APPENDIX B
Methodology for 2004 Annual Report

This appendix summarizes the methodology utilized to calculate many of the statistics shown in the Urban Mobility Report. The methodology is divided into eight sections:

- **Constants**
- **Travel Delay**
- **Travel Rate Index**
- **Travel Time Index**
- **Fuel Economy**
- **Wasted Fuel**
- **Congestion Cost**
- **Percent of Congested Travel**
- **Roadway Congestion Index**

Some of these sections refer to variables that were calculated in other sections. Generally, the sections are listed in the order that they will be needed to complete all calculations. An example calculation is shown with most equations utilizing 2002 Houston data. Because of rounding, some calculations shown here may not exactly match the data in the UMS database.

CONSTANTS

The congestion cost estimate calculations utilize the constant values in Exhibit B-1.

Exhibit B-1. Cost Estimate Constants for 2002 Annual Report

Constant	Value
Vehicle Occupancy	1.25 persons per vehicle
Working Days	250 days per year
Average Cost of Time ($2002)*	$13.45 per person hour[1]
Commercial Vehicle Operating Cost ($2002)	$71.05 per vehicle hour
Vehicle Mix	95 percent passenger & 5 percent commercial
Percent of Daily Travel in Peak Periods	Variable percent – Exhibit B-5
Vehicle Speeds	Exhibit B-6

[1] Adjusted annually using the Consumer Price Index.

*Source: (Ref. 1)

In addition to the derived constants, five urbanized area or state specific variables 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.

Example: 20 vehicles x 10-mile average trip = 200 vehicle-miles of travel

Population

Population data were obtained from the combination of U.S. Census Bureau estimates and population estimates reported in the Federal Highway Administration's Highway Performance Monitoring System (HPMS). Exhibit B-2 shows the population and urban area size for the 85 urban areas in the study.

Fuel Costs

Statewide average fuel cost estimates were obtained from data published by the American Automobile Association (AAA) (2). Values for different fuel types used in motor vehicles, i.e., diesel and gasoline, did not vary enough to be reported separately. Therefore, an average rate for fuel was used in cost estimate calculations.

Exhibit B-2. Population and Urban Area Size

Urban Area	Population (000)	Urban Area Size (square miles)
Akron OH	550	355
Albany-Schenectady NY	525	375
Albuquerque NM	575	280
Allentown-Bethlehem PA-NJ	600	290
Anchorage AK	270	195
Atlanta GA	2,995	1,820
Austin TX	840	440
Bakersfield CA	425	185
Baltimore MD	2,295	765
Beaumont TX	145	110
Birmingham AL	675	610
Boston MA-NH-RI	3,030	1,165
Boulder CO	110	45
Bridgeport-Stamford CT-NY	850	470
Brownsville TX	160	55
Buffalo NY	1,120	580
Cape Coral FL	315	275
Charleston-North Charleston SC	465	285
Charlotte NC-SC	720	300
Chicago IL-IN	8,115	2,780
Cincinnati OH-KY-IN	1,325	690
Cleveland OH	1,875	850
Colorado Springs CO	475	255
Columbia SC	425	220
Columbus OH	1,055	495
Corpus Christi TX	320	200
Dallas-Fort Worth-Arlington TX	4,150	1,920
Dayton OH	595	370
Denver-Aurora CO	2,030	850
Detroit MI	4,035	1,325
El Paso TX-NM	665	250
Eugene OR	235	110
Fresno CA	585	190
Grand Rapids MI	530	355
Hartford CT	875	550
Honolulu HI	700	140
Houston TX	3,720	1,790
Indianapolis IN	1,035	500
Jacksonville FL	905	745
Kansas City MO-KS	1,475	1,035
Laredo TX	190	50
Las Vegas NV	1,370	300
Little Rock AR	340	250
Los Angeles-Long Beach-Santa Ana CA	12,775	2,270
Louisville KY-IN	845	405
Memphis TN-MS-AR	980	425
Miami FL	5,000	1,705
Milwaukee WI	1,445	580
Minneapolis-St. Paul MN	2,440	1,240
Nashville-Davidson TN	700	605
New Haven CT	545	350
New Orleans LA	1,095	370
New York-Newark NY-NJ-CT	17,305	4,075
Oklahoma City OK	1090	695
Omaha NE-IA	635	245
Orlando FL	1,260	680
Oxnard-Ventura CA	565	200
Pensacola FL-AL	310	200
Philadelphia PA-NJ-DE-MD	4,815	1,590
Phoenix AZ	2,950	1,140
Pittsburgh PA	1,760	1,015
Portland OR-WA	1,605	495
Providence RI-MA	1,235	795
Raleigh-Durham NC	780	540
Richmond VA	840	500
Riverside-San Bernardino CA	1,610	565
Rochester NY	660	350
Sacramento CA	1,505	420
Salem OR	215	80
Salt Lake City UT	910	400
San Antonio TX	1,260	505
San Diego CA	2,825	765
San Francisco-Oakland CA	4,120	1,265
San Jose CA	1,680	390
Sarasota-Bradenton FL	540	490
Seattle WA	2,700	1,240
Spokane WA	330	175
Springfield MA-CT	650	460
St. Louis MO-IL	2,065	1,140
Tampa-St. Petersburg FL	2,025	1,340
Toledo OH-MI	500	255
Tucson AZ	710	320
Tulsa OK	805	405
Virginia Beach VA	1,530	990
Washington DC-VA-MD	3,790	1,040

TRAVEL DELAY

Most of the basic performance measures presented in the Urban Mobility Study Annual Report are developed as part of calculating travel delay—the amount of extra time spent traveling due to congestion. An overview of the process is followed by more detailed descriptions of the individual steps. For the 2004 Annual Report, the delay from this estimation process and delay values developed from automated data collection processes are not combined. Future research efforts may examine how those two processes might be combined; the automated data is used in presenting statistics for individual corridors and multimodal transportation improvement analyses.

Travel delay calculations are performed in two steps—recurring (or usual) delay and incident delay (due to crashes, vehicle breakdowns, etc.).

Recurring Travel Delay

Travel delay estimated from vehicle traffic per lane and traffic speed equations. The calculation proceeds through the following steps (also displayed in Exhibit B-3):

- Estimate daily miles traveled.
- Reduce the travel miles examined to only peak period travel.
- Estimate the amount of travel in times that might encounter congestion; place remainder of the travel in the uncongested category (or bucket).
- Separate congested travel into peak and off-peak directions.
- Place each in a congestion bucket (one of four congestion levels for peak and off-peak or the uncongested bucket).
- Calculate a speed for each "bucket" of travel based on the equations shown in Exhibit B-6.
- Calculate average speed on each portion of road system based on the amount of person travel in each "bucket."

Collect Travel and Roadway Characteristics

Information for each section of roadway includes daily traffic volume, length and number of lanes.

Isolate Peak-Period Travel

The times of the day outside of the peak-period are typically uncongested. Even though some sections of road in larger areas can be congested for 10 to 12 hours of the day, the Mobility Study methodology only examines the peak-periods—estimated as 6:00 to 9:30 a.m. and 3:30 to 7:00 p.m. These time periods are estimated to include **50 percent of the daily vehicle travel**. The rationale for eliminating the remainder of the day is that an area's mobility statistics should not be "credited" for having an uncongested system at 3:00 a.m.

