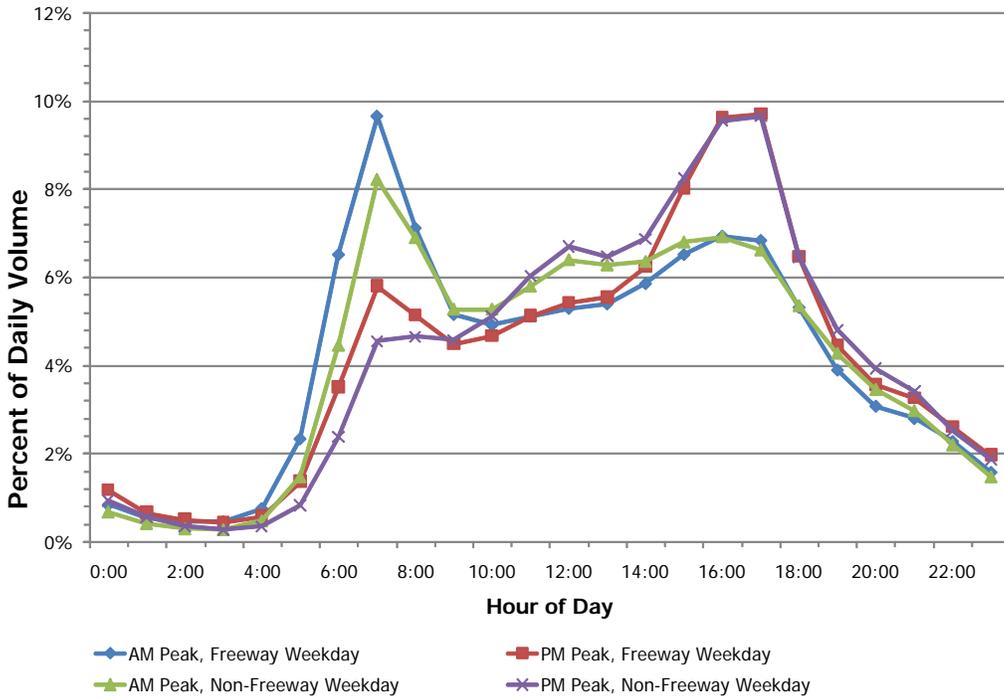


Exhibit A-3. Weekday Traffic Distribution Profile for Moderate Congestion

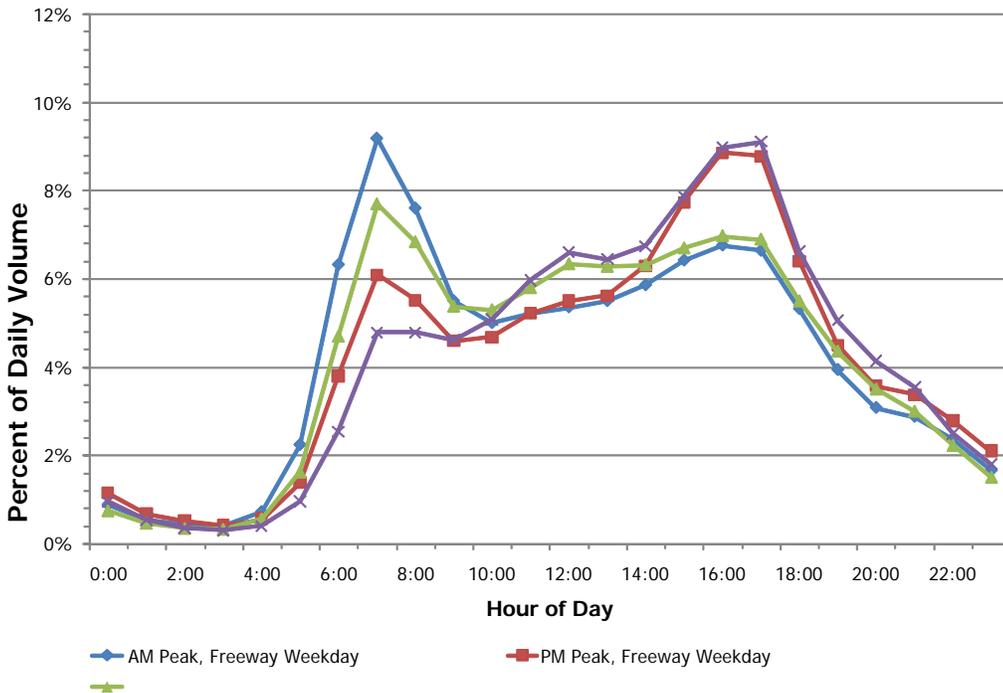


Exhibit A-4. Weekday Traffic Distribution Profile for Severe Congestion

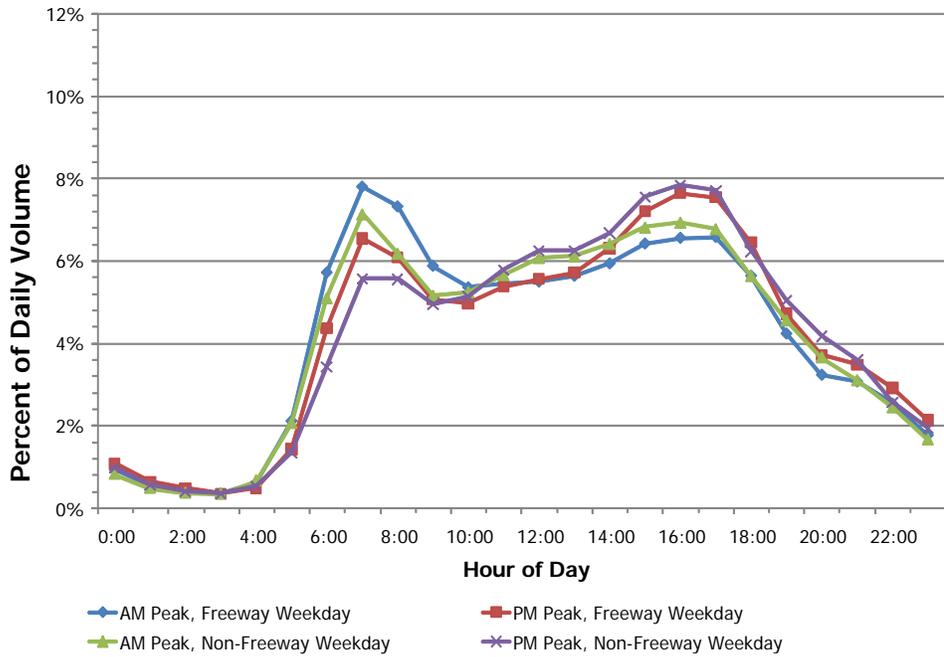


Exhibit A-5. Weekend Traffic Distribution Profile

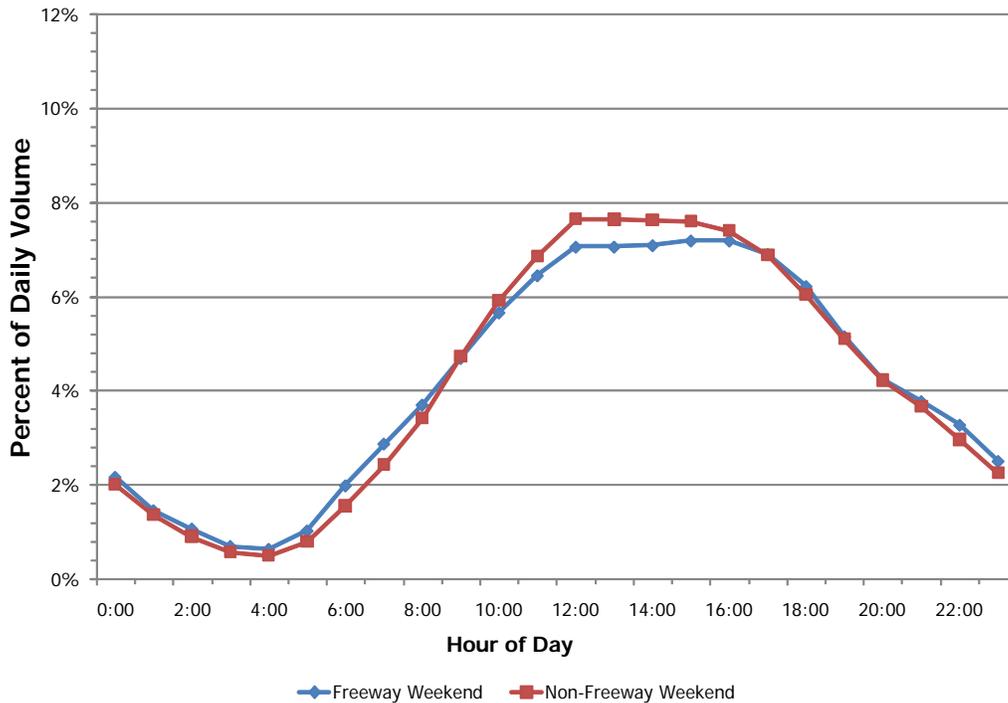
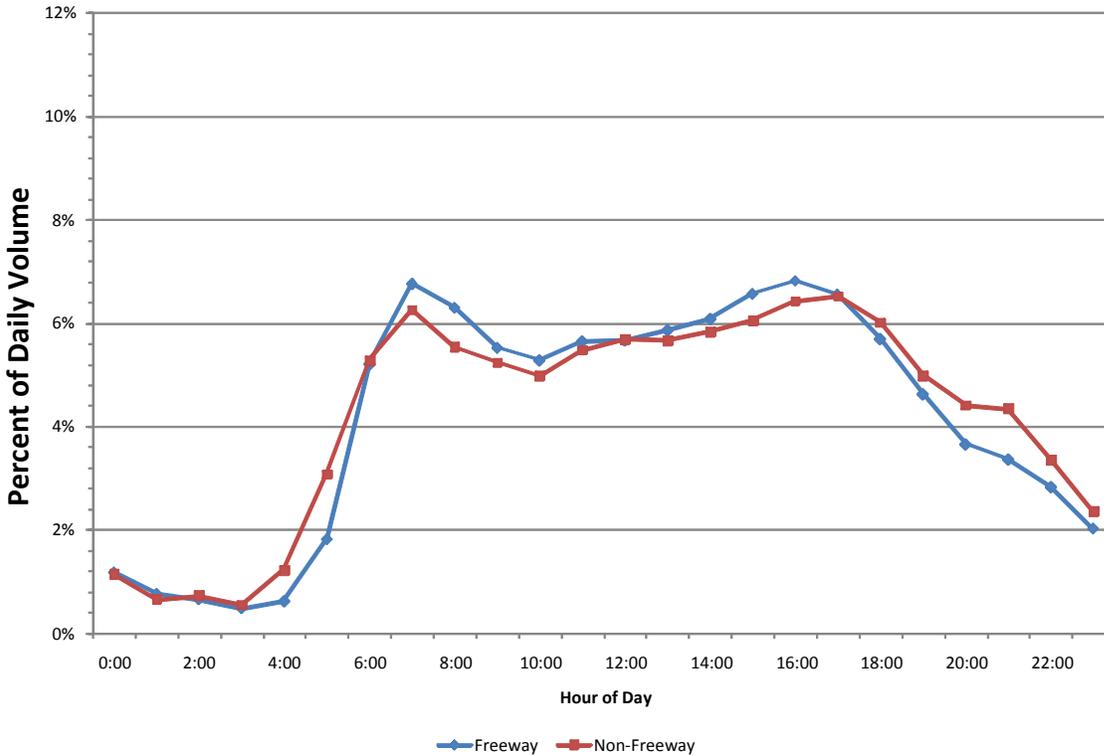


Exhibit A-6. Weekday Traffic Distribution Profile for Severe Congestion and Similar Speeds in Each Peak Period



The next step in the traffic flow assignment process is to determine which of the 16 traffic distribution profiles should be assigned to each XD Network roadway link (“XD Network” is the “geography” used by INRIX to define the roadways), 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 XD Network

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.

Truck-Only Volume Profiles

New to the 2015 Urban Mobility Scorecard is the use of truck-only volume curves. The mixed-vehicle process is repeated to create 15-minute truck volumes from daily truck volumes. However, much of the necessary information (e.g., facility type, day type, and time of day peaking) have already been determined in the mixed-vehicle volume process. The eight truck-only profiles used to create the 15-minute truck volumes are shown in Exhibits A-7 through A-9. The truck-only profiles are identical for all congestion levels.

