Appendix I

FINAL TECHNICAL REPORT:
CONGESTION MONITORING TOOL FOR FRESNO COG

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INTRODUCTION

Fresno COG first developed its Congestion Management Program (CMP) based on legislative requirements. The CMP network included Regionally Significant Roads that "maintain and improve access between cities, accommodate a high level-of-service access to and within the Fresno-Clovis Metro Area, and to link regionally significant commercial, education, industrial and recreational facilities." Similar to other counties at the time, the 2009 CMP was presented in an extensive electronic (PDF) report and published on the Fresno COG website for review by the communities.

In 2015, an update was initiated to the federally mandated CMP for Fresno County. Through a collaborative process with the local and federal agencies, Fresno COG led the following tasks to:

- **Redefine the CMP network:** The new CMP network consists of major freeways in the metropolitan areas in Fresno County, which are all part of the National Highway System (NHS). The new network allows for congestion monitoring where traffic congestion tends to be highest in the County.
- **Identify congestion performance measures:** using travel time and speed-based methods.
- **Gain agreement to use Big Data sources for the congestion analysis**.

This project builds upon the outcomes of the 2015 efforts and implements a Congestion Monitoring Tool. At a high level, the congestion monitoring tool has two main components:

1. Real Time Data on the CMP Network;
2. Historical data from the National Performance Management Research Data Set (NPMRDS) on the National Highway System (NHS).

This report records the goals of the congestion monitoring tool, a description of its features and assumptions made.

OBJECTIVES

The goal of the congestion monitoring tool is to provide a web-based portal that allows Fresno COG (and member agencies) to monitor the performance of the:

1. CMP network; and
2. NHS network.

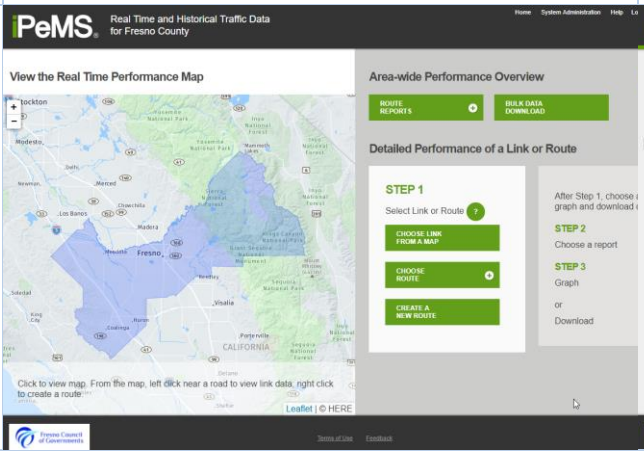
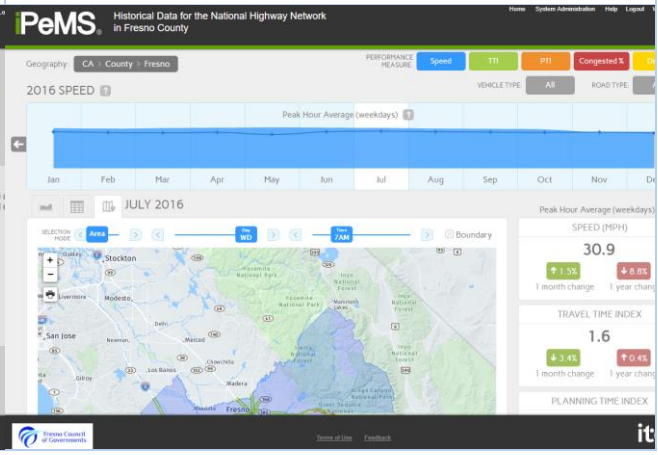
OVERVIEW OF THE FUNCTIONALITY

Fresno COG has indicated that the Congestion Monitoring Tool should do the following:

- Provide real time traffic performance information for the identified CMP network.
- Develop traffic performance analysis for the National Highway System (NHS) network and each of Traffic Message Channel (TMC) segment.
- Perform system-wide analysis for NHS network using travel time index, planning time index and delay developed by the CMP Steering Committee.

The tool is broken into two sections. The first section provides access to real time speed data on the CMP network. The second section provides access to historical NPMRDS data on the National Highway Network. A high level summary is provided in Table 1.

Table 1: High Level Summary

	Section 1: Real time data on the CMP network (TrafficML®*)	Section 2: Historical data on the NHS network (NPMRDS)
Description of Tasks:	Real time monitoring on the CMP network	Historical monitoring on the NHS network, both on a TMC basis and an area-wide basis.
Description of Data:	TrafficML® Data provided by HERE	NPMRDS Data provided by FHWA
Procured by:	Iteris on behalf of Fresno COG	Federal Highway Administration (FHWA) and provided free of charge to state departments of transportation and metropolitan planning organizations.
Applicable road segments	Fresno COG CMP Network	NHS in Fresno County
Real Time or Historical	Real time data which is stored so that users can look back at this data over time.	Historical data provided monthly and uploaded
Ingested into iPeMS by:	Connecting to a real time feed.	Provided through the FHWA Vendor Download Center on a monthly basis.
Screenshot		

* TrafficML is a registered trademark of HERE, North America LLC. HERE offers real-time speed and travel time data via their TrafficML® data feed.

BACKGROUND

SUMMARY OF RELEVANT LEGISLATION

Federal CMP legislation is applicable to this CMP effort and federal requirements are codified in the Code of Federal Regulations (CFR) Section 450.320. This section summarizes relevant parts from this document:

- The congestion management process shall include the methods of monitoring the Fresno CMP network, identify the causes of recurring and non-recurring congestion and measure the extent of congestion.
- The performance measures shall be tailored to the specific needs of the affected MPO.

THE MONITORING NETWORK

As part of this project, performance monitoring is conducted on two distinct networks of roads including:

1. The CMP Network
2. The NHS Network

Further details about each network are provided below.

Fresno CMP Network

In 2015, Fresno COG, in conjunction with the CMP Steering Committee, redefined the CMP network. It now consists of four freeway including SR 99, SR 41, SR 168 and SR 180. Refer to Table 2 and Figure 1. This network applies to the monitoring in Section 1 of the Congestion Monitoring Tool.