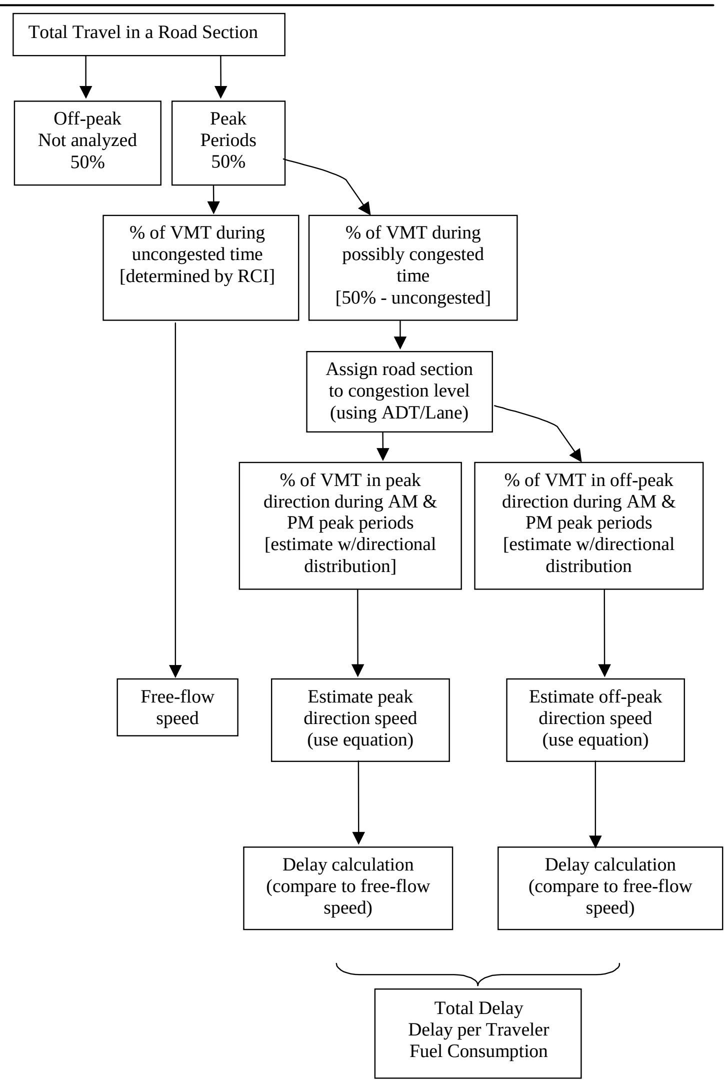
Identify the Usually Congested Time of the Day

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 3½ hours in the morning and evening. The variable between the urban areas studied is the length of time when congestion may be encountered. This typically varies with the average congestion level and population of the area. 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 Urban Mobility Study and in the 2000 report the maximum value was increased from 45% to 50% and a time variable added to modify the estimates based on area characteristics.

Exhibit 3. Overview of Speed and Delay Calculation Process

Step	Why? or What
Collect travel and roadway characteristics	Get data for an average day
Isolate peak-period travel	Remove off-peak, uncongested travel (50% of day)
Identify the usually congested time of day	Varies for each area; congestion usually lasts longer in larger areas
Identify congestion level of each section of roadway	Use daily traffic/lane and Exhibit B-6
Assign travel to peak/off-peak directions	Accumulate VMT by congestion level and direction, determine average VMT per lane-mile
Apply speed estimates to each congestion level and direction	Using speed curves, determine average speed for each direction and level
Calculate delay	Compare average speeds to free-flow speeds
Calculate other measures	Use VMT, speeds and remaining methodology to determine other measures

The 'Process'



The Urban Mobility Study Annual Report procedure estimates the length of the peak period using the roadway congestion index (RCI)—a ratio of daily traffic volume to the supply of roadway. The RCI is explained in more detail later in this methodology. The RCI is, therefore, a measure of both intensity and duration of congestion. In this application, the RCI acts as an indicator of the number of hours of the day that might be affected by congested conditions. Exhibits B-4 and B-5 illustrate the process used to estimate the amount of the day (and the amount of travel) when travelers might encounter congestion. Areas with roadway congestion index values near 0.6 typically have congestion during the morning and evening peak hours but not much time beyond that. Congestion typically extends to 2 hours in each peak when the RCI value exceeds 1.0. Travel during the peak period, but outside these possibly congested times, is assigned a free-flow speed. The speed information is used in the delay, fuel economy, system average speed and travel rate index calculations.

Exhibit B-4. Percent of Daily Travel in Congested Conditions

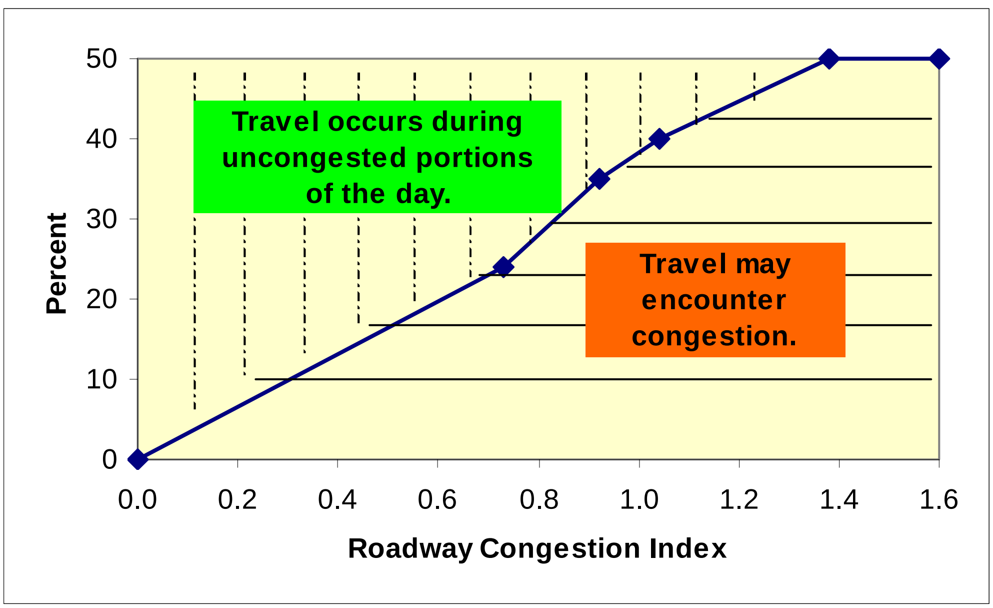


Exhibit B-5. Percentage of Daily Travel Used in Delay Estimation Procedure for 2002 Annual Report

Urban Area	Roadway Congestion Index	% of Daily Travel in Congested Conditions
Los Angeles-Long Beach-Santa Ana CA	1.57	50.0
San Francisco-Oakland CA	1.41	50.0
Chicago IL-IN	1.38	49.7
Washington DC-VA-MD	1.36	49.3
Atlanta GA	1.35	49.2
San Jose CA	1.35	49.1
Boston MA-NH-RI	1.31	48.5
Riverside-San Bernardino CA	1.31	48.4
Sacramento CA	1.30	48.3
Miami FL	1.29	48.2
Oxnard-Ventura CA	1.29	48.2
San Diego CA	1.29	48.2
Portland OR-WA	1.28	48.0
Detroit MI	1.26	47.7
Denver-Aurora CO	1.25	47.5
Phoenix AZ	1.24	47.4
Seattle WA	1.24	47.4
Houston TX	1.22	46.9
Minneapolis-St. Paul MN	1.22	47.0
Las Vegas NV	1.21	46.8
Tampa-St. Petersburg FL	1.21	46.9
Baltimore MD	1.20	46.6
Bridgeport-Stamford CT-NY	1.20	46.7
Charlotte NC-SC	1.18	46.4
New York-Newark NY-NJ-CT	1.16	46.1
Austin TX	1.15	45.9
Sarasota-Bradenton FL	1.15	45.9
Salt Lake City UT	1.14	45.6
Dallas-Fort Worth-Arlington TX	1.13	45.5
Indianapolis IN	1.13	45.5
Orlando FL	1.13	45.5
Cincinnati OH-KY-IN	1.12	45.4
Louisville KY-IN	1.12	45.3
Philadelphia PA-NJ-DE-MD	1.11	45.2
St. Louis MO-IL	1.10	45.0
Tucson AZ	1.09	44.7
Columbus OH	1.08	43.9
Milwaukee WI	1.06	43.0
San Antonio TX	1.06	43.0
Memphis TN-MS-AR	1.04	41.8
Virginia Beach VA	1.04	41.9
Honolulu HI	1.03	41.4
Jacksonville FL	1.03	41.7
Nashville-Davidson TN	1.03	41.7
New Haven CT	1.03	41.4
Albuquerque NM	1.02	41.2
New Orleans LA	1.02	40.9
Cape Coral FL	1.01	40.3
Birmingham AL	1.00	40.1
Raleigh-Durham NC	0.99	39.6
Grand Rapids MI	0.98	39.1
Charleston-North Charleston SC	0.97	38.7
El Paso TX-NM	0.97	38.6
Fresno CA	0.96	37.8
Hartford CT	0.96	37.9
Providence RI-MA	0.96	38.1
Allentown-Bethlehem PA-NJ	0.95	37.6
Omaha NE-IA	0.95	37.6
Cleveland OH	0.92	36.1
Eugene OR	0.91	35.3
Pensacola FL-AL	0.91	35.3
Salem OR	0.91	35.3
Toledo OH-MI	0.91	35.4
Dayton OH	0.90	34.9
Beaumont TX	0.89	34.7
Oklahoma City OK	0.89	34.2
Akron OH	0.88	33.7
Colorado Springs CO	0.86	32.1
Little Rock AR	0.86	32.1
Columbia SC	0.85	32.0
Boulder CO	0.84	31.1
Brownsville TX	0.84	30.8
Kansas City MO-KS	0.84	30.8
Spokane WA	0.84	31.3
Springfield MA-CT	0.84	31.3
Tulsa OK	0.82	29.7
Albany-Schenectady NY	0.81	29.1
Rochester NY	0.80	28.3
Richmond VA	0.79	27.5
Pittsburgh PA	0.78	27.1
Bakersfield CA	0.77	26.5
Buffalo NY	0.76	25.5
Corpus Christi TX	0.71	23.8
Anchorage AK	0.67	22.3
Laredo TX	0.65	21.6

Identify Congestion Level of Each Section of Roadway

Each roadway link is assigned to one of five congestion levels—uncongested, moderate, heavy, severe or extreme. These are based on the daily traffic volume per lane. The portion of this traffic that is considered to be peak direction—as determined by the directional factor for the link—is separated from the portion considered off-peak.