Exhibit A-7. Weekday Freeway Truck-Traffic Distribution Profiles

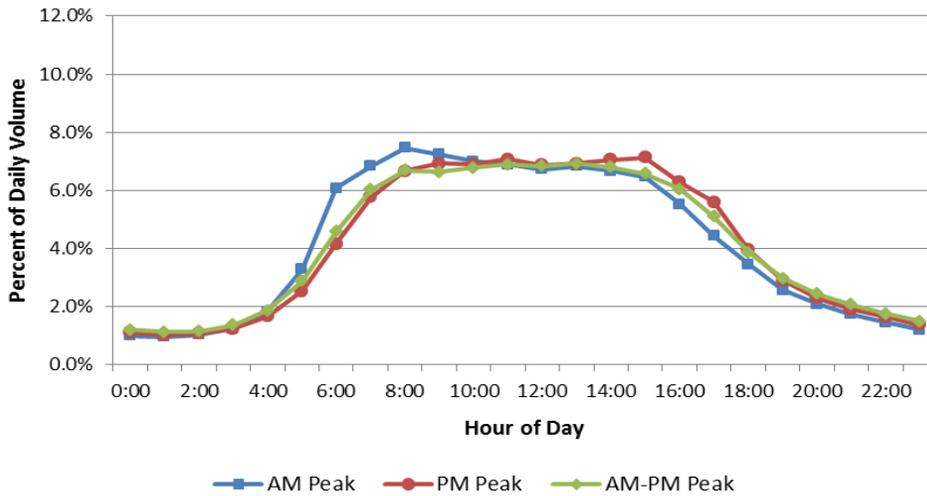


Exhibit A-8. Weekday Non-Freeway Truck-Traffic Distribution Profiles

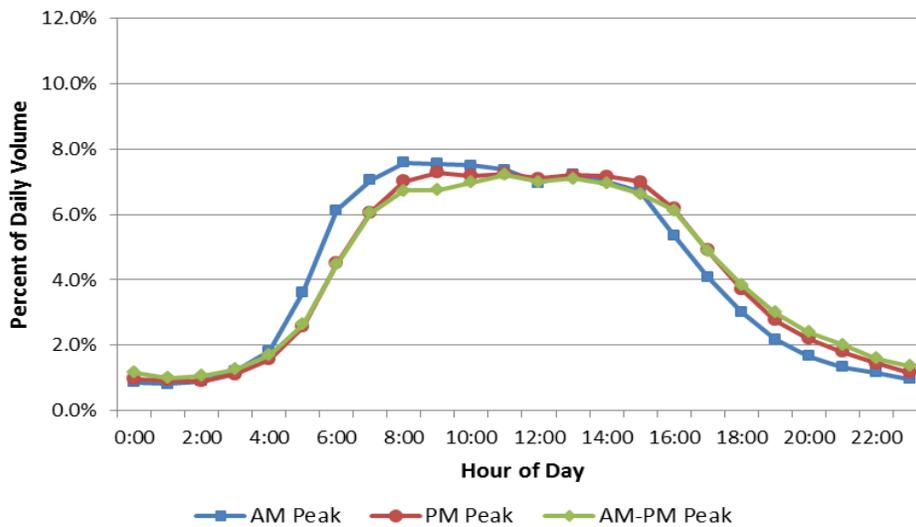
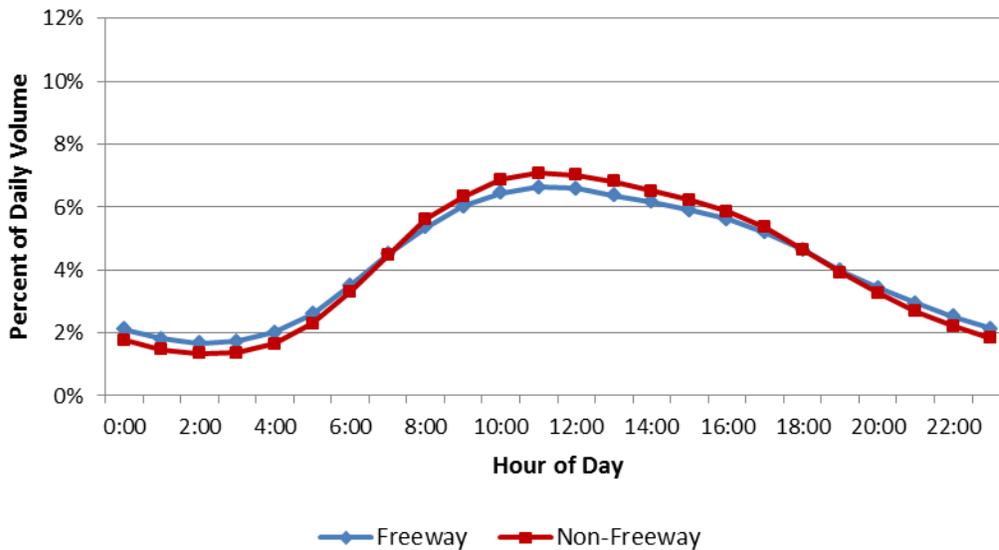


Exhibit A-9. Weekend Truck-Traffic Distribution Profiles



Step 4. Calculate Travel Time

The hourly speed and volume data were combined to calculate the total travel time for each 15-minute time period. The 15-minute volume for each segment was multiplied by the corresponding travel time to get a quantity of vehicle-hours; these were summed for all 24 hours 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 UMS methodology, the data were 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 15-minute 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 UMS 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 eventually be added to the GIS roadway shapefiles by the state DOTs as mandated by FHWA). A technique for handling the unmatched sections of roadway was used in the 2015 UMS. The percentage of arterial streets that had INRIX speed data is approximately 75 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 free-flow 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 were 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 Scorecard* 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. Not all of the measures are reported in the *2015 Urban Mobility Scorecard*. In some cases, the measures below were last reported in the *2012 Urban Mobility Report (UMR)*; this is noted in the pages that follow.

