Oklahoma Long Range TRANSPORTATION PLAN

Moving Oklahoma FORWARD

Technical Memorandum

TRAVEL TIME BASED OKLAHOMA CONGESTION ANALYSIS: Pilot Study

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Oklahoma Department of Transportation

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The Technical Memos were written to document early research for the 2015 2040 Oklahoma Long Range Transportation Plan (LRTP). Most of these memos were written in 2014; all precede the writing of the 2015-2040 Oklahoma LRTP *Document* and 2015-2040 Oklahoma LRTP *Executive Summary*.

The 2015-2040 Oklahoma LRTP *Document* and 2015-2040 Oklahoma LRTP *Executive Summary* were composed in Spring 2015.

If there is an inconsistency between the Tech Memos and the 2015-2040 Oklahoma LRTP *Document* or 2015-2040 Oklahoma LRTP *Executive Summary*, the reader should assume that the *Document* and *Executive Summary* contain the most current and accurate information.

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1. INTRODUCTION

As a part of Oklahoma Department of Transportation (ODOT) 2040 Long Range Transportation Plan (LRTP), a pilot study is being conducted to assist with identifying, understanding, and addressing congestion levels in Oklahoma. Additionally the study explores use of travel time data as a tool to measure and manage congestion.

1.1 PURPOSE

As a part of 2015-2040 Oklahoma Long Range Transportation Plan (LRTP), a set of performance measures were developed that are intended to be consistent with a broader framework of Plan goals and objectives. The performance measures identified for the 2040 Oklahoma LRTP provide a framework to address the requirements of the Moving Ahead for Progress in the 21st Century Act (MAP 21). This pilot study complements the performance measures developed for the 2040 Oklahoma LRTP by providing in greater detail the complex characteristics of freight and commuter travel on the Oklahoma highway system.

This pilot study analyzes the vehicle probe data provided by Federal Highway Administration (FHWA)[i] along two corridors – I 40 and U.S. 69 – and develops congestion measures that are useful for addressing freight and commuter travel on the Oklahoma highway system. This study will provide ODOT with a better understanding of vehicle probe data and will complement the Performance Measure report being developed as a separate piece of the 2015-2040 Oklahoma Long Range Transportation Plan.[ii]

2. VEHICLE PROBE DATA

During the past several years, the private sector has been playing an increasing role in collecting and disseminating real-time traffic information by acquiring travel time and speed data on roadways using probe technology. The sources of the data include commercial fleet, delivery and taxi vehicles that use GPS, toll tag data, occupancy and speed measurements from Department of Transportation sensor networks, etc. The data from various sources is combined to present a comprehensive picture of vehicle speed and travel time for each road segment.

The vehicle probe data has been primarily used by state departments of transportation (DOTs) for daily management and operations, such as providing real-time travel time on dynamic message signs and for incident and emergency management. In recent years, the potential use of the probe data in planning purposes has been explored by FHWA, state DOTs, and metropolitan planning organizations (MPOs). Some of the planning applications of the vehicle probe data include congestion monitoring, evaluation of the congestion management process, validation of travel demand forecasting models, speed distribution inputs for air-quality modeling, etc.

This section provides a detailed description of the vehicle probe data provided by FHWA as well as other available data sources and the differences between them.

2.1 NATIONAL DATA SET FOR FREIGHT AND URBAN CONGESTION MEASUREMENT

FHWA Office of Operations was interested in new data sources for two of its programs: Freight Performance Measures (FPM), and Urban Congestion Reports (UCR). In 2013, the Office of Freight Management and Operations (HOFM), on behalf of both HOFM and Office of Transportation Management (HOTM), contracted with HERE North America, LLC (formerly known as Nokia/NAVTEQ) to acquire the National Performance Measure Research Data Set (NPMRDS) vehicle probe data. After the passage of the Moving Ahead for Progress (MAP-21) legislation highlighting tools for analysis, freight planning and other asset management activities, FHWA determined this dataset could also assist states and Metropolitan Planning Organizations (MPOs) in their freight planning, congestion management, and other operations efforts. Therefore, FHWA decided to make this data set available to a broader community of users.

The NPMRDS is a national data set of average travel times for use in analyzing highway system performance. The data provided is actual observed measurement of travel times. No estimates or historical data substitutions of missing data are included. The data is provided to DOTs and MPOs on a monthly basis.

Data validation and data quality review is also provided by the provider (HERE North America, LLC) to ensure that the travel time data is accurate enough to be used in highway system performance measurement. The details of data validation and data quality review for NPMRDS are presented in Section 2.2.

The NPMRDS data includes distinct average travel time information for each five minute interval – freight, passenger and all traffic – on the entire National Highway System (NHS). The travel time for all traffic is obtained by a weighted average of freight and passenger travel time based on the respective traffic volumes. The data sources for NPMRDS include the following:

- Passenger probe data is obtained from a number of sources including mobile phones, vehicles and portable navigation devices
- Freight probe data is obtained from the American Transportation Research Institute (ATRI) leveraging embedded fleet systems.

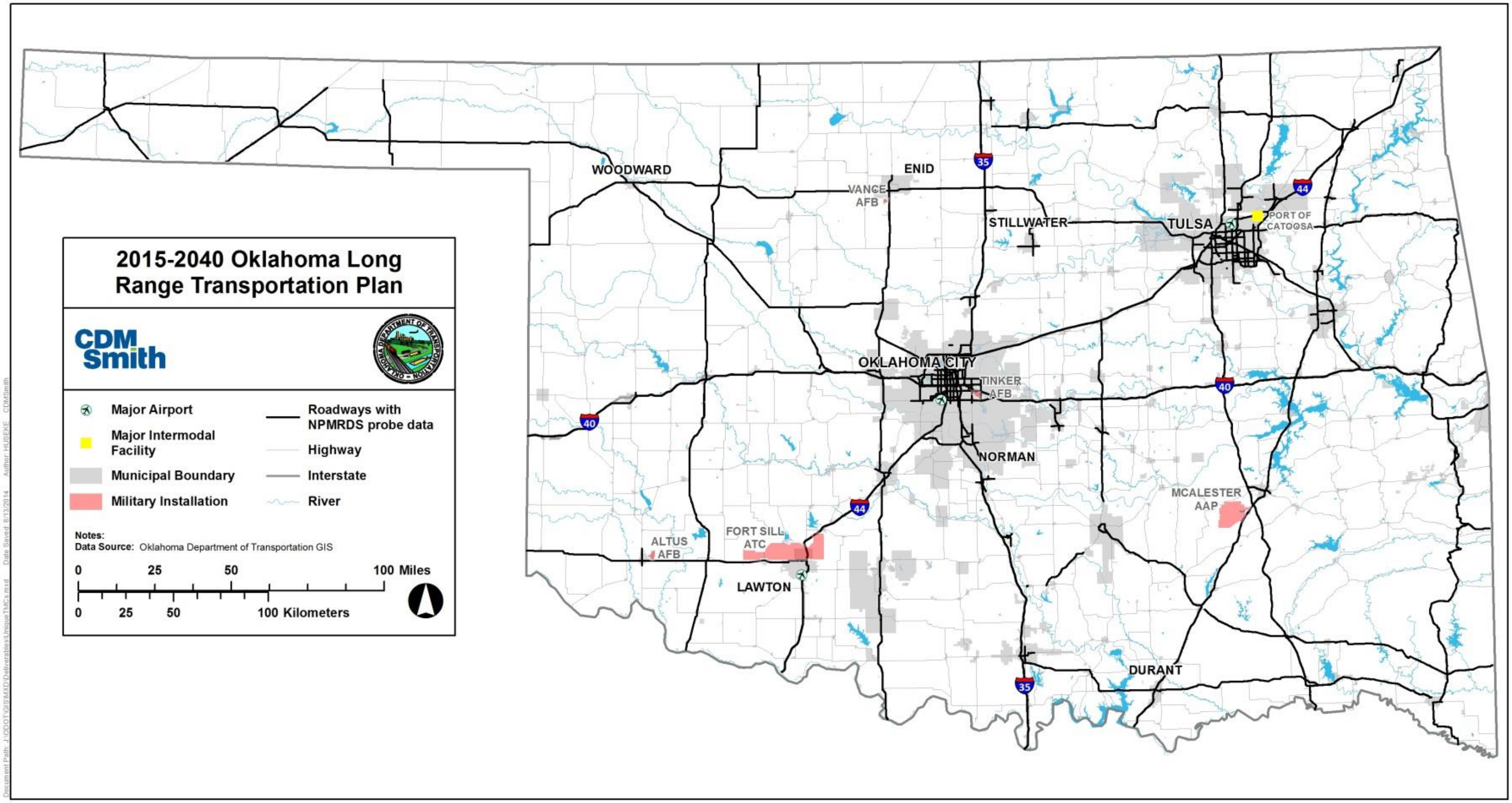
2.1.1 Temporal Coverage

The NPMRDS data is available at five minute granularity for 24 hours a day, 7 days a week and 365 days a year. A historical archive of five minute intervals on the Interstate system only is available dating back to October 2011. The travel time data for the NHS is available beginning in July 2013.

2.1.2 Geographic Coverage

The NPMRDS provides average travel times along the entire National Highway System (NHS) as defined by MAP-21. For Oklahoma, the NPMRDS data covers approximately 4,057 centerline miles of the NHS. **Figure 2-1** illustrates the coverage of NPMRDS data for Oklahoma.

Figure 2-1 Geographic Coverage of NPMRDS on Oklahoma Roadways



2.1.3 Contents of NPMRDS

The NPMRDS data is provided in two parts. The first part is a Traffic Message Channel (TMC) static file that contains TMC information that does not change frequently and will only be updated as necessary. This data file includes the following information:

- TMC Code – The Traffic Message Channel (TMC) code is an industry convention that defines a specific directed section of a road. The definition of TMC is based on logical breaks in facilities where one would expect the potential for different traffic conditions, such as an interchange or major at-grade intersections. The attributes of each TMC code are defined by a consortium consisting of Tele Atlas and NAVTEQ (two major digital map providers), who then publish the location data for each code.
- Country
- State
- County
- Length of TMC in miles
- Road Number
- Road Name
- Latitude
- Longitude
- Road Direction (northbound, southbound, eastbound or westbound)

The second part of NPMRDS is a database file set of average travel times for roadways geo-referenced to TMC location codes. This data file includes the following information:

- TMC Code
- Date – The data of the vehicle probe data in MMDDYYYY format.
- EPOCH – Each five minute interval in a day is known as an epoch. Epochs are referenced to local time, so there is no need to account for time zones or seasonal time changes.
- Travel Time – Travel time information in seconds is provided for three categories – freight, passenger and all vehicles.

2.1.4 Advantages and Challenges

The continuous, large scale and probe based traffic monitoring method used for obtaining NPMRDS data presents new challenges and opportunities for ODOT to make the most of the data.

2.1.4.1 Advantages[iii]

Continuous Monitoring – The data provides continuous monitoring for every covered road segment (TMC). This enables data users not only to capture the normal (or robust) conditions of highways, as separated periodic surveys do, but also to gain insights into unusual conditions of highway congestion (e.g., conditions related to incidents or inclement weather). This enables ODOT to look beyond traditional congestion analysis and to carry out travel time reliability analysis.

Probe-Based Data – Probe data overcomes some typical uncertainties of location-fixed detector data in measuring vehicle speed and travel time. Location-fixed detector data have to rely on assumptions of vehicle length or road segment length to estimate segment vehicle speed and travel time indirectly. Detectors can be installed only at certain locations because of financial and infrastructure physical constraints, and thus tend to provide lower granularity of travel time or speed information compared with probe-based data.

TMC Geo-reference – The data have a geo-reference, so the analysis results can be conveniently and accurately visualized on a geographic information system (GIS) network.

Data Validation – The NPMRDS data has an ongoing validation effort which gives data credibility for transportation planning applications.

Immediate Availability – The NPMRDS data is usually made available by FHWA on a monthly basis within 1-2 weeks into the following month.

2.1.4.2 Challenges

Database Management – Given that the NPMRDS contains vehicle probe data at every five-minute interval on the National Highway System (NHS), the size of the database has the potential to increase tremendously over time. The hardware requirements to store the data and software tools to analyze the enormous data should be thoroughly investigated to meet the needs of ODOT for the long run.

Outliers – NPMRDS provided by FHWA is raw vehicle probe data and is not processed in any manner. Because of the raw nature of the NPMRDS, the data usually contains outliers. Outliers are vehicle probe observations with speed data which are considered further away from the average than what is deemed reasonable. The outliers exist due to several reasons – individual probe vehicles are driven at the driver's pleasure, error in data collection or processing, etc.

Outlier data points can therefore include faulty data or erroneous data processing of vehicle probe data. In large data sets such as NPMRDS, such outlier data points are usually anticipated and they should be accounted for before analyzing the data. Including the outliers in reporting of speed and travel time measures can potentially result in erroneous interpretation of data.

Missing Data – In addition to the outliers, NPMRDS contains missing data. The maximum number of vehicle probe data points in NPMRDS per day for each roadway segment is 288 (12 five minute intervals times 24 hours in a day). However, if probes are not observed during a particular five minute interval, speed is not reported on the roadway for that five minute interval. Additionally, the freight vehicle probe data has less data than the maximum possible data points due to the smaller number of trucks on several non-interstate roadways.

Large TMCs – The vehicle probe data from NPMRDS is aggregated and provided based on a Traffic Message Channel (TMC) location referencing system. These segments vary in length based on the density of the roadway network. This criterion creates short segments in urban areas (the length of a block) and very long segments in rural areas (the distance between two interchanges). Therefore, speed and other system performance measurement statistics on roadway segments shorter than the entire TMC segment can be distorted.

2.2 NPMRDS DATA VALIDATION AND QUALITY REVIEW

As with any technical analysis that employs a large dataset from multiple sources, it is necessary to perform data validation analyses to ensure that the data is accurate and irregularities are minimized and mitigated. FHWA has developed “Data Validation, Calibration and Quality Plan” to share the quality validations that will be performed on the NPMRDS. The objective of this validation plan is to provide a proposed framework of internal and external validation analyses that will result in assurances to FHWA and its licensed users that the data provided is within acceptable error tolerances. **Appendix A** provides the latest version of this plan and a summary of the plan is presented below.

The data validation plan includes a combination of existing internal analyses and proposed external analyses to be performed by the team’s independent data evaluator. The results of the external analyses will be presented to FHWA in the form of a quarterly report.

2.2.1 Internal Analyses

2.2.1.1 HERE Data Set

HERE uses several processes to meet data quality standards. These analyses types are described briefly below.

Raw Probe Data – HERE collects data from a wide variety of sources to ensure broad and appropriate geographic coverage. Probe data providers are first screened based on a variety of criteria and then on-going monitoring is conducted.

Data Set Creation and Validation – HERE creates the data set using the probe data that has been cleaned, filtered and map matched. HERE will perform automated validation tests on the newly created data set.

HERE Ground Truth Testing – HERE regularly field tests its data to validate the traffic speeds and travel times in its traffic data products. Traffic data is tested using the following approaches:

- Ground truth testing using trained drivers to collect real world conditions
- Ground truth testing using Bluetooth collection devices.

These testing methods allow HERE to validate the traffic speeds and travel times in its traffic data products.

2.2.1.2 ATRI Data Set

Since ATRI's and FHWA's inception of the Freight Performance Measure program in 2002, several analyses have been conducted on ATRI's truck probe data. The studies have found that ATRI data is a reliable proxy for actual truck speeds and travel times in a variety of road types and congestion levels. **Appendix A** addresses the quality of ATRI's data.

2.2.2 External Analyses

In addition to the internal analyses that are already routinely performed, an independent data evaluator will facilitate a series of external validation analyses and will report the findings of those analyses to FHWA on a quarterly basis.

The analysis will include 15 geographic locations as validation test segments. These test segments will be located throughout the U.S. in a mix of urban, suburban, and rural locations, where benchmark data is available.

Two principal measures will be employed during the data validation process: Average Absolute Speed Error (AASE) and Standard Error of the Mean (SEM).

- Average Absolute Speed Error (AASE) – The AASE is defined as the mean absolute value of the difference between the mean speed computed from the HERE travel time data and the reference mean speed for each 5-minute time period. AASE below 10 MPH are usually considered as meeting specifications and AASE below 5 MPH are considered exceptional quality.

- Standard Error of the Mean (SEM) – SEM is the standard deviation of the error in the average probe vehicle speed relative to the mean of reference speed. SEM below 5 MPH is usually considered as meeting specifications.

2.3 OTHER PROBE DATA SOURCES

In addition to the NPMRDS provided by FHWA, several other options are available to obtain the vehicle probe data. Each of the other data providers has their own proprietary methodology to process the raw data and address some of the data challenges described above. The data providers also provide additional products which provide analysis of the vehicle probe data and include data visualization at additional cost.

3. ODOT'S TRAFFIC CHARACHTERISTICS REPORT

The Traffic Characteristics Report is prepared by the Oklahoma Department of Transportation, Strategic Asset & Performance Management Division's Engineering Services Branch. The latest version of the report is from 2012. The report provides a summary of traffic data collected at 95 continuous traffic recorder locations on Oklahoma Highways. The traffic information in this report is organized to furnish hourly traffic totals, daily traffic totals, truck percentages, and adjustment factors. I-40 has five traffic recorders while US 69 has four traffic recorders monitoring the traffic count data.

NPMRDS vehicle probe data does not contain traffic volume information. ODOT's traffic characteristics report is used to furnish this missing piece to calculate the congestion measures.

