Technical Memorandum
Analysis Procedures and Mobility Performance Measures
100 Most Congested Texas Road Sections
Prepared by Texas A&M Transportation Institute
November 2020

This memo documents the analysis conducted for the 2020 edition of the Texas "100 Most Congested Road Sections" (Texas 100) list. This revision incorporates traffic volume data and private-company traffic speed data from calendar year 2017 to calculate mobility performance measures. This analysis includes over 1,800 sections of road from all the Texas urban areas (populations over 50,000) covering almost 10,000 miles of roadway. For a complete list of the reporting sections, please refer to TTI's web site
 http://mobility.tamu.edu/texas-most-congested-roadways/.

New Data and Calculation Procedures for 2020

The general methodology used to calculate the Texas 100 statistics has been virtually the same since the 2010 report—the first report in the series to make use of the private-company speed datasets. However, the quality of the data (both private sector speeds and the roadway inventory) has continued to improve due to expanded coverage and completeness of the input datasets.

The speed data obtained from INRIX for calendar year 2019 is again point-paired. Until 2015, the data had been based on individual GPS speed reports. The point-paired data combines consecutive GPS reports to calculate a travel time between the points which is converted to average speed. The 2019 data from INRIX is based on the latest version of the INRIX XD network (Version 2). This update includes new roads and some re-segmentation of existing roads which could influence the results of the congestion calculations.

The INRIX speed data for calendar year 2019 also contains more autos in the vehicle mix than in previous years. The addition of more autos can have an effect on the reported speeds, especially in the more congested times, as autos tend to be able to drive a few miles per hour faster than trucks in slower traffic and stop-and-go conditions. The result for the Texas 100 statistics is potentially "improved" congestion conditions because speeds may be slightly faster, on average, as have been reported in previous year. The improvement that is seen cannot be completely contributed to operations on the roadways themselves but would also be due to the shift in the vehicle mix of the INRIX data.

TTI is again calculating its own reference or uncongested speeds for use in the calculations. Through the 2015 100 Most Congested Texas Road Sections report, TTI used the reference speeds provided by INRIX which were based on the 85th percentile of all individual GPS speed reports at a given location. Beginning with the 2016 report, TTI is calculating the reference speed by taking the 85th percentile of the weeknight speeds between 10:00pm and 6:00am. If

at least half of the 15-minute time periods on the weeknights are not populated with a speed, the weekday speeds between 11:00am and 4:00pm are also added to the pool of speeds and the 85th percentile is used for the combination of the overnight and mid-day speeds.

The Data Improvements - Overview
TxDOT's 100 Most Congested Road Sections website (http://www.txdot.gov/inside-txdot/projects/100-congested-roadways.html) was designed to illustrate the severity and extent of Texas' traffic congestion problem. The analysis is conducted on all roads in Texas regardless of the agency that built or maintains them.

This memo documents the calculation procedure that uses a dataset of traffic speeds from INRIX, a private company that provides speed information to a variety of customers. INRIX's 2018 data is an annual average of traffic speed for each section of road for every 15 minutes of each average day for a total of 672 day/time period cells (24 hours x 7 days each week x 4 times per hour).

INRIX's speed data improves the freeway and arterial street congestion measures available in many traditional analyses in the following ways:
- "Real" rush hour speeds were 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 are used as the comparison standard.*
- The volume and roadway inventory data from TxDOT's files were used with the speeds to calculate travel delay statistics; *the best speed data are combined with the best volume information to produce high-quality congestion measures.*

Congestion Measure Calculation
The following steps were used to calculate the congestion performance measures and identify the 100 most congested road sections.
1. Obtain TxDOT Roadway-Highway Inventory (RHiNo) traffic volume data by road section
2. Match the RHiNo road network sections with the traffic speed dataset road sections
3. Estimate traffic volumes for each 15-minute time interval from the daily volume data
4. Calculate average travel speed and total delay for each 15-minute interval
5. Establish free-flow (i.e., low volume) travel speed
6. Calculate congestion performance measures
7. Combine road segments into sections

The mobility measures require four data inputs:
- Actual travel speed
- Free-flow travel speed
- Vehicle volume (total vehicle and truck)
- Vehicle occupancy (persons per vehicle) to calculate person-hours of travel delay

The 2018 private sector traffic speed data provides an excellent data source for the first two inputs, actual and free-flow travel time. The top 100 congestion analysis required vehicle and person volume estimates for the delay calculations; these were obtained from TxDOT's RHiNo 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 TxDOT RHiNo road section for the purposes of calculating the 100 most congested section performance measures.

Process Description
The following sections describe the details for the seven calculation steps and the performance measures that were generated for the determination of the Texas 100 sections. In general, road sections are between 3 and 10 miles long. If a major road is less than 3 miles (e.g., a short section of freeway) it is included in the list.

Step 1. Identify Traffic Volume Data

The RHiNo dataset from TxDOT provided the source for traffic volume data, although the geographic designations in the RHiNo dataset are not identical to the private-sector speed data. The daily traffic volume data must also be divided into the same time interval as the traffic speed data (15-minute intervals). While there are some detailed traffic counts on major roads, the most widespread and consistent traffic counts available are average annual daily traffic (AADT) counts. The 15-minute traffic volumes for each section, therefore, were estimated from these AADT counts using typical time-of-day traffic volume profiles developed from local continuous count locations or ITS data (see Appendix A for the average hourly volume profiles used in the measure calculations).