- 1. National Constants**
- 2. Urban Area Constants and Inventory Values**
- 3. Variable and Performance Measure Calculation Descriptions**
 - 1) Travel Delay
 - 2) Annual Person Delay
 - 3) Annual Delay per Auto Commuter
 - 4) Total Peak Period Travel Time (last reported in *2012 UMR*)
 - 5) Travel Time Index
 - 6) Commuter Stress Index
 - 7) Planning Time Index
 - 8) Carbon Dioxide (CO₂) Production and Wasted Fuel (CO₂ last reported in *2012 UMR*)
 - 9) Total Congestion Cost and Truck Congestion Cost
 - 10) Truck Commodity Value (last reported in *2012 UMR*)
 - 11) Number of Rush Hours
 - 12) Percent of Daily and Peak Travel in Congested Conditions
 - 13) 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-10 as national constants—values used in all urban areas to estimate the effect of congestion.

Exhibit A-10. National Congestion Constants for 2015 Urban Mobility Scorecard

Constant	Value
Vehicle Occupancy	1.25 persons per vehicle
Average Cost of Time (\$2014) (2)	\$17.67 per person hour ¹
Commercial Vehicle Operating Cost (\$2014) (3)	\$94.04 per vehicle hour ¹
Total Travel Days (7x52)	364 days

¹ Adjusted annually using the Consumer Price Index.

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 2014 value of person time used in the report is \$17.67 per hour based on the value of time, rather than the average or prevailing wage rate (2).

Commercial Vehicle Operating Cost

Truck travel time and operating costs (excluding diesel costs) are valued at \$94.04 per hour (3).

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) (1,4). Estimates of peak period travelers are derived from the National Household Travel Survey (NHTS) (5) 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 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 (e.g., high tourism areas) may not represent all of the transportation users on an average day. The same NHTS data were also used to estimate the 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) (6). 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 Delay

Most of the basic performance measures presented in the *2015 Urban Mobility Scorecard* 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. Any observed speed faster than the free-flow speed is changed to the free-flow speed so that delay is zero, rather than providing a ‘delay credit’ (negative delay value) to the calculation.

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

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 52 weeks per year (Equation A-3).

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

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*

Scorecard applies estimates of the number of people and trip departure times during the morning and

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evening peak periods from the National Household Travel Survey (5) to the urban area population estimate to derive the average number of auto commuters and number of travelers during the peak periods (7).

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 (Last reported in the 2012 UMR)

Total travel time is the sum of travel delay and free-flow travel time. 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.

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

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.

$$\text{Peak Free-Flow Travel Time (Person-Hours)} = \frac{1}{\text{Free-Flow Travel Speed}} \times \text{Daily Vehicle-Miles of Travel} \times \frac{\text{Percent of Vehicle Miles of Travel During the Peak}}{100} \times \frac{1.25 \text{ Persons}}{\text{per Vehicle}} \quad (\text{Eq. A-6})$$

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.

$$\text{Total Daily Peak Period Travel Time (Minutes per Commuter)} = \left(\frac{\left[\frac{\text{Primary Road Peak Delay} + \text{Minor Road Peak Delay}}{\text{Auto Commuters}} \right] + \left[\frac{\text{Primary Road Peak Free-Flow Travel Time} + \text{Minor Road Peak Free-Flow Travel Time}}{\text{Auto Commuters}} \right]}{\text{Auto Commuters}} \right) \times 60 \text{ Minutes} \quad (\text{Eq. A-7})$$

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).

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

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

The change in Travel Time Index values is computed by subtracting 1.0 from all the TTI values so that the resulting values represent the change in extra travel time rather than the change in the numerical TTI values. For example, the increase in extra travel time from a TTI of 1.25 to 1.50 is 100 percent (extra travel time of 50 percent compared to 25 percent).

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) was new beginning with the *2012 Urban Mobility Report*. Results are shown in Table 3 of the *2015 Urban Mobility Scorecard*. The PTI is based on the idea that travelers want to be on-time for an important trip 19 out of 20 times; so one would be late to work only one day per month (on-time for 19 out of 20 work days each month). For example, a PTI value of 1.80 indicates that a traveler should allow 36 minutes to make an important trip that takes 20 minutes in low traffic volumes. The PTI values in Table 3 are for freeways only.