4. CONGESTION MEASURES

In recent years, congestion on streets and highways has grown to critical dimensions in many areas of the United States and Oklahoma. This congestion has become a major problem and has many detrimental effects including lost time, higher fuel consumption, more vehicle emissions, increased accident risk and greater transportation costs. Quantifying congestion is needed for analytical purposes, such as system evaluations and improvement prioritization, and for use by policy makers and the public.

The concept of measuring traffic congestion has evolved over the past several decades. National Cooperative Highway Research Program (NCHRP) Report 398 Volume 1: *Quantifying Congestion* presented methods to measure congestion on roadway systems. The report noted that, traditionally, traffic volume and roadway capacity-based measure were used to quantify congestion and evaluate new infrastructure projects. These measures work well for many purposes, and will be used by many agencies for a long time.

Measures related to travel time and speed are the most flexible and useful for a wide range of analyses. This information is used by professionals, is readily understood by the public and is appropriate for a broad range of contexts. Travel time based measures are consistent, address transportation and land use systems, and are responsive to concerns of residents, businesses and travelers.

The report finds that while it is difficult to conceive of a single value that will describe all of the travelers' concerns about congestion, there are four components that interact in a congested roadway or system. These components are duration, extent, intensity and reliability. They vary among and within urban areas – smaller urban areas, for example, have shorter durations of congestion than larger areas.

- **Duration** – this is defined as the amount of time congestion affects the travel system.
- **Extent –** this is described by estimating the number of people or vehicles affected by congestion, and by the geographic distribution of congestion.
- **Intensity** – this is the severity of the congestion that affects travel. It is typically used to differentiate between levels of congestion on transportation systems and to define the total amount of congestion.
- **Reliability** – this component of congestion estimation is described as the variation in the other three elements. Reliability is the impact of non-recurrent congestion on the transportation system.

5. CURRENT PRACTICES TO MEASURE CONGESTION

Several state DOTs, MPOs and local governments collect a variety of highway data. This data is used for various reasons, such as analyzing system performance, responding to legislative mandates, preparing budget and funding allocations, improving quality of transportation services, developing congestion management systems, safety management systems, etc.

The data collected by the agencies usually includes pieces of information related to mobility, as well as other indicators like sustainability, safety, environmental quality, customer satisfaction, etc. This section summarizes some of the federal, state, and local agency practices in the areas of data collection and congestion measurement for the operational effectiveness of highway segments and systems as they pertain to highway congestion.

5.1 NATIONAL HIGHWAY CONGESTION REPORTS

5.1.1 Urban Congestion Reports by FHWA

FHWA's Office of Operations produces Urban Congestion Reports (UCR) on a quarterly basis and characterizes emerging traffic congestion and reliability trends at the national and city level. The reports utilize archived traffic operations data gathered from state DOTs and a private traffic information company. The reports are currently using data from 19 urban areas in the U.S. The UCR includes only those roadways that are instrumented with traffic sensors for the purposes of real-time traffic management and/or traveler information. In many cities, this typically includes the most congested parts of the freeway system. The Report currently does not include congestion information on arterial streets.

The UCR uses the following three measures to quantify congestion and travel reliability information. In this report, the AM peak period is considered as 6 am to 9 am and the PM peak period is 4 pm to 7 pm on non-holiday weekdays. Additionally, the off-peak times are considered as 9 am to 4 pm on weekdays and from 6 am to 10 pm on weekends.

- **Congested Hours** – The average number of hours during specified time periods in which instrumented road sections are congested. For this measure, congestion is defined to occur when link speeds are less than 45 mph.
- **Travel Time Index** – The ratio of the average peak period travel time as compared to a free-flow travel time. The free-flow travel time for each road section is the 15th percentile travel time during traditional off-peak times, not to exceed the travel time at the posted speed limit (or 60 mph where the posted speed is unknown). For example, a value of 1.20 means that average peak travel times are 20 percent longer than free-flow travel times.

- **Planning Time Index** – The ratio of the total time needed to ensure 95 percent on-time arrival as compared to a free-flow travel time. The planning time index is computed as the 95^{th} percentile travel time of the month divided by the free-flow travel time for each road section and time period. For example, a value of 40 percent means that a traveler should budget an additional 8 minute buffer for a 20-minute average peak trip time to ensure 95 percent on-time arrival.

5.1.2 Urban Mobility Report by Texas Transportation Institute

Texas Transportation Institute (TTI) at Texas A&M University has been publishing Urban Mobility Reports annually since 1982. The Urban Mobility Report (UMR) procedures provide estimates of mobility at the area wide level. The approach that is used describes congestion in consistent ways allowing for comparisons across urban areas or groups of urban areas.

Until 2009, the UMR methodology used a set of estimation procedures and data provided by state DOT's and regional planning agencies to develop a set of mobility measures. Beginning in 2010, the UMR is being prepared in partnership with INRIX, a private sector provider of travel time information. The travel speed data addresses the biggest shortcoming of previous editions of the UMR – the speed estimation process. UMR methodology uses the following input data to calculate the congestion measures for each urban roadway section:

- Volume and roadway inventory data from FHWA's Highway Performance Monitoring System (HPMS)
- INRIX's speed data
- National congestion constants like vehicle occupancy, average cost of time, etc.

The report calculates several congestion performance measures and ranks the urban areas based on the following measures:

- **Yearly delay per auto commuter** – the extra time spent traveling at congested speeds rather than at free-flow speeds.
- **Travel Time Index** – the ratio of travel time in the peak period to travel time at free-flow conditions. A Travel Time Index of 1.30 indicates a 20-minute free-flow trip takes 26 minutes in the peak period.
- **Wasted fuel** – extra fuel consumed during congested travel.
- **Congestion cost** – the yearly value of delay time and wasted fuel.

5.2 STATE DOT PRACTICES

5.2.1 Washington State Department of Transportation (WSDOT)

Since 1988, the WSDOT has been collecting, analyzing, and reporting on congestion to help the public and officials better understand how congestion is evolving and what mitigation strategies are effective for improving commutes. Over the years, WSDOT has adapted and expanded its congestion reporting to include mobility and congestion relief programs in all of its strategic and performance-based reporting. WSDOT publishes quarterly and annual updates on mobility titled Gray Notebook and Annual Congestion Report respectively.

The Annual Congestion Report provides detailed analysis on where and how much congestion occurs, and whether it has grown on state highways. The report focuses on the most traveled commute routes in the urban areas, and where data are available around the state. WSDOT and University of Washington experts use a two-year span to more accurately identify changes and trends seen on the state highway system that may be missed looking at a one-year comparison.

WSDOT produces the following statewide congestion measures:

- Total Statewide Delay
- Per Person Delay
- Percentage of the State Highway System Delayed and Congested
- Vehicle Miles Traveled

WSDOT produces the following additional congestion measures for its major urban areas:

- 95 percent Reliable Travel Times
- Percentage of days when speeds were less than 36 mph
- HOV Lane reliability standard
- HOV Lane travel times

5.2.2 Florida Department of Transportation (FDOT)

In 2000, Florida DOT developed a framework for performance measurement designed to characterize mobility in a manner understandable to the general public and decision makers. The recommended mobility measures reflect mobility from the users' perspectives, based on the following:

- The quantity of the travel (number of persons served)
- The quality of travel (travelers' satisfaction with travel)
- The accessibility of travel (ability to reach the destination and mode choice), and

- The utilization of a facility or service (the quantity of operations with respect to capacity)

The mobility measures for Florida were modified in 2013. The new mobility measures include items such as hours of delay for person and freight travel, travel time reliability, and percent miles severely congested. **Appendix B** provides further information about the 2013 FDOT's Mobility Performance Measures.

5.3 MPO/LOCAL GOVERNMENT PRACTICES

5.3.1 Chicago Metropolitan Agency for Planning

Chicago Metropolitan Agency for Planning (CMAP)'s Congestion Management Process (CMP) provides an ongoing, systematic method of managing congestion that provides information about both system performance and potential alternatives for solving congestion-related problems. CMAP's use and continual development of a regional CMP will help advance the quality of life and mobility goals described in the comprehensive regional plan. In order to be effective, the CMP incorporates extensive monitoring of the transportation network through the use of measures such as the following:

- Freeway Congestion Scans
- Travel Time Index
- 95th percentile Travel Time
- Planning Time Index
- Congested Hours

5.3.2 Association of Central Oklahoma Governments (ACOG)

ACOG is currently determining appropriate congestion measures for the Central Oklahoma region which will be reported in the Congestion Management Process. ACOG is currently investigating the use of NPMRDS for determining the congestion measures. For Oklahoma City Area Regional Transportation Study (OCARTS) area, a month's data of NPMRDS contains roughly 2-2.5 million records. ACOG notes that the temporal and region-wide nature of this data provides a much more complete picture of the region's traffic than has ever been available using traffic counts or earlier GPS travel time surveys, and will therefore be able to feed richer analyses.[iv]

In an effort to quantitatively measure the extent of congestion on the region's road network and identify congested corridors in need of attention, a Travel Time Index (TTI) was calculated for road links.

5.4 MISCELLANEOUS

5.4.1 University of Maryland's Vehicle Project Probe (VPP) Analysis Suite

The Vehicle Probe Project Suite allows agencies to support operations, planning, analysis, research, and congestion measures generation using probe data from INRIX mixed with other agency transportation data.

The suite consists of a collection of data visualization and retrieval tools. These web-based tools allow users to download reports, visualize data on maps or in other interactive graphics, and even download raw data for off-line analysis.

Each tool has its own unique purposes. Among many other uses, the Vehicle Probe Project Suite can provide insight on:

- Real-time Speed Data
- Travel Time Index
- Travel Time Reliability metrics
- Queue Measurements
- Statewide bottleneck ranking
- Corridor Congestion Charts

5.4.2 NCHRP Report 398: Quantifying Congestion

As indicated in Section 3, in 1997, NCHRP published Report 398 entitled *Quantifying Congestion*. This report is a user's guide on how to measure congestion. The suggested measures of congestion in the report include:

- **Travel rate** – Travel rate, expressed in minutes per mile, is how quickly a vehicle travels over a certain segment of roadway.

- **Delay rate** – The delay rate is "the rate of time loss for vehicles operating in congested conditions on a roadway segment or during a trip."

- **Total delay** – Total delay is the sum of time lost on a segment of roadway for all vehicles.

- **Relative delay rate** – The relative delay rate can be used to compare mobility levels on roadways or between different modes of transportation.

- **Delay ratio** – The delay ratio can be used to compare mobility levels on roadways or among different modes of transportation.

- **Congested travel** – This measure concerns the amount and extent of congestion on roadways. Congested travel is a measure of the amount of travel that occurs during congestion in terms of vehicle-miles.

- **Congested roadway –** This measure concerns the amount and extent of congestion that occurs on roadways. It describes the degree of congestion on the roadway.

5.4.3 SCOPM Task Force Findings on National-Level Congestion Measures

Following the passage of the federal transportation legislation – Moving Ahead for Progress in the 21st Century (MAP-21) in July, 2012, the Federal Highway Administration (FHWA) began work on developing a Notice of Proposed Rulemaking (NPRM) for the provisions of the legislation—including the establishment and implementation of national performance measures.

The American Association of State Highway Transportation Officials (AASHTO) Standing Committee on Performance Management (SCOPM) created a Task Force on Performance Measure Development, Coordination and Reporting charged to "assist SCOPM and AASHTO to develop a limited number of national performance measures and help prepare AASHTO members to meet new Federal performance management requirements." In relation to congestion measurement and management, the Task Force recommended a speed threshold to be determined by the State DOTs and MPOs. The recommended performance measures by SCOPM Task Force related to congestion measurement are as follows:

- **Annual Hours of Truck Delay (AHTD)** – Travel time above the congestion threshold in units of vehicle-hours for trucks on the Interstate Highway System.
- **Truck Reliability Index (RI_{80})** – The RI is defined as the ratio of the total truck travel time needed to ensure on-time arrival to the agency-determined threshold travel time (e.g., observed travel time or preferred travel time).
- **Annual Hours of Delay (AHD)** – Travel time above a congestion threshold (defined by State DOTs and MPOs) in units of vehicle-hours of delay on Interstate and NHS corridors.
- **Reliability Index (RI_{80})** – The Reliability Index is defined as the ratio of the 80^{th} percentile travel time to the agency-determined threshold travel time.

6. RECOMMENDED CONGESTION PERFORMANCE MEASURES FOR ODOT

The previous sections described the contemporary practices in the field of congestion measurement being implemented at the national, state and local governments as well as the research findings in this arena. As indicated in the findings of NCHRP Report 398: *Quantifying Congestion*, while it is difficult to conceive of a single value that will describe all of the travelers' concerns about congestion, there are four components that interact in a congested roadway or system. These components are duration, extent, intensity, and reliability.

As a part of 2015-2040 Oklahoma Long Range Transportation Plan (LRTP), a set of performance measures were developed that are intended to be consistent with a broader framework of Plan goals and objectives. The performance measures relevant to congestion and economic vitality are identified as follows:

- Economic Vitality (Freight Movement)
  - Measure of freight travel time reliability and/or speed (To be developed based on truck-specific, travel time data)
- Economic Vitality (Congestion)
  - Travel time-based measure(s) of congestion, such as hours of delay or travel time reliability index for Interstate or major commuter corridors.

As indicated earlier, the above identified performance measures provide a framework to address the requirements of the Moving Ahead for Progress in the 21st Century Act (MAP 21). This pilot study complements the above listed performance measures by providing in greater detail the complex characteristics of freight and commuter travel on the Oklahoma highway system.

Maintaining consistency with the performance measures framework identified for 2015-2040 Oklahoma Long Range Transportation Plan (LRTP), this pilot study recommends the following travel time-based congestion measures, one for each component of congestion. These congestion measures are further described as follows:

- Duration
  - **Frequency of congestion –** This is typically expressed as the percent of time that travel speeds fall below a certain threshold.

- Extent
  - **Congested Vehicle Miles Traveled –** This is typically expressed as the number of vehicle miles traveled along the region's roadways – where travel speeds fall below a certain threshold.

- Intensity
  - **Annual Hours of Delay** – Travel time above a congestion threshold in units of vehicle-hours of delay.

- Reliability
  - **Planning Time Index –** In order to calculate the Planning Time Index, one needs to determine the ratio of the total time needed to ensure 90 percent on-time arrival as compared to a free-flow travel time. The planning time index is computed as the 90th percentile travel time divided by the free-flow travel time for each road section and for each time period. Travel Time Index is another alternate measure to quantify reliability component of congestion. Either the Planning Time Index or Travel Time Index can be recommended based on the MAP-21 guidelines.
  - **Reliability Index (RI_{80})** – The Reliability Index is defined as the ratio of the 80th (or selected) percentile travel time to the agency-determined threshold travel time. The threshold travel time is discussed below

6.1 MEASUREMENT PERIOD

Each of the above listed congestion measures should be calculated for either the peak period or daily weekday travel conditions, excluding the state and national holidays. As a result of feedback during the planning process, it is recommended that for this pilot study, the measures be calculated for both the peak period and daily weekday travel conditions. An appropriate decision about further actions can be made based on the findings of the pilot study as well as the finalized MAP-21 rules.

6.2 THRESHOLD SETTING[v]

Each of the above listed measures requires a "Threshold Speed" to be set by ODOT based on ODOT's practices and defensible factors. These factors could include items such as:

- Corridor characteristics

- Local conditions; operational factors

- Community opinion about the desirability of additional capacity in a corridor; existing capacity

- Population growth

- Rural/urban routes

- Level of existing revenues

- Potential investment required to achieve desired performance levels

Different agencies have different thresholds and criteria for measuring congestion. For example, California uses 35 mph on freeways as a threshold to identify serious congestion problems. Washington State uses a maximum productivity-based threshold where a value of 85 percent of the free-flow speed (51 mph) is used to define the point where the maximum vehicle volume per hour per lane occurs; the freeway is not as productive at moving people at speeds above this level. Rural areas, or areas with less congestion, may use the speed limit or free-flow speeds as the basis to identify the size of the congestion problem.

Any of these threshold approaches can be used for communicating the congestion problems or for analysis of potential solutions. They all can illustrate the effect of a full range of congestion reduction strategies. Using one ODOT-determined threshold speed, for all the congestion measures simplifies the communication of the results (particularly with non-technical audiences) and supports the expectations of the local community as expressed in the threshold.

An appropriate selection of the threshold seed can be made based on the findings of the pilot study – which are described in the following section.

7. RESULTS OF PILOT STUDY

For this pilot study, ODOT has identified two corridors – I-40 and US 69 – to analyze the NPMRDS and develop congestion measures. This section summarizes the analysis for the two selected corridors.

7.1 COVERAGE OF NPMRDS ON SELECTED CORRIDORS

7.1.1 Geographic Coverage

NPMRDS probe data is available on entire sections of I-40 and US 69 in Oklahoma. I-40 has more data coverage than US 69. In addition, the passenger only probe data points are observed to be higher in number than the freight only probe data points. **Figures 7-1 through 7-3** illustrate the geographic coverage of NPMRDS probe data along I-40 and US 69.