Table 2: Fresno CMP Network

Route	From	To	Length (miles)
SR 99	Madera/Fresno County Line	Jensen Avenue Interchange	13
SR 41	SR 99 Interchange	Madera/Fresno County Line	11
SR 168	SR 168/SR 180 Interchange	Herndon Avenue Interchange	7
SR 180	SR 99/SR 180 Interchange	SR 168/SR 180 Interchange	4
Total			35

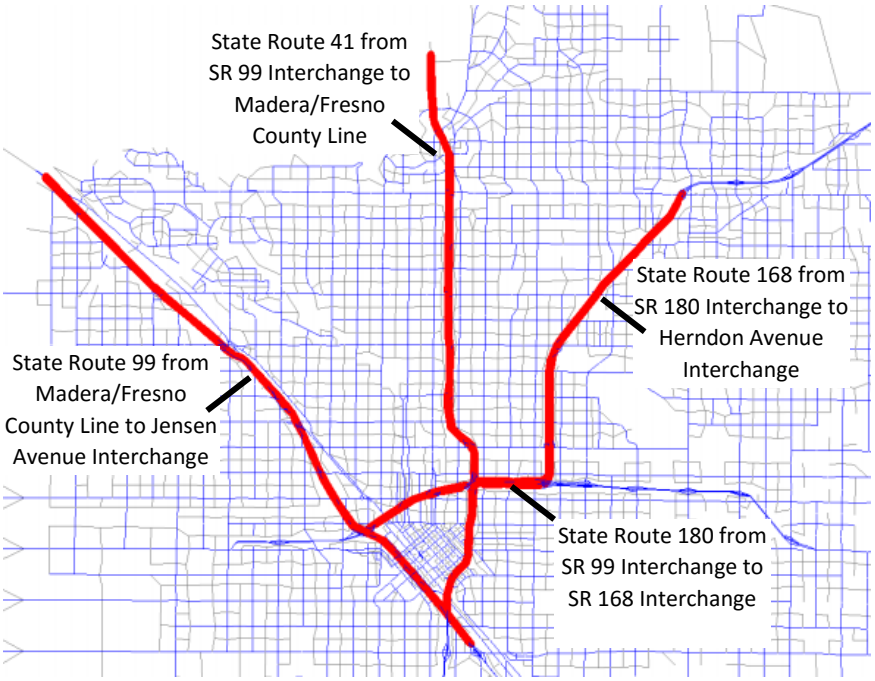


Figure 1: Fresno COG CMP Network

National Highway System (NHS) in Fresno County

FHWA has defined a network of roads that have national significance and provide the backbone transportation network for the country. Nationwide it consists of 160,000 miles, which is equivalent to approximately four percent of the nation's roads; yet it carries 40 percent of all highway traffic, 75 percent of heavy truck traffic and 90 percent of tourist traffic[1]. This network of roads applies to the monitoring in Section 2 of the Congestion Monitoring Tool.

The NHS is comprised of the following road networks:

- Interstates: The Eisenhower Interstate System of highways retains its separate identity within the NHS.
- Map-21 Principal Arterials: These are highways in rural and urban areas which provide access between an arterial and a major port, airport, public transportation facility, or other intermodal transportation facility.
- Strategic Highway Network (STRAHNET): This is a network of highways which are important to the United States' strategic defense policy and which provide defense access, continuity and emergency capabilities for defense purposes.
- Major Strategic Highway Network Connectors: These are highways which provide access between major military installations and highways which are part of the Strategic Highway Network.
- Intermodal Connectors: These highways provide access between major intermodal facilities and the other four subsystems making up the National Highway System.

For this project, additional monitoring is undertaken on the NHS within Fresno County. Refer to Figure 2.

[1] Slater (1996) The National Highway System: A Commitment to America's Future http://www.fhwa.dot.gov/publications/publicroads/96spring/p96sp2.cfm

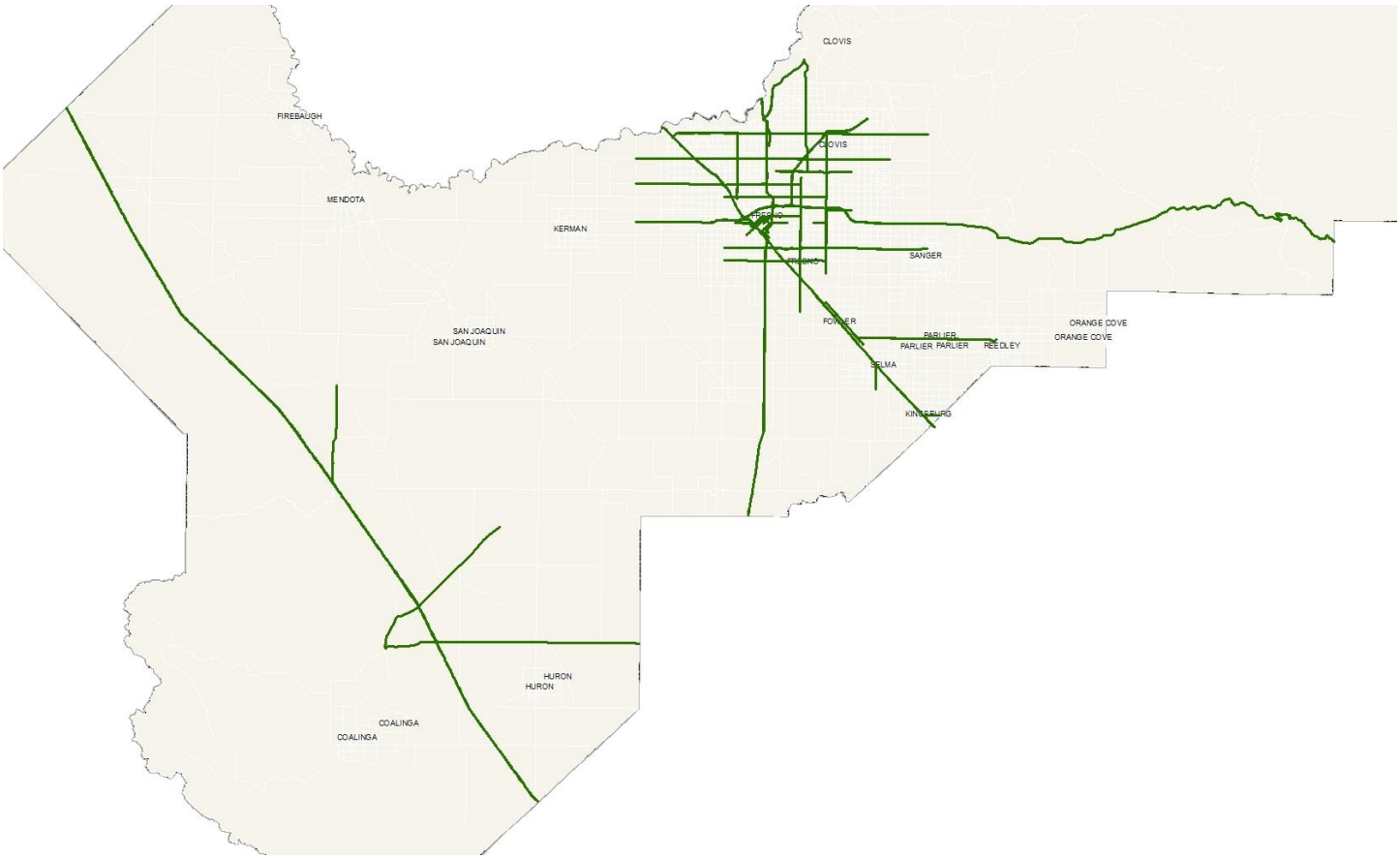


Figure 2: NHS in Fresno County

OTHER TERMINOLOGY

Third Party Data – Average speed and travel time data that is collected using vehicle probes that is provided by third party vendors like HERE, TomTom, or INRIX. Third party data may also be called probe data, commercial speed data or referred to by the vendor name i.e. HERE data, TomTom data or INRIX data.

