U.S. Department of Transportation
Federal Highway Administration

Congestion and Bottleneck Identification (CBI) Software Tool User's Guide

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FOREWORD

This Guide contains use instructions for the Congestion and Bottleneck Identification (CBI) software tool. The CBI was developed as part of the Federal Highway Administration's (FHWA's) Traffic Bottlenecks Identification, Diagnosis, and Innovative Solutions to Local/Systemic Problems task order from 2014–2016. The purpose of this task order was to investigate new methods of bottleneck identification, and cost-effective strategies for bottleneck mitigation. The task order was focused on cost-effective strategies that were not dependent on advanced vehicle technology.

The CBI tool introduces novel analysis methods and performance metrics for comparing and ranking traffic bottlenecks. These methods involve processing millions of probe data records for the target years of analysis. Bottlenecks can then be ranked on the basis of annual delay intensity and travel time reliability. It is hoped that the new methods will be adopted by States and/or commercial products for a new level of robustness in congestion measurement. This Guide will be of interest to practitioners involved in the transportation operations discipline.

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16. Abstract
To justify investments towards improved traffic operations, engineers and policy-makers need accurate and scientific methods of congestion measurement. However, conventional methods are limited and/or outdated. Peak-hour analyses fail to account for changing conditions throughout the year. Reliability modeling in the Highway Capacity Manual (HCM), which attempts to capture these annual effects, has significant input data and calibration requirements. Data-driven intelligent transportation system (ITS) technologies, which identify congestion in real time, still have room for improvement in the robustness of performance measures derived from them. Finally, comparing and ranking congested locations (i.e., bottlenecks) on the basis of experience and judgment lacks credibility unless backed by quantitative results. This guide discusses project-specific software that produced new and innovative performance measures for congestion measurement. Case studies of rankings of eight real-world bottlenecks demonstrated the benefits of multivariate analysis backed by intuitive visualizations. It is hoped that the new methods will be adopted by States and/or commercial products for a new level of robustness in congestion measurement.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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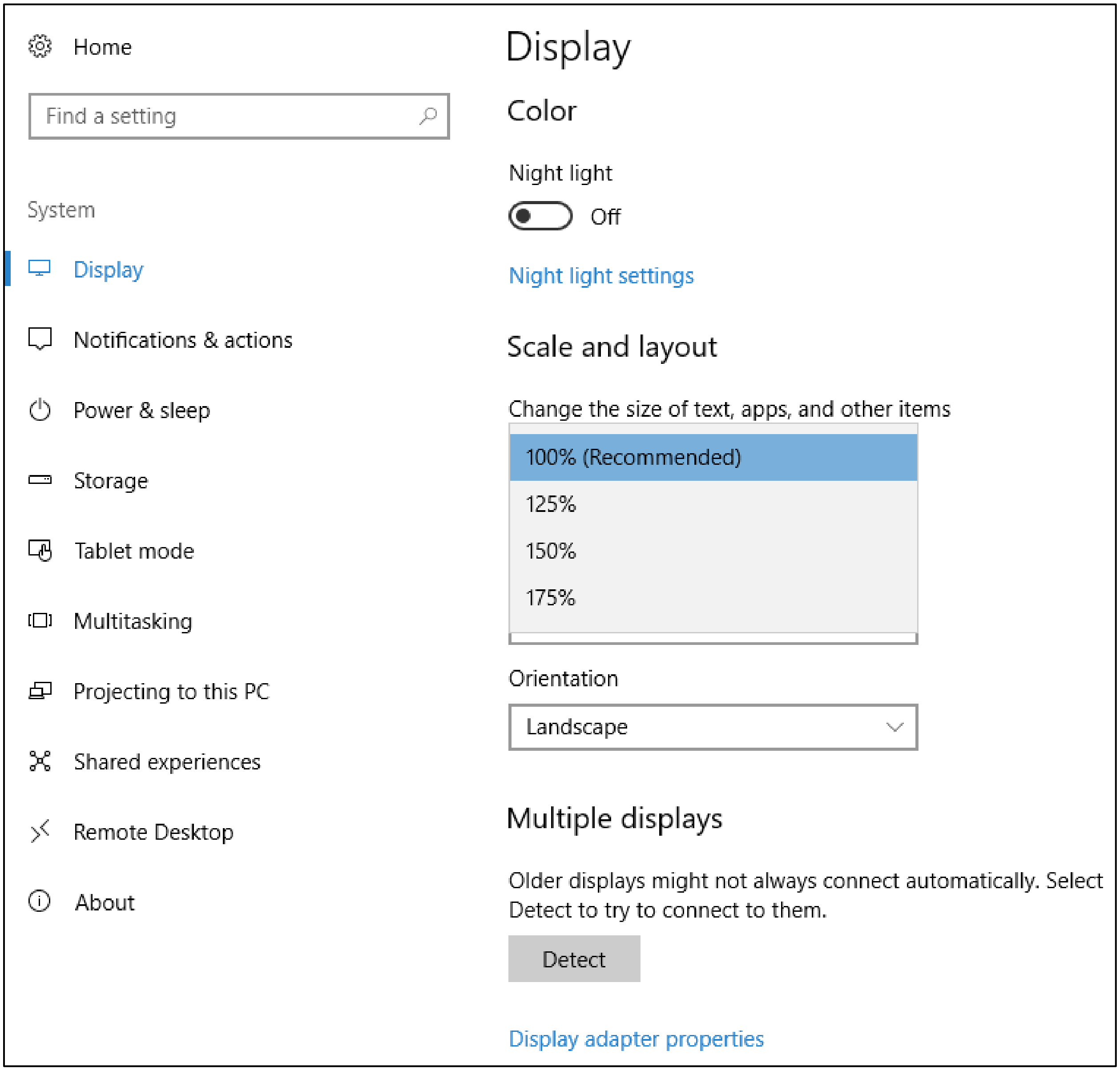
DISPLAY REQUIREMENTS