Figure 7-1 Geographic Coverage of NPMRDS along I-40 and US 69 (All Traffic)

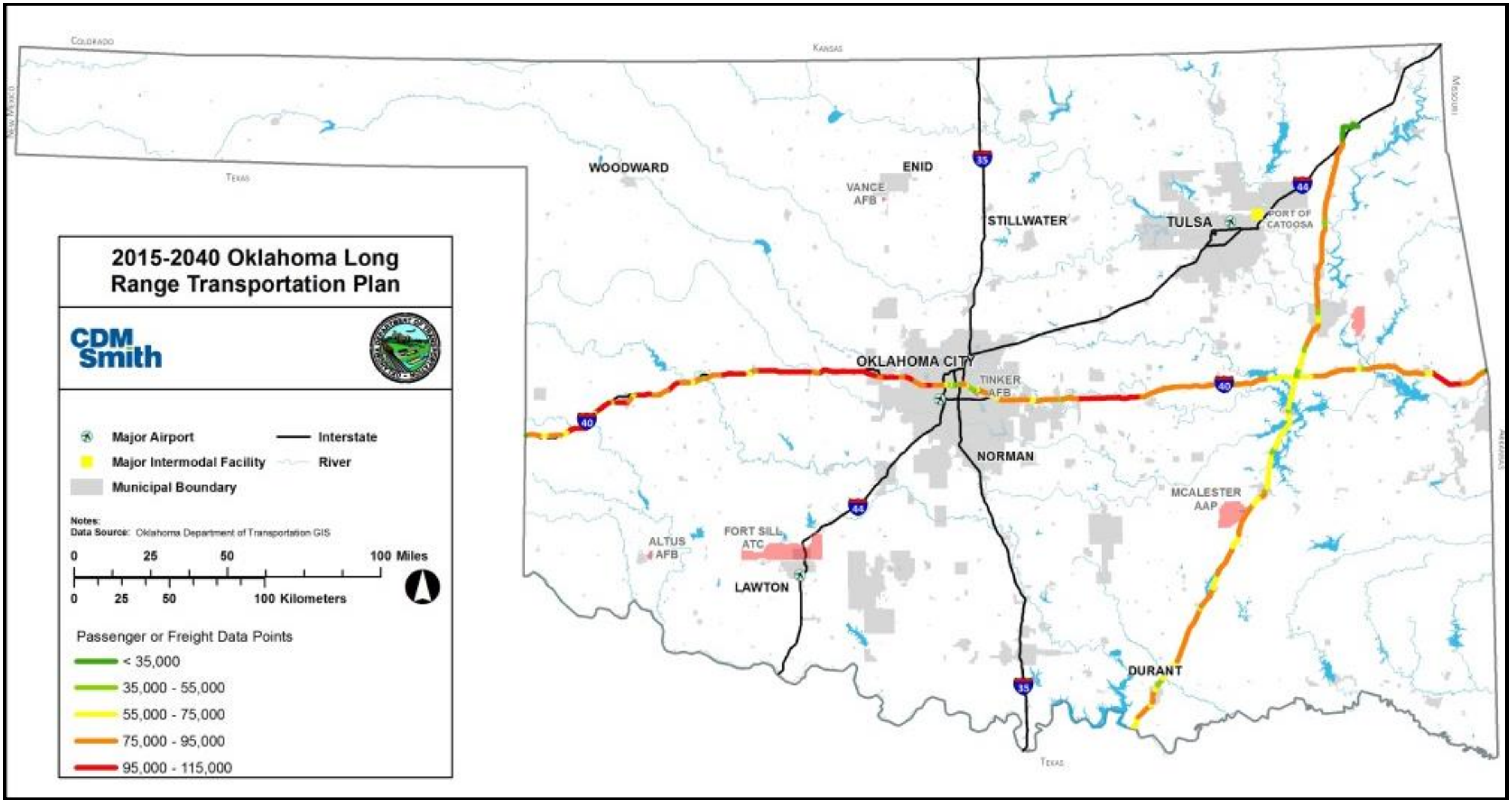


Figure 7-2 Geographic Coverage of NPMRDS along I-40 and US 69 (Passenger Traffic)

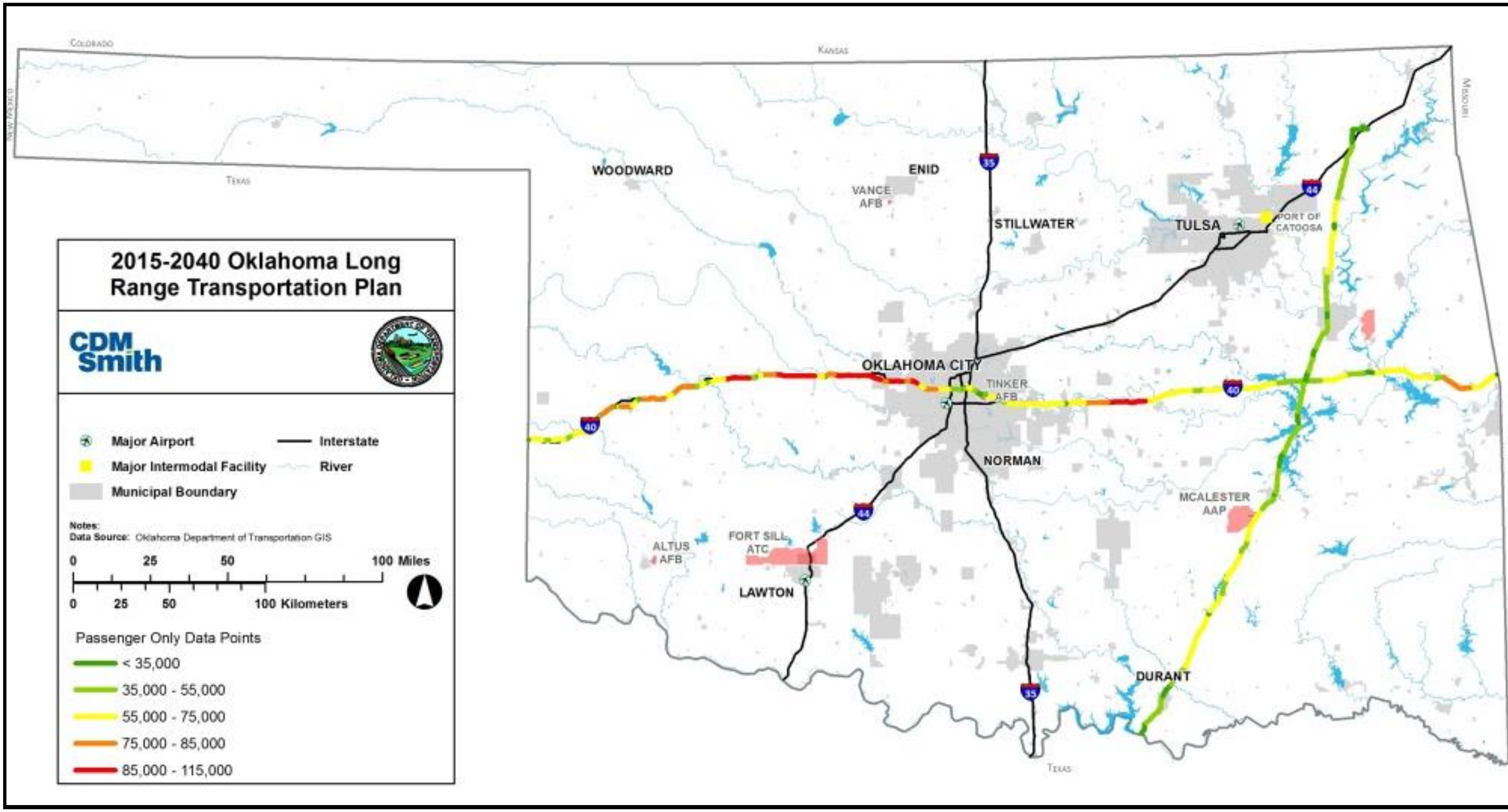
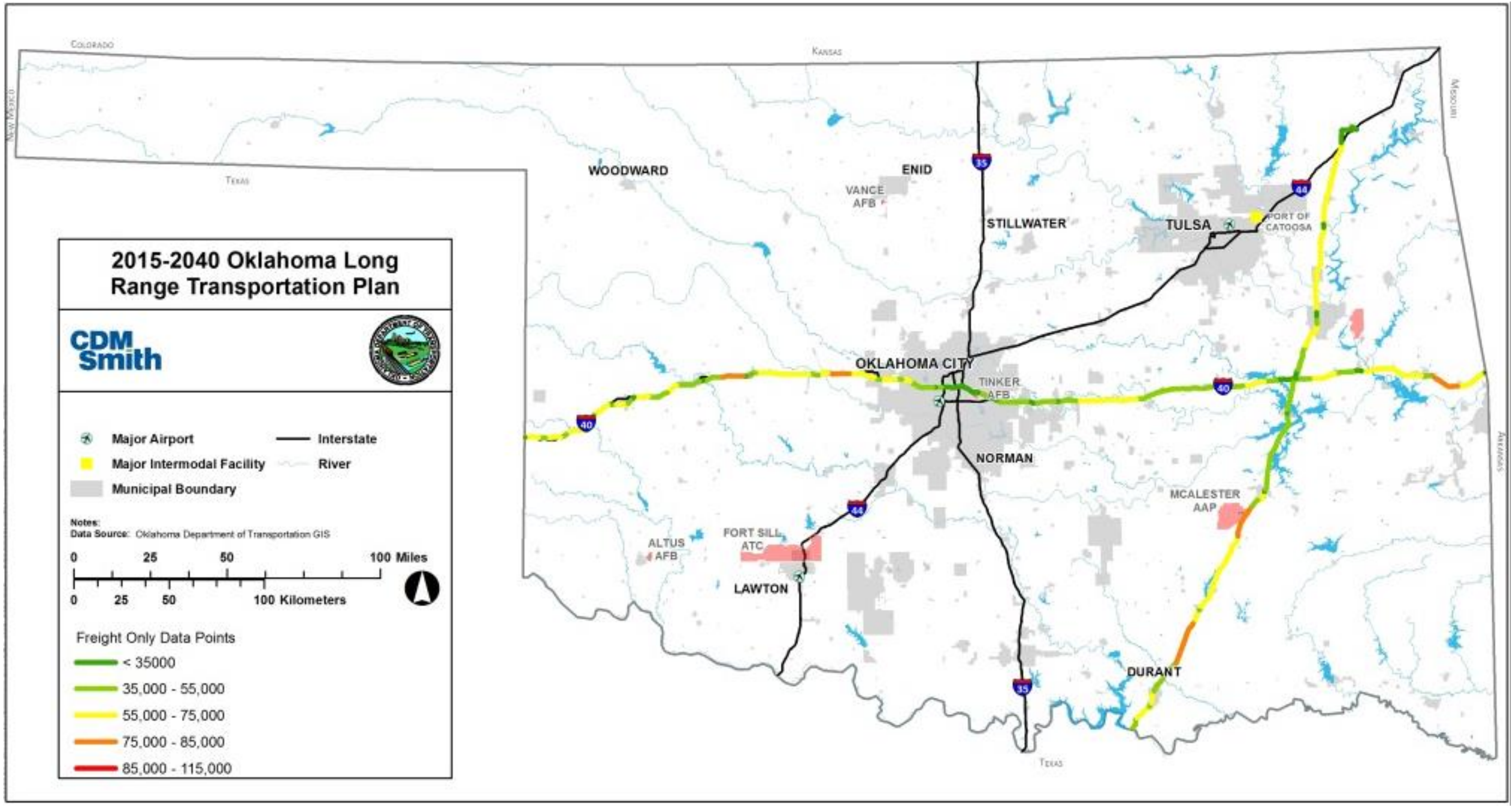


Figure 7-3 Geographic Coverage of NPMRDS along I-40 and US 69 (Freight Traffic)



7.1.2 Temporal Coverage

Figure 7-4 illustrates the temporal coverage of NPMRDS probe data along I-40. Majority of the probe data points are observed during the day time and during weekdays. Additionally, the coverage of NPMRDS has been observed to increase drastically beginning in March 2014.

Figure 7-4 Temporal Coverage of NPMRDS along I-40 (All Traffic)

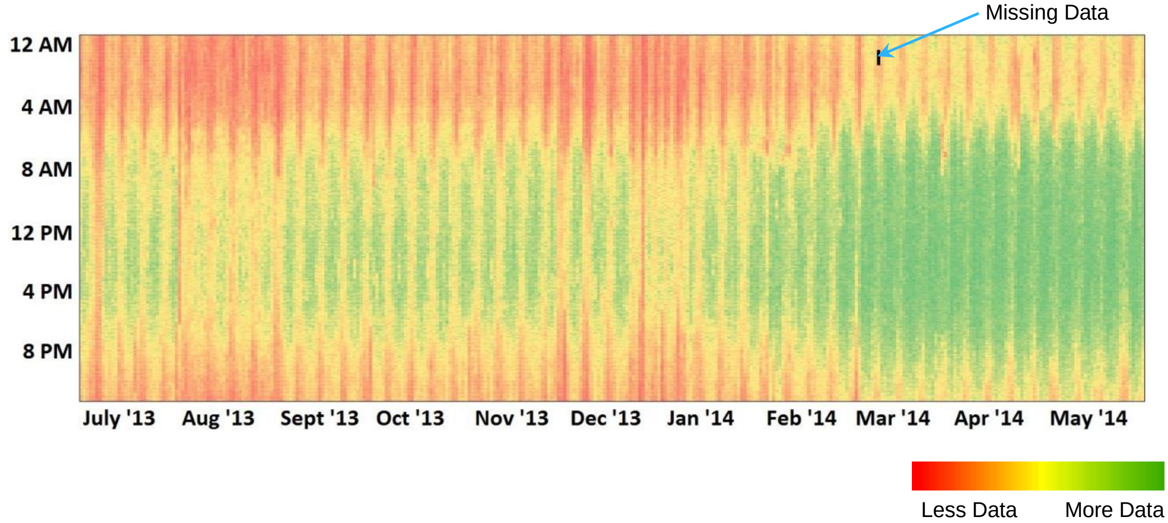
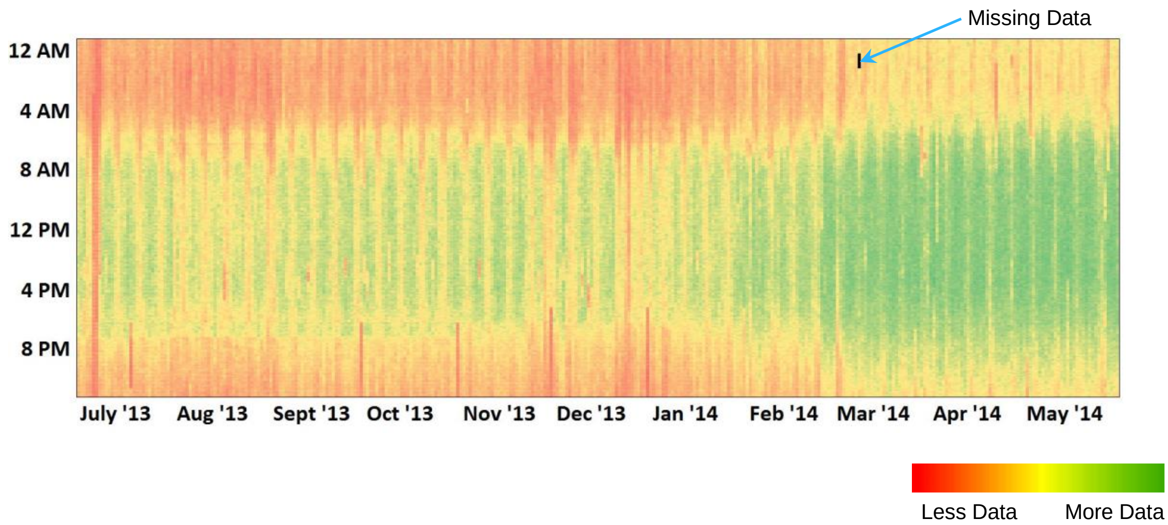


Figure 7-5 illustrates the temporal coverage of NPMRDS probe data along US 69. The temporal coverage of NPMRDS for US 69 is similar to I-40, with the only difference being the less data points for US 69 as compared to I-40.

Figure 7-5 Temporal Coverage of NPMRDS along US 69 (All Traffic)



7.1.3 Variation of NPMRDS Data

Figure 7-6 illustrates the hourly, daily and monthly variation of NPMRDS probe data along I-40. The majority of the probe data points are observed during the day time hours of 6 am to 7 pm, while weekdays are observed to have more data points than the weekends. Additionally, as indicated earlier, the coverage of NPMRDS has been observed to increase drastically beginning in March 2014.