NPMRDS – The National Performance Management Research Data Set (NPMRDS) is a third party dataset procured by the Federal Highway Administration (FHWA) and provided by HERE and INRIX.

Link – A small length of roadway reference to by third party data vendors when assigning traffic data.

- For HERE, this may also be called a Traffic Message Channel (TMC)
- For INRIX, this may also be called an XD segment or TMC

Route - A user defined directional path between two points containing one or more links.

Real time data – Data collected and/or presented as it occurs in the (or close to) actual time.

Historical data – Archived data of past conditions.

Report – This term is used in iPeMS to talk about graphs, maps or tabulated exports of performance data.

For descriptions of the performance measures used, refer to the Performance Measures section.

DATASETS

The project uses third party probe data from two sources:

- HERE TrafficML® Data – Sourced from HERE, this real time data is used on this project to provide performance monitoring on the CMP Network. Iteris procures this data directly from HERE.
- NPMRDS Data – The NPMRDS dataset is also sourced by HERE and provided to the project by Federal Highway Administration (FHWA). This historical dataset provides performance monitoring on the National Highway System (NHS).

This section describes the datasets in more detail.

HERE TRAFFICML DATA

HERE offers real-time speed and travel time data via their TrafficML® data feed. The system connects to the TrafficML® data feed to download the updated traffic information on each TMC for each minute. This data is then stored in the cloud. This data is used in Section 1 of the Congestion Monitoring Tool.

Under this arrangement, the data obtained includes the average speed and travel time of all sampled vehicles for a link of roadway for the given time period. It is not the average speed of each individual vehicle passing over the roadway; and transportation professionals should bear this in mind while using the data.

While there are no absolute conventions, typically:

- Freeways begin and end at interchange ramps. This means that there is generally a link on the freeway within the interchange and another link between interchanges;
- Arterials begin and end at major intersections;
- Rural roads begin and end at major cross roads; and
- Interchange ramps begin and end at the endpoints of each ramp. Where there are major merges and diverges within a ramp, i.e. commonly encountered on system interchanges, new links may start at these points as well.

It is noted that HERE links do not cover all roadways particularly as the roadways get smaller and less traveled. Where link codes do not exist, data from commercial speed providers is missing.

For Fresno COG's iPeMS instance, data is provided on four freeways as discussed in the Section titled Fresno CMP Network on page 3.

Important Points from the HERE TrafficML Data Sharing License Agreement

On behalf of Fresno COG, Iteris accesses the HERE data to use in the iPeMS tool. Refer to the Hosted Service Agreement in the contract. Access to this portion of the tool is provided to:

- Fresno COG employees;
- Fresno COG member agencies as designated by Fresno COG.

NPMRDS DATA

NPMRDS is produced for the Federal Highway Administration (FHWA) as a source for assessing mobility performance measures. FHWA makes the dataset available to State Departments of Transportation and Metropolitan Planning Organizations (MPOs) on a monthly basis to use for performance management activities. Data is also aggregated at a TMC level; similar to the TrafficML® data.

NPMRDS is an unmolded data set that only contains data if there was an actual observation, resulting in the prevalence of gaps. The system translates the raw NPMRDS into information that can be used for meaningful traffic performance analysis for Fresno County. Since the NPMRDS contains separate data for passenger cars and truck traffic, the Congestion Monitoring Tool evaluates these metrics for all traffic, passenger cars only, and truck traffic only.

This data is used in Section 2 of the Congestion Monitoring Tool.

Important Points from the NPMRDS Data Sharing License Agreement

The NPMRDS data agreement between FHWA and HERE® expired in February 2017 and the new contract between FHWA and INRIX® started in July 2017. FHWA is currently rolling out access to the new dataset and as of writing this report we do not yet have access to it. Our expectation is that that FHWA will continue to provide a comparable dataset available for performance monitoring purposes.

The data license agreement contains text specifying the permitted users of the dataset and the purposes in which they may use it. The following text is extracted from the NPMRDS Data Sharing License Agreement:

> *"Agency warrants that it is a State Department of Transportation or Metropolitan Planning Organization receiving federal transportation funds and is authorized by the US Federal Highway Administration to receive Data."*
>
> *"AGENCY may use Data:*
>
> - *to support performance management activities such as creating performance indicators, measures and evaluations;*
> - *to disseminate summaries of the Data to the public consistent with the organizations' transportation planning, programming, management and operations responsibilities as they pertain to performance management activities;*
> - *in transportation planning and operational analyses, service and data quality validation analyses; and*
> - *in applications for Agency's internal business.*
> - *to provide a copy of a spreadsheet of the data used in developing a plan or capital program based in part or on performance measurement if requested for validation of decisional materials.*
>
> *AGENCY may not use Data to make data sets or aggregated average travel time databases publicly available. For avoidance of doubt, the intent of this license is to enable AGENCY to provide summaries and statistics based on the Data but not to provide the Data in a form that would enable unlicensed parties to build databases of the Data."*
>
> *"Contractors. Agency may grant contractors the right to use Data for work performed for Agency under the Purpose defined in this Agreement."*
>
> NPMRDS Data Sharing License Agreement

In response to these requirements, the Congestion Monitoring Tool must be adapted to ensure that any raw NPMRDS data or aggregated NPMRDS travel time data is only available to:

- Staff at State Departments of Transportation i.e. Caltrans and Metropolitan Planning Organizations i.e. Fresno COG; and

- Contractors when they are carrying out work on behalf of an agency. Fresno COG shall grant Iteris the right to use the NPMRDS data for work under the purpose to support performance management activities. Iteris will hold in confidence and not disclose any confidential information of Fresno COG.

Summaries and statistics are provided to all users.

PERFORMANCE MEASURES

The congestion monitoring tool calculates a number of different performance measures on the data provided for both the CMP network and the NHS network. The resulting output can be used to meet the requirements of the CMP legislation and to support Fresno COG planning efforts. This section documents each performance metric and the calculation methods.

Figure 3 defines the performance metrics used in the monitoring tool. Table 3 presents information on which part of the dashboard implements a given performance measure. It also provides information on which road segments a particular performance measure is applicable to. For example, average speed is calculated on both a TMC basis and an area-wide basis under the NPMRDS section of the tool.