The truck volumes were calculated in the same way by applying the truck-only 15-minute volume profiles to the truck AADTs reported in RHiNo. These 15-minute truck volumes were split into values for combination trucks and single-panel trucks using the percentages for each from RHiNo. These truck-only profiles account for the fact that trucks volumes tend to peak at very different rates and times than do the mixed-vehicle traffic.

Volume estimates for each day of the week (to match the speed database) were created from the annual average volume data using the factors in Exhibit 1. Automated traffic recorders from the Texas metropolitan areas were reviewed and the factors in Exhibit 1 are a "best-fit" average for both freeways and major streets. Creating a 15-minute 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 15-minute factor.

Exhibit 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 desired roadway segment. The combination (also known as conflation) of the traffic volume and traffic speed networks was accomplished using Geographic Information Systems (GIS) tools. The TxDOT traffic volume network (RHiNo) was chosen as the base network; a set of speeds from the XD network used by INRIX was applied to each segment of the traffic volume network. This will also provide flexibility in later analyses. However, exceptions are possible and the segmentation was made on a case-by-case basis. Each road segment was coded as part of a section by TTI as the re-segmentation of the sections was performed for the 2014 Texas 100 report (multiple segments make up a section). The traffic count and speed data for each segment were then combined into section performance measures by TTI.

Step 3. Estimate Traffic Volumes for Shorter Time Intervals

The third step was to estimate passenger car and truck traffic volumes for the 15-minute time intervals. This step and the derivation of the 15-minute traffic volume percentages are described in more detail in Appendix A. A summary of the process includes the following tasks:
- A simple average of the 15-minute traffic speeds for the morning and evening peak periods was used to identify which of the time-of-day volume pattern curves to apply. The morning and evening congestion levels were an initial sorting factor (determined by the percentage difference between the average peak period speed and the free-flow speed).
- The most congested period was then determined by the time period with the lower speeds (morning or evening); or if both peaks have approximately the same speed, another curve was used.   The traffic volume profiles developed from Texas sites and the national continuous count locations are shown in Appendix A.
- Low, medium or high congestion levels – The general level of congestion is determined by the amount of speed decline from the off-peak speeds. Lower congestion levels typically have higher percentages of daily traffic volume occurring in the peak, while higher congestion levels are usually associated with more volume in hours outside of the peak hours.

- Morning or evening peak; or approximately even peak speeds – The speed database has values for each direction of traffic and most roadways have one peak direction. This step identifies the time periods when the lowest speed occurs and selects the appropriate volume distribution curve (the higher volume was assigned to the peak period with the lower speed). Roadways with approximately the same congested speed in the morning and evening periods have a separate volume pattern; this pattern also has relatively high volumes in the midday hours.
- Separate 15-minute traffic volumes for trucks were created from the 15-minute traffic volume percentages shown in Appendix A.

Step 4. Calculate Travel Speed and Time

The 15-minute 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.

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 Texas 100 list, the data was used to identify the speed at low volume conditions (for example, 10 p.m. to 6 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 and the speed limit for each section was used as an upper limit for free-flow speed on all roads.

Step 6. Calculate Congestion Performance Measures

Once the dataset of 15-minute actual speeds, free-flow travel speeds and traffic volumes was prepared, the mobility performance measures were calculated using the equations in Exhibit 2. For the purposes of the top 100 list, the measures were calculated in person terms.

- Total delay per mile of road – One combination of a delay measure and the "indexed" approach is to divide total section delay (in person-hours) by the road length. So the measure of "hours of delay per mile of road" indicates the level of congestion problem without the different section lengths affecting the ranking. **This is the performance measure that best identifies most congested segments.**
- Texas Congestion Index – The TCI is a unitless measure that indicates the amount of extra time for any trip. A TCI value of 1.40 indicates a 20-minute trip in the off-peak will take 28 minutes in the peak. Rider 56 specified the TCI as the performance measure for congestion.

- Total delay – The best measure of the size of the congestion problem is the annual travel delay (in person-hours). This measure combines elements of the TCI (intensity of congestion on any section of road) with a magnitude element (the amount of people suffering that congestion). This combination will prioritize highly traveled sections above those that are less heavily traveled. For example, a four-lane freeway can operate at the same speed (and have the same TCI value) as a 10-lane freeway. But the higher volume on the 10-lane freeway will mean it has more delay and, thus, is a bigger problem for the region.
- Planning Time Index (95th) – The PTI is a travel time reliability measure representing the total travel time that should be planned for a trip. Computed as the 95th percentile travel time divided by the free-flow travel time, it shows the amount of time that should be planned for a trip to be late for only one day a month. A PTI of 3.00 means that for a 20-minute trip in light traffic, 60 minutes should be planned. The PTI value represents the "worst trip of the month". This measure resonates with individual commuters and truck drivers delivering goods – they need to allow more time for urgent trips.
- Total delay – The best measure of the size of the congestion problem (in annual person-hours). This measure combines elements of the TCI (intensity of congestion on a section of road) with a magnitude element (the amount of people suffering that congestion). This combination will prioritize highly traveled sections above those that are less heavily traveled. For example, a four-lane freeway can operate at the same speed (and have the same TCI value) as a 10-lane freeway. But the higher volume on the 10-lane freeway will mean it has more delay and, thus, is a bigger problem for the region.
- 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 cost of delay and fuel in the equation in Exhibit 2 are based on the procedures used in TTI's 2019 Urban Mobility Report. In 2019, the value of time for a person-hour of time was $19.14 and $61.03 for a truck-hour of time. The 2019 prices for a gallon of gasoline and diesel in Texas was $2.37 and $2.73 respectively.
  Passenger vehicle delay cost is based on person-hours of delay which is the passenger vehicle-hours of delay multiplied by 1.50 persons per vehicle to put the units in person-hours which is multiplied by the $19.14 per person-hour. For trucks, the delay needs to be in vehicle-hours for assigning the truck cost. The truck delay statistics are often shown in person-hours of delay so that a one-to-one comparison can be made with passenger vehicle delay to show what percentage of overall delay is due to trucks. When placing a cost on the truck delay the person-hours of delay needs to be divided by 1.14 which is the assumed occupancy of a truck to get vehicle-hours of delay and apply the $61.03 value.
- Commuter Stress Index – Most of the transportation network operates with much more volume or ridership (and more congestion) in one direction during each peak period. Averaging the conditions for both directions in both peaks (as with the Texas Congestion Index) provides an accurate measure of congestion, but does not always match the perception of the majority of commuters. The CSI measure uses the travel speed from the direction with the most congestion in each peak period to illustrate the conditions experienced by the commuters traveling in the predominant directions (for example,