Apply Speed Estimates to Each Congestion Group

Exhibits B-6, B-7 and B-8 present the relationships used to estimate the speed for each congestion level and direction on freeways and principal arterial streets. These speeds were developed from a combination of travel time data from several traffic management centers across the U.S. and computer simulation speed estimating methodologies. These speeds include the effects of incidents on congestion. Exhibits B-7 and B-8 show the speed curves used in this report and the curves used in previous reports. In general, the new freeway speeds are higher at traffic levels until volume reaches about 25,000 vehicles per lane (extreme level)

Generally arterial street speeds are higher with the new curves (Exhibit B-8) than with the previous speed estimates, especially on higher traffic volume per lane levels.

Exhibit B-6. Daily Traffic Volume per Lane and Speed Estimating Used in Delay Calculation

Facility	Direction	Congestion Level		Speed Function[1]	Notes
Freeway/Expressway	Peak	Uncongested	Under 15,000	60	
		Moderate	15,001-17,500	74.45-(1.09 ADT/Lane)	
		Heavy	17,501-20,000	109.76-(3.10 ADT/Lane)	
		Severe	20,001-25,000	135.08-(4.33 ADT/Lane)	
		Extreme	Over 25,000	72.03-(1.75 ADT/Lane)	Set Floor at 20
	Off-Peak	Uncongested	Under 15,000	60	
		Moderate	15,001-17,500	68.72-(0.65 ADT/Lane)	
		Heavy	17,501-20,000	72.46-(0.88 ADT/Lane)	
		Severe	20,001-25,000	103.54-(2.44 ADT/Lane)	
		Extreme	Over 25,000	123.57-(3.21 ADT/Lane)	Set Floor at 25
Principal Arterial	Peak	Uncongested	Under 5,500	35	
		Moderate	5,501-7,000	33.58-(0.74 ADT/Lane)	
		Heavy	7,001-8,500	33.80-(0.77 ADT/Lane)	
		Severe	8,501-10,000	31.65-(0.51 ADT/Lane)	
		Extreme	Over 10,000	32.57-(0.62 ADT/Lane)	Set Floor at 25
	Off-Peak	Uncongested	Under 5,500	35	
		Moderate	5,501-7,000	33.82-(0.59 ADT/Lane)	
		Heavy	7,001-8,500	33.90-(0.59 ADT/Lane)	
		Severe	8,501-10,000	30.10 (0.15 ADT/Lane)	
		Extreme	Over 10,000	31.23-(0.27 ADT/Lane)	Set Floor at 27

Note: [1]ADT/Lane in thousands.

Exhibit B-7. Freeway Speed Estimation Curves

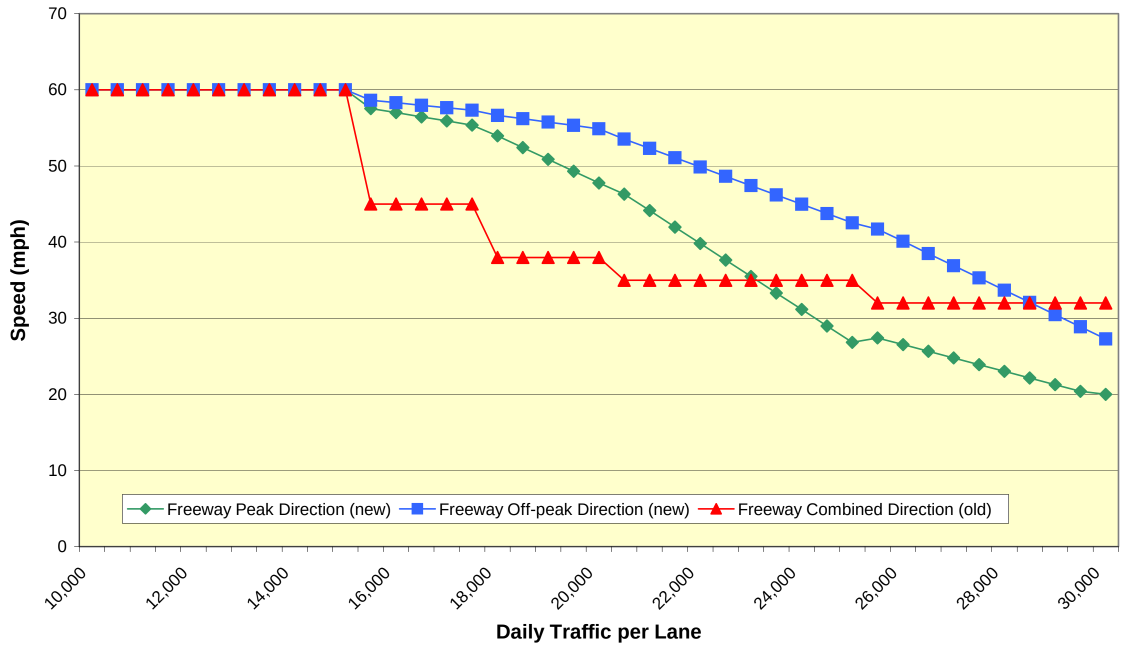
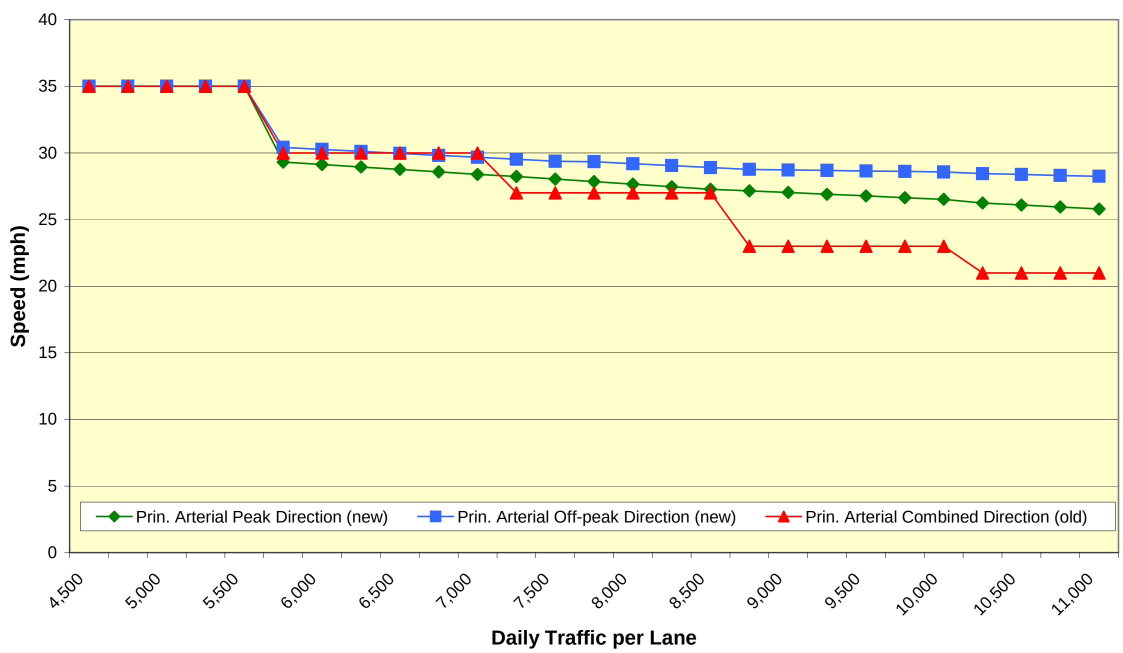


Exhibit B-8. Principal Arterial Speed Estimation Curves



Average the Speed Estimates for All Groups

The amount of travel (measured in vehicle-miles) is summed for each congestion level and direction. The average ADT per lane is determined by dividing the VMT by lane-miles for each congestion level and direction. The speed for each congestion level and direction is determined by applying the ADT per lane value to the appropriate speed function in Exhibit B-2. The average speed is obtained by weighting each congestion level by the total amount of travel at that level. The uncongested category includes travel on the uncongested portions of roadway, as well as travel during portions of the day that are estimated to rarely have congestion. The uncongested portion of the day varies for each city, but the total amount of travel included in the speed averaging procedure is **50 percent of the average daily** vehicle-miles of travel for all urban areas.