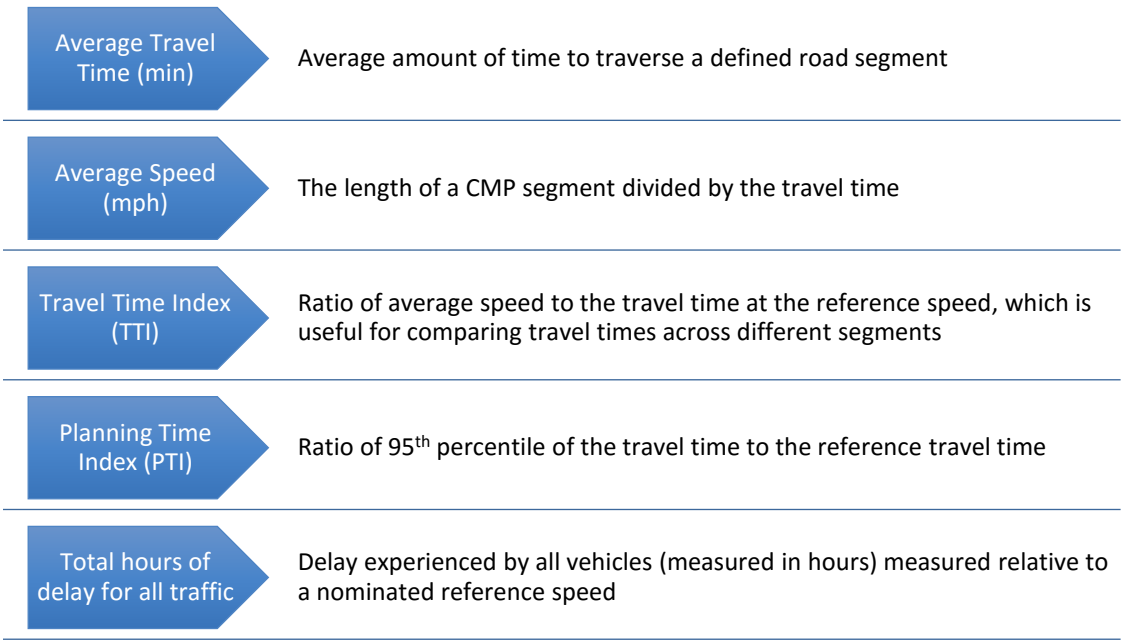


Figure 3: Summary of Performance Measures

Table 3: Performance Measures and their applicability to each section of the Congestion Monitoring Tool

Performance Measure	Section 1: Real time TrafficML data on the CMP network		Section 2: Historical NPMRDS data on the NHS network	
	Spatial Unit	Vehicles	Spatial Unit	Vehicles
Travel Time	TMC or User Defined Route	Auto	-	-
Average Speed	TMC or User Defined Route	Auto	TMC † Area-wide	Auto, Freight, Both
Travel Time Index	TMC or User Defined Route	Auto	TMC † Area-wide	Auto, Freight, Both
Planning Time Index	TMC or User Defined Route	Auto	TMC † Area-wide	Auto, Freight, Both
Total Hours of Delay for all Traffic *	-	-	Area-wide	Auto, Freight, Both

* Incorporates volumes from Fresno COG, Caltrans PeMS and from other local traffic counts
† Access provided to those permitted under NPMRDS license agreement

The following sections provide additional details on each of the performance measures.

TRAVEL TIME (MINS)

Commercial speed data provides the average speed and travel time on lengths of road called links or Traffic Message Channel (TMC) links.

In Section 1 of the Congestion Monitoring Tool, individual links will be grouped together in order to report the travel time on user defined routes. In order to aggregate the travel time information, links in the correct direction are identified and the corresponding travel times are summed together. The travel time will also be available for any individual link.

Other performance measures are calculated from the travel time.

AVERAGE SPEED (MPH)

The average speed is a performance measure commonly used in congestion analyses. It is easy for the community to understand as they can equate it to their own driving experience.

The following equation is used to calculate the average speed based on the travel time and length.

$$Link\ Speed\ (mph) = \frac{Link\ Length\ (mi) \times 60}{Travel\ Time\ (min)}$$

TRAVEL TIME INDEX (TTI)

The travel time index is the ratio of the actual travel time (typically during a peak period) to a free-flow travel time. For example, if it takes 3 minutes to traverse a segment in peak hour and the free-flow travel time is 2 minutes, then the travel time index is 1.5. This metric allows for a comparison of travel time performance across many segments; it assesses the severity of congestion levels.

In the Congestion Monitoring Tool, the TTI is available on the same spatial segments and for the same vehicles as for the speed performance measure; except that for Section 2 of the Congestion Monitoring Tool, the TTI is also available to calculate area-wide performance measures on the NHS network.

PLANNING TIME INDEX (PTI)

The planning time index is the ratio of the 95th percentile travel time as compared to the free-flow travel time. This index is a measure of travel reliability. This measure represents how much total time a traveler should allow beyond the free-flow travel time to ensure on-time arrival in 95% of trips.

The PTI is presented similarly to the TTI for both sections of the dashboard.

TOTAL HOURS OF DELAY FOR ALL TRAFFIC

The total hours of delay for all traffic, is a measure of delay experienced by all vehicles relative to a nominated reference travel time. For this project, it will be calculated as an area-wide performance metric across the NHS network in Section 2 of the Congestion Monitoring Tool. It is calculated using the following information:

- Actual travel time experience for a specified time period;
- Reference travel time; and
- Volume of vehicles traversing over the segment.

Firstly, the excessive delay is calculated by subtracting the reference travel time from the actual travel time. Where a positive number remains, excessive delay is indicated. Next, the excessive delay is multiplied by the volume of vehicles on the segment to estimate the total delay experienced by all vehicles.

The reference travel time be calculated using a speed of:

- 35 mph for Interstates, freeways, or expressways
- 15 mph for principal arterials and all other NHS roads

Since NPMRDS does not provide volume information, the total hours of delay is calculated using average hourly traffic volumes for each day of the week using data provided by Fresno COG. They provided several spreadsheets containing hourly volumes for several county locations throughout Fresno County. Hourly volume data from the City of Fresno, City of Clovis, Fresno County, and Caltrans were also used. It should also be noted that the Fresno COG Travel Model was used in determining the annual growth rate for Fresno County (2% per year), and this was also used in developing the hourly volumes.

TOOL FUNCTIONALITY

Development of the tool revolves around three main efforts, as follows:

- Hosting operations
- Development of Section 1 of the Congestion Monitoring Tool: Real Time TrafficML® Data on the CMP Network
- Development of Section 2 of the Congestion Monitoring Tool: Historical NPMRDS data on the NHS network

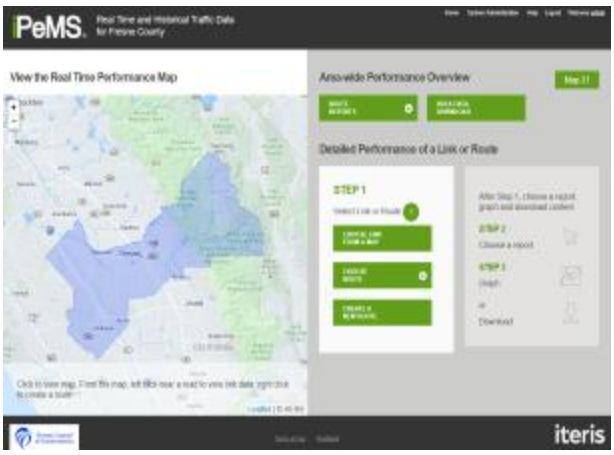
These efforts are described below as they relate to both Section 1 and 2 of the Congestion Monitoring Tool.

HOSTING OPERATIONS

The Congestion Monitoring Tool uses the established iPEMS architecture developed for the Fresno COG (http://fresnocog.iteris-pems.com) and provide customization as discussed below. HERE TrafficML® data and NPMRDS data is stored in the cloud on an Amazon Web Service. The hosting operations is similar for both Sections 1 and 2 of the Congestion Monitoring Tool.