inbound from suburbs in the morning and outbound to the suburbs in the evening). The calculation is conducted with the TCI formula, but only for the peak directions.

- Time of Congestion – Providing the time when congestion might be encountered is one method of explaining both the congestion problem and illustrating some of the solutions. The times of day when each road direction speed is below 75 percent of the street free-flow speed or 80 percent of the freeway free-flow speed is shown for each of the 100 most congested sections (for example, below 48 mph on a 60 mph freeway). The times are calculated based on 15-minute increments.

Exhibit 2. Equations for Selected Mobility Measures

INDIVIDUAL MEASURES[1]

Delay per Mile	$\begin{array}{l}\text{Delay per}\\\text{Mile}\\\left(\substack{annual\ hours\\per\ mile}\right)\end{array} = \dfrac{\left(\substack{Actual\\Travel\ Time\\(minutes)} - \substack{Free-Flow\\Travel\ Time\\(minutes)}\right) \times \substack{Vehile\ Volume\\(vehiles)} \times \substack{Vehicle\ Occupancy\\(\frac{persons}{vehile})} \times \frac{hour}{60\ minutes}}{Road\ Miles}$
Texas Congestion Index[2]	$Texas\ Congestion\ Index = \dfrac{Actual\ Travel\ Time\ (minutes)}{Free-Flow\ Travel\ Time^3\ (minutes)}$
Planning Time Index[2]	$\substack{Planning\ Time\\Index} = \dfrac{95th\ Percentile\ Travel\ Time\ (minutes)}{Free-Flow\ Travel\ Time\ (minutes)}$

AREA MOBILITY MEASURES[1]

Total Delay	$\substack{Total\ Segment\ Delay\\(person - minutes)} = \left[\substack{Actual\\Travel\ Time\\(minutes)} - \substack{Free-Flow\\Travel\ Time^3\\(minutes)}\right] \times \substack{Vehicle\ Volume\\(vehicles)} \times \substack{Vehicle\ Occupancy\\(persons/vehicle)}$
Congestion Cost	$\substack{Congestion\\Cost} = \substack{Annual\ Passenger\\Vehicle\ Cost} + \substack{Annual\ Truck\\Cost}$ $\substack{Annual\ Passenger\\Vehicle\ Cost} = \left[\substack{Annual\ Passenger\ Vehicle\\Hours\ of\ Delay} \times \substack{Vehicle\ Occupancy\\(person/vehicle)} \times \substack{Value\ of\\Person\ Time\\(\$19.14/hour)}\right]$ $+ \left[\substack{Annual\ Gallons\ of\\Excess\ Fuel\ Consumed\\by\ Passenger\ Vehicles} \times \substack{Price\ Per\ Gallon\\of\ Gasoline\\(\$2.37/gallon)}\right]$ $\substack{Annual\\Truck\ Cost} = \left[\substack{Annual\ Truck\\Hours\ of\ Delay} \times \substack{Value\ of\ Time\\for\ Trucks\\(\$61.03/hour)}\right] + \left[\substack{Annual\ Gallons\\of\ Excess\ Fuel\\Consumed\ by\ Trucks} \times \substack{Price\ per\ Gallon\\of\ Diesel\\(\$2.73/gallon)}\right]$

[1]"Individual" measures are those measures that relate best to the individual traveler, whereas the "area" mobility measures are more applicable beyond the individual (e.g., corridor, area, or region). Some individual measures are useful at the area level when weighted by PMT (Passenger Miles Traveled) or VMT (Vehicles Miles Traveled).

- Excess CO_2—This portion of the methodology was developed using the EPA's Motor Vehicle Emission Simulator (MOVES) model which considers such factors as vehicle emission rates, climate data, and vehicle speeds to generate CO_2 from mobile sources. The model is run for each 15-minute period for both the measured speed and corresponding free-flow speed to calculate the amount of excess CO_2 produced during congestion.
- Excess fuel consumed—based on the relationship between CO_2 emissions and fuel usage, the amount of excess fuel consumed in congestion is calculated concurrently when the excess CO_2 is calculated by comparing rates at the measured speed and the free-flow speed for each segment.
- Total CO2 produced— annual tons of excess CO_2 produced in congestion plus during free-flow driving conditions

Step 7. Calculate Congestion Performance Measures for Each Road Section

Steps 1 through 6 were performed using the short road segments for analysis. The 100 most congested sections list was intended to identify longer sections of congested road, rather than short bottlenecks. The short road segment values from four measures – **delay, congestion cost, excess fuel consumed, and CO₂ produced** – can be added together to create a section value.