The PTI is the 95th percentile travel time relative to the free-flow travel time as shown in Equation A-10. The *2015 Urban Mobility Scorecard* estimates the PTI for trips using average link (XD Network link) freeway PTI values. Researchers compute these trip PTI estimates using Equation A-11, which is from the Strategic Highway Research Program, 2 (SHRP2) *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies* (8).

$$\text{Planning Time Index (PTI)} = \frac{\text{95th Percentile Travel Time (minutes)}}{\text{Free-Flow Travel Time (minutes)}} \tag{Eq. A-10}$$

$$\text{PTI}_{\text{trip}} = (\text{PTI}_{\text{link}})^{0.8014} \tag{Eq. A-11}$$

Where:

- PTI_{trip} = PTI for a trip (reported for freeways in Table 3 of the *2015 UMS*); and
- PTI_{link} = Average of PTIs for all the XD Network links weighted by VMT in the urban area.

Exhibit A-11 illustrates a distribution of travel times for a morning commute. Travel times can vary over a calendar year; the extreme cases usually have identifiable causes. 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.

Carbon Dioxide (CO₂) Production and Wasted Fuel (CO₂ was last reported in 2012 UMR)

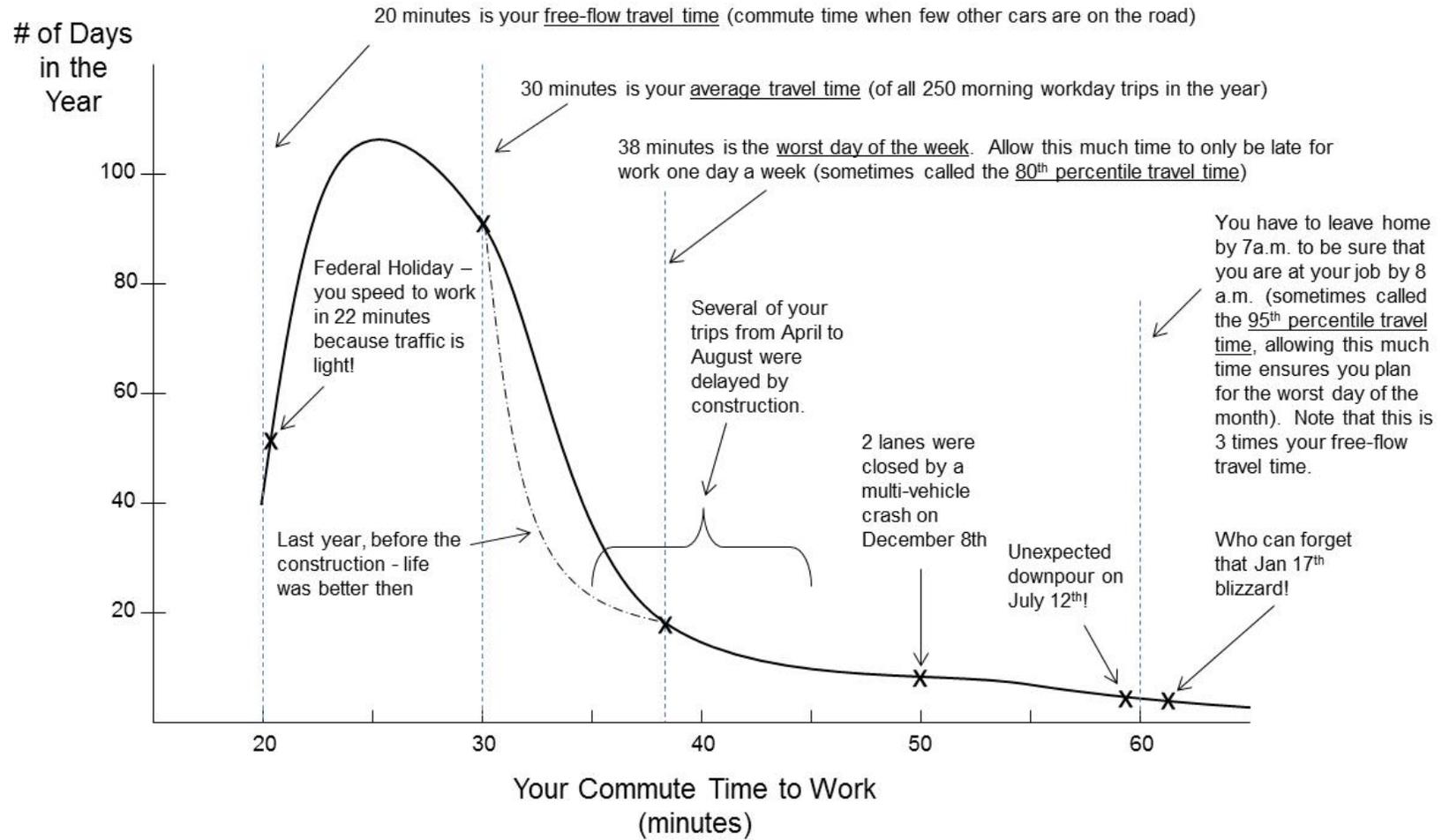
This methodology uses data from the United States Environmental Protection Agency's (EPA) MOtor Vehicle Emission Simulator (MOVES) model. MOVES is a model developed by the EPA to estimate emissions from mobile sources. Researchers primarily used MOVES to obtain vehicle emission rates, climate data, and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