Figure 7-6 Variation of NPMRDS along I-40

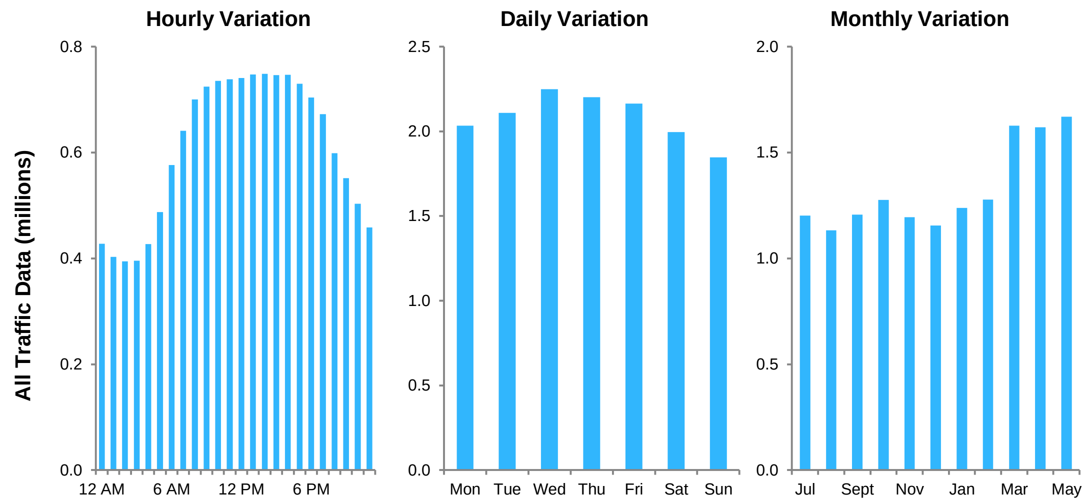
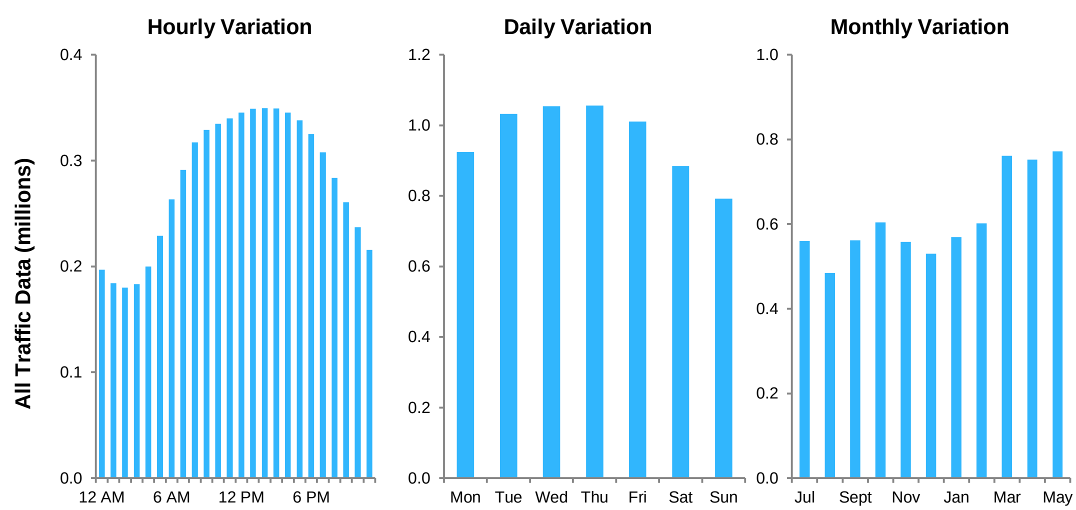


Figure 7-7 illustrates the hourly, daily and monthly variation of NPMRDS probe data along US 69. The variation of NPMRDS for US 69 is similar to I-40, with the only difference being that there are fewer data points for US 69 as compared to I-40.

Figure 7-7 Variation of NPMRDS along US 69



7.2 ANALYSIS PARAMETERS

Table 7-1 lists the various parameters used for conducting the analysis of NPMRDS. The congestion threshold is set as 85% of the free-flow speed for this analysis. However, in order to understand the implications of this parameter on the congestion measures, analysis was conducted using a different threshold (75% of the free-flow speed) as well and the results are presented in Section 7.5.

Table 7.1 Analysis Parameters

Parameter	Definition
Weekday	Monday – Friday (excluding holidays)
Daytime hours	6 am to 7 pm
Overnight hours	10 pm to 5 am
Peak periods	Morning: 6 am to 9 am; Evening: 4 pm to 7 pm
Free-flow speed	85th percentile of travel speeds during overnight hours
Congestion threshold speed	85% of free-flow speed

7.3 CONGESTION MEASURES FOR DAY TIME

This section presents the summary of results for the recommended measures calculated based on day time hours (6 am to 7 pm).

7.3.1 Frequency of Congestion

Frequency of congestion is typically expressed as the percent of time that travel speeds fall below the threshold speed. The higher the frequency of congestion, the longer is the duration for which travelers experience slower speeds. **Figure 7-8** illustrates the frequency of congestion along I-40 and US 69 for all traffic during day time hours.

7.3.2 Congested Vehicle Miles Traveled

Congested vehicle miles traveled is typically expressed as the number of vehicle miles traveled along the region's roadways while travel speeds fall below the threshold. The higher the congested vehicle miles traveled, the higher the geographic extent of congestion. **Figure 7-9** illustrates the congested vehicle miles traveled along I-40 and US 69 for all traffic during day time hours.

7.3.3 Annual Hours of Delay

Annual hours of delay is typically expressed as travel time above the congestion threshold in units of vehicle-hours of delay. Delay indicates the severity of the congestion that affects travel. It is typically used to differentiate between levels of congestion on transportation systems and to define the total amount of congestion.

Figure 7-10 illustrates the annual hours of delay along I-40 and US 69 for all traffic during day time hours.

7.3.4 Planning Time Index

Planning time index is the ratio of the total time needed to ensure 90 percent on-time arrival as compared to a free-flow travel time. For example, a planning time index of 1.40 means that a traveler should budget for an additional 8 minutes for a 20-minute free-flow trip time to ensure 90 percent on-time arrival. The higher the planning time index, the longer the travelers will have to allow beyond the free-flow trip time in order to reach a destination on time. **Figure 7-11** illustrates the planning time index along I-40 and US 69 for all traffic during day time hours.

7.3.5 Reliability Index (RI_{80})

The Reliability Index (RI_{80}) is defined as the ratio of the 80^{th} percentile travel time to the agency-determined threshold travel time. The higher the reliability index, the less reliable are the travel times in the region or along a roadway. **Figure 7-12** illustrates the reliability index along I-40 and US 69 for all traffic during day time hours.

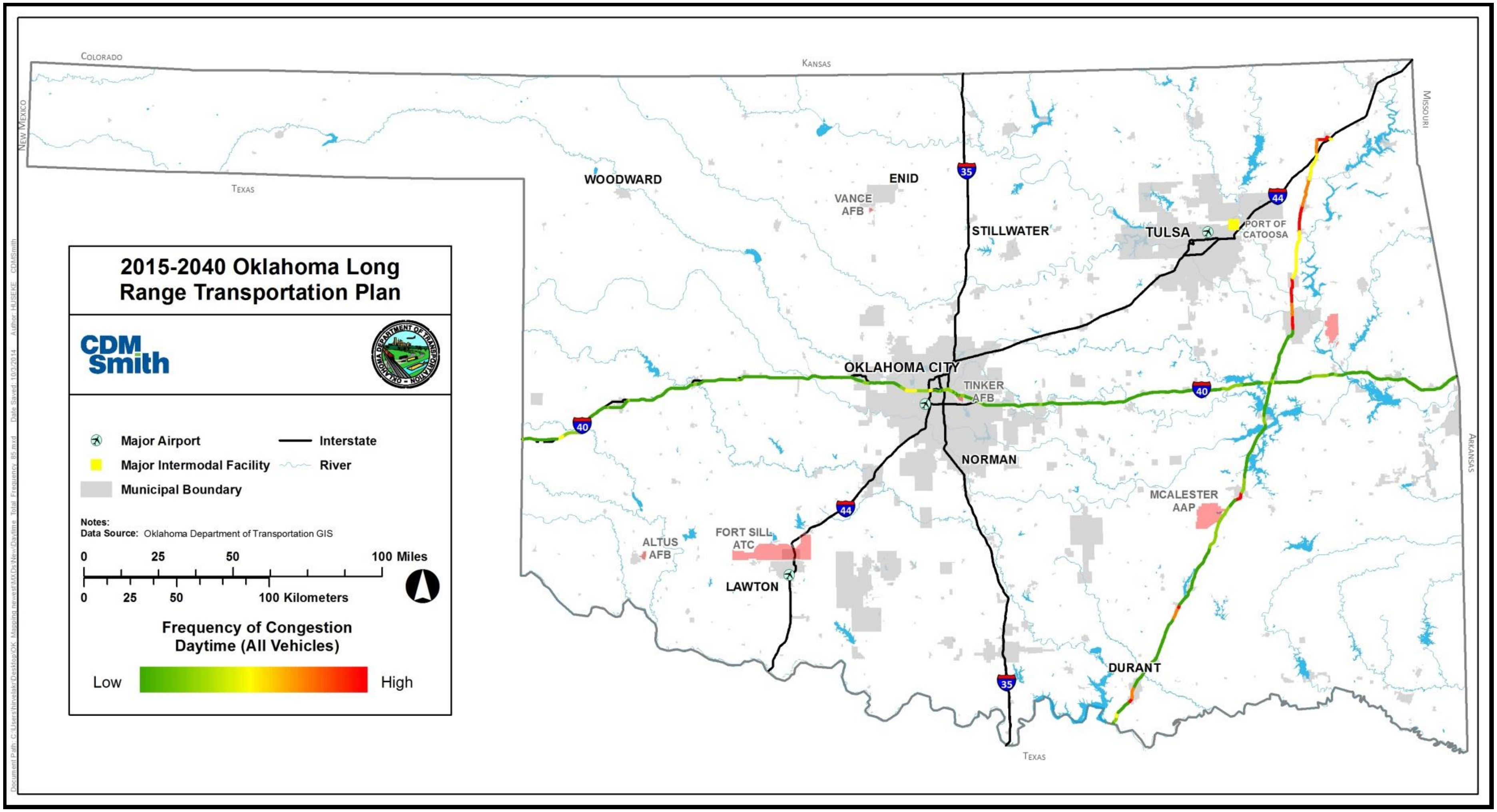
7.3.6 Congested Roadways

As observed from the findings of NCHRP Report 398: *Quantifying Congestion*, a comprehensive picture of congestion on a roadway or a system can be developed by understanding its four components – duration, extent, intensity and reliability. Congested roadways along I-40 and US 69 were developed using a combination of the performance measures developed for each of the four components of congestion – frequency of congestion, congested vehicle miles traveled, annual vehicle hours of delay and reliability index. **Figure 7-13** illustrates the congestion along I-40 and US 69 for all traffic during day time hours.

Using the NPMRDS and ODOT's traffic characteristics report, congested roadways can be developed for passenger only traffic as well as freight only traffic. **Figure 7-14** illustrates the congestion along I-40 and US 69 for passenger only traffic during day time hours. **Figure 7-15** illustrates the congestion along I-40 and US 69 for freight only traffic during day time hours.

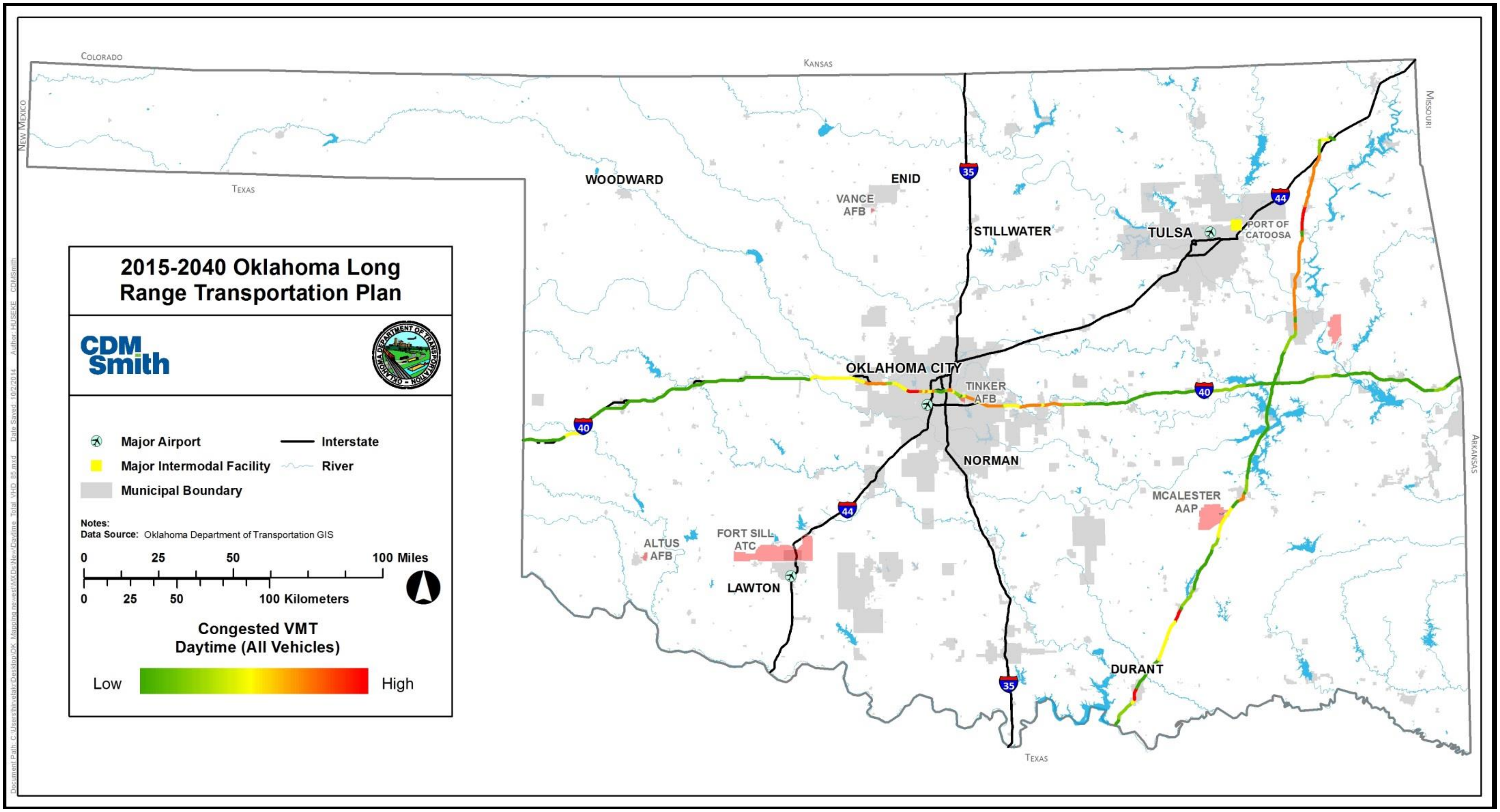
These figures illustrate that the congestion for passengers occurs differently than the congestion for freight traffic. This can be attributed to the different characteristics and proportion of passenger and freight traffic along the roadways. For example, US 69, in northeast Oklahoma, experiences medium to heavy congestion for freight as well as passenger traffic where as I-40 within Oklahoma City limits experiences medium congestion for passenger only traffic. This can be attributed to the higher

Figure 7-8 Frequency of Congestion – All Traffic (Day Time)



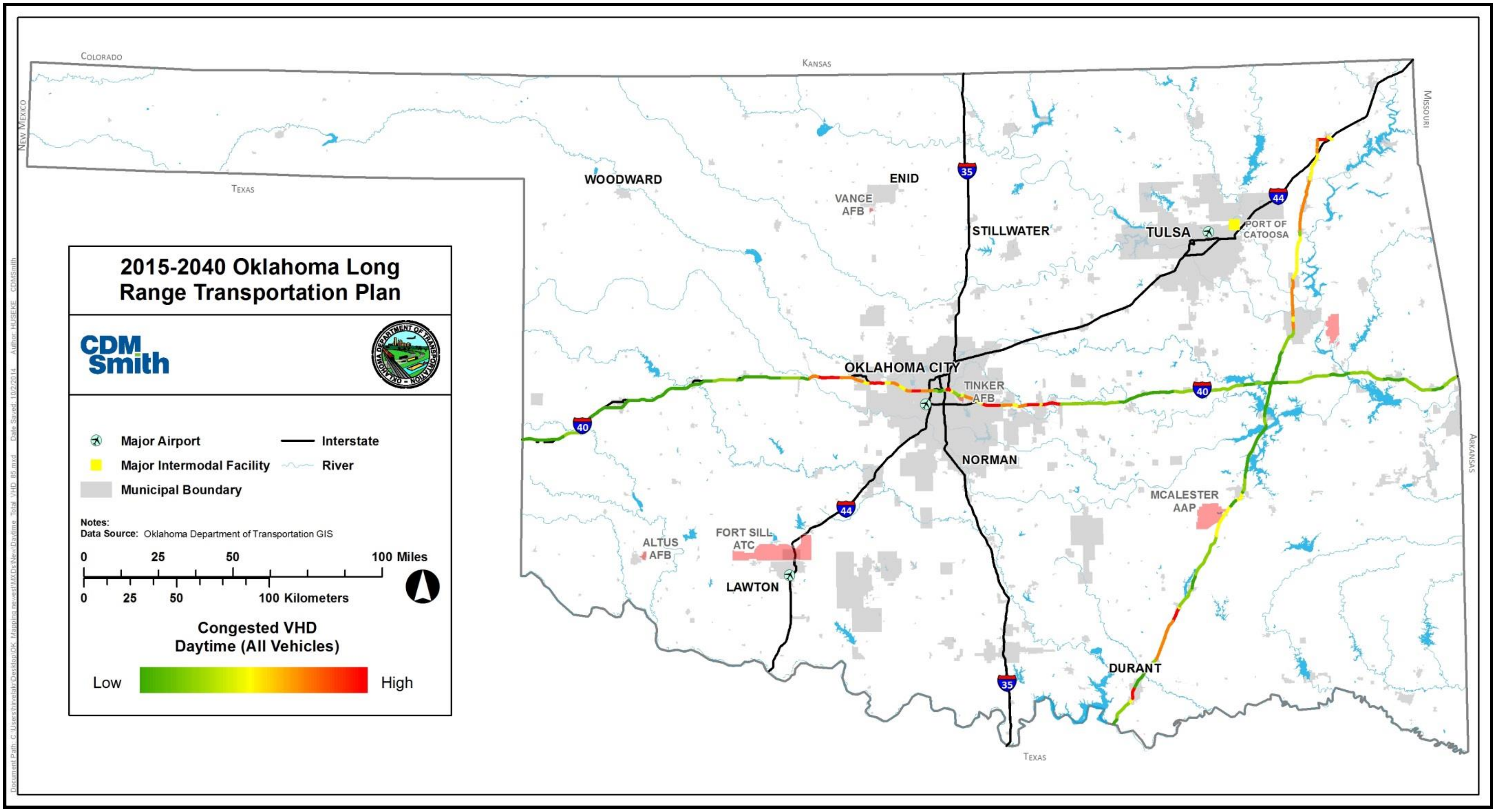
US 69 in northeast Oklahoma experiences a high frequency of congestion during the day time. This indicates that speeds on this section of US 69 fall below the threshold speed for an extended period of time.