The remaining measures require an averaging process; a weighted average of traveler experience was used in these cases. Time periods or road segments with more volume should "count for more" than time periods/segments with less volume. The following steps were used:

- **Delay per mile** – The delay from the section was divided by the length of the section
- **Texas Congestion Index, Planning Time Index** and **Commuter Stress Index** –The 12 time period values (four 15-minute values for each of the three peak hours) for travel time, speed and delay were summed and divided by the total volume to obtain a weighted average travel time, speed and delay for each peak period. A similar approach was used to calculate the combined morning and evening peak period index values.

APPENDIX A: Estimation of Time Period Traffic Volumes for 100 Most Congested Texas Road Sections

Mixed-Traffic Methods

Typical time-of-day traffic distribution profiles are needed to estimate 15-minute traffic flows from average daily traffic volumes. Previous analytical efforts (3,4) have developed typical traffic profiles at the 15-minute 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

Additional work by TTI has generated eight additional truck distribution profiles for the following different scenarios (5):
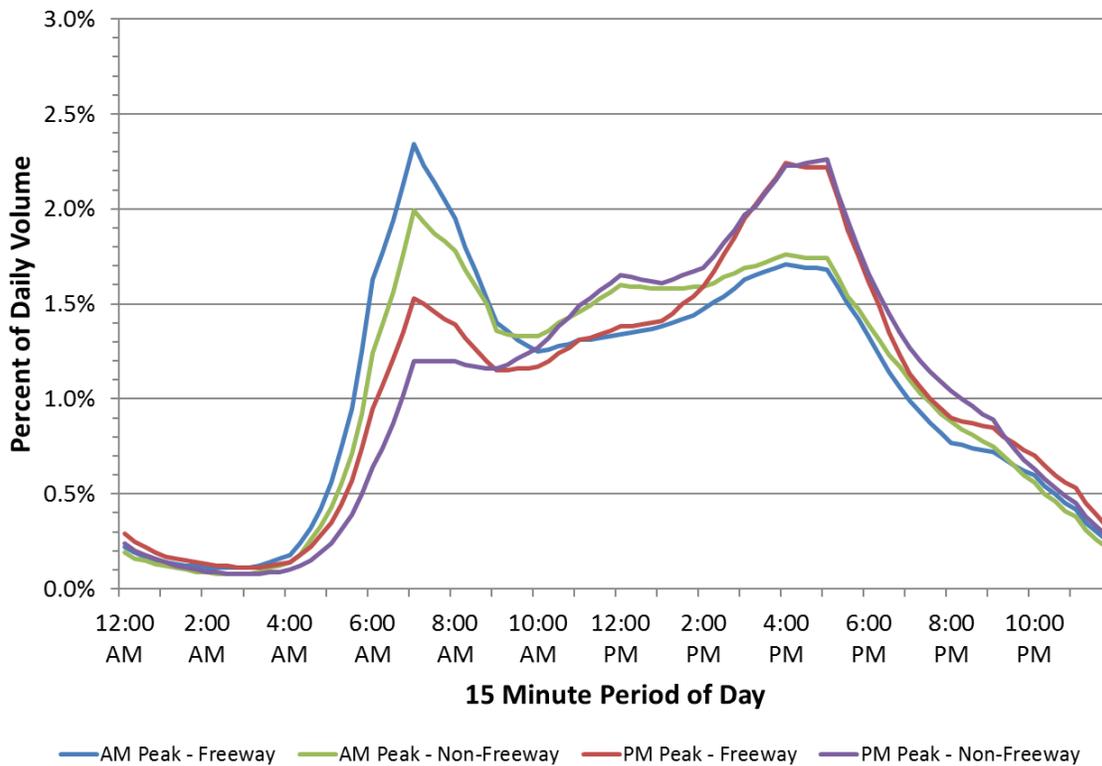
- Functional class: freeway and non-freeway
- Day type: weekday and weekend
- Directionality: peak traffic in the morning (AM), peak traffic in the evening (PM), approximately equal traffic in each peak