In order for the CBI tool to display properly, Windows display settings must be set according to figure 1. Screen magnification must be set to 100 percent, as shown below under “Scale and layout”.



Source: FHWA

FIGURE 1. Windows Display Settings.

INTRODUCTION

On both State and national levels, transportation must compete for funding against other social priorities. In order to justify monetary investments towards improved traffic operations, engineers and policymakers need access to accurate and scientific methods of congestion identification. Subsequently, these methods can help to quantify specific amounts of time and money that could be saved, or have recently been saved, by transportation improvements. However, status quo methods of congestion identification are either limited or outdated. Traditional traffic modelers have performed peak-hour analyses, oftentimes using the peak hour factor, to identify proper designs. Simple peak-hour analyses are becoming outdated as a sole source of congestion identification, because they fail to account for various changing conditions throughout the year. Consequently, there has been a movement towards reliability modeling, which attempts to capture these annual effects. But the reliability models have significant input data requirements, and in some cases, may have significant calibration requirements. Next, there have been recent improvements in data-driven intelligent transportation system (ITS) technologies that can identify congestion in real time. But industry tools based on these measurement technologies do not appear to provide much reliability analysis, and are typically limited to evaluating past performance. Finally, some engineers have compared and ranked traffic bottlenecks on the basis of experience and judgment. Despite their cost-effectiveness, qualitative assessments based on judgment will always lack credibility unless backed by quantitative, scientific results.

In a recent study directed by the Federal Highway Administration, congestion identification was one of the primary areas of emphasis. Some of the researchers developed innovations to account for visibility and weather effects on traffic congestion. Other researchers prepared models that filter out congestion caused by traffic signals, to better identify congestion caused by neighboring vehicles. This guide will discuss the results of a software development effort, during which new performance measures were also created. The software development effort involved a congestion and bottleneck identification (CBI) tool, containing both numeric and graphical performance measures. The CBI tool was designed to compare and rank traffic bottlenecks in greater detail than existing methods.

The first key feature is an annual reliability matrix (ARM), capable of displaying annual congestion levels at a glance. The ARM allows simultaneous visualization of both bottleneck delay intensity and delay variability. Another key feature is a new set of performance measures that convey the size and shape of the ARM within multivariate numeric metrics. These measures go beyond bottleneck rankings currently available in the industry by accounting for both intensity and variability. Next, reliability performance measures from the CBI tool provide explicit consideration of vehicle throughput. This offers more detail than the commonly-used travel time index, which considers throughput implicitly instead of explicitly. Next, wavelet filtering of signalized intersection delays facilitates improved bottleneck identification on surface arterials. Further, a Google Maps feature provides enhanced visualization. Finally, the tool reports on the amount of missing data within the analysis, for quality control purposes. It is hoped that the tool and its methods will be embraced by States, for a new level of robustness in congestion identification.

BACKGROUND

The Spatiotemporal Traffic Matrix (STM), illustrated below in figure 2, is a key concept within congestion and bottleneck identification.[1] Each cell of this matrix simultaneously represents a specific roadway segment, and a specific time period. In the previous century, traffic engineers were taught to perform peak-hour analyses. However, a peak-hour analysis only represents four cells within this STM matrix; where each cell might contain performance measures like speed, delay, or level of service. By carefully analyzing traffic demand variability that occurs throughout the year, it becomes possible to account for the complex effects of weather, work zones, incidents, and even seasonal effects.