Figure 7-9 Congested Vehicle Miles Traveled – All Traffic (Day Time)



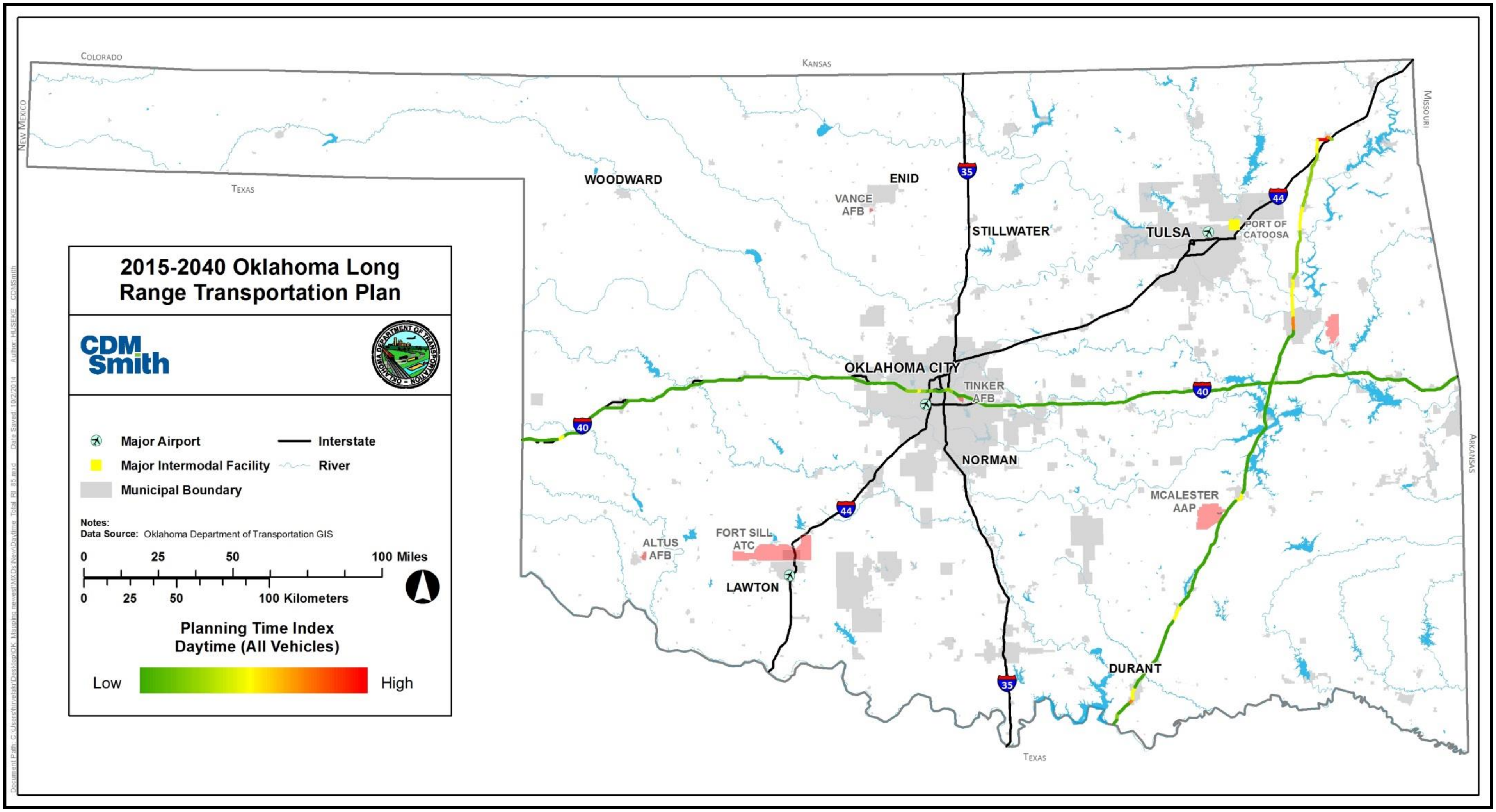
I-40 within the limits of Oklahoma City experiences medium to high congestion during the day time.
US 69 in northeast Oklahoma and near Durant experiences medium to high congestion levels during the day time.

Figure 7-10 Vehicle Hours of Delay – All Traffic (Day Time)



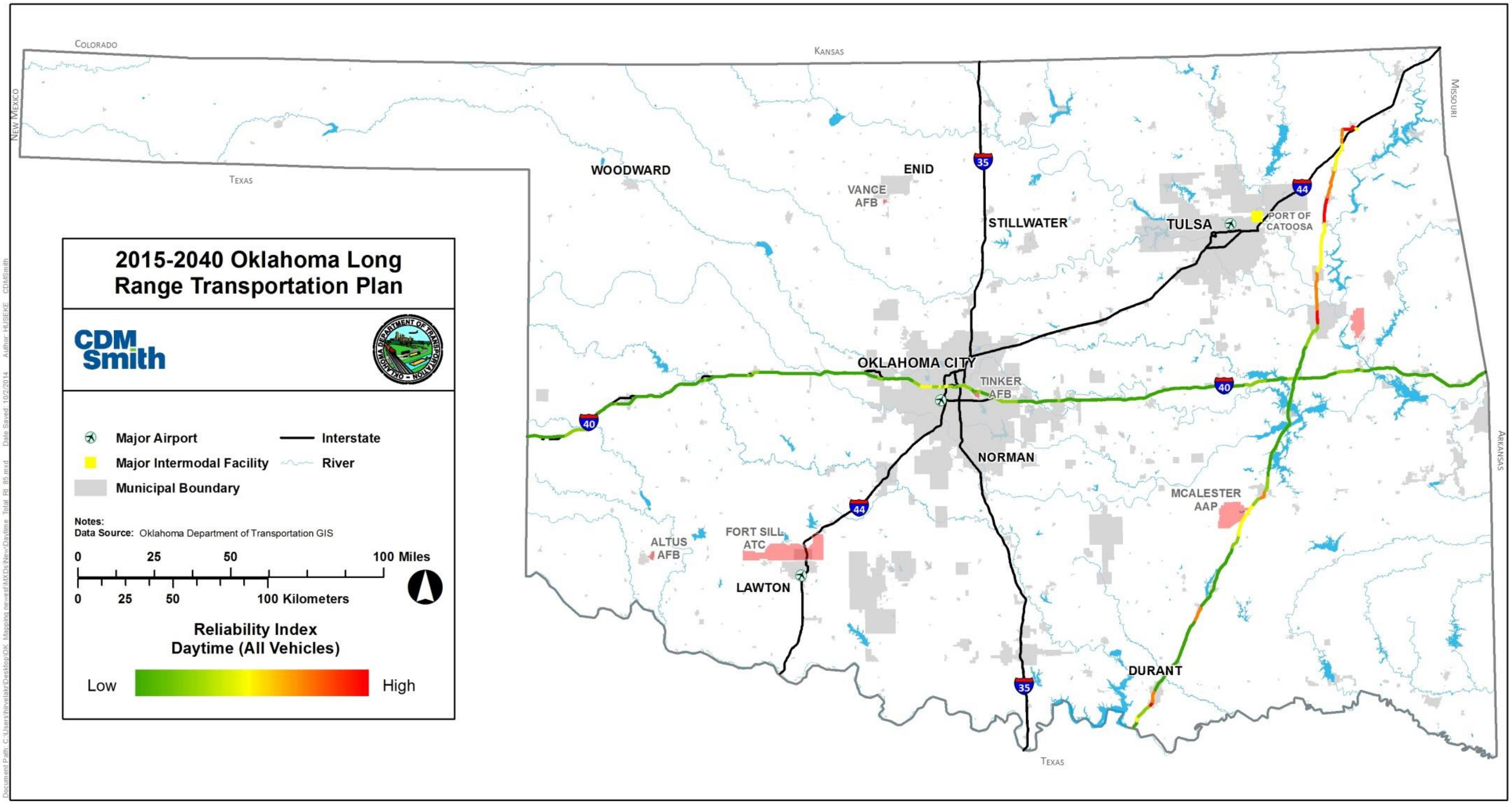
I-40 within the limits of Oklahoma City experiences high delay during the day time.
US 69 in northeast Oklahoma and near Durant experiences medium to high delay during the day time.

Figure 7-11 Planning Time Index – All Traffic (Day Time)



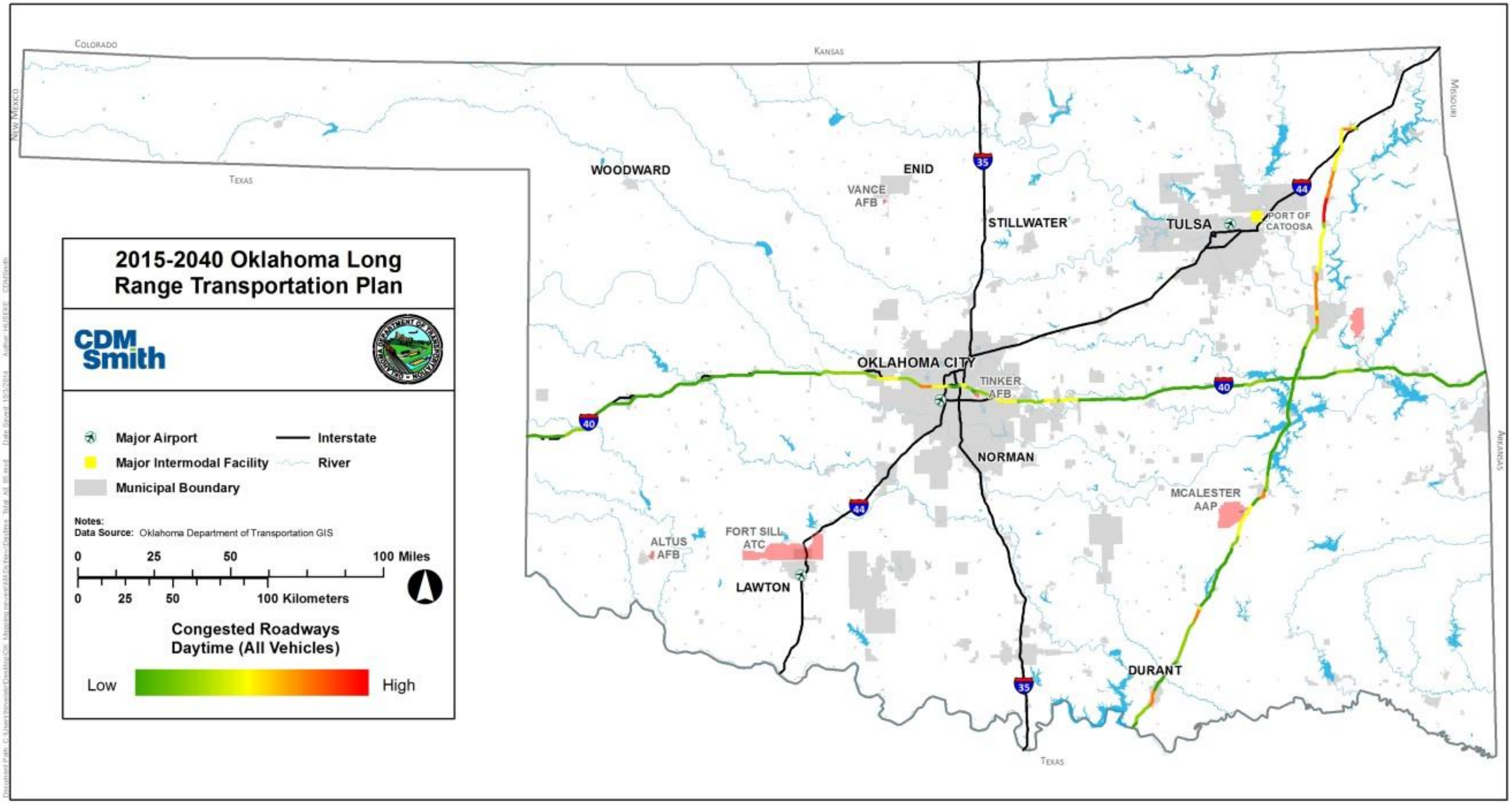
US 69 in northeast Oklahoma experiences a low to medium planning time index during day time.

Figure 7-12 Reliability Index – All Traffic (Day Time)



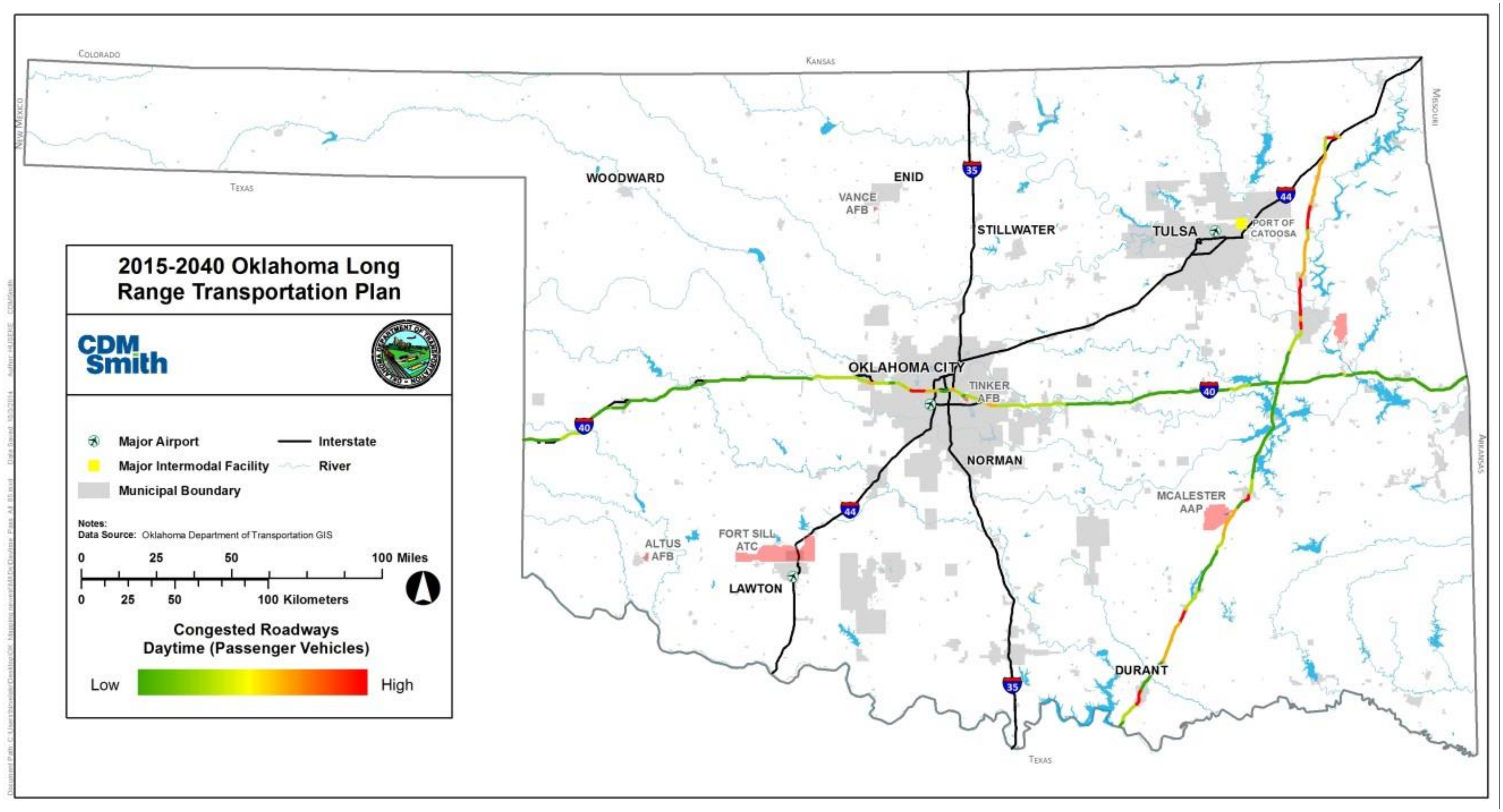
US 69 in northeast Oklahoma experiences a medium to high planning time index during the day time.