The 16 mixed-traffic distribution profiles shown in Exhibits A-1 through A-5 are very comprehensive; they were developed using 713 continuous traffic monitoring locations in urban areas of 37 states. TTI compared these reported traffic profiles with readily-available, recent empirical traffic data in Houston, San Antonio and Austin to confirm that these reported profiles remain valid for Texas.
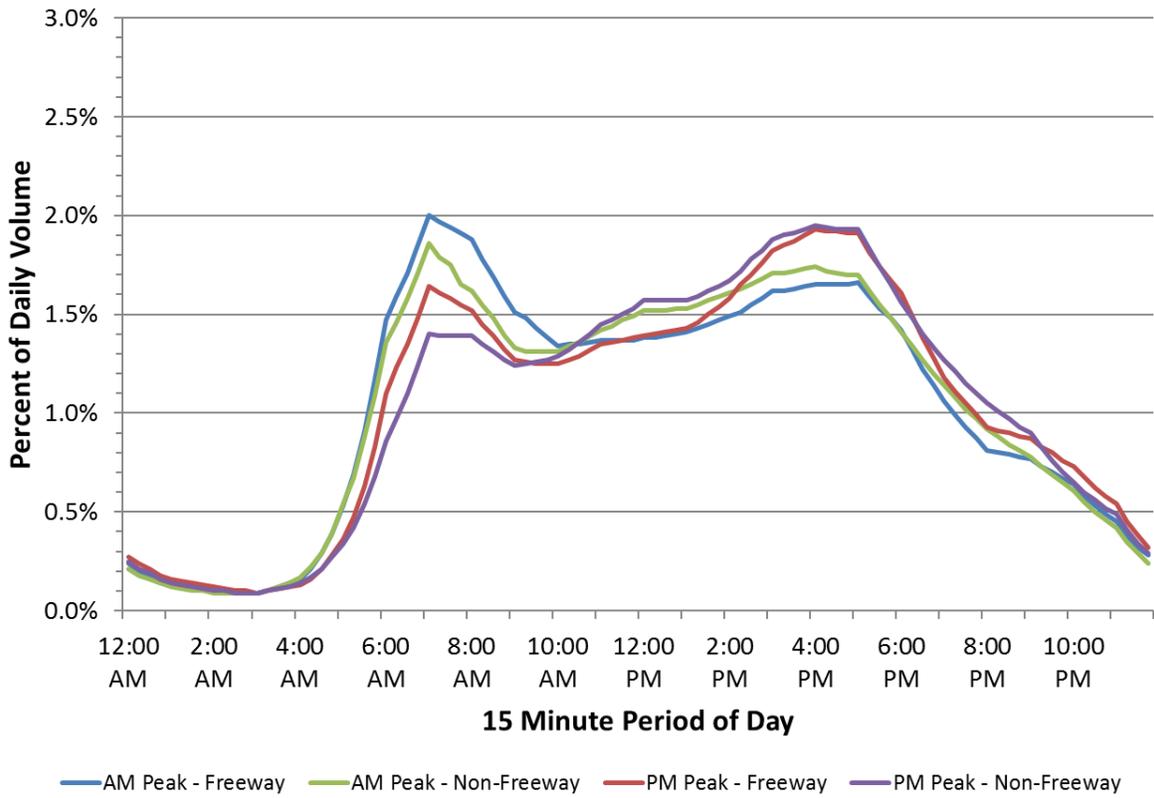
Exhibit A-1. Weekday Mixed-Traffic Distribution Profile for No to Low Congestion
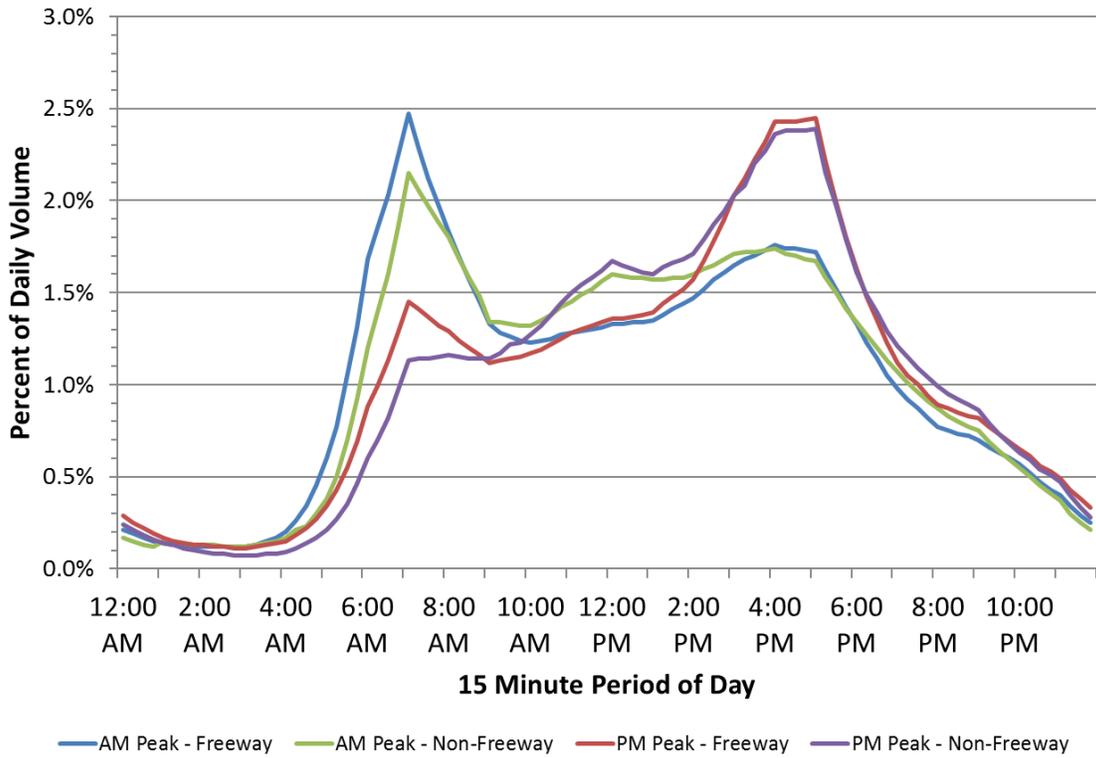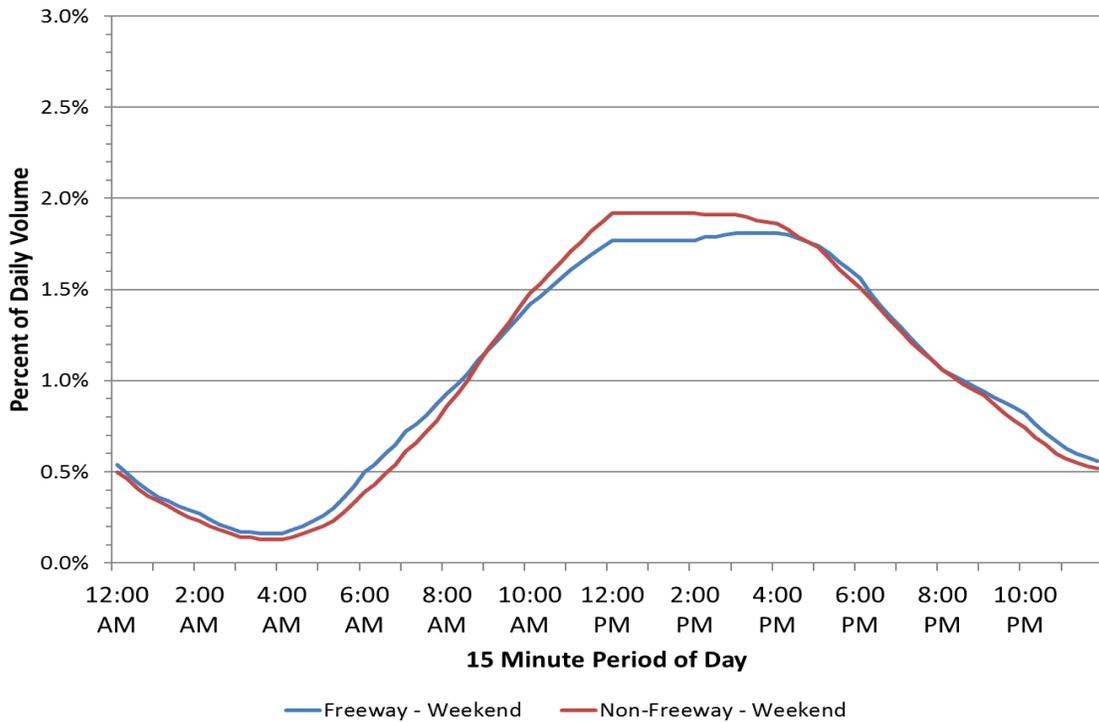