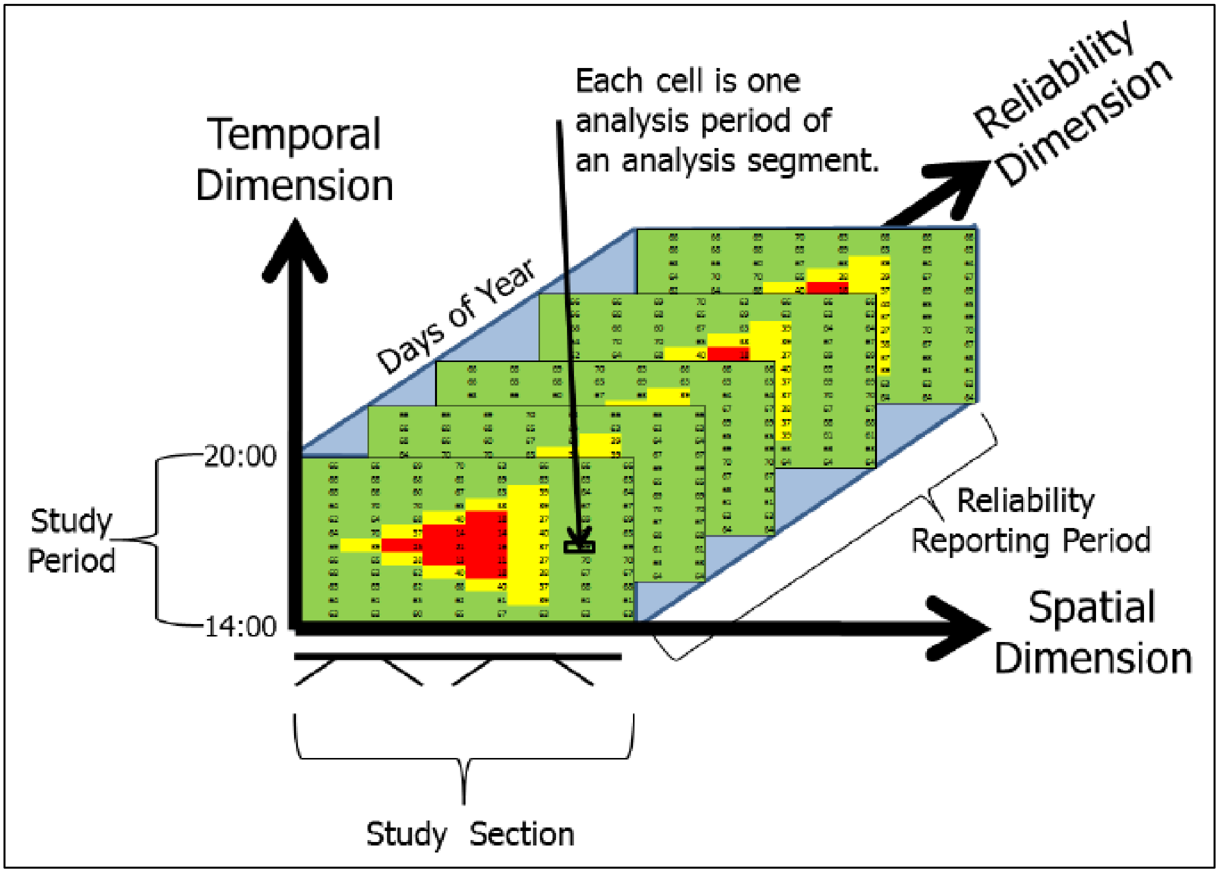


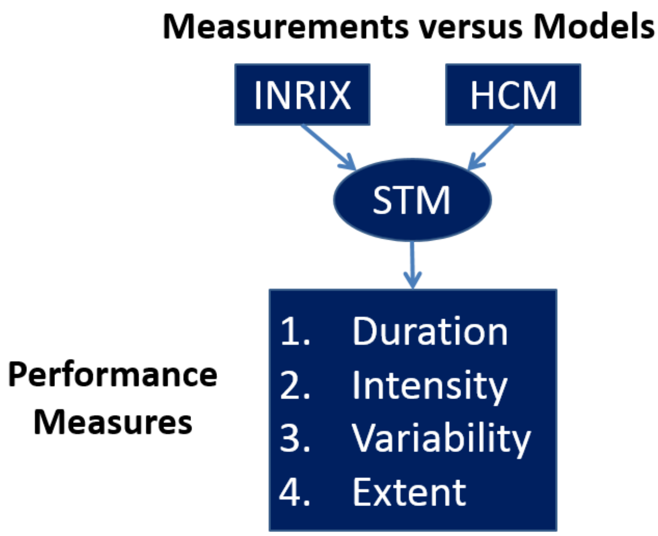
FIGURE 2. Three-Dimensional STM

"Big data" has become a hot topic within not only the transportation industry, but other industries as well. Relative to traditional peak-hour analyses, the STM could be considered a step in the direction of big data. By analyzing what goes on throughout the year, instead of just during the peak hour, it becomes possible to see a more complete picture of where the traffic problems are. It becomes possible to put a more precise price tag on transportation investments.

The STM can be generated by measurements or by models. When an STM is generated by INRIX, it is a measurement-based STM.[2] Conversely, when an STM is generated by the

Highway Capacity Manual procedures, it is a model-based STM.[1] Microsimulation models are also capable of generating STMs, although the computer runtimes required for doing so might be much longer. Both paradigms have strengths and weaknesses. Measurements such as those available through INRIX are expected to be more accurate than models. However, measurements are sometimes more expensive than models; and unlike models, they are not designed to predict the future.

Once the STM has been generated, it can be analyzed by software such as the CBI tool to automatically produce performance measures related to duration, intensity, variability, and extent. These performance measures can then be used to compare and prioritize bottleneck locations. Figure 3 illustrates the sequence of data processing and analysis.