Estimate Travel Delay Using Speed and Travel Volume

The amount of delay incurred in the peak period is a function of the average speed and distance. This value is calculated for both the peak-period conditions, and for free-flow speed conditions. The delay rate—the minutes per mile lost in congestion—is used in the calculation process with the travel mileage used to weight each congestion group.

Estimate Travel Delay

The difference in the amount of time it takes to travel the peak-period vehicle-miles at the average speed and at free-flow speeds is termed delay. Travel standards other than free-flow are useful, especially for analyses conducted by individual areas for corridors or portions of a city.

Incident-Related Travel Delay

Another type of delay encountered by travelers is incident delay. This is the delay that results from an accident or disabled vehicle. Incident delay is related to the frequency of crashes or vehicle breakdowns and how easily those incidents are removed from the traffic lanes and shoulders. The basic procedure used to estimate incident delay in this study is to multiply the recurring delay by a ratio (Equation B-1).

The process used to develop the ratio is a detailed examination of the freeway characteristics and volumes. In addition, a methodology developed by FHWA (3) is used to model the effect of incidents based on the design characteristics and estimated volume patterns. The resulting ratios are presented in Exhibit B-9.

$$\begin{matrix} \text{Daily Freeway} \\ \text{Incident} \\ \text{Vehicle - Hours} \\ \text{of Delay} \end{matrix} = \begin{matrix} \text{Daily Freeway} \\ \text{Recurring} \\ \text{Vehicle - Hours} \\ \text{of Delay} \end{matrix} \times \begin{matrix} \text{Freeway} \\ \text{Recurring} \\ \text{to Incident} \\ \text{Delay Ratio} \end{matrix} \qquad \text{(Eq. B-1)}$$

$$\text{(Ex.)}\ 161{,}306 = 179{,}230 \times 0.9$$

Exhibit B-9. Incident Delay Ratios

Urban Area	Freeway Incident Delay Ratio	Principal Arterial Street Incident Delay Ratio
Akron OH	1.4	1.1
Albany-Schenectady NY	2.3	1.1
Albuquerque NM	1.1	1.1
Allentown-Bethlehem PA-NJ	1.4	1.1
Anchorage AK	2.5	1.1
Atlanta GA	1.1	1.1
Austin TX	1.5	1.1
Bakersfield CA	1.8	1.1
Baltimore MD	1.3	1.1
Beaumont TX	2.5	1.1
Birmingham AL	1.9	1.1
Boston MA-NH-RI	1.5	1.1
Boulder CO	2.5	1.1
Bridgeport-Stamford CT-NY	1.4	1.1
Brownsville TX	2.5	1.1
Buffalo NY	2.2	1.1
Cape Coral FL	2.5	1.1
Charleston-North Charleston SC	2.0	1.1
Charlotte NC-SC	1.0	1.1
Chicago IL-IN	0.8	1.1
Cincinnati OH-KY-IN	1.2	1.1
Cleveland OH	1.5	1.1
Colorado Springs CO	2.2	1.1
Columbia SC	1.8	1.1
Columbus OH	1.3	1.1
Corpus Christi TX	2.3	1.1
Dallas-Fort Worth-Arlington TX	1.2	1.1
Dayton OH	1.3	1.1
Denver-Aurora CO	1.1	1.1
Detroit MI	1.3	1.1
El Paso TX-NM	1.6	1.1
Eugene OR	2.4	1.1
Fresno CA	2.3	1.1
Grand Rapids MI	2.0	1.1
Hartford CT	2.1	1.1
Honolulu HI	0.7	1.1
Houston TX	0.9	1.1
Indianapolis IN	1.0	1.1
Jacksonville FL	1.5	1.1
Kansas City MO-KS	2.5	1.1
Laredo TX	2.5	1.1
Las Vegas NV	0.8	1.1
Little Rock AR	1.5	1.1
Los Angeles-Long Beach-Santa Ana CA	0.7	1.1
Louisville KY-IN	1.6	1.1
Memphis TN-MS-AR	1.7	1.1
Miami FL	1.0	1.1
Milwaukee WI	1.0	1.1
Minneapolis-St. Paul MN	1.4	1.1
Nashville-Davidson TN	1.8	1.1
New Haven CT	1.3	1.1
New Orleans LA	1.3	1.1
New York-Newark NY-NJ-CT	2.5	1.1
Oklahoma City OK	2.0	1.1
Omaha NE-IA	2.5	1.1
Orlando FL	1.3	1.1
Oxnard-Ventura CA	1.3	1.1
Pensacola FL-AL	2.5	1.1
Philadelphia PA-NJ-DE-MD	2.2	1.1
Phoenix AZ	0.8	1.1
Pittsburgh PA	2.5	1.1
Portland OR-WA	1.2	1.1
Providence RI-MA	2.2	1.1
Raleigh-Durham NC	1.5	1.1
Richmond VA	2.3	1.1
Riverside-San Bernardino CA	0.9	1.1
Rochester NY	2.3	1.1
Sacramento CA	1.0	1.1
Salem OR	2.5	1.1
Salt Lake City UT	1.2	1.1
San Antonio TX	0.8	1.1
San Diego CA	0.6	1.1
San Francisco-Oakland CA	0.9	1.1
San Jose CA	1.1	1.1
Sarasota-Bradenton FL	2.5	1.1
Seattle WA	1.2	1.1
Spokane WA	2.4	1.1
Springfield MA-CT	1.6	1.1
St. Louis MO-IL	1.2	1.1
Tampa-St. Petersburg FL	1.5	1.1
Toledo OH-MI	2.2	1.1
Tucson AZ	1.5	1.1
Tulsa OK	2.2	1.1
Virginia Beach VA	2.2	1.1
Washington DC-VA-MD	0.9	1.1

Incident delay occurs in different ways on streets than freeways. While there are driveways that can be used to remove incidents, the crash rate is higher and the recurring delay is lower on streets. Arterial street designs are more consistent from city to city than freeway designs. For the purpose of this study, incident delay for arterial streets is estimated as 110 percent of arterial street recurring delay. Incident delay is calculated using Equation B-2.

$$\begin{array}{c}\text{Daily Principal Arterial} \\ \text{Street Incident} \\ \text{Vehicle - Hours of Delay}\end{array} = \begin{array}{c}\text{Daily Principal Arterial} \\ \text{Street Recurring} \\ \text{Vehicle - Hours of Delay}\end{array} \times \begin{array}{c}\text{Principal Arterial Street} \\ \text{Recurring to Incident} \\ \text{Delay Factor}\end{array} \qquad \text{(Eq. B-2)}$$

$$\text{(Ex.)}\ 53{,}969 = 49{,}063 \times 1.1$$

Estimate Annual Person Delay

This calculation is performed to expand the daily recurring and incident delay estimates for freeways and principal arterial streets to a yearly estimate in each study area. The daily vehicle-hours of delay is the sum of the delay resulting from all four levels of congestion on both types of facilities. To calculate the annual person-hours of delay, multiply the daily delay estimates by the average vehicle occupancy (1.25 persons per vehicle) and by 250 working days per year (Equation B-3). Exhibit B-5 presents the 2002 total delay and delay per traveler values.