Figure 7-13 Congested Roadways – All Traffic (Day Time)



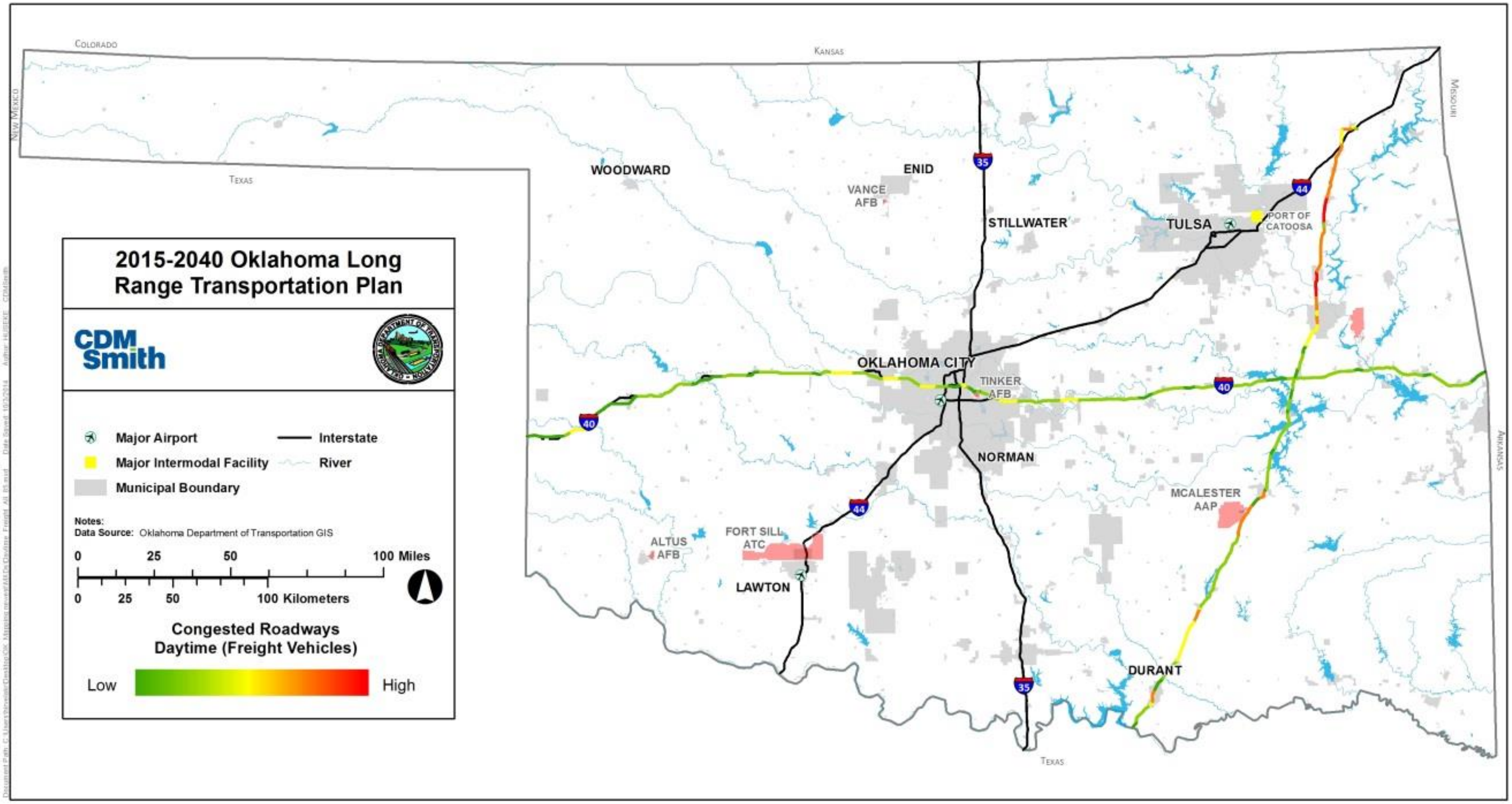
US 69 in northeast Oklahoma experiences medium to high congestion for all traffic during the day time.
I-40 within Oklahoma City limits experiences low to medium congestion for all traffic during day time hours.

Figure 7-14 Congested Roadways – Passenger Only Traffic (Day Time)



US 69 in northeast Oklahoma experiences medium to high congestion during the day time, which can be attributed to passenger only traffic. I-40 within Oklahoma City limits experiences medium congestion during day time which can be attributed to passenger only traffic.

Figure 7-15 Congested Roadways – Freight Only Traffic (Day Time)

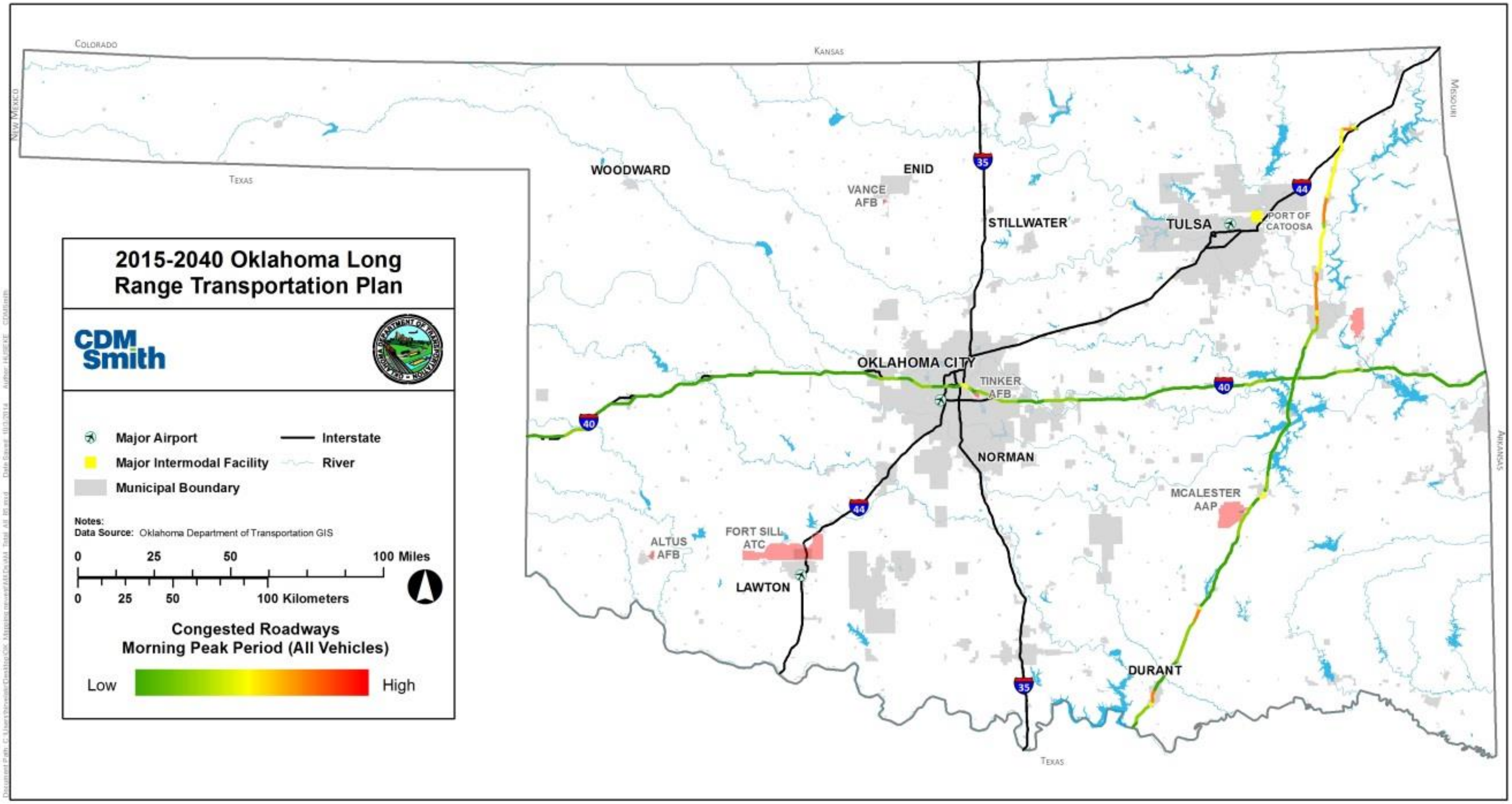


US 69 in northeast Oklahoma experiences medium to high congestion during the day time, which can be attributed to freight only traffic. However, I-40 experiences low congestion attributable to freight only traffic.

7.1 CONGESTION MEASURES FOR PEAK PERIODS

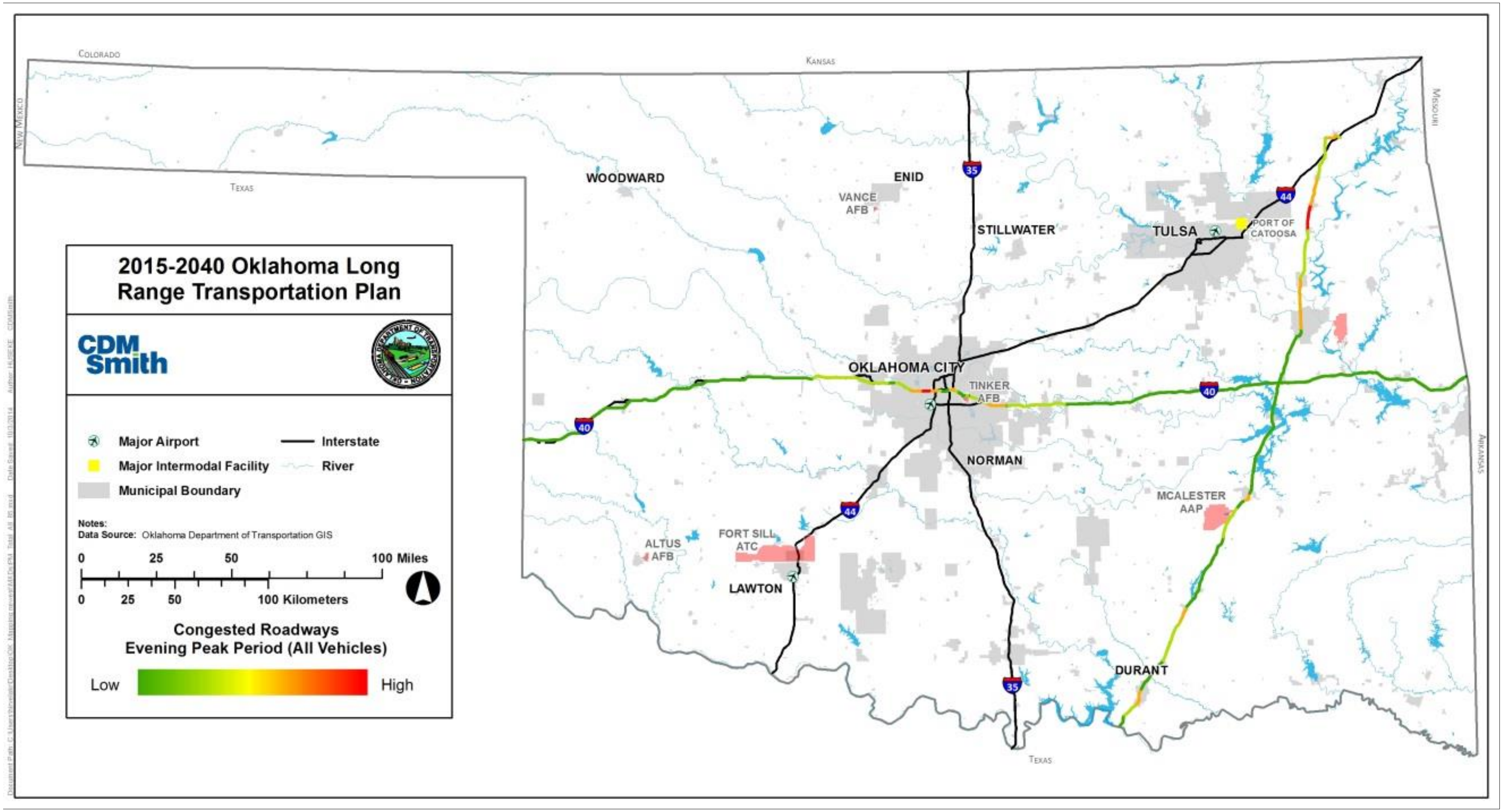
Using the same methodology employed for day time hours, the congestion measures were developed for morning and evening peak periods. **Figure 7-16** illustrates the congestion along I-40 and US 69 for all traffic morning peak period (6 am to 9 am) while **Figure 7-17** illustrates the same for evening peak period (4 pm to 7 pm).

Figure 7-16 Congested Roadways – All Traffic (Morning Peak Period)



During the morning peak period, US 69 expereinces medium congestion in northeast Oklahoma, while I-40 expereinces low congestion.

Figure 7-17 Congested Roadways – All Traffic (Evening Peak Period)



During the evening peak period, US 69 expereinces medium congestion between in northeast Oklahoma while I-40 expereinces medium to high congestion within Oklahoma City limits.

7.2 IMPACT OF THRESHOLD SETTING

All the measures described above were calculated using a congestion threshold speed of 85 percent of free-flow speed. Section 6.2 described the various factors that ODOT should consider while determining the congestion threshold speed. This section presents the results of congested roadways (which uses a combination of four measures) using a congestion threshold speed of 75 percent of free-flow speed.

Figure 7-18 illustrates the congestion along I-40 and US 69 for all traffic during day time using a congestion threshold speed of 75 percent of free-flow speed. Comparing Figure 7-18 to Figure 7-13 provides an understanding of the impacts of different congestion thresholds. Since Figure 7-18 was created using a lower threshold speed for congestion than Figure 7-13, slightly more roadway segments are observed to be congested. If the threshold was set even lower, more roadway segments would be considered as congested. Understanding this impact will be very useful to ODOT in determining a threshold for the congestion measures.

Figure 7-19 and 7-20 illustrate the congestion along I-40 and US 69 for passenger only traffic and freight only traffic respectively during day time using a congestion threshold speed of 75 percent of free-flow speed. Comparing these figures to Figure 7-14 and Figure 7-15 indicates a similar trend as observed for day time conditions.

Figure 7-18 Congested Roadways
(Congestion Threshold Speed = 75% of Free-Flow Speed) – All Traffic, Day Time

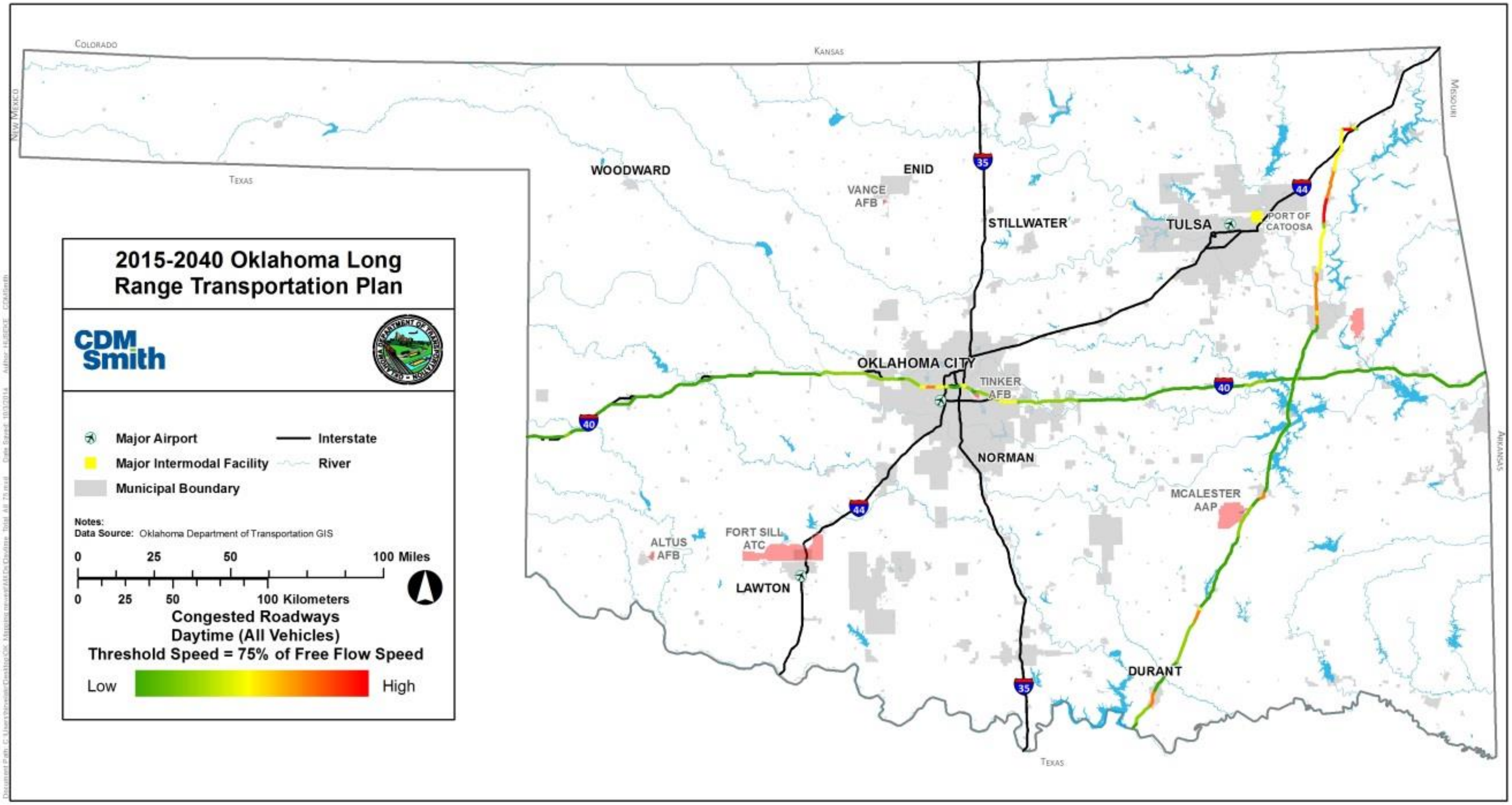


Figure 7-19 Congested Roadways
(Congestion Threshold Speed = 75% of Free-Flow Speed) – Passenger Traffic, Day Time