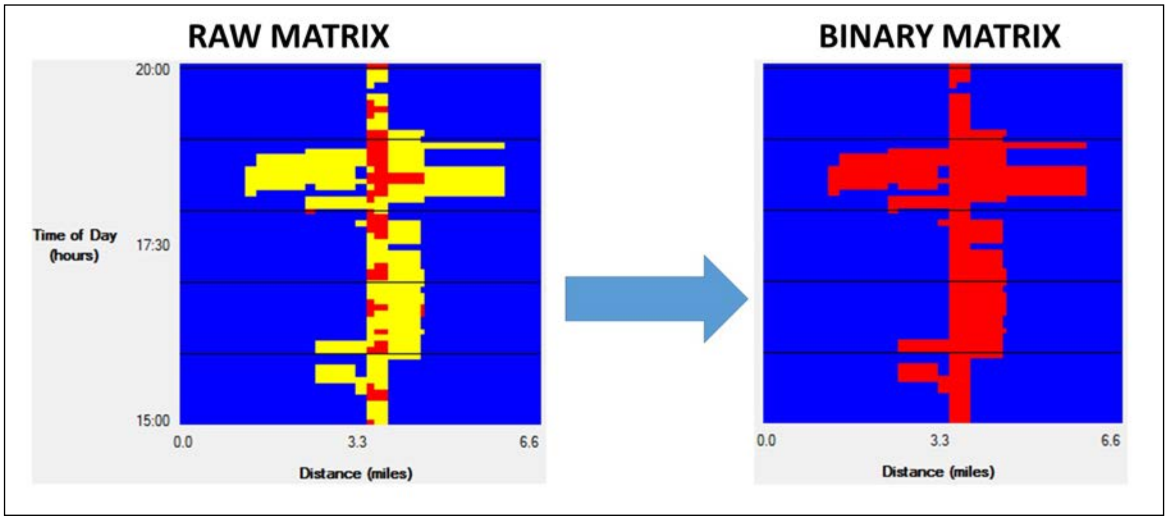


Source: FHWA

FIGURE 3. STM Generation and Postprocessing.[3]

The original purpose of the CBI tool was to compare and rank traffic bottlenecks. The first step in comparing and ranking bottlenecks should be defining what constitutes a bottleneck. One group of researchers proposed a bottleneck quantification method based on the STM concept.[4] They proposed using average vehicle speeds as a basis for determining which cells within the matrix would be classified as congested cells. For example, if the average speed within a given cell would fall below a user-defined cutoff speed, the cell would be classified as congested.

Vehicle speed appears to be an appropriate choice for comparing bottlenecks in the STM framework. Travel time has also been a key performance measure in reliability modeling, but could be more difficult to apply in practice, or at least within the context of the CBI tool. This is because instead of defining a cutoff speed for each segment, users would need to define cutoff travel times, which are more difficult to estimate. Thus in the CBI tool, cutoff speeds are used to define congestion and to differentiate between congested and uncongested conditions. Figure 4 illustrates an application of cutoff speeds for converting a typical STM into a binary matrix. In typical STMs, multiple colors are often used to depict various levels of congestion. In the binary matrix, there are only two levels of congestion: congested (red) and uncongested (blue).