$$\begin{array}{c}\text{Annual} \\ \text{Person - Hours} \\ \text{of Delay}\end{array} = \begin{array}{c}\text{Daily} \\ \text{Vehicle - Hours} \\ \text{of} \\ \text{Incident + Recurring} \\ \text{Delay}\end{array} \times \begin{array}{c}\text{250} \\ \text{Working} \\ \text{Days} \\ \text{per Year}\end{array} \times \begin{array}{c}\text{1.25} \\ \text{Persons} \\ \text{per} \\ \text{Vehicle}\end{array} \qquad \text{(Eq. B-3)}$$

$$\text{(Ex. Freeway)}\ 138{,}615{,}000 = 443{,}568 \times 250 \times 1.25$$

Exhibit B-10. Estimated Travel Delay Statistics

Urban Area	2002 Total Delay (000)	2002 Delay per Traveler
Los Angeles-Long Beach-Santa Ana CA	700,707	104
New York-Newark NY-NJ-CT	452,440	57
Chicago IL-IN	250,956	59
San Francisco-Oakland CA	175,242	84
Dallas-Fort Worth-Arlington TX	157,549	65
Miami FL	157,365	57
Houston TX	138,615	65
Washington DC-VA-MD	133,547	71
Detroit MI	115,727	56
Philadelphia PA-NJ-DE-MD	113,960	44
Atlanta GA	106,151	66
Boston MA-NH-RI	86,682	58
San Diego CA	81,074	53
Phoenix AZ	78,219	49
Seattle WA	72,187	50
Minneapolis-St. Paul MN	65,104	50
Baltimore MD	62,043	50
Denver-Aurora CO	57,352	47
Riverside-San Bernardino CA	56,717	65
San Jose CA	53,312	59
Tampa-St. Petersburg FL	49,022	45
St. Louis MO-IL	42,392	38
Portland OR-WA	36,965	46
Orlando FL	36,072	53
Sacramento CA	32,747	40
Cincinnati OH-KY-IN	29,086	40
San Antonio TX	25,607	38
Virginia Beach VA	25,350	31
Austin TX	23,106	52
Indianapolis IN	21,780	39
Providence RI-MA	21,724	33
Las Vegas NV	20,781	28
Milwaukee WI	19,365	25
Charlotte NC-SC	18,000	47
Louisville KY-IN	17,788	40
Columbus OH	17,286	30
Salt Lake City UT	17,049	35
Memphis TN-MS-AR	16,941	33
Nashville-Davidson TN	16,434	44
Jacksonville FL	16,040	33
Bridgeport-Stamford CT-NY	14,822	33
Kansas City MO-KS	12,603	16
Pittsburgh PA	12,175	13
Cleveland OH	12,139	12
Tucson AZ	11,482	30
Raleigh-Durham NC	10,971	26
New Orleans LA	10,545	18
Birmingham AL	9,893	28
Oxnard-Ventura CA	9,677	32
Albuquerque NM	9,271	30
Omaha NE-IA	8,520	25
Hartford CT	8,367	18
Oklahoma City OK	8,166	14
El Paso TX-NM	7,097	20
Richmond VA	7,062	16
Honolulu HI	6,859	18
New Haven CT	6,521	23
Sarasota-Bradenton FL	6,189	22
Tulsa OK	6,006	14
Colorado Springs CO	5,946	24
Grand Rapids MI	5,785	21
Charleston-North Charleston SC	5,479	22
Buffalo NY	5,379	10
Fresno CA	4,949	16
Dayton OH	4,628	15
Allentown-Bethlehem PA-NJ	4,426	14
Akron OH	3,572	12
Toledo OH-MI	3,477	13
Albany-Schenectady NY	3,277	12
Pensacola FL-AL	3,166	19
Springfield MA-CT	3,147	9
Cape Coral FL	2,513	15
Rochester NY	2,035	6
Columbia SC	1,831	8
Spokane WA	1,714	10
Bakersfield CA	1,687	7
Little Rock AR	1,686	9
Salem OR	1,662	15
Eugene OR	1,207	10
Beaumont TX	1,155	15
Corpus Christi TX	1,065	6
Laredo TX	750	7
Anchorage AK	728	5
Boulder CO	588	10
Brownsville TX	433	5

TRAVEL RATE INDEX

The travel rate index (TRI) shows the amount of additional time that is required to make a trip because of congested conditions on the roadways. A number such as 1.30 would show that it takes 30 percent more time to make a trip in the peak period than if the motorist could travel at freeflow speeds. Equations B-4 to B-6 show how to calculate the TRI.

Equation B-4 shows the calculation for a weighted average of speed. The average speed for each element of the road system is multiplied by the amount of travel on that set of roads. Using the amount of travel as a weighting factor provides a way to get an average “system experience” of travelers based on the amount of travel that occurs within each portion of the road system. This fundamental concept is used elsewhere in the Urban Mobility Study methodology. The travel rate index also uses a weighting process based on travel rate values. Equation B-5 shows how to convert an average speed (in miles per hour) to a travel rate (in minutes per mile). The TRI is calculated in Equation B-6 by weighting the freeway and principal arterial travel rates with the amount of travel.

$$\text{Average Speed (mph)} = \frac{\left(\text{Average Freeway Speed}\right)\left(\text{Freeway VMT}\right) + \left(\text{Average Arterial Street Speed}\right)\left(\text{Arterial VMT}\right)}{\text{Freeway VMT} + \text{Street VMT}} \qquad \text{(Eq. B-4)}$$

$$\text{Travel Rate} = \frac{60}{\text{Average System Element Speed}}$$

$$\text{(Ex. Congested Freeway) } 1.25 = \frac{60}{45.92} = 1.29 \qquad \text{(Eq. B-5)}$$

$$\text{Travel Rate Index} = \frac{\left(\frac{\text{Freeway Travel Rate}}{\text{Freeway Freeflow Rate}} \times \text{Peak Period Freeway VMT}\right) + \left(\frac{\text{Principal Arterial Street Travel Rate}}{\text{Principal Arterial Street Freeflow Rate}} \times \text{Peak Period Principal Arterial Street VMT}\right)}{\left(\text{Peak Period Freeway VMT} + \text{Peak Period Principal Arterial Street VMT}\right)}$$

$$\text{(Ex.) } 1.26 = \frac{\left(\frac{1.306}{1.0} \times 21{,}375{,}000\right) + \left(\frac{1.992}{1.71} \times 9{,}550{,}000\right)}{\left(21{,}375{,}000 + 9{,}550{,}000\right)} \qquad \text{(Eq. B-6)}$$

Exhibit B-11. Speed Estimates and Travel Rate Index Values

Urban Area	Average Speed (mph) Freeway	Average Speed (mph) Principal Arterial Street	Travel Rate Index
Los Angeles-Long Beach-Santa Ana CA	34.7	29.9	1.53
San Francisco-Oakland CA	42.0	29.5	1.37
Chicago IL-IN	41.3	29.0	1.34
Washington DC-VA-MD	44.9	28.3	1.30
San Diego CA	45.6	29.9	1.28
Houston TX	45.9	30.1	1.26
Riverside-San Bernardino CA	45.2	30.7	1.25
Atlanta GA	47.6	28.9	1.25
Miami FL	45.1	30.0	1.25
Denver-Aurora CO	47.3	28.7	1.25
Boston MA-NH-RI	47.8	28.8	1.24
Phoenix AZ	45.8	30.8	1.23
San Jose CA	48.2	29.0	1.23
Portland OR-WA	48.2	29.3	1.23
Las Vegas NV	48.3	29.6	1.22
Dallas-Fort Worth-Arlington TX	48.4	30.2	1.21
New York-Newark NY-NJ-CT	49.8	28.9	1.21
Sacramento CA	48.7	30.2	1.21
Seattle WA	49.1	30.2	1.20
Minneapolis-St. Paul MN	49.7	29.5	1.20
Baltimore MD	49.5	30.1	1.20
Detroit MI	50.2	29.1	1.20
Charlotte NC-SC	50.7	29.4	1.19
Philadelphia PA-NJ-DE-MD	52.1	29.0	1.18
Tampa-St. Petersburg FL	54.0	29.3	1.17
Austin TX	52.0	29.5	1.17
Salt Lake City UT	51.5	30.1	1.16
Orlando FL	52.6	29.8	1.16
Tucson AZ	53.8	29.9	1.15
San Antonio TX	52.0	30.7	1.15
Milwaukee WI	50.3	32.1	1.15
Bridgeport-Stamford CT-NY	52.4	30.5	1.15
Cincinnati OH-KY-IN	52.2	31.3	1.14
Sarasota-Bradenton FL	59.9	30.2	1.13
Indianapolis IN	55.1	29.3	1.13
St. Louis MO-IL	54.8	28.9	1.13
Louisville KY-IN	53.8	30.5	1.13
Memphis TN-MS-AR	53.6	31.2	1.12
Honolulu HI	54.6	30.3	1.11
Albuquerque NM	53.9	31.5	1.11
Virginia Beach VA	55.5	30.5	1.11
Columbus OH	54.8	30.5	1.11
Oxnard-Ventura CA	54.6	31.2	1.11
Nashville-Davidson TN	55.3	30.4	1.10
Providence RI-MA	55.1	31.0	1.10
New Orleans LA	56.1	30.9	1.10
Colorado Springs CO	55.1	31.5	1.10
Omaha NE-IA	57.1	31.0	1.09
Raleigh-Durham NC	56.7	30.3	1.09
El Paso TX-NM	54.4	32.4	1.09
Cape Coral FL	59.7	31.6	1.09
Jacksonville FL	56.7	31.0	1.09
Charleston-North Charleston SC	58.6	30.3	1.09
Birmingham AL	57.7	29.7	1.08
New Haven CT	56.0	31.5	1.08
Allentown-Bethlehem PA-NJ	57.3	30.9	1.08
Fresno CA	58.1	31.1	1.08
Grand Rapids MI	58.7	30.8	1.08
Pensacola FL-AL	59.7	32.1	1.07
Hartford CT	57.7	31.6	1.06
Salem OR	59.5	31.9	1.06
Tulsa OK	57.8	31.7	1.06
Cleveland OH	57.1	32.7	1.06
Eugene OR	59.3	31.1	1.05
Pittsburgh PA	58.1	32.5	1.05
Dayton OH	58.3	32.0	1.05
Boulder CO	59.9	32.0	1.05
Oklahoma City OK	58.1	32.3	1.05
Toledo OH-MI	57.5	32.8	1.05
Akron OH	57.8	32.6	1.05
Kansas City MO-KS	58.2	31.9	1.05
Laredo TX	59.9	33.1	1.04
Richmond VA	58.3	32.8	1.04
Buffalo NY	58.0	33.4	1.04
Albany-Schenectady NY	59.5	32.1	1.04
Spokane WA	59.2	33.2	1.04
Springfield MA-CT	59.7	32.2	1.04
Brownsville TX	59.9	33.0	1.04
Beaumont TX	58.8	33.0	1.04
Bakersfield CA	58.8	33.5	1.03
Anchorage AK	60.0	32.1	1.03
Little Rock AR	59.2	32.5	1.03
Columbia SC	59.5	32.6	1.03
Rochester NY	58.9	32.6	1.03
Corpus Christi TX	59.1	33.6	1.02