SECTION 1: REAL TIME TRAFFICML DATA ON THE CMP NETWORK

The purpose of Section 1 of the Congestion Monitoring Tool is to display real time and detailed information on Fresno COG's CMP network. The goals of the tool are to:



- Display trends on the CMP Network on a real time basis to allow users to examine the severity and reliability of congestion levels.
- Allow for creating and searching for customized routes.
- Calculate the performance measures on a CMP route or individual link.
- Visualize performance on graphs and tables.
- To allow users to export extracts of data or visuals for further analysis in tools such as Microsoft Excel.
- View and export the performance of all Fresno COG CMP routes.

Real Time Map

Section 1 of the Fresno COG Congestion Monitoring Tool displays congestion information in a map format, allowing users to observe traffic conditions at a high level. As is widely used in the industry, traffic conditions are displayed using red/yellow/green lines correlating with the amount of congestion. In Figure 4, for any colored congestion line appearing on the map, the user is able to bring up a performance report comparing today's performance to the normal range. In addition to the speed layer, uses are able to view speed anomalies, data quality and the functional class (as designated by HERE).

HERE TrafficML® data for four freeways (SR 99, SR 41, SR 168, SR 180) in the CMP network is displayed on a map

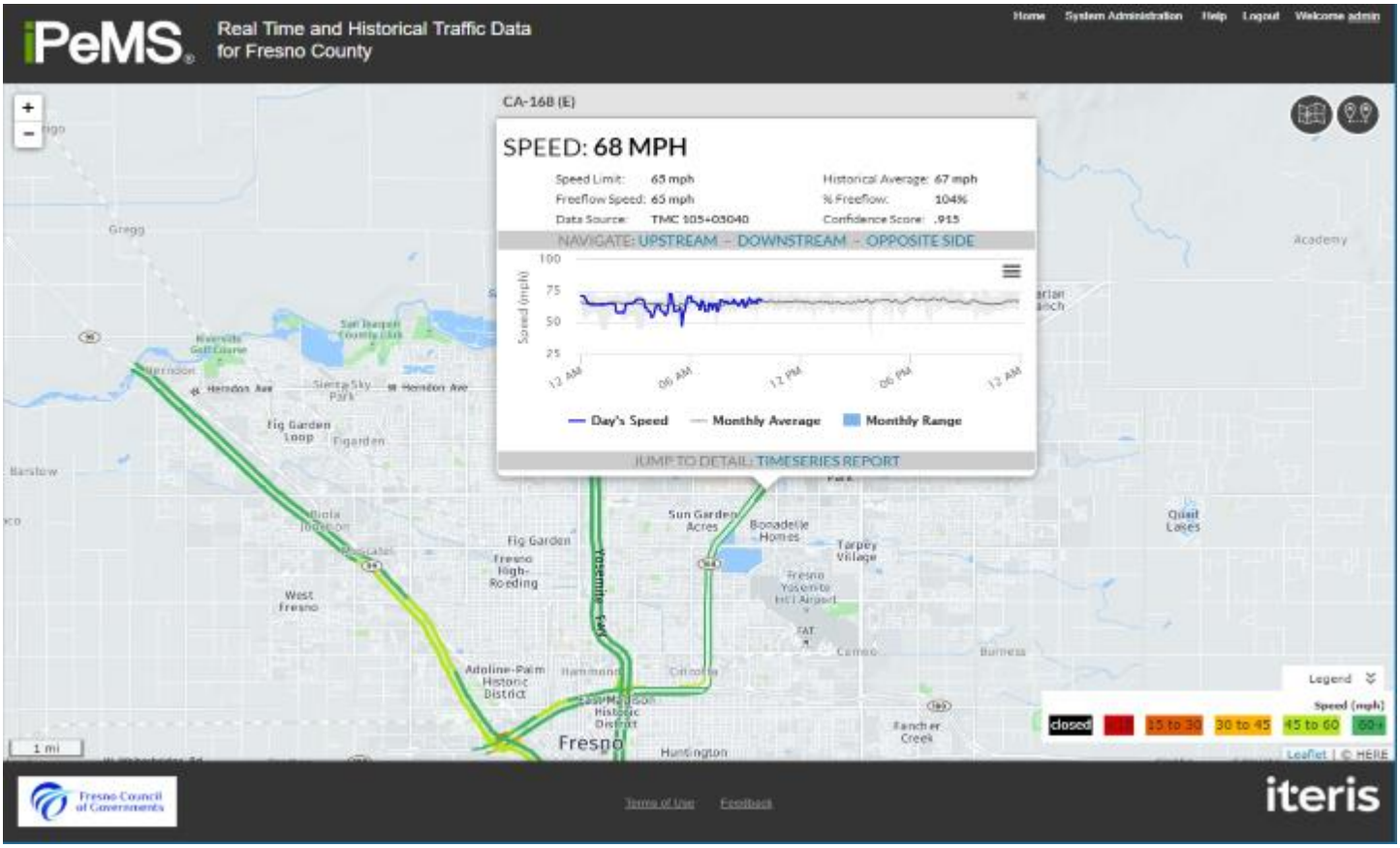


Figure 4: Example iPeMS Real-Time Congestion Map using HERE Data

Link Data

After finding a specific link from the real time map and clicking on the link to display the popup, the user is presented with an option to jump to the Timeseries report (Refer to Figure 4). At this point, users have the option to extract data using three reports, as follows:

- Timeseries: Shows variables over time.
- Time of Day: Shows averages of variables by the time of day; and
- Day of Week: Shows averages of variables by the day of week.