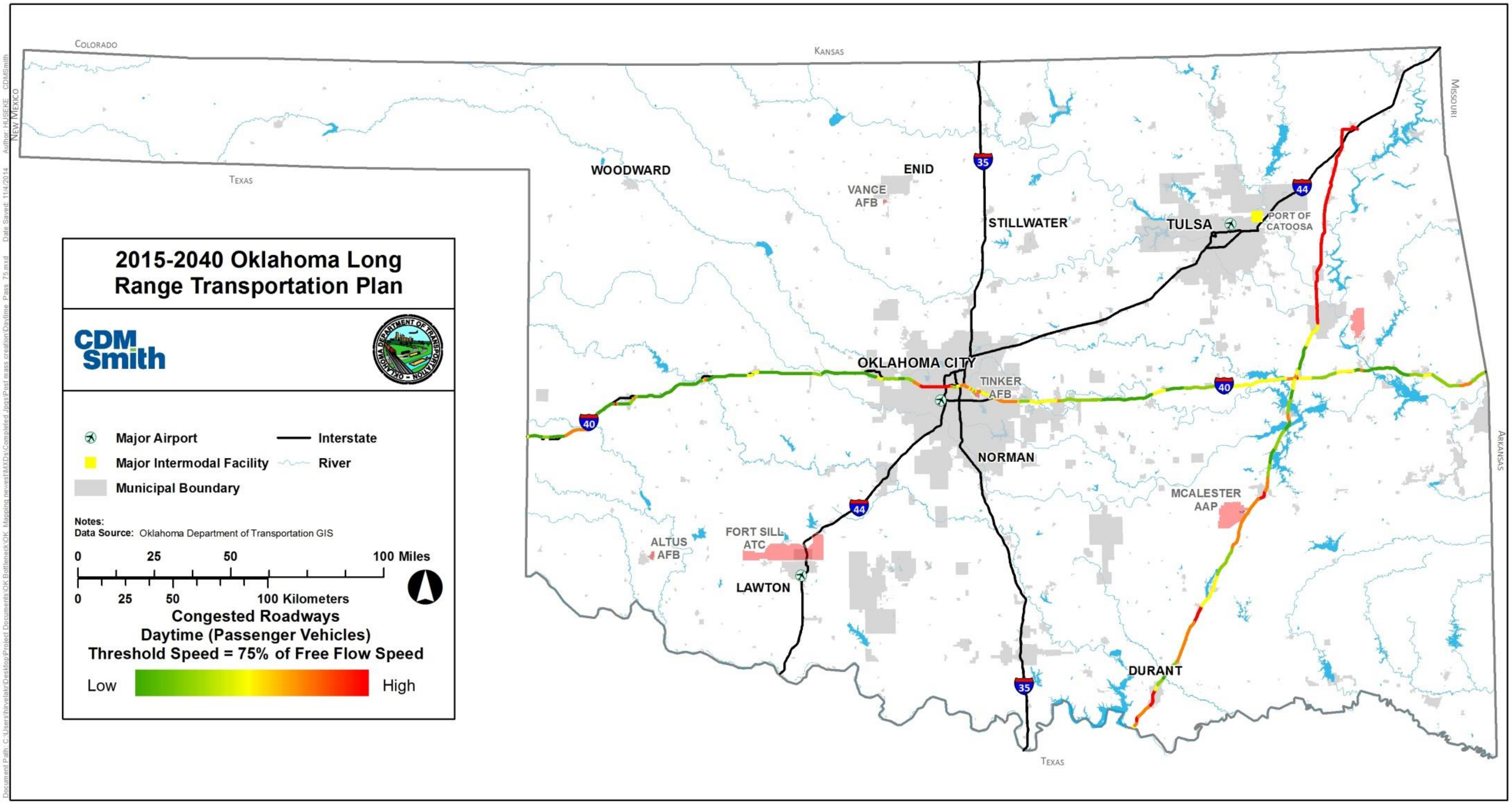
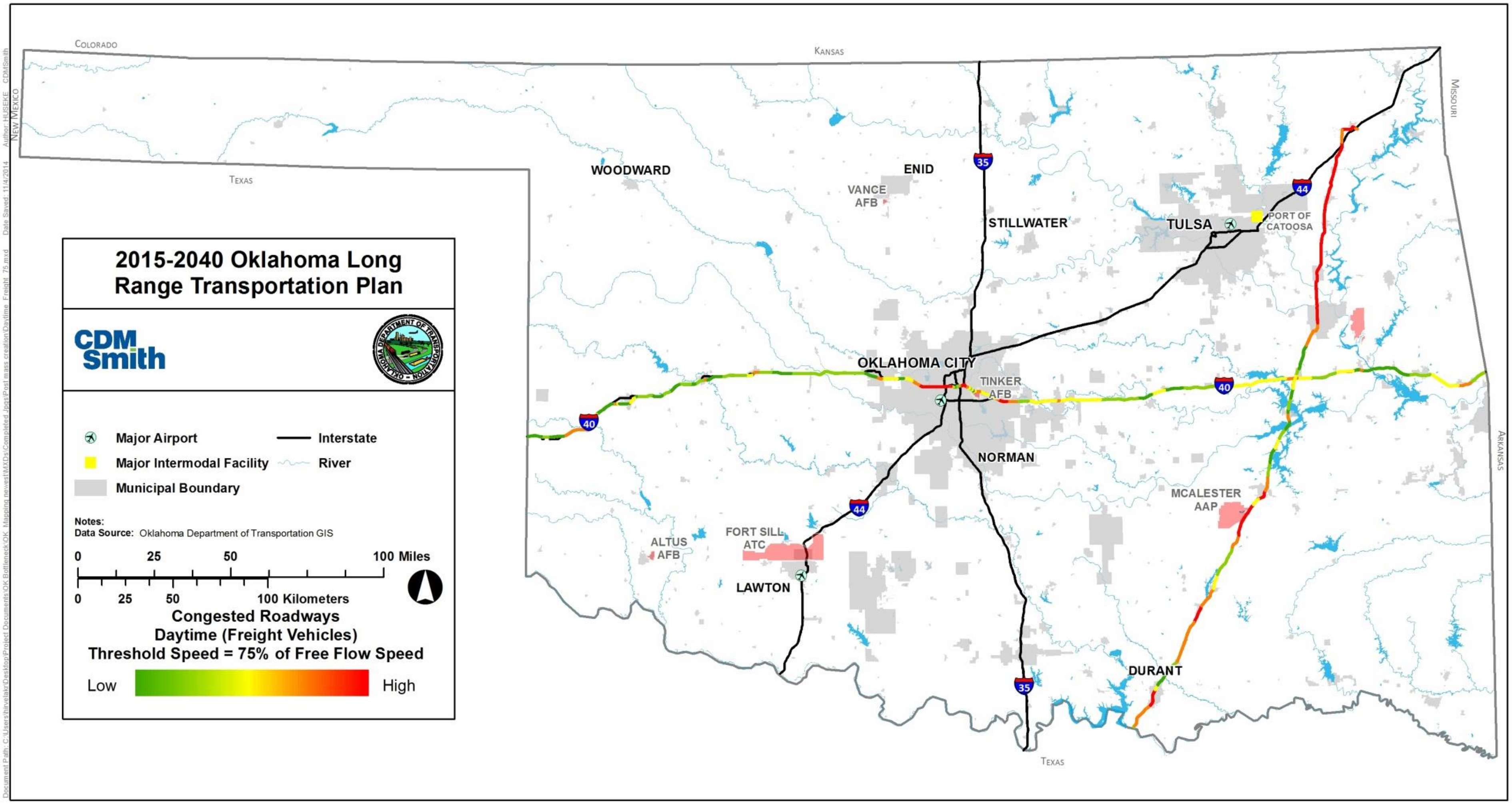


Figure 7-20 Congested Roadways
(Congestion Threshold Speed = 75% of Free-Flow Speed) – Freight Traffic, Day Time



8. CONCLUSIONS

This technical memorandum summarized the results of the pilot study and developed travel time based congestion measures. This study proposes an innovative methodology to use the latest vehicle probe data to develop an understanding of congestion along Oklahoma's roadways. The methodology was used to develop congestion measures along two selected corridors – I-40 and US 69.

This methodology can be used to understand and address roadway congestion using the latest vehicle probe data. Applying the methodology routinely over time allows the identification of new congested roadway segments and monitoring of existing ones to discern congestion trends. This methodology is also helpful to develop meaningful criteria and communicate complex ideas related to congestion and reliability.

APPENDX A:
NPMRDS DATA VALIDATION, CALIBRATION AND QUALITY PLAN

National Performance Management Research Data Set
DTFH61-13-R-00002

Data Validation, Calibration and Quality Plan

Prepared For

Federal Highway Administration (FHWA)

U.S. Department of Transportation Federal Highway Administration

Prepared By

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in conjunction with
ATRI and Chen Fu Liao, University of Minnesota

November 21, 2013

here

1 Introduction

FHWA is taking proactive steps to support transportation agencies needs by obtaining a comprehensive and reliable set of data that can be broadly deployed for use in measuring, managing and improving the US transportation system. FHWA selected HERE North America, LLC (formerly known as Nokia/NAVTEQ) to provide the National Performance Management Research Data Set (NPMRDS).

The purpose of this document is to share the quality validations that will be performed on the NPMRDS. The NPMRDS dataset is derived based on passenger vehicle data from HERE probe sources and truck data from American Transportation Research Institute (ATRI). Quality validations and testing will be conducted by both HERE and a third party independent data evaluator.

Mr. Chen-Fu Liao from the Minnesota Traffic Observatory at the University of Minnesota (UMN) will serve as the independent data evaluator for the NPMRDS. Mr. Liao is an expert independent data quality testing engineer with over 16 years of experience in embedded system computing, database analysis and management, wireless communications, intelligent transportation systems, traffic simulation, and visualization. His research includes freight and transit performance analysis, and human interaction with transportation systems and transportation system integration and control.

2 Validation Plan Objectives

As with any technical analysis that employs a large dataset from multiple sources, it is necessary to perform data validation analyses to ensure that the data is accurate and irregularities are minimized and mitigated. HERE and ATRI routinely perform a series of internal quality assurance tests to validate their probe sources and datasets. In addition to the internal quality tests, external analyses will be performed to compare the dataset to a variety of references. The objective of this validation plan is to provide a proposed framework of internal and external validation analyses that will result in assurances to FHWA and its licensed users that the data provided is within acceptable error tolerances.

3 Data Description, Composition & Formats

The NPMRDS dataset is derived based on passenger vehicle data from HERE probe sources and ATRI truck data. The following section provides an overview of the HERE and ATRI data sources to provide context for the proposed data validation analyses.

HERE Data

HERE has more than 25 years of experience in collecting, managing and processing large amounts of real world data to deliver high quality map and traffic products. HERE provides speed data, travel times, speed limits, incident data, routing information, and many other location-based data elements and analytics. HERE collects passenger data from consumer mobile phones, vehicles, and portable navigation devices and currently processes billions of probe measurements monthly through its real time system. HERE has created comprehensive data archives that include 300+ billion probe data readings for North America. For NPMRDS, HERE has selected a set of probe sources that best represent passenger vehicle behavior through a process described in Section 4.1.1.1.

ATRI Data

ATRI maintains one of the largest databases in the world of vehicle probe data that is exclusively comprised of freight data. ATRI captures and processes billions of unique probe points annually from several hundred thousand large freight trucks. A device is truck-embedded to ensure that travel points represent truck flows, rather than hand-held devices. ATRI's large database skews towards tractor-trailer combination trucks, medium- to large fleet trucks and dry van and flatbed trailers. These truck sectors and configurations represent more than 85 percent of all domestic tonnage moved by the trucking industry.

ATRI's commercial fleet data provides stakeholders with the ability to distinguish passenger vehicle travel times provided by HERE from freight travel times provided by ATRI. ATRI produces measurements and analyses of average speed, travel time, reliability, truck routing, freight flows, demand and origin/destination along freight corridors throughout North America.

Data Formats

The composition of the NPMRDS includes the following elements:

- Date (MMDDYYYY)
- Epoch (5 minute increment)
- Travel Time – all vehicles, passenger vehicles, freight vehicles (seconds)
- TMC code and segment length
- Country, State, County
- Road Number and Local Name
- Latitude/Longitude
- Road direction (Northbound, Southbound, Westbound, Eastbound)

Geographic Coverage

The coverage provided represents the FHWA defined National Highway System network, plus additional coverage needed to understand traffic conditions at border crossings and major freeway interchanges.

4 Data Validation Metrics & Analyses

The proposed data validation plan includes a combination of existing internal analyses and proposed external analyses to be performed by the team's independent data evaluator, Chen-Fu Liao. The results of the external analyses will be presented to FHWA in the form of a quarterly report.

4.1 Internal Analyses

4.1.1 HERE Data Sets

HERE uses several processes to meet data quality standards. The Internal Analyses include: 1) Raw Probe Data 2) Data Set Creation 3) Ground Truth Validation. These analyses types are described in the sections below.

4.1.1.1 Raw Probe Data

HERE collects data from a wide variety of sources to ensure broad and appropriate geographic coverage. Probe data providers are first screened based on a variety of criteria, listed below, and then on-going performance monitoring is performed.

Probe Source Screening and Monitoring

Internal quality teams use the following criteria to rigorously evaluate probe providers before utilizing their data

1. Qualitative Evaluation
2. Accuracy
3. Data Volume
4. Temporal Distribution
5. Spatial Distribution
6. Data Frequency
7. Data Latency
8. Speed Profile

Once a provider is selected, HERE routinely evaluates performance of providers by:

1. Running automated performance monitoring for key data characteristics
2. Addressing issues directly with the provider

Probe Data Validation

A number of steps are taken to cleanse, normalize, filter and map match the raw probe data.

Step 1: Probe Adapter cleanses and normalizes probe data

Data is validated from the sources for geo-location, heading, map matching, speed validity and other traffic metrics to filter flawed data from entering the data stream. Provider-specific formats are converted into a standard internal format, using validations that are appropriate to each individual provider's proprietary format.

Step 2: Probe Filtering removes invalid probe points

The following filters are applied to incoming probe data:

1. Filter out probes with invalid speeds
2. Filter out compass point degrees that are less than zero or greater than 359
3. Ignore duplicates
4. Match probes to closest link

Step 3: Map Matcher assigns probes to the roadway links

The GPS probe points are map matched using sophisticated algorithms. The algorithms have been verified for accuracy using independent ground truth validation. GPS probes are discarded that do not meet the map matching criteria, are stationary, or have outlier characteristics. This computationally intensive process leverages HERE's scalable big data platform to support growing probe volumes.

4.1.1.2 Data Set Creation and Validation

HERE creates the data set using the probe data that has been cleaned, filtered and map matched. HERE will perform automated validation tests on the newly created data set. The validations are run for the following conditions:

1. Number of TMCs with constant null speed values
2. Number of TMCs with missing dates
3. Number of TMCs with excessively long travel times with low speeds (5mph or less)
4. Comparing data points to the average passenger and freight travel times
5. Checking percent of data available for the AM peak, PM peak, off-peak daytime and off-peak nighttime for passenger, freight and combined data.

4.1.1.3 HERE Ground Truth Testing

HERE regularly field tests its data to validate the traffic speeds and travel times in its traffic data products. Traffic data is tested using the following approaches: a) ground truth testing using trained drivers to collect real world conditions b) ground truth testing using Bluetooth collection devices. These testing methods allow HERE to validate the traffic speeds and travel times in its traffic data products.

Ground truth testing allows for an independent data set to be compared to HERE's data set to test traffic data quality. Each ground truth test is conducted over the course of a week, and is concentrated on rush hour and congested roadway conditions. In most US markets, HERE typically collects speed data variance and aggregates to speed band tolerances. A chart is built that partitions the speed differences into bins of 5, 10, or 20 mph, centered around 0, and ground congestion level (free flow, medium, or heavy). Each bin contains a percentage of the valid segments produced by the flow drive. This approach has been adopted by clients over the past 5 years to use for contract service level agreements.

In addition, HERE also collects ground truth using Bluetooth collection devices and tests the traffic data on a rotating set of markets in the US where it has obtained permission to install Bluetooth collection systems. Bluetooth data is aggregated and travel times calculated using industry standards. Resulting travel times and speeds are compared back to HERE's traffic data.

4.1.2 ATRI Data Set

Since ATRI's and FHWA's inception of the Freight Performance Measure program in 2002, several analyses have been conducted on ATRI's truck probe data. The studies have found that ATRI data is a reliable proxy for actual truck speeds and travel times in a variety of road types and congestion levels. The following analyses specifically addressed the quality of ATRI's data:

- **SAIC Analysis.** This study was commissioned by FHWA to independently verify the ability to use ATRI's truck probe as an accurate and reliable indicator of overall travel conditions. The study compared the ATRI data to benchmark conditions captured by roadside sensor systems (e.g., Bluetooth, RADAR, etc.) and assessed the data's accuracy using two metrics: Percentage Correctly Classified and Mean Absolute Error. The study confirmed methods for using ATRI's truck GPS data as a surrogate for automobile-sourced and fixed-source travel time measures.
- **Texas Transportation Institute/FHWA Market Study .** TTI conducted a market study of viable sources of vehicle probe data as part of an analysis to determine available sources of probe data in the marketplace (see "Private Sector Data for Performance Management"). The study, which included ATRI's truck GPS data and a small list of other providers, assessed data requirements, reviewed the data marketplace and data quality assurance methods, and finally examined several legal issues.
- **Texas Transportation Institute Analysis.** In 2011, the Texas Transportation Institute (TTI) reviewed a sample of ATRI's data for the Maricopa Association of Governments (MAG) to determine the suitability of the data for several planning analyses. TTI researchers investigated truck ping rates, frequency of trucks in the study region, spatial and temporal distributions of trucks in the region, and link speeds. The 2010

data sample, which was ultimately used by Maricopa, was found to be "relatively robust" for producing speed profiles.