TRAVEL TIME INDEX

The travel time index (TTI) illustrates the same type of comparison as the travel rate index—peak period travel to freeflow travel. The travel time index, however, includes both recurring and incident conditions, where the travel rate index only includes recurring. The travel delay estimate is used as a starting point, and the average condition travel rate is "back-calculated" (Equation B-7). The TTI, conceptually, is closer to the value that will be calculated from automated data collection systems that include all operating conditions. Exhibit B-12 presents the 2002 travel time index values.

The index is calculated with a procedure consistent with the methods and data that will be used in the automated travel management centers. Since these centers will monitor the transportation system, the databases will include information about segments of the system. The TTI calculation process, therefore categorizes each segment into one of five congestion levels and uses the delay rate - the difference between free-flow and average speeds—as a method to calculate the delay in each congestion level as weighted by the amount of travel. The free-flow travel rate for each functional class is subtracted from the average travel rate (from the recurring delay calculations – Exhibit B-3) to get the delay rate. The delay rate is multiplied by the incident-to-recurring delay ratio to estimate the delay rate that would be obtained for the incident conditions. For each congestion level, the delay rate from incident calculations is added to the delay rate from the recurring delay and the free-flow travel rate for the functional class. The "all-conditions" travel rate average is then computed for each functional class using the VMT in each congestion level to weight the travel rate values. The travel time index is calculated by comparing the travel rates for each functional class to the freeflow travel rates.

$$\text{Travel Time Index} = \frac{\text{All Conditions Peak Period Travel Rate (minutes/mile)}}{\text{Average Freeflow Travel Rate}} \quad \text{(Eq. B-7)}$$

Calculation Steps

For each congestion level:

$$\text{All Conditions Travel Rate} = \text{Freeflow Travel Rate} + \text{Recurring Delay Rate} + \text{Incident Delay Rate}$$

$$\begin{matrix}\text{For each Functional Class} \\ \text{(obtain the weighted} \\ \text{average travel rate)}\end{matrix} \quad \begin{matrix}\text{All Conditions} \\ \text{Functional Class} \\ \text{Travel Rate}\end{matrix} = \frac{\begin{matrix}\text{The sum of the products} \\ \text{from this equation for} \\ \text{each congestion level}\end{matrix} \left(\begin{matrix}\text{Each Congestion} \\ \text{Level Travel Rate}\end{matrix} \times \begin{matrix}\text{Vehicle - miles of} \\ \text{Travel in the} \\ \text{Congestion Level}\end{matrix} \right)}{\left(\begin{matrix}\text{Vehicle - miles of} \\ \text{Travel in the Functional Class}\end{matrix} \right)}$$

$$\begin{matrix}\text{For all Functional Classes} \\ \text{(obtain weighted average travel rate)}\end{matrix} \quad \begin{matrix}\text{Travel} \\ \text{Time Index}\end{matrix} = \frac{\left(\dfrac{\begin{matrix}\text{All Conditions} \\ \text{Freeway Travel Rate}\end{matrix}}{\begin{matrix}\text{Freeway Freeflow} \\ \text{Travel Rate}\end{matrix}} \right) \begin{matrix}\text{Freeway} \\ \text{VMT}\end{matrix} + \left(\dfrac{\begin{matrix}\text{All Conditions} \\ \text{Arterial Travel Rate}\end{matrix}}{\begin{matrix}\text{Arterial Freeflow} \\ \text{Travel Rate}\end{matrix}} \right) \begin{matrix}\text{Arterial} \\ \text{VMT}\end{matrix}}{\text{Freeway VMT} + \text{Arterial VMT}}$$

Exhibit B-12. 2002 Travel Time Index Values

Urban Area	Travel Time Index
Los Angeles-Long Beach-Santa Ana CA	1.84
San Francisco-Oakland CA	1.61
Chicago IL-IN	1.56
Washington DC-VA-MD	1.52
Boston MA-NH-RI	1.47
Atlanta GA	1.45
New York-Newark NY-NJ-CT	1.43
Riverside-San Bernardino CA	1.42
San Diego CA	1.42
Portland OR-WA	1.42
Miami FL	1.42
San Jose CA	1.42
Denver-Aurora CO	1.42
Houston TX	1.41
Minneapolis-St. Paul MN	1.38
Detroit MI	1.38
Seattle WA	1.38
Phoenix AZ	1.37
Sacramento CA	1.37
Baltimore MD	1.37
Philadelphia PA-NJ-DE-MD	1.36
Las Vegas NV	1.36
Dallas-Fort Worth-Arlington TX	1.36
Tampa-St. Petersburg FL	1.32
Charlotte NC-SC	1.32
Austin TX	1.32
Orlando FL	1.30
Tucson AZ	1.30
Bridgeport-Stamford CT-NY	1.29
Salt Lake City UT	1.29
Sarasota-Bradenton FL	1.26
Milwaukee WI	1.26
Cincinnati OH-KY-IN	1.25
Indianapolis IN	1.25
Louisville KY-IN	1.25
St. Louis MO-IL	1.25
San Antonio TX	1.24
Memphis TN-MS-AR	1.23
Virginia Beach VA	1.22
Oxnard-Ventura CA	1.21
Nashville-Davidson TN	1.20
Albuquerque NM	1.20
Providence RI-MA	1.20
Columbus OH	1.19
Colorado Springs CO	1.19
New Orleans LA	1.19
Omaha NE-IA	1.19
Raleigh-Durham NC	1.18
Honolulu HI	1.18
Charleston-North Charleston SC	1.18
Cape Coral FL	1.17
El Paso TX-NM	1.17
Jacksonville FL	1.17
Birmingham AL	1.17
Fresno CA	1.16
Grand Rapids MI	1.15
Allentown-Bethlehem PA-NJ	1.15
New Haven CT	1.14
Pensacola FL-AL	1.12
Hartford CT	1.12
Tulsa OK	1.11
Eugene OR	1.11
Salem OR	1.11
Toledo OH-MI	1.11
Oklahoma City OK	1.11
Cleveland OH	1.10
Kansas City MO-KS	1.10
Pittsburgh PA	1.10
Boulder CO	1.10
Dayton OH	1.10
Akron OH	1.09
Richmond VA	1.08
Buffalo NY	1.08
Spokane WA	1.08
Laredo TX	1.08
Albany-Schenectady NY	1.07
Springfield MA-CT	1.07
Brownsville TX	1.07
Beaumont TX	1.07
Bakersfield CA	1.07
Rochester NY	1.06
Little Rock AR	1.06
Columbia SC	1.06
Anchorage AK	1.05
Corpus Christi TX	1.04