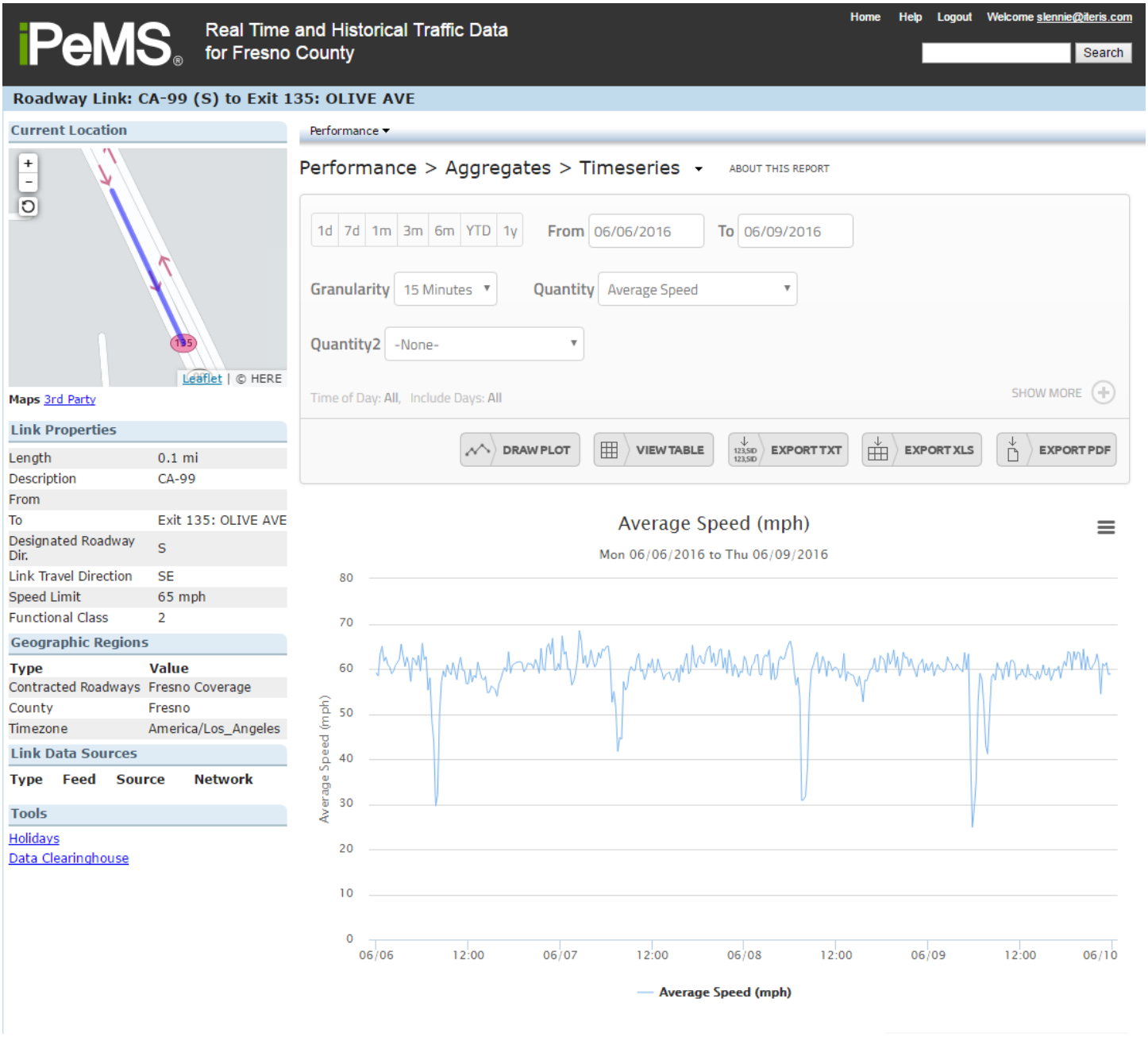


Figure 5: Example Timeseries Report

Route Data

A route is a user defined directional path between two points. Data is aggregated from multiple links by summing together the travel times. The tool provides functionality to search for existing routes, create new routes, obtain the performance of all routes in a single report and get detailed data for a specific route (Figure 6). An example route report is presented in Figure 7. The user are able to export these reports as an Excel compatible file and PDF file.

1. Searching for a Route

- Users are able to search for a Route using text searching.

2. Creating a Route

- Using a map, users are able to create a route by specifying the start and end locations of their route.

3. Area-wide Route Reports

- Users are able to extract the performance of all routes for a given time and date range. This report is useful for meeting legislative requirements. In addition, there is another report that can compare the performance from two different time periods.

4. Detailed Data

- In addition to the timeseries, time of day and day of week reports, users are able to review congestion visually in a contour or heat map.

Figure 6: Summary of Route Functionality

Figure 7: Example Daily Contour Plot showing average speeds along a route throughout the day

Analysis of CMP Segments

To meet CMP legislative requirements, it is recommended that the tool's route functionality should be utilized. The 'Create new route' function can be used to define each CMP segment on Fresno COG's CMP network. While the definition of the start / end points of each segment are completely at the discretion of Fresno COG and its stakeholders, it is recommended that new CMP segments be defined at:

- Major Interchanges on Freeways;
- Major changes in performance, such as at a bottleneck; and / or
- Major changes in land use on Arterials (not applicable for the current CMP effort, but a consideration if the CMP network is expanded in future monitoring cycles).

We recommend using a consistent description syntax to ensure that the routes are easily identifiable in later monitoring cycles. For example:

- CMP ID: ROAD NAME from START to END
- F3: CA-168 from E McKinley Ave to Shaw Ave.

Table 4: Syntax for defining CMP segments

CMP Text Description	Example	Comment
CMP ID	F3	It is recommended that each CMP segment be assigned an ID. Where multiples classes of road network are proposed, it is recommend that a letter be placed in front of the ID to designate the class of road eg F – Freeway, A – Arterial, R-Rural Highway. While Fresno COG's current CMP only contain one class of CMP segment, it is recommended that a letter be used in case future cycles expand the network to other classes of road. However, it is acceptable to use a simple ID numbering i.e. 1, 2, 3, 4 and so on.
Road Name	CA168	The road name and any potential cosigning alternatives or names.
Start	E McKinley Ave	The intersecting road at the beginning of the CMP segment or other placemark such as a County Line, culvert / bridge, major access point etc. It is recommended the consistent abbreviations be used for street suffixes eg St, Ave, Blvd, Rd.
End	Shaw Ave	Similar to the start point.

In addition to the description field, it is recommended that a tag 'Fresno COG CMP Network' be included. Refer to Figure 8.

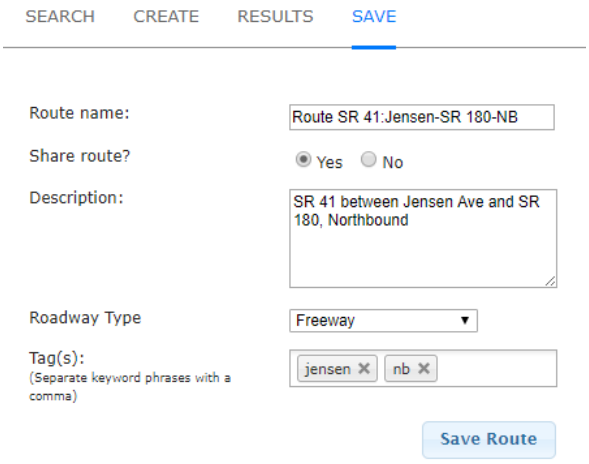


Figure 8: Text used to define the CMP network

Once the CMP routes are defined, the iPeMS system begins to aggregate the data from that point in time. It is for this reason, that we recommend defining the routes early in the monitoring project. Next, the area-wide reports can be used to extract the performance of all CMP segments for the nominated monitoring period(s) (Figure 9). The nominated monitoring should be defined with consultation from the CMP steering committee. It typically includes a 6-8 week period in the fall or spring when school is in session. It is also typical to define the monitoring peaks and we recommend 7-9 am and 4-6 pm. Other off-peak or weekend monitoring periods may be defined as well.