Source: FHWA

FIGURE 4. Creation of Binary Matrix via Cutoff Speeds.[(4)]

DATA FILES

The CBI tool is designed to import INRIX files. More specifically, there are two files that must be imported: the Readings file and the TMC Identification file. The Readings file is much larger than the TMC Identification file. The Readings file has a default file name of "Readings.csv". The TMC Identification file has a default file name of "TMC_Identification.csv". One way of obtaining INRIX files is through the RITIS (Regional Integrated Transportation Information System) website[(5)], where States and departments of transportation (DOTs) have free access to INRIX data.[(2)] The first step of downloading INRIX files from RITIS is to log in to https://vpp.ritis.org/suite/download/. Figure 5 illustrates the typical RITIS web interface for specifying what type of INRIX data should be downloaded. The user can specify a date range for the downloaded data. Certain days of the week—Saturday and Sunday, for example—can be excluded. Some might even choose to exclude Mondays and Fridays. Figure 5 shows the options that can be selected for data download. To use the CBI tool, one must download at least Speed data. If a user wants to model different free-flow speeds on each segment, he or she would need to download Reference speed data as well. Under "8. Select averaging," 5-minute intervals are recommended for the best modeling accuracy. Whatever is typed under "9. Provide title" will become the filename of the downloaded Readings file. However, if this field is left blank, the Readings file will simply be called "Readings.csv." Make a note of where data files are being saved; you'll need to access them when you open the CBI tool.

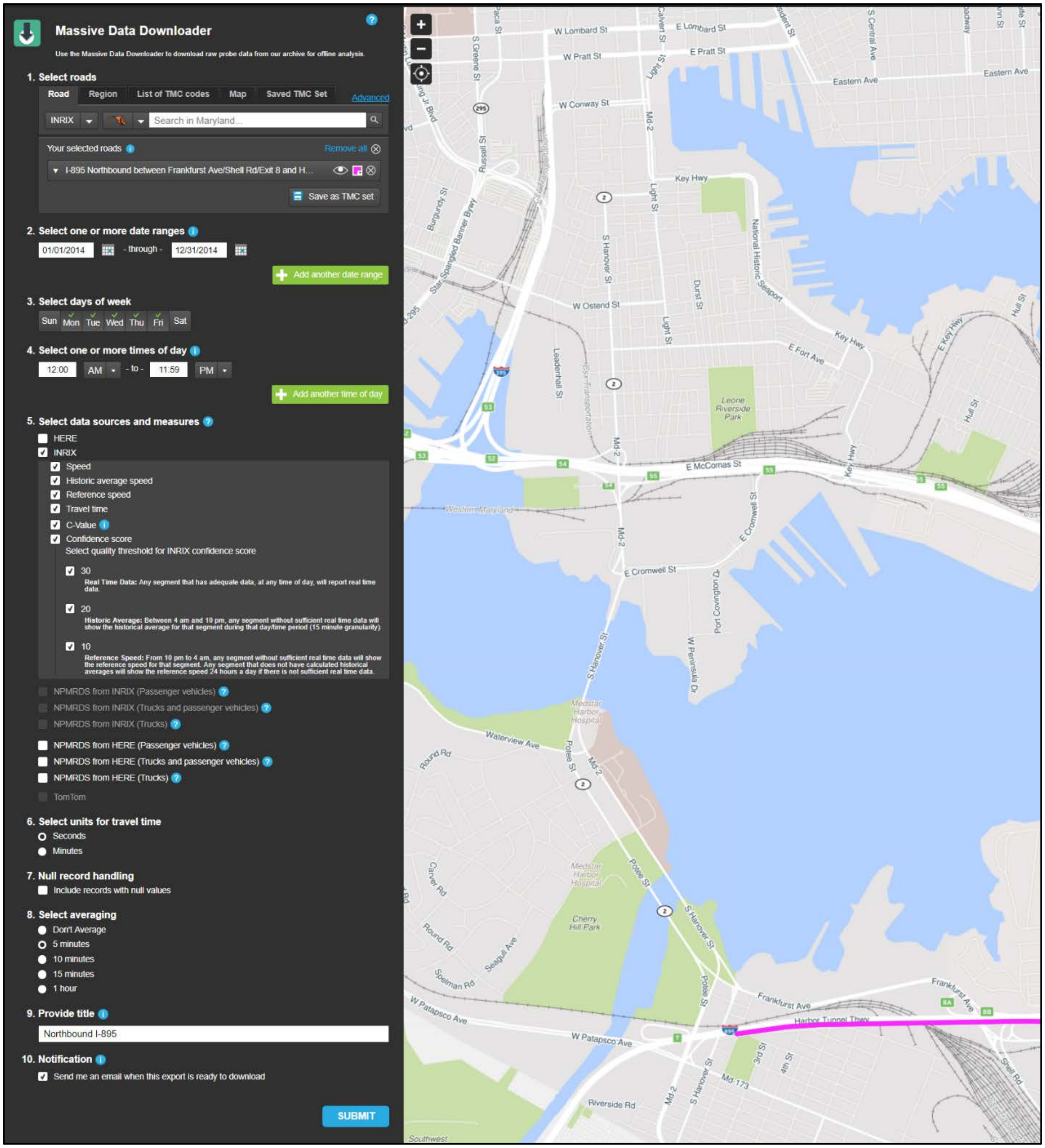
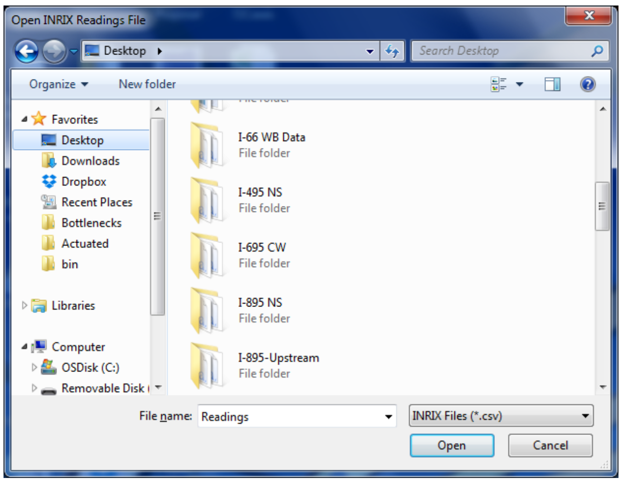