Exhibit A-11. Example of Morning Commute Travel Time Distribution

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



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.

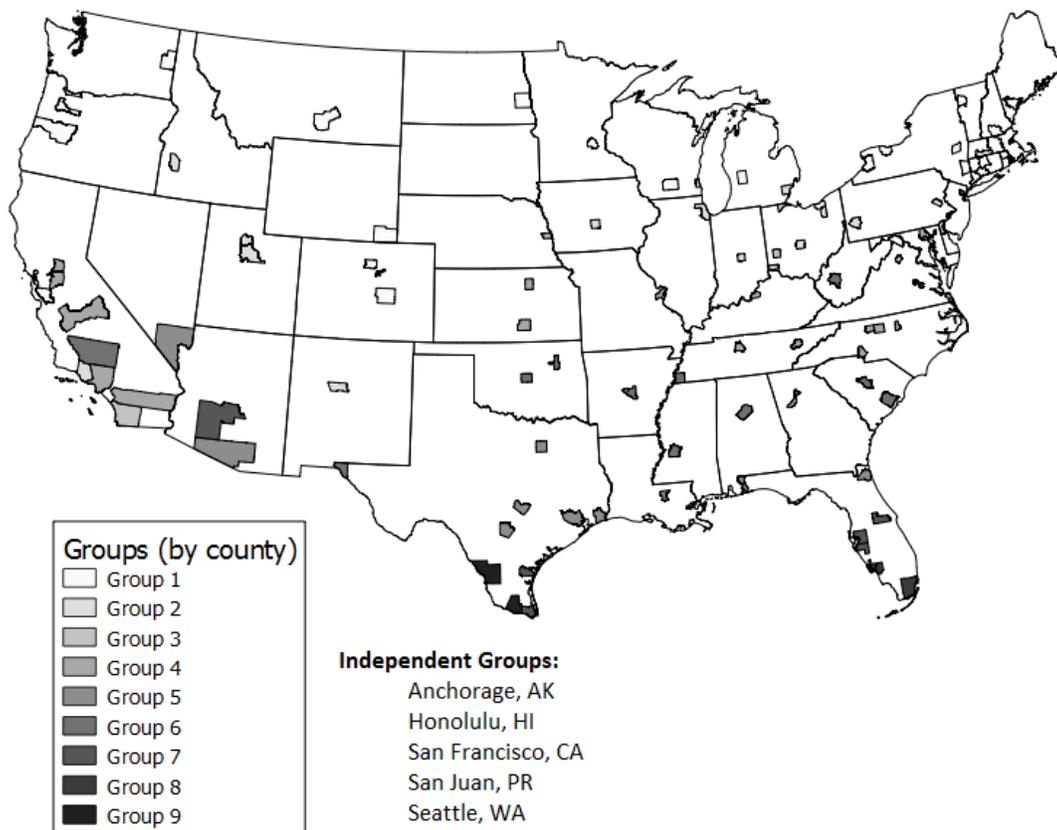
For simplicity, one county per urban area (or city) was selected because the climate differences between adjacent counties were not significant.

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-12 shows the groupings of urban areas.

Exhibit A-12. The Continental United States with Each County Shaded by Group



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 "SourceTypes" 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 "SourceTypes" 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 "SourceTypes" 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 "SourceTypes" – 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.