FUEL ECONOMY

The average fuel economy calculation is used to estimate the fuel consumption of the vehicles operating in congested and uncongested conditions. Equation (Eq. B-8) is a linear regression applied to a modified version of fuel consumption reported by Raus (4).

$$\begin{array}{c}\text{Average Fuel}\\ \text{Economy}\\ \text{in Congestion}\end{array} = 8.8 + 0.25 \left(\begin{array}{c}\text{Average Peak}\\ \text{Period Congested}\\ \text{System Speed}\end{array}\right)$$

$$\text{(Ex.)}\ 17.89 = 8.8 + 0.25\ (36.35) \qquad \text{(Eq. B-8)}$$

WASTED FUEL

Equation B-9 calculates the wasted fuel due to vehicles moving at speeds slower than free-flow during peak period travel. Equation B-9 calculates the fuel wasted in recurring and incident delay conditions from Equation B-3, the average peak period speed (Equation B-4), and the average fuel economy associated with the peak speed (Equation B-7).

$$\begin{array}{c}\text{Annual}\\ \text{Fuel Wasted}\end{array} = \begin{array}{c}\text{Travel Delay}\\ \text{(vehicle - hours)}\\ \text{(Eq. B - 3)}\end{array} \times \begin{array}{c}\text{Average}\\ \text{Peak Period}\\ \text{System}\\ \text{"Congested"}\\ \text{Speed}\\ \text{(Eq. B - 4)}\end{array} \div \begin{array}{c}\text{Average Fuel}\\ \text{Economy}\\ \text{(Eq. B - 8)}\end{array} \times \begin{array}{c}\text{250 Working}\\ \text{Days per Year}\end{array}$$

$$\text{(Ex.)}\ 225{,}317{,}170 = 443{,}568 \times 36.35 \div 17.89 \times 250 \qquad \text{(Eq. B-9)}$$

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 describe how to calculate the costs associated with each component.

Passenger Vehicle Delay Cost

The delay cost is an estimate of the value of lost time in passenger vehicles and the increased operating costs of commercial vehicles in congestion. Equations B-10 through B-12 show how to calculate the cost of delay. Equation B-10 shows how to calculate the passenger vehicle delay costs that result from lost time.

$$\begin{array}{lcccccccc} & \begin{array}{c}\text{Annual Passenger}\\ \text{Vehicle Delay Cost}\end{array} & = & \begin{array}{c}\text{Daily Passenger Vehicle -}\\ \text{Hours of Delay}\\ \text{(Eq. B - 3)}\end{array} & \times & \begin{array}{c}\text{Value of}\\ \text{Person Time}\\ \text{(\$/hour)}\end{array} & \times & \begin{array}{c}\text{Vehicle}\\ \text{Occupancy}\\ \text{(persons/vehicle)}\end{array} & \times \text{ Days} \\ \text{(Ex.)} & \$1,771,153,160 & = & (443,568 \times 0.95) & \times & \$13.45 & \times & 1.25 & \times\ 250 \end{array} \quad \text{(Eq. B-10)}$$

Passenger Vehicle Fuel Cost

Fuel cost due to congestion is calculated for passenger vehicles in Equation B-11. This is done by associating the peak period congested speeds, the average fuel economy, and the fuel costs with the vehicle-hours of delay.

$$\text{Annual Fuel Cost} = \begin{matrix}\text{Daily}\\\text{Vehicle - Hours}\\\text{of Delay}\\\text{(Eq. B - 3)}\end{matrix} \times \begin{matrix}\text{Percent of}\\\text{Passenger}\\\text{Vehicles}\end{matrix} \times \begin{matrix}\text{Average Peak}\\\text{Period}\\\text{Congested}\\\text{System Speed}\\\text{(Eq. B - 4)}\end{matrix} \div \begin{matrix}\text{Average}\\\text{Fuel}\\\text{Economy}\\\text{(Eq. B - 7)}\end{matrix} \times \begin{matrix}\text{Fuel}\\\text{Cost}\end{matrix} \times \text{Days} \quad \text{(Eq. B-11)}$$

$$\text{(Ex.) } \$282{,}547{,}730 = 443{,}568 \times 0.95 \times 36.35 \div 17.89 \times \$1.32 \times 250$$

Commercial Vehicle Cost

The cost of both wasted time and fuel are included in the value of commercial vehicle time ($71.05 in 2002). Thus, there is not a separate value for wasted time and fuel. The equation to calculate commercial vehicle cost is shown in Equation B-12.

$$\begin{matrix}\text{Annual}\\\text{Commercial}\\\text{Cost}\end{matrix} = \begin{matrix}\text{Delay}\\\text{Vehicle Hours}\\\text{of Delay}\end{matrix} \times \begin{matrix}\text{Percent of}\\\text{Commercial}\\\text{Vehicles}\end{matrix} \times \begin{matrix}\text{Value of}\\\text{Commercial}\\\text{Vehicle Time}\end{matrix} \times \text{Days} \quad \text{(Eq. B-12)}$$

$$\text{(Ex.) } \$393{,}943{,}830 = 443{,}568 \times 0.05 \times 71.05 \times 250$$

Total Congestion Cost

Equation B-13 combines the cost due to travel delay and wasted fuel to determine the annual cost due to congestion resulting from incident and recurring delay. Exhibit B-8 illustrates the congestion cost estimated in the 2004 report with the new methodology for 2002 data.

$$\begin{matrix}\text{Annual Cost}\\\text{Due to}\\\text{Congestion}\end{matrix} = \left(\begin{matrix}\text{Annual}\\\text{Passenger}\\\text{Vehicle}\\\text{Delay Cost}\\\text{(Eq. B - 11)}\end{matrix} + \begin{matrix}\text{Annual}\\\text{Passenger}\\\text{Fuel Cost}\\\text{(Eq. B - 12)}\end{matrix}\right) + \begin{matrix}\text{Annual}\\\text{Commercial}\\\text{Cost}\\\text{(Eq. B - 12}\end{matrix} \quad \text{(Eq. B-13)}$$

$$\text{(Ex.) } \$2{,}447{,}644{,}720 = (\$1{,}771{,}153{,}160 + \$282{,}547{,}730) + 393{,}943{,}830$$

Exhibit B-13. 2002 Congestion Cost

Urban Area	Total Congestion Cost ($ Million)	Congestion Cost per Traveler ($)
Los Angeles-Long Beach-Santa Ana CA	12,590	1,870
New York-Newark NY-NJ-CT	8,115	1,024
Chicago IL-IN	4,454	1,040
San Francisco-Oakland CA	3,179	1,516
Dallas-Fort Worth-Arlington TX	2,781	1,153
Miami FL	2,779	1,007
Houston TX	2,444	1,153
Washington DC-VA-MD	2,398	1,278
Detroit MI	2,058	996
Philadelphia PA-NJ-DE-MD	2,020	773
Atlanta GA	1,874	1,163
Boston MA-NH-RI	1,539	1,024
San Diego CA	1,477	972
Phoenix AZ	1,397	880
Seattle WA	1,299	906
Minneapolis-St. Paul MN	1,158	882
Baltimore MD	1,110	899
Riverside-San Bernardino CA	1,029	1,188
Denver-Aurora CO	1,011	833
San Jose CA	967	1,070
Tampa-St. Petersburg FL	865	794
St. Louis MO-IL	753	678
Portland OR-WA	666	828
Orlando FL	639	943
Sacramento CA	599	739
Cincinnati OH-KY-IN	521	716
San Antonio TX	454	670
Virginia Beach VA	449	546
Austin TX	410	918
Providence RI-MA	388	589
Indianapolis IN	385	692
Las Vegas NV	376	511
Milwaukee WI	347	450
Charlotte NC-SC	319	833
Louisville KY-IN	316	704
Columbus OH	310	547
Salt Lake City UT	305	631
Memphis TN-MS-AR	300	576
Nashville-Davidson TN	292	785
Jacksonville FL	287	597
Bridgeport-Stamford CT-NY	268	593
Kansas City MO-KS	225	283
Cleveland OH	218	216
Pittsburgh PA	215	223
Tucson AZ	204	541
Raleigh-Durham NC	195	471
New Orleans LA	187	317
Oxnard-Ventura CA	177	589
Birmingham AL	176	491
Albuquerque NM	164	538
Omaha NE-IA	152	449
Hartford CT	151	327
Oklahoma City OK	145	247
Honolulu HI	126	339
El Paso TX-NM	126	357
Richmond VA	125	281
New Haven CT	118	407
Sarasota-Bradenton FL	109	379
Tulsa OK	106	248
Colorado Springs CO	105	416
Grand Rapids MI	103	366
Buffalo NY	97	186
Charleston-North Charleston SC	96	389
Fresno CA	90	289
Dayton OH	83	263
Allentown-Bethlehem PA-NJ	78	246
Akron OH	64	220
Toledo OH-MI	62	234
Albany-Schenectady NY	59	212
Springfield MA-CT	56	162
Pensacola FL-AL	56	339
Cape Coral FL	44	264
Rochester NY	37	106
Columbia SC	32	143
Bakersfield CA	31	137
Spokane WA	31	175
Little Rock AR	30	167
Salem OR	30	260
Eugene OR	22	174
Beaumont TX	20	266
Corpus Christi TX	19	111
Laredo TX	13	130
Anchorage AK	13	91
Boulder CO	10	177
Brownsville TX	8	89