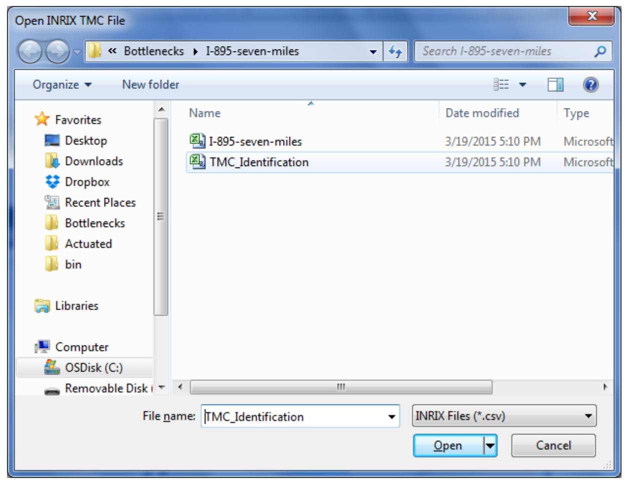
FIGURE 5. Requesting INRIX Data Specifications on the RITIS Website.[(5)]

Opening Data

When the tool (i.e., the “CBI.exe” file) is initially launched, it will search for “Readings.csv” and “TMC_Identification.csv.” If these two files are present within the same folder as “CBI.exe,” they will be opened automatically. If the two files are in a different folder than “CBI.exe,” the program will display the figure 6 dialog boxes in succession. For the first dialog box (figure 6a), browse the computer until the Readings file is located. Remember that text entered in the “9. Provide title” box (figure 5) will be used for the filename, so it will not be labeled “Readings.csv” unless the title box was left blank. After the Readings file is opened, the second dialog box (figure 6b) will appear, to open the TMC Identification file.



a. Readings File Dialog Box.



b. TMC Identification File Dialog Box.