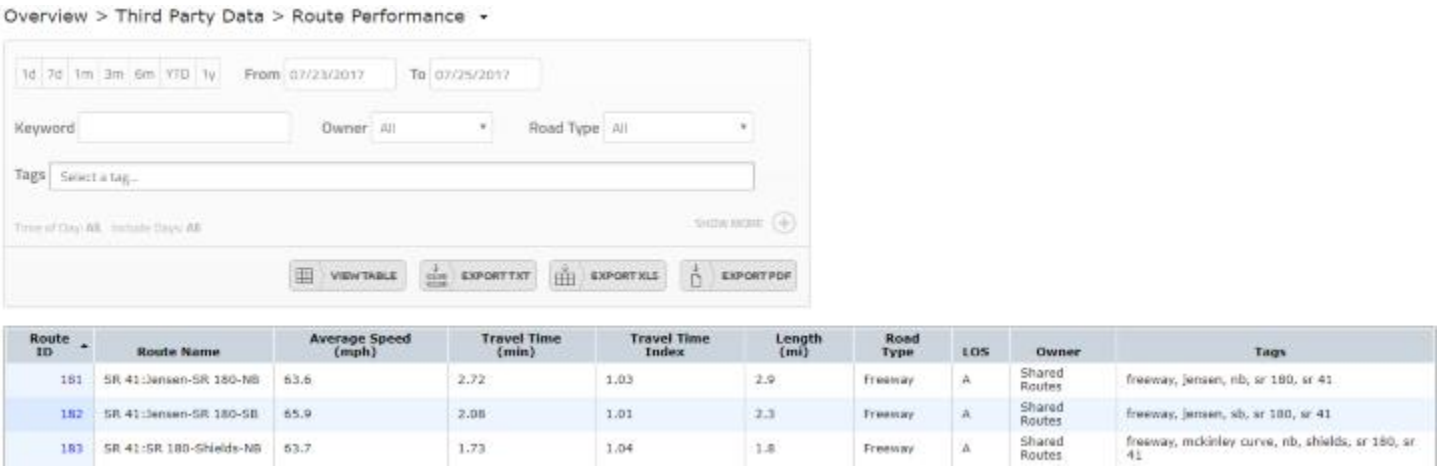
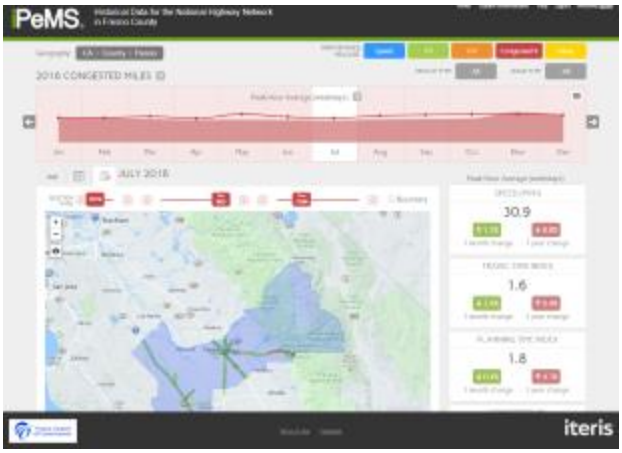


Figure 9: Route Performance Report can be used to Extract CMP Network Results

SECTION 2: HISTORICAL NPMRDS DATA ON THE NHS NETWORK



The purpose of Section 2 of the Congestion Monitoring Tool is to display ***aggregated*** performance measures using the NPMRDS dataset from FHWA. The NPMRDS dataset contains average speed data for links on the National Highway System (NHS) for cars, trucks and all vehicles. The goals of the dashboard are:

- Display trends on the National Highway Network on a monthly basis to allow users to examine the severity and reliability of congestion levels.
- Calculate the performance measures on an area-wide basis.
- Visualize performance across the network in map and graph / table based formats.
- To allow users to export extracts of data or visuals for further analysis.

At a high level, the tool connects to the NPMRDS feed and ingest the data on a monthly basis. Since the NPMRDS data contains only observed data points, when there is no observation, there will be a gap in the dataset. Therefore, algorithms are applied to backfill the data. Once the dataset is ready, the system allows users to filter the data in order to isolate the relevant data. The system then aggregates the data and output the results. This process is summarized in Figure 10.

Figure 10: High Level Process for Building the Dashboard's Capability

As shown in Figure 11 the dashboard is split into two sections. The first section includes the MAP-21 performance reporting and the second section includes more traditional measures that display high level trends of the data. For Fresno COG, the team delivers the second section which displays high levels trends in the data (including travel time, average speed, travel time index, planning time index and delay). This part of the dashboard is useful for planners who want a more traditional approach to aggregating the data and more conventional performance measures; rather than the specific, and somewhat unusual requirements by MAP-21. For the MAP-21 part of the dashboard, Iteris undertook its development once the rulemaking is finalized, and Iteris have made this part of the dashboard available to Fresno COG as well.

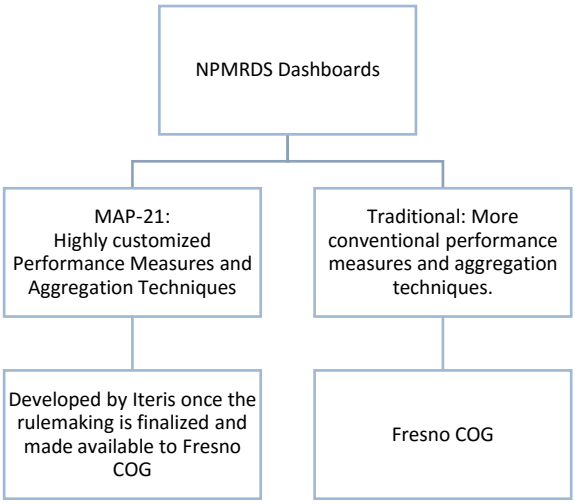


Figure 11: High level summary of Congestion Monitoring Tool Dashboards

The remaining sections in this document expand the effort needed to get the traditional dashboard implemented.

1. Ingesting the data

This task is to set up a process that collects NPMRDS data that is provided monthly from the NPMRDS login site hosted by HERE. Next, the team stores the data into a cloud hosted database.

There are a few considerations for this task, as follows:

- First, the NPMRDS data is provided monthly as a file that contains observed data points for each 5-minute period when data was collected. The system contains an automated process to load this file once per month.
- Second, Section 1 of the Congestion Monitoring Tool also currently processes data from real-time HERE data collected on the CMP network. Since the data overlaps for the two data sources, the design stores the NPMRDS and the aggregated HERE data separately. This means that the aggregation of the MAP-21 measures are based solely on the NPMRDS data.

At the end of this task, as is currently designed, the NPMRDS data is enabled into tables. A method is written to process the NPMRDS data monthly as it becomes available.

2. Backfilling the data

The NPMRDS only provides travel times on a link if there are actual observed probes during the 5-minute period. There are links where no data is provided for certain periods of the day. In order to produce meaningful performance measures from the NPMRDS, these gaps where no data is provided must be filled in through a data imputation process.

Using long standing practices from Caltrans PeMS, the gaps in the NPMRDS data are imputed using a series of imputation routines including temporal median, spatial link profiles, corridor profiles and corridor medians (Figure 11).