Exhibit A-2. Weekday Mixed-Traffic Distribution Profile for Moderate Congestion

Exhibit A-3. Weekday Mixed-Traffic Distribution Profile for Severe Congestion

Legend: AM Peak - Freeway · AM Peak - Non-Freeway · PM Peak - Freeway · PM Peak - Non-Freeway

X-axis: 15 Minute Period of Day

Y-axis: Percent of Daily Volume

Exhibit A-4. Weekend Mixed-Traffic Distribution Profile

Legend: Freeway - Weekend · Non-Freeway - Weekend

X-axis: 15 Minute Period of Day

Y-axis: Percent of Daily Volume

Exhibit A-5. Weekday Mixed-Traffic Distribution Profile for Severe Congestion and Similar Speeds in Each Peak Period
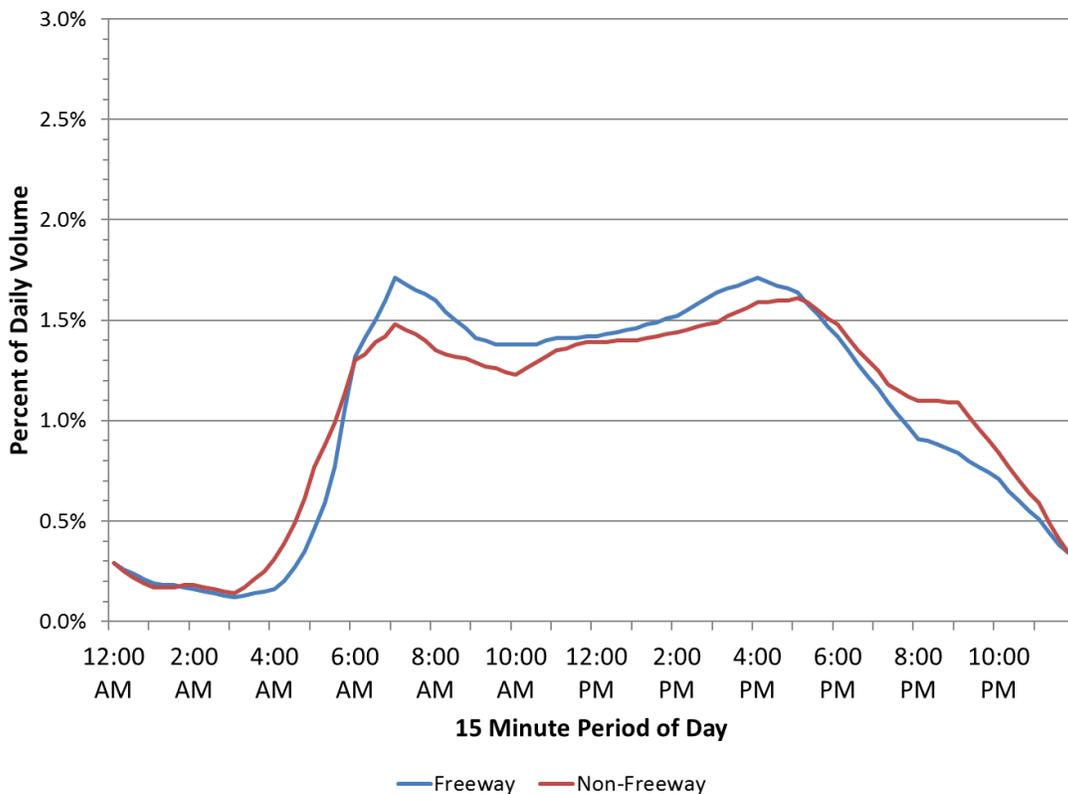
The next step in the traffic flow assignment process is to determine which of the 16 mixed-traffic distribution profiles should be assigned to each XD-Network route (the "geography" used by the private sector data providers), such that the 15-minute traffic flows can be calculated from TxDOT's RHiNo data. The assignment should be as follows:

- Functional class: assign based on RHiNo 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 24 15-minute periods in the six peak

hours) for each TMC path using speed data from 6 a.m. to 9 a.m. (morning peak period) and 4 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.