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 peak congested periods (Equation B-14), 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 and is eligible to be congested (see Section on Recurring Travel Delay). For the daily percentage (Equation B-15), the factor in the denominator is set to 100 percent of travel. Exhibit B-13 shows the 2002 percent of congested travel values.

$$\begin{matrix}\text{Congested}\\ \text{Travel}\end{matrix} = \begin{matrix}\text{Percent of Congested}\\ \text{Peak Period Travel}\end{matrix} \times \begin{matrix}\text{VMT for}\\ \text{Functional Class}\end{matrix}$$

$$\begin{matrix}\text{Percent Congested}\\ \text{Peak Travel}\end{matrix} = \begin{matrix}\text{Percent Congested}\\ \text{Daily Travel}\end{matrix} \div 50\text{ percent}$$

(Eq. B-14)

$$\begin{matrix}\text{Congested}\\ \text{Peak Travel}\\ \text{Percentage}\end{matrix} = 0.689 = \frac{(0.75 \times 42{,}750{,}000 \times 0.469\ ) + (0.70 \times 19{,}100{,}000 \times 0.469)}{(42{,}750{,}000 + 19{,}100{,}000\text{l}) \times 0.50}$$

$$\begin{matrix}\text{Percent Congested}\\ \text{Daily Travel}\end{matrix} = \frac{\begin{matrix}\text{Freeway}\\ \text{Congested Travel}\end{matrix} + \begin{matrix}\text{PAS}\\ \text{Congested Travel}\end{matrix}}{\text{Daily Travel}}$$

(Eq. B-15)

$$\begin{matrix}\text{Congested}\\ \text{Daily Travel}\\ \text{Percentage}\end{matrix} = 0.34 = \frac{(0.75 \times 42{,}750{,}000 \times 0.469\ ) + (0.70 \times 19{,}100{,}000 \times 0.469)}{(42{,}750{,}000 + 19{,}100{,}000) \times 1.0}$$

Exhibit B-14. Percentage of Congested Travel

Urban Area	Percent of Travel that is Congested in Peak Period	Percentage of Daily Travel that is Congested
Los Angeles-Long Beach-Santa Ana CA	88	44
Atlanta GA	88	44
Washington DC-VA-MD	86	43
Chicago IL-IN	85	42
San Francisco-Oakland CA	83	41
San Diego CA	79	40
Sacramento CA	79	39
Portland OR-WA	77	38
Boston MA-NH-RI	77	38
Detroit MI	76	38
Denver-Aurora CO	75	38
Seattle WA	74	37
Riverside-San Bernardino CA	74	37
San Jose CA	73	36
Las Vegas NV	72	36
Phoenix AZ	72	36
Minneapolis-St. Paul MN	72	36
Philadelphia PA-NJ-DE-MD	72	36
Miami FL	70	35
Baltimore MD	70	35
New York-Newark NY-NJ-CT	69	35
Austin TX	69	35
Tucson AZ	69	35
Tampa-St. Petersburg FL	69	35
Houston TX	69	34
Indianapolis IN	67	33
Bridgeport-Stamford CT-NY	66	33
Charlotte NC-SC	66	33
Orlando FL	65	33
St. Louis MO-IL	64	32
Dallas-Fort Worth-Arlington TX	64	32
Salt Lake City UT	63	32
Sarasota-Bradenton FL	62	31
Cincinnati OH-KY-IN	61	31
Milwaukee WI	57	29
Columbus OH	56	28
Louisville KY-IN	55	27
Memphis TN-MS-AR	54	27
San Antonio TX	54	27
Virginia Beach VA	53	26
Albuquerque NM	52	26
Oxnard-Ventura CA	50	25
Jacksonville FL	49	24
Nashville-Davidson TN	49	24
New Orleans LA	49	24
Raleigh-Durham NC	48	24
Omaha NE-IA	48	24
Honolulu HI	48	24
Charleston-North Charleston SC	46	23
Cape Coral FL	46	23
Birmingham AL	46	23
El Paso TX-NM	45	22
Providence RI-MA	43	21
Grand Rapids MI	42	21
New Haven CT	40	20
Fresno CA	39	20
Hartford CT	39	19
Allentown-Bethlehem PA-NJ	39	19
Dayton OH	39	19
Colorado Springs CO	38	19
Oklahoma City OK	35	17
Pensacola FL-AL	34	17
Cleveland OH	33	17
Akron OH	32	16
Kansas City MO-KS	32	16
Toledo OH-MI	31	15
Eugene OR	30	15
Salem OR	29	15
Little Rock AR	29	14
Tulsa OK	28	14
Boulder CO	27	13
Pittsburgh PA	26	13
Spokane WA	25	12
Albany-Schenectady NY	24	12
Richmond VA	24	12
Springfield MA-CT	23	12
Bakersfield CA	23	11
Buffalo NY	23	11
Rochester NY	23	11
Laredo TX	21	11
Brownsville TX	21	11
Columbia SC	20	10
Beaumont TX	20	10
Anchorage AK	15	7
Corpus Christi TX	14	7

ROADWAY CONGESTION INDEX

Urban roadway congestion levels are estimated using a formula that measures the density of traffic. Average daily travel volume per lane on freeways and principal arterial streets are estimated using areawide estimates of vehicle-miles of travel (VMT) and lane-miles of roadway (Ln-Mi). The resulting ratios are combined using the amount of travel on each portion of the system so that the combined index measures conditions on the freeway and principal arterial street systems. This variable weighting factor allows comparisons between areas such as Phoenix, where principal arterial streets carry 50% the amount of travel of freeways, and cities such as Portland where the ratio is reversed.

The traffic density ratio is divided by a similar ratio that represents congestion for a system with the same mix of freeway and street volume. 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.

Equation 16 illustrates the factors used in the congestion index. The resulting ratio indicates an undesirable level of areawide congestion if a value greater than or equal to 1.0 is obtained.

$$\begin{matrix}\text{Roadway} \\ \text{Congestion} \\ \text{Index}\end{matrix} = \frac{\begin{matrix}\text{Freeway} \\ \text{VMT/Ln.-Mi.}\end{matrix} \times \begin{matrix}\text{Freeway} \\ \text{VMT}\end{matrix} + \begin{matrix}\text{Prin Art Str} \\ \text{VMT/Ln-Mi.}\end{matrix} \times \begin{matrix}\text{Prin Art Str} \\ \text{VMT}\end{matrix}}{14{,}000 \times \begin{matrix}\text{Freeway} \\ \text{VMT}\end{matrix} + 5{,}500 \times \begin{matrix}\text{Prin Art Str} \\ \text{VMT}\end{matrix}} \qquad \text{(Eq. 16)}$$

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 of treatments designed to give a travel speed advantage to transit and carpool riders.

- ♦ Typical commute time not more than 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 not more than 1 1/2 to 2 hours during each peak-period.
- ♦ Wait through one or two red lights at heavily traveled intersections, but not 3 or 4.

- The RCI includes 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 (e.g., a narrow bridge or tunnel crossing a harbor or river), or missing capacity due to a gap in the system.
- The congestion study averages all the developments within an urban area; there will be locations where congestion is much worse or better than average.

REFERENCES

1. Chui, Margaret K. and William E. McFarland. "The Value of Travel Time: New Estimates Developed Using a Speed Choice Model." Texas Transportation Institute, January 1987.

2. American Automobile Association, "Fuel Gauge Report," 2000.

3. Lindley, Jeffrey A. "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures," FHWA-RD-87-052, October 1986.

4. Raus, J. "A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks," Report No. FHWA-TS-81-210, April 1981.