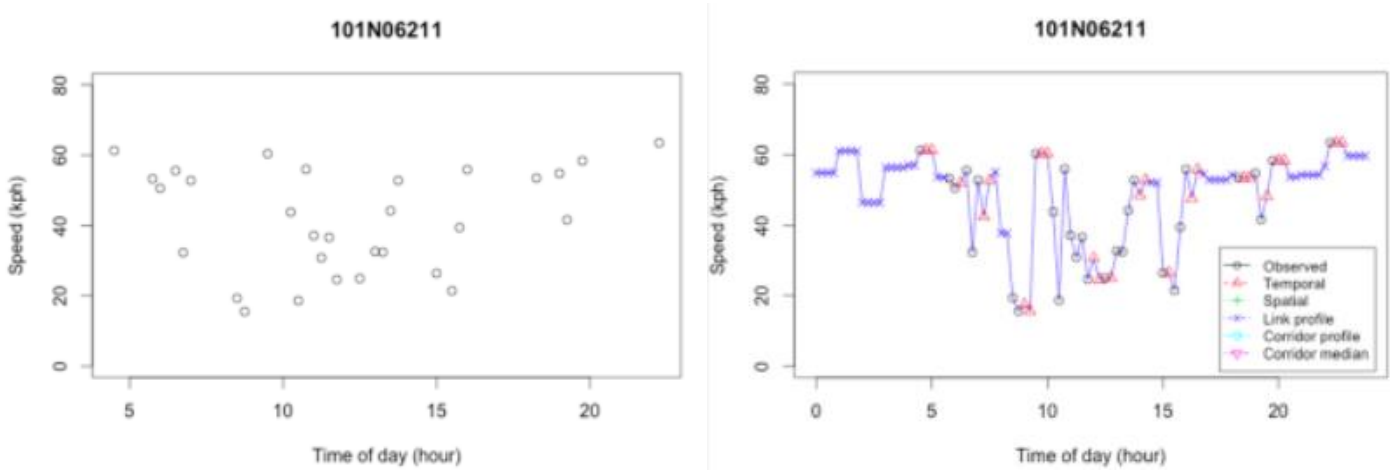


Figure 11: Imputation Processes a) Raw NPMRDS data before processing b) Processed data that fills in the data holes

3. Filtering the dataset

The NPMRDS dataset is a large dataset which provides data across a number of different dimensions, including:

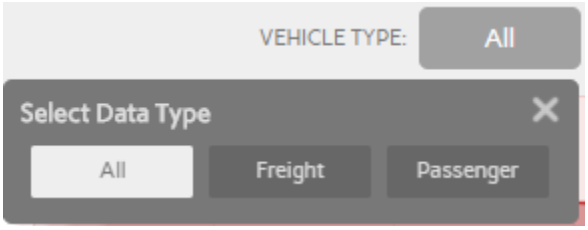
- Cars, trucks, all vehicles
- Varying times of the day
- Different days of the week
- Different performance measures including the average speed, travel time, levels of congestion, TTI, PTI and delay

- Interstate and non-interstate routes across many routes
- The ability to display the data in different formats

In order for the tool to accommodate all these dimensions, careful consideration is needed to layout the various choices to users. The dashboard provides access to data on these varying dimensions as follows:

Select Vehicle Type

At the upper level of the dashboards, users can update their analysis to include freight vehicles only, passenger vehicles only or all vehicles.



Select the Time of the Day / Day of the Week

In order to specify the time of day, users have an option to input the hour of the day in which they want to conduct the analysis for. Users have a further option to define the day of week to include.

Select the Performance Measure

As defined above, the user has the ability to select the performance measures including Average Speed, Travel Time Index, Planning Time Index, Congestion Percentage, and Delay.

Select Type of Road

The area-wide performance measures runs separately for interstate and non-interstate sections of the NHS network.

4. Aggregate

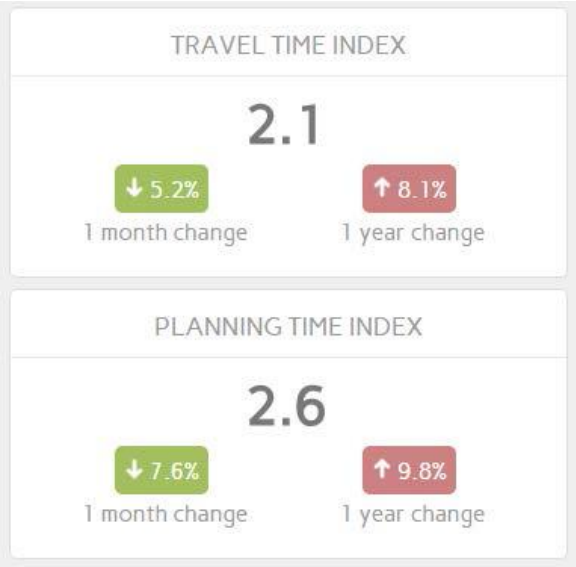
Using the backfilled NPMRDS data stored in the database and the inputs specified by the user, the system aggregates the data and calculate the performance measures. This is a backend process and the results are displayed as specified in the following section.

5a. Output Area-wide Results

The last task for the system is to display and export the results. Knowing that different audiences seek the results in different formats, the system provides options to report values, display the results on a map, display on a graph / table, and export the results in a variety of formats.

Report Dashboard Values

Using a display similar to the figure below, high-level values are displayed for each of the performance measures. It is noted however, that the results are displayed separately for interstate and non-interstate roadways.



Visualize on a Map

The map-based output is used for two purposes:

Firstly, colored lines are displayed that correspond to the performance of that particular road segment for the given filters. The colors can be cross referenced to a legend to understand the cut off points for each color. Separate cut-off points and legends are used for interstate routes and non-interstate routes as the flow characteristics are different on uninterrupted flow routes such as freeways compared to interrupted flow routes such as arterials. For example, if the user has selected the Travel Time Index performance measure, the cut off for the 'green' category may be <= 1.0 for interstate routes, but 1.2 for non-interstate routes. The exact thresholds for each of the categories have been reviewed during the development of the map and shown as legends on the dashboard.

Secondly, the map is made clickable so that users can select a single link and review traffic data associated with the link for the given filters. Refer to 5b. Select and Output Link Results below for more details.

Visualize on a Table / Graph

Alternatively to viewing on a map, the data may be viewed on a graph or displayed on a table. The data is displayed on an area-wide basis such that the performance is summarized over the entire selected region. Graphs and tables are displayed separately for interstate and non-interstate links.

Table 5: Day of Week Table showing the average performance for different days of the week.

Days of Week	This Month	Previous Month	Previous Year
SUNDAY	1.3	1.2	1.2
MONDAY	1.9	2.0	1.8
TUESDAY	2.3	2.2	2.0
WEDNESDAY	2.3	2.2	2.0
THURSDAY	2.3	2.1	2.2
FRIDAY	2.2	2.0	2.1
SATURDAY	1.4	1.4	1.3

Export Results

Once, filtered and aggregated, the results can be exported in a variety of formats including:

- Comma Separated File (.csv)
- Microsoft Excel Format (.xlsx)
- PDF
- Copied to a clipboard
- Printed

5b. Select and Output Link Results

Similar to Section 1 of the Congestion Monitoring Tool, users are able to select a link from the map. After clicking on the map, a pop-up appears that confirms the name, length, direction, and ID. A graph is displayed showing the historical performance of autos, freight and all vehicles for the given day. To investigate further and extract more data for the link, the user can click the report link. Users can then extract the average performance by the time of day, or day of week using an interface similar to the link reports in Section 1 of the Congestion Monitoring Tool.