Speed   <u>Average Peak Period Speed</u>
Reduction =   Free-flow Speed (10 p.m. to 5 a.m.)
Factor

For Freeways (roads with a free-flow (baseline) speed more than 55 mph):
  o speed reduction factor ranging from 90% to 100% (no to low congestion)
  o speed reduction factor ranging from 75% to 90% (moderate congestion)
  o speed reduction factor less than 75% (severe congestion)

For Non-Freeways (roads with a free-flow (baseline) speed less than 55 mph):
  o speed reduction factor ranging from 80% to 100% (no to low congestion)
  o speed reduction factor ranging from 65% to 80% (moderate congestion)
  o 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 9 a.m.) and the average evening peak period speed (4 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 to the even volume distribution.

The final step is to apply the daily adjustment factor to the annual average volume. Exhibit A-6 illustrates the factors for the four different daily periods.

Exhibit A-6. 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%

Truck-Only Methods

This process is repeated to create 15-minute truck volumes from daily truck volumes. However, much of the necessary information, 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. There are no truck-only profiles by congestion level.
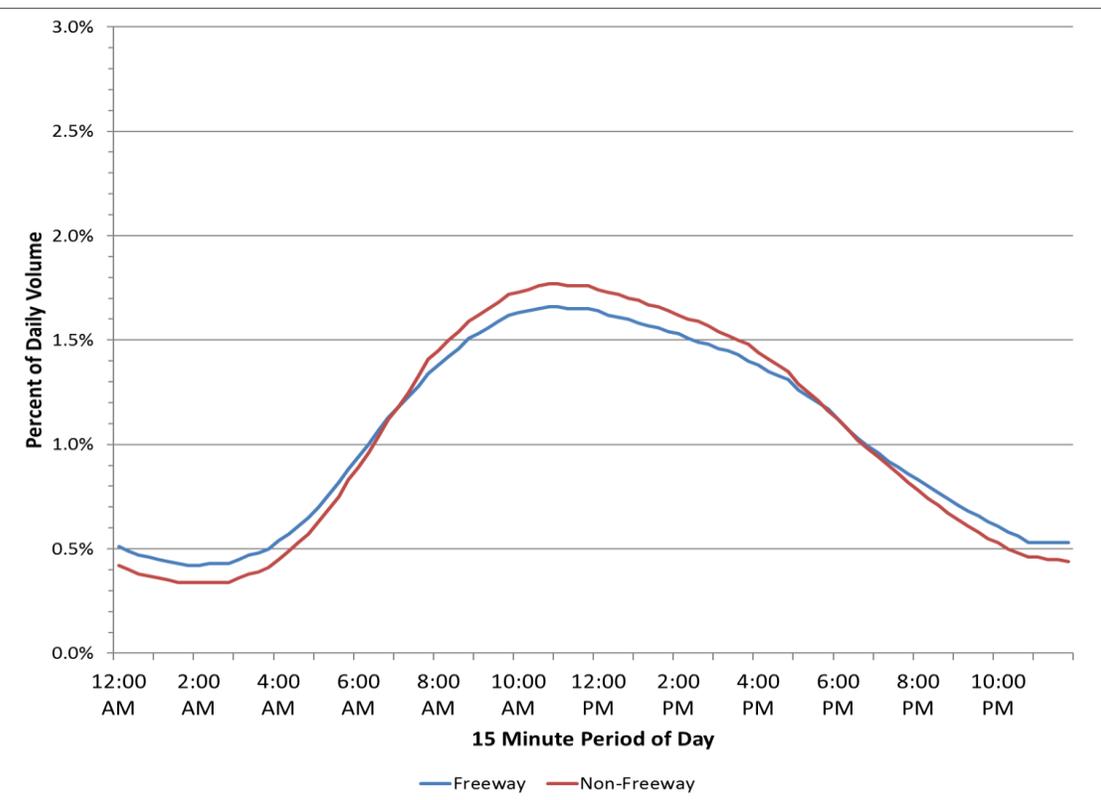
Exhibit A-7. Weekday Freeway Truck-Traffic Distribution Profiles
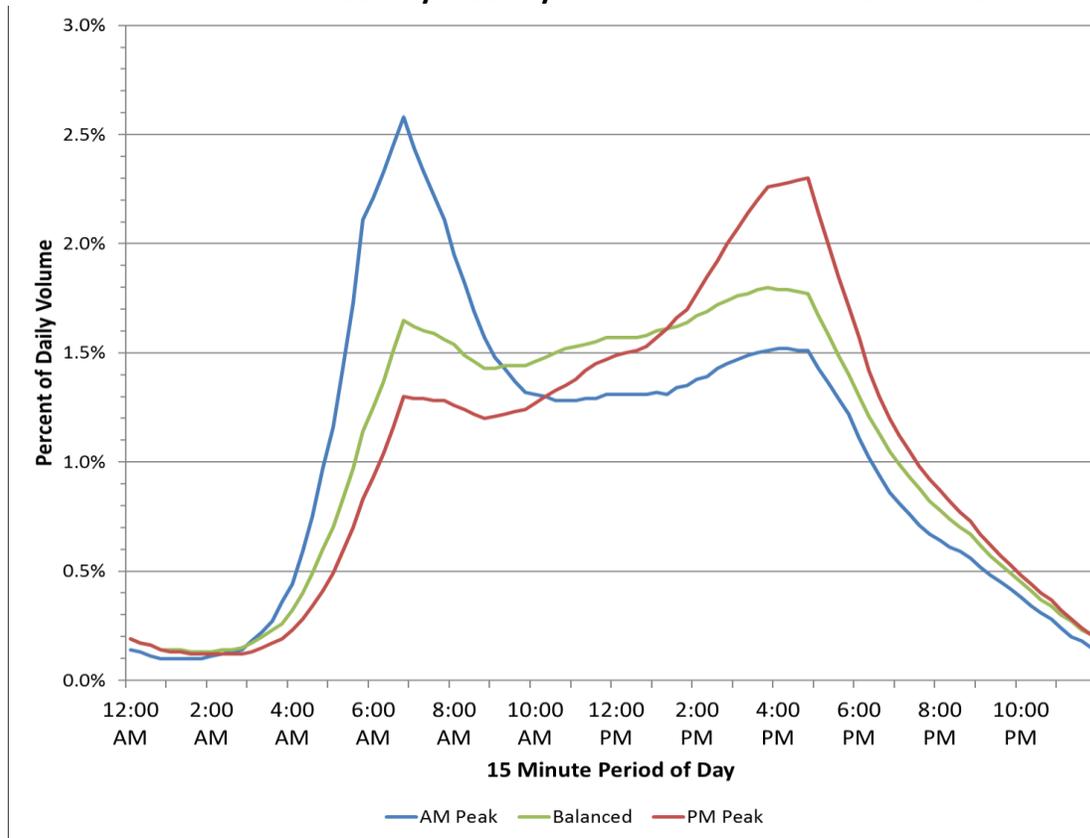
Exhibit A-8. Weekday Non-Freeway Truck-Traffic Distribution Profiles
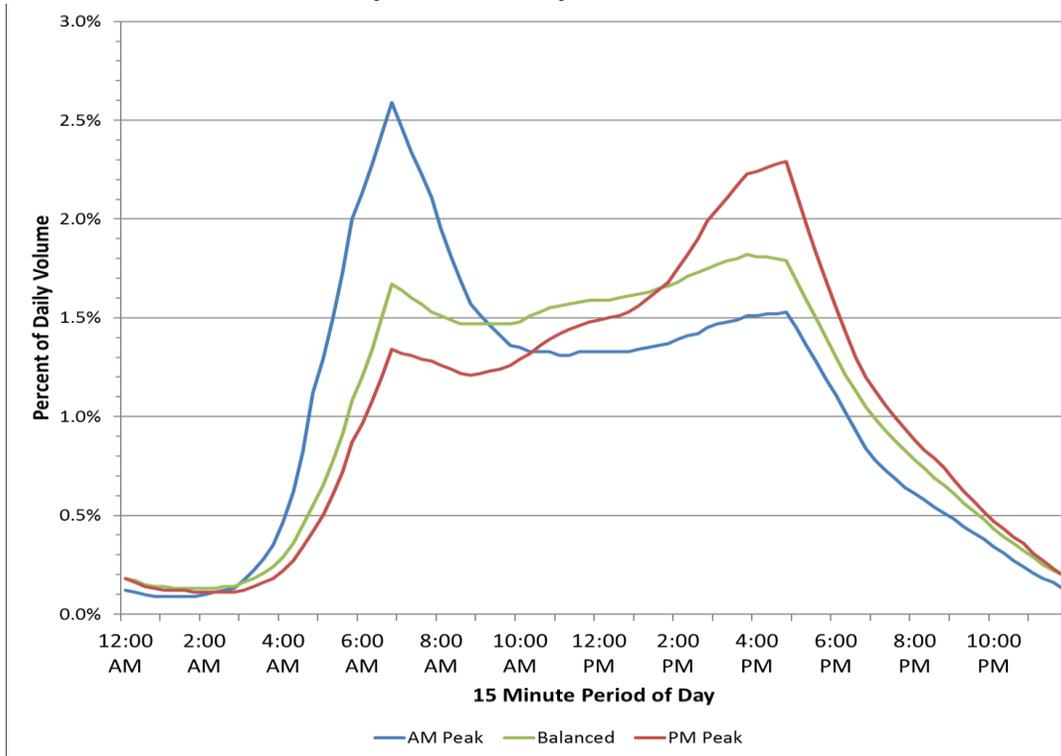
Exhibit A-9. Weekend Truck-Traffic Distribution Profiles

References

1 Brianne A. Glover. *Value of Delay Time for Use in Mobility Monitoring Efforts*. Texas A&M Transportation Institute. September 2020.

2 Phil Lasley, Appendix B: Change in Vehicle Occupancy Used in Mobility Monitoring Efforts. Texas A&M Transportation Institute. July 2019. (http://mobility.tamu.edu/umr/report/#appx-b)

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5 FHWA Pooled Fund Project TPF-5(198): Mobility Measurement in Urban Transportation. 2009-2016 Continuation. Texas A&M Transportation Institute, 2014.