Source: FHWA

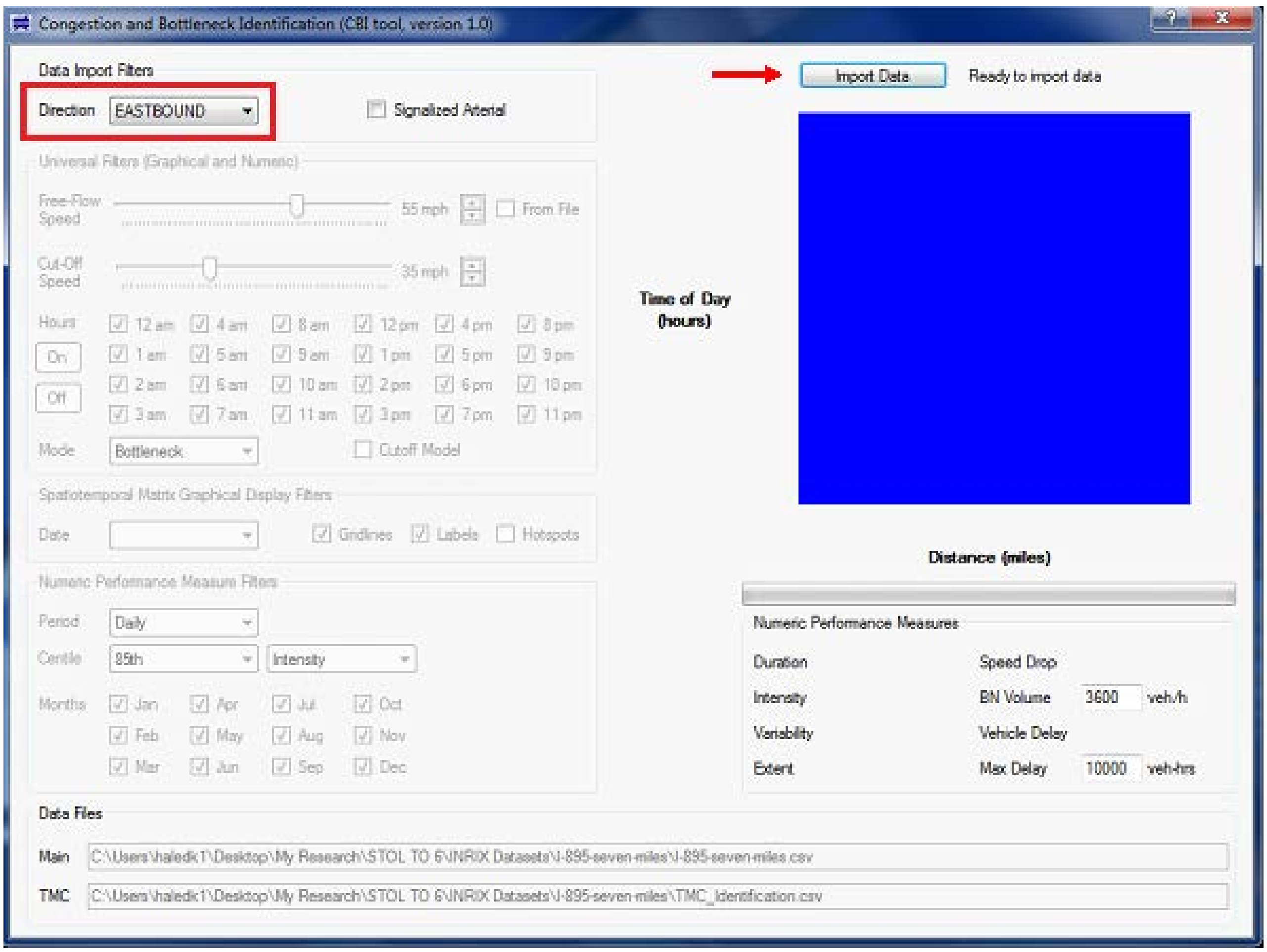
FIGURE 6. Opening INRIX Files from the CBI Tool.

In the CBI tool, opening data and importing data are two different operations. When data files are opened, the CBI tool simply identifies their file names, and the folder location containing those files. When data files are imported, the CBI tool will spend several seconds or minutes parsing the data files, and storing their values into memory.

Importing Data

Figure 7 illustrates the CBI screen after INRIX files have been opened, but before INRIX data have been imported. INRIX file names are shown at the bottom of the screen. To enable most features, it is necessary to actually import the INRIX data. To do this, select a Direction from the dropdown menu (i.e. EASTBOUND, WESTBOUND, NORTHBOUND, SOUTHBOUND, CLOCKWISE, or COUNTERCLOCKWISE, whichever corresponds to the data files you've downloaded), and click on the "Import Data" button. The program will only import INRIX data records for the chosen direction; other data records will be ignored.

Turning on the "Signalized Arterial" checkbox is recommended when analyzing traffic signal corridors; wavelet filtering is designed to reduce spotty patterns in the STM, making it easier to identify bottlenecks. After the "Import Data" button has been clicked, the CBI screen will display status messages (e.g., "Imported 0.5 million records"), to demonstrate that it is still properly importing data.



Source: FHWA

FIGURE 7. CBI Screen Prior to Importing INRIX Data.