- **Cambridge Systematics Market Analysis.** CS presented a market analysis of vehicle probe data to identify the best sources of probe data in the marketplace for truck model development (see presentation "Use of Probe Data for truck Model Development," Arun Kuppam). The study compared the data coverage, vehicle types included, and temporal availability of multiple data sources, and found the ATRI truck probe data to be favorable in almost all categories of analysis. CS exclusively demonstrated the use of ATRI data to identify weekday truck trips, trip times, distances and speeds.
- **Florida Department of Transportation/University of South Florida.** ATRI was a member of a team, along with the University of South Florida (USF), that was tasked with conducting a variety of FPM analyses for the Florida Department of Transportation (FDOT). As part of these activities, USF conducted a comparative analysis of ATRI's probe data and FDOT's traffic counting systems. The analysis favorably assessed the coverage of ATRI's data, expressed as a percentage of actual truck volume. Florida DOT and USF developed an innovation within the practice of freight modeling by developing a nationwide truck trip table for the State of Florida using ATRI's truck GPS data.
- **Minnesota Department of Transportation.** In 2010, the University of Minnesota (UMN) conducted freight reliability and mobility analyses using the FPM data along the I-94/90 corridor from Twin Cities to Chicago. Truck travel time reliability, seasonal variation, and stop duration were analyzed. The UMN analysis process demonstrated the superior capability of FPM data (over loop detector data) to support freight transportation planning and infrastructure investment decision-making for the public agencies.

4.2 Proposed External Analyses

In addition to the internal analyses that are already routinely performed, Chen-Fu Liao from the Minnesota Traffic Observatory at the University of Minnesota (UMN) and his data validation team will facilitate a series of external validation analyses and will report the findings of those analyses to FHWA on a quarterly basis.

Geographic Locations

The analysis will include 15 geographic locations as validation test segments. Each location will be analyzed during the morning peak period, evening peak period, and off-peak period to study accuracy in varying levels of congestion and volume. The 15 test segments will be located throughout the U.S. in a mix of urban, suburban, and rural locations, where benchmark data is available. FHWA will provide the data validation team with lists of sites that have the equipment to provide the reference data. The data validation team will use these lists, as well as additional identifying information to ensure a range of sites with varying characteristics to evaluate the data. The data validation team will attempt to determine sites that represent all the regions in the nation.

Criteria for Locations Selection

Upon final acceptance of the data validation methodology by FHWA, the data validation team will select the 15 locations and submit a draft list of for review and approval. A core basis for site selection will be adequate availability of Bluetooth, Weigh-In-Motion, sensor and/or other potential reference data sources. Optimal comparison data is best achieved from the following criteria:

- Traffic volume (greater than 8000 vehicles per day)
- Within 2 miles of a WIM station or available reference data source
- Roadway type (interstate, state highway, arterial, etc.)
- Roadway geometry (grade < 6% and curve radius > 100 m)

Assumption and Limitation

With the assistance of FHWA, the data validation team will obtain WIM and other type of reference data from state DOTs and other sources. It is assumed that the reference data received from public agencies are correct. If there are issues with the reference data or if the data looks suspicious, further investigation of the source data may be conducted.

One limitation of the reference data used for this validation is that these data are collected from a fixed location within each TMC segment. Because the reference data is from a fixed location/point, it may not fully represent travel time across the full TMC. Reported travel time is based on instantaneous probe speeds reported across the full TMC, so the comparison to reference data is an approximation. Factors such as entry/exit points, weigh stations, rest areas and steep grade may influence the speeds recorded across a TMC.

As we recognize some of the imperfections in the reference data and its ability to verify the accuracy of the data set, the team will need to be flexible in the monitoring and selection of the reference data locations.

Existing reference data are often collected from locations (for example, interstate or state highways in urban or suburban areas) where traffic volumes are relatively high. Currently, the reference data sources on rural arterials with low traffic volume are very limited. The data validation team recognizes this limitation and will work with FHWA to identify locations with a variety of attributes from which the team can collect reference data. The data validation team will continuously explore ways to obtain or collect reference data in rural and low traffic volume locations.

Data Collection

The analysis will include the collection of two data types for use in the passenger probe analysis and two data types for use in the truck probe analysis.

For the passenger probe analysis, the analysis will include Bluetooth data collected from the proposed locations. Since Bluetooth data collection is not yet common, collection locations may have to be selected based on Bluetooth data availability.

The second data source would be embedded loop/sensor detectors obtained from state departments of transportation.

For truck probe data analysis, weigh-in-motion (WIM) data and embedded loop/sensor detectors will be used. These data are readily available. Access to this data may require a formal partnership to ensure that consistent and reliable data transfers occur between the public agencies and the UMN.

Test Metrics

Two principal measures will be employed during the data validation process: Average Absolute Speed Error (AASE) and Standard Error of the Mean (SEM).

The data validation procedure includes collecting reference data and reducing it to the five minute time period and roadway segmentation. Examples of reference data include travel time data from Bluetooth enabled devices, license plates, electronic toll tags or point speeds from WIM and embedded loop and sensor detectors. A TMC path or a similar link will be used for the roadway segment for validation. Sample NPMRDS data sets will be selected to be compared to the reference data sets for the respective geographic location and time period.

4.2.1 Threshold Targets

The data quality threshold selected for Average Absolute Speed Error (AASE) is 10 MPH based on the limitation of reference data as described in section 2.2. AASE below 10 MPH are usually considered as meeting specifications and AASE below 5 MPH are considered exceptional quality. The data quality threshold selected for Standard Error of the Mean (SEM) is 5 MPH. SEM below 5 MPH is usually considered as meeting specifications.

4.2.2 Average Absolute Speed Error (AASE)

The AASE is defined as the mean absolute value of the difference between the mean speed computed from the HERE travel time data and the reference mean speed for each epoch (5-minute) time period. The validation team uses AASE as the primary accuracy metric.

The speed data from the probe vehicles shall have a maximum average absolute error of 10 miles per hour (MPH) in each of four speed ranges: 0-30 MPH, 30-45 MPH, 45-60 MPH, and ≥ 60 MPH. The AASE in the lower two speed bands have proven to be the critical specification (and most difficult) to attain.

For each speed bin, the AASE is calculated as follows.

$$ASE_i = |V\_probe_i - V\_benchmark_i| \quad \text{Eq. (1)}$$

$$AASE_p = {\sum_p ASE_i}/{N_p} \quad \text{Eq. (2)}$$

Where,

$AASE_p$ is the AASE in time period p,

i is the i[th] epoch (5-minute interval),

V_probe_i is the average probe vehicle speed in epoch i,

$V\_benchmark_i$ is the average reference vehicle speed in epoch i,

ASE_i is the absolute vehicle speed error in epoch i,

p is the AM/PM peak or morning off-peak time period,

$\sum_p ASE_i$ is the sum of absolute vehicle speed errors in time period p, and

N_p is the number of epochs in time period p.

Numerical Example

Assume 11 reference travel speeds were collected as listed in Table 1 during 8 5-minute periods (epoch 73-80) along a 1-mile roadway segment.

Table 1 Reference Travel Speed

Epoch	73	74	75	76	77	78	79	80
Reference Travel Speed 1	56	65	49	69	58	67	53	63
Reference Travel Speed 2	67	59	70	65	59	70	66	62
Reference Travel Speed 3	58	66	65	65	55	59	60	57
Reference Travel Speed 4	62	70	58	61	61	56	63	61
Reference Travel Speed 5	65	58	68	58	66	67	54	66
Reference Mean Travel Speed (MPH)	61.6	63.6	62	63.6	59.8	63.8	59.2	61.8

Input data:

- Site location
- Measurement period – peak/off-peak period
- Reference travel speed
- Probe vehicle travel time
- AASE threshold, 10 MPH

Procedure:

1. Select a site location
2. Select 5-min periods in a time period (morning peak period, evening peak period, or off-peak period)
3. Gather the reference data (use Table 1 as an example)
4. Gather the TMC segment distance (use 1.0 mile as an example)
5. Compute the mean of the reference data for each epoch
   Reference mean (μ) for epoch 73 = (56+67+58+62+65)/5 = 61.6 MPH
6. Continue step 5 for all other epochs.

7. Gather probe vehicle travel time in the same time period and at the same location. Compute the probe vehicle travel speed (divide TMC segment distance, 1 mile, by each travel time. Assume probe vehicle travel times in 7 epochs were processed and listed in Table 2 at the same TMC segment.
8. Compute the probe vehicle travel speed by taking TMC distance (1-mile) divided by travel time for each epoch. For example, for epoch 73, 1-mile x 3600 / 64 sec = 56.3 MPH
9. Use equation (1) to compute the absolute speed error. For example,
   Epoch 73, ASE_{73} = |56.3-61.6| = 5.3 MPH,
   Epoch 74, ASE_{74} = |58.1-63.6| = 5.5 MPH,
   Epoch 75, ASE_{75} = |53.7-62.0| = 8.3 MPH,
   Epoch 76, ASE_{76} = |60-63.6| = 3.6 MPH,
   Epoch 77, ASE_{77} = |59-59.8| = 0.8 MPH,
   Epoch 78, ASE_{78} = |65.5-63.8| = 1.7 MPH,
   Epoch 79, ASE_{79} = |52.2-59.2| = 7.0 MPH,
   Epoch 80, ASE_{80} = |50-61.8| = 11.8 MPH

   Compute AASE using equation (2), (5.3+5.5+8.3+3.6+0.8+1.7+7.0+11.8)/8 = 5.5 MPH
10. Repeat steps 2 to 9 for other periods

Table 2 Probe Vehicle Travel Time Data

Epoch	73	74	75	76	77	78	79	80
Probe Mean Travel Time (sec)	64	62	67	60	61	55	69	72
Probe Mean Travel Speed (MPH)	56.3	58.1	53.7	60.0	59.0	65.5	52.2	50.0

Output:

- Absolute speed error (ASE) for each epoch
- Average absolute speed error (AASE) in morning peak period, evening peak period, or off-peak period

4.2.3 Standard Error of the Mean (SEM)

The Standard Error of the Mean (SEM) is the standard deviation of the error in the average probe vehicle speed relative to the mean of reference speed. SEM is estimated by the probe vehicle speed standard deviation divided by the square root of the sample size.

$$SEM_i = {SD_i}/{\sqrt{S_i}}$$

Eq. (3)

Where,

SEM_i is the SEM in epoch i,

SD_i is the speed standard deviation in epoch i, and

S_i is the number of samples in epoch i.

Numerical Example

Input data:

- Site location
- Measurement period – peak/off-peak period
- Probe vehicle travel time in an epoch

Procedure:

1. Select a site location
2. Select a 5-min period in a time period (morning peak period, evening peak period, or off-peak period)
3. Gather the probe vehicle data (use Table 3 as an example)
4. Compute the mean of the probe vehicle data
   Probe mean speed (μ) =

(62.1+53.7+62.1+60+65.5+52.2+50.7)/7 = 58

6. 5.Compute the standard deviation of probe speed data

$$SD = \sqrt{\frac{(62.1-58)^2+(53.7-58)^2(62.1-58)^2(60-58)^2(65.5-58)^2(52.2-58)^2(50.7-58)^2}{7-1}} = 5.75$$

6. Compute SEM using equation (3)
   SEM=5.75/$\sqrt{7}$=2.17
7. Repeat steps 2 to 6 for all 5-minute intervals in a morning peak period, evening peak period, and off-peak period

Table 3 Probe Vehicle Travel Time Data

Probe Data Index	1	2	3	4	5	6	7
Probe Travel Time (sec)	58	67	58	60	55	69	71
Probe Mean Travel Speed (MPH)	62.1	53.7	62.1	60.0	65.5	52.2	50.7

Output:

- SEM in 5-minute interval
- Average SEM in morning peak period, evening peak period, or off-peak period

4.2.4 Data Calibration

Calibration is a process of determining the relationship between the processed data and the reference values in morning peak period, evening peak period, and off-peak period. The purpose of a calibration procedure is to determine and document the measurement relationships of the processed data being calibrated.

A statistical test of two population means (e.g., t-test) can be simply performed to check if the means of two dataset in the same 5-minute interval are significantly different. When the processed results from the probe vehicle data deviate significantly away from the reference data, further examination and investigation will be conducted. Potential causes of significant data deviation may include:

- Small data set – For example, the number of data points in a 5-minute period may be relatively small. Further data validation may be performed by extending the time period or combining the same 5-minute period of data from multiple days depending on reference data availability. The number of reference data will be selected based on the standard deviation, marginal error of the reference data at a confidence interval (for example, 95%).
- Power analysis - Power refers to the probability that your test will find a statistically significant difference when such a difference actually exists [3]. In general, the power of a statistical test increases as the sample size increases. It is generally accepted that power should be .8 or greater [1]. Power analysis calculations will be performed based on data sample size using available software programs such as described in *Statistical power analysis for the behavioral sciences* and *Getting the Sample Size Right: A Brief Introduction to Power Analysis* [2&3]. The ability to reject a null hypothesis is depending on [4]:
  - Sample size: A larger sample size leads to more accurate parameter estimates.
  - Alpha (α): Usually 0.05. This is the probability of a type I error, that is the probability of rejecting the null hypothesis given that that the null hypothesis is true.
  - Effect Size: The size of the effect in the population. The bigger it is, the easier it will be to find. When a difference is statistically significant, it does not necessarily mean that it is big, important, or helpful in decision-making. It simply means you can be confident that there is a difference. Common practice is to use a value of 0.5 as it indicates a moderate to large difference.

  A power analysis program will be used to determine power given the values of alpha, sample size and effect size. If the power is insufficient, steps can be taken to increase the power, for example, by increasing the sample size.
- Roadway segment geometry – A curved roadway segment, urban canyon, or a tunnel may significantly affect the GPS data accuracy.

- Corrupted reference data – Depending on data type and source, the reference values may be corrupted due to sensor/loop failure or calibration issues. Reference data in the neighboring time period, on a different day or adjacent roadway section will be investigated and analyzed.
- Error from processed probe vehicle data – Further examination of the raw data during the same time period or on a different day could be conducted to ensure the raw data are processed correctly.
- Inclusion of outliers – this data set does not filter outliers. If an accident occurred that blocked several lanes on a particular day, the travel times for the affected time periods are included in the data set even though they may deviate from normal travel conditions.

A calibration process may be needed when causes of the significant deviations are identified. Depending on the causes of data disparity between processed and reference data, a local or global setting will be determined prior to applying calibration factors to the processed data. Common adjusting factors may include scale, offset or a combination of both. Adjustment factors applied to the processed data will be noted in the calibrated data and documented in the quarterly report. If the deviation occurs due to an identifiable and explainable cause (such as an accident or lane closures), calibration may not be required.

Quality data results are used as part of HERE's Continuous Quality Improvement program. Results are reviewed with operational teams on a regular basis. When major issues are identified, root cause evaluation initiates change control, where appropriate. Development and Research teams also work with the Quality team and utilize test results to ensure continuous improvement in processes.

It is important to note that not all data that appears outside of expected norms will be eliminated as this data often reflects actual conditions. The results of the root cause analyses will deem if action is required.

If any issues are discovered there are typically three courses of action based on root cause analysis. The first course of action is data may be eliminated if it does not meet quality criteria. This may be implemented in the beginning of the process of screening probe sources through creation of travel time data. Second, process adjustments may be implemented to re-calibrate the process and then affected processes may be re-run. Third, HERE may work with source providers to correct issues and may eliminate providers that are not able to meet standards.

References:

[1] Lenth, R. V. (2001), "Some Practical Guidelines for Effective Sample Size Determination," The American Statistician, 55, 187-193.

[2] Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). New Jersey: Lawrence Erlbaum.

[3] Jeremy Miles, "Getting the Sample Size Right: A Brief Introduction to Power Analysis", http://www.jeremymiles.co.uk/misc/power/, accessed September 2013.

[4] Russell V. Lenth , Java applets for power and sample size, http://homepage.stat.uiowa.edu/~rlenth/Power/index.html, accessed September 2013.

APPENDX B:
FDOT MOBILITY PERFORMANCE MEASURES

Table B.1 FDOT Mobility Performance Measures Matrix

	Mode	Quantity	Quality	Accessibility	Utilization
People	Highway	Vehicle miles traveled	Average travel speed		Vehicles per lane mile
		Person miles traveled	Hours of Delay (Person & Vehicle)		% miles severely congested
			Travel time reliability and variability		% travel severely congested
			% travel meeting LOS criteria		Hours severely congested
			% miles meeting LOS criteria		
	Aviation	Passengers	Departure reliability		
	Rail	Passengers			
	Seaport	Passengers			
	Transit	Passenger trips	Average headway		
		Passenger miles traveled			
	Pedestrian			% Sidewalk coverage	
	Bicycle			% Bike lane/shoulder coverage	
Freight	Highway	Combination truck miles traveled	Combination truck average travel speed		Vehicles per lane mile
		Truck miles traveled	Combination truck hours of delay		% miles severely congested
			Travel time reliability and variability		
	Aviation	Tonnage			
	Rail	Tonnage			
	Seaport	Tonnage			
		Truck equivalent units			

Source: FDOT Transportation Statistics Office

Endnotes

[i] In 2013, the Office of Freight Management and Operations (HOFM), on behalf of both HOFM and Office of Transportation Management (HOTM), contracted with HERE North America, LLC (formerly known as Nokia/NAVTEQ) to acquire the National Performance Measure Research Data Set (NPMRDS) vehicle probe data.

[ii] The Performance Measures report is intended to address the requirements of the Moving Ahead for Progress in the 21st Century Act (MAP 21), which requires each state DOT to select and periodically report on a set of performance measures which describes the state transportation system. These performance measures are by no means the only criteria a state uses to develop and maintain its system – rather a manageable set of measures that can meet the needs for transparency and public information.

[iii] Andre J. Meese and Wenjing Pu. Applying Emerging Private-Sector Probe-Based Speed Data in the National Capital Region's Planning Processes. Transportation Research Record: Journal of the Transportation Research Board, No. 2243, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp 17-26.

[iv] http://acogblog.org/2014/04/21/travel-time-data-transportation-analysis/

[v] AASHTO SCOPM Task Force Findings on National-Level Performance Measures, 2012.