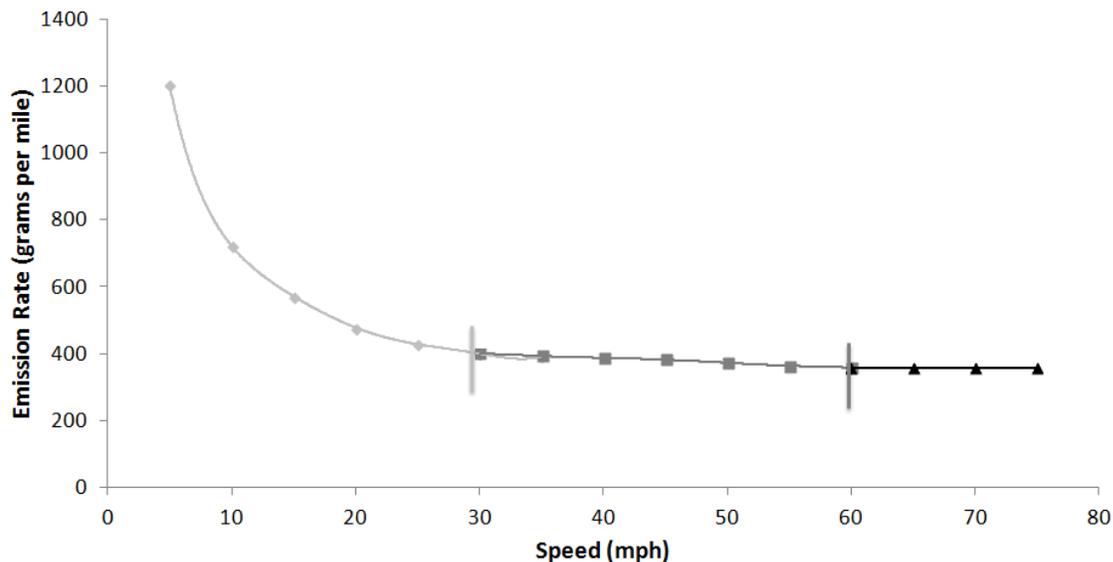
TTI researchers ran MOVES for the appropriate vehicle types, fuel types, and road types to obtain emission rates in grams per mile.

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 fitting one to three polynomial curves (spline) to the emission rate data from MOVES (see Exhibit A-13 example). Researchers compared emission rates generated with the polynomial spline to the underlying MOVES-generated emission rates.

**Exhibit A-13. Example Light-duty Vehicle Emission Rate Curve-set
Showing Three Emission Rate Curves**



The polynomial spline that was deemed sufficiently accurate by researchers was a two-segment spline using one 6th-order polynomial for the 0 – 30 mph segment and another 6th-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 CO₂ 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 CO₂ 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 speeds when few cars are on the road to estimate free-flow emissions and fuel consumption. To estimate the CO₂ emissions from congestion, researchers subtracted the free-flow condition 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).

$$\begin{array}{l} \text{Annual Additional CO}_2 \\ \text{Because of} \\ \text{Congestion} \end{array} = \begin{array}{l} \text{Annual CO}_2 \\ \text{Emissions Produced} \\ \text{in Congestion} \end{array} - \begin{array}{l} \text{Annual CO}_2 \\ \text{Emissions Produced} \\ \text{in Free-Flow Conditions} \end{array} \quad (\text{Eq. A-12})$$

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

A Word about Assumptions in the CO₂ and Fuel Methodology

Table 4 of the main *2012 Urban Mobility 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 each urban area. 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 *UMS* 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 all urban areas.

Total Congestion Cost and Truck Fuel 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.

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

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.

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

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.

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

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.

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

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.

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

Truck Commodity Value (Last reported in 2012 UMR)

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.

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.

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

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

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

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).

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

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

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

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

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*.

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

Number of “Rush Hours” (Congested Hours), Congested Lane-Miles, and Congested VMT

The number of “rush hours” (congested hours) is computed with a new method in the *2015 Urban Mobility Scorecard*. For each XD Network directional roadway link the 15-minute average speeds during the peak eight hours are evaluated for all five weekdays. If any 15-minute speed is less than 90 percent of the uncongested speed on a freeway, or less than 75 percent of the uncongested speed on an arterial, the section of road is marked as “congested” for that 15-minute period (9). If 30 percent of the urban area freeway system is congested, the 15-minute period is considered congested. Similarly, if 50 percent of the arterial road sections across the urban area are congested, the associated 15-minute period is considered congested. The number of congested 15-minute periods across the urban area (freeway or arterial) are summed to determine the urban area congested hours (“rush hours”) (10).

Congested lane-miles are similarly identified; speed below congestion threshold (90 percent/75 percent of uncongested speed on freeways/arterials). These lane-miles are summed for those time periods across the urban area separately for freeways and arterials. Congested vehicle-miles of travel is also summed for each 15-minute period for urban area freeways and arterial streets. These summations of peak period vehicle-miles of travel and lane-miles are compared with the peak-period totals to determine the percent that is congested.

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