For large corridors, it might take a minute or two for the program to import the data on some computers. However, if the objective is to compare and rank bottlenecks, it is probably best to download only those segments containing a known bottleneck, as opposed to downloading an entire corridor. If data files representing entire corridors are downloaded, one may then be comparing and ranking entire corridors; this might be less helpful than comparing and ranking bottlenecks.

BASIC FEATURES

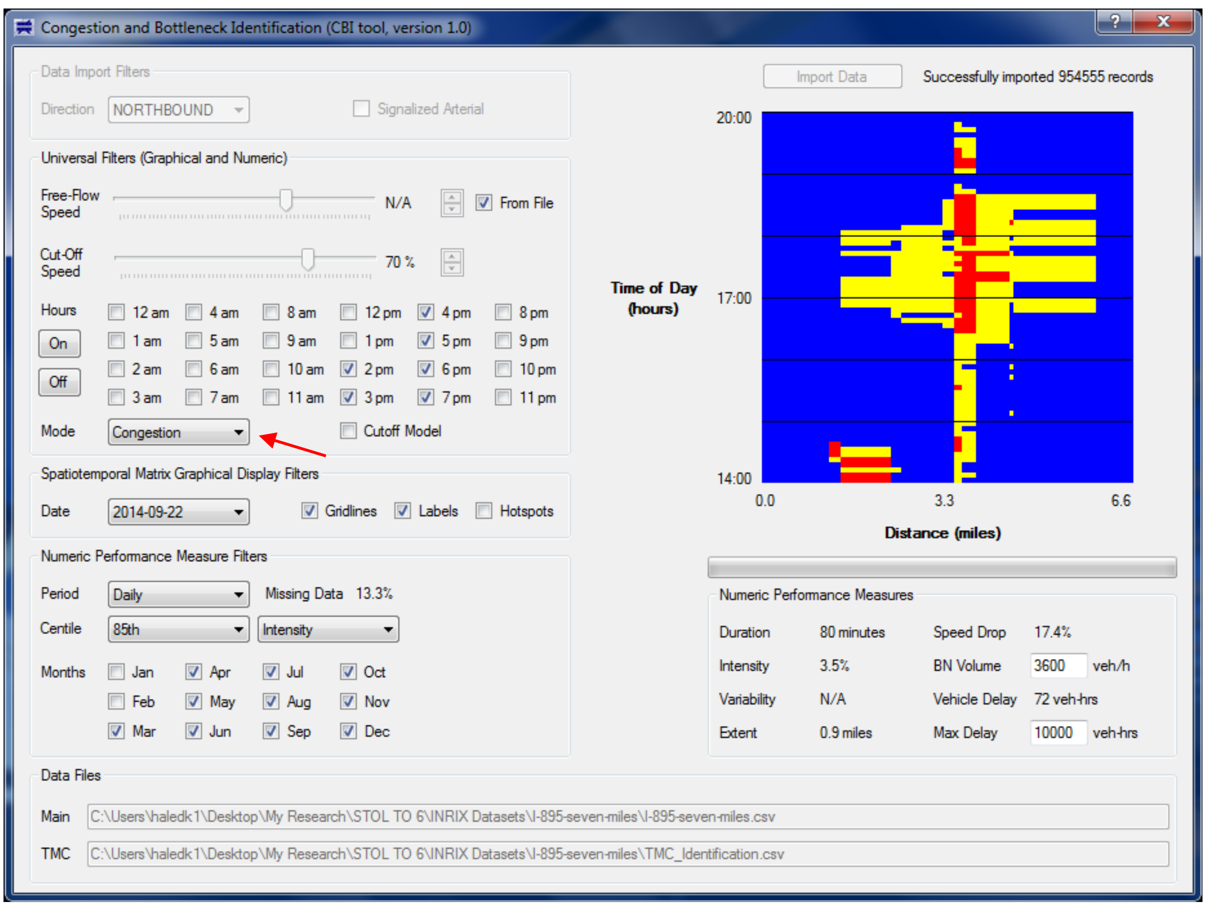
A question mark button ("?" in the upper right-hand corner of the screen) provides a link to this PDF-format users' guide, contact information for technical support, and background information on the bottleneck research project that produced this tool.

The left side of the CBI tool is where you will filter the data. You will generally work from top to bottom on the left. The upper right side shows the STM graphical display.

Congestion and Bottleneck Mode

There are two basic modes of analysis: congestion mode (figure 8) and bottleneck mode (figure 9). Toggle between these using the "Mode" dropdown menu (see red arrows in figures 8 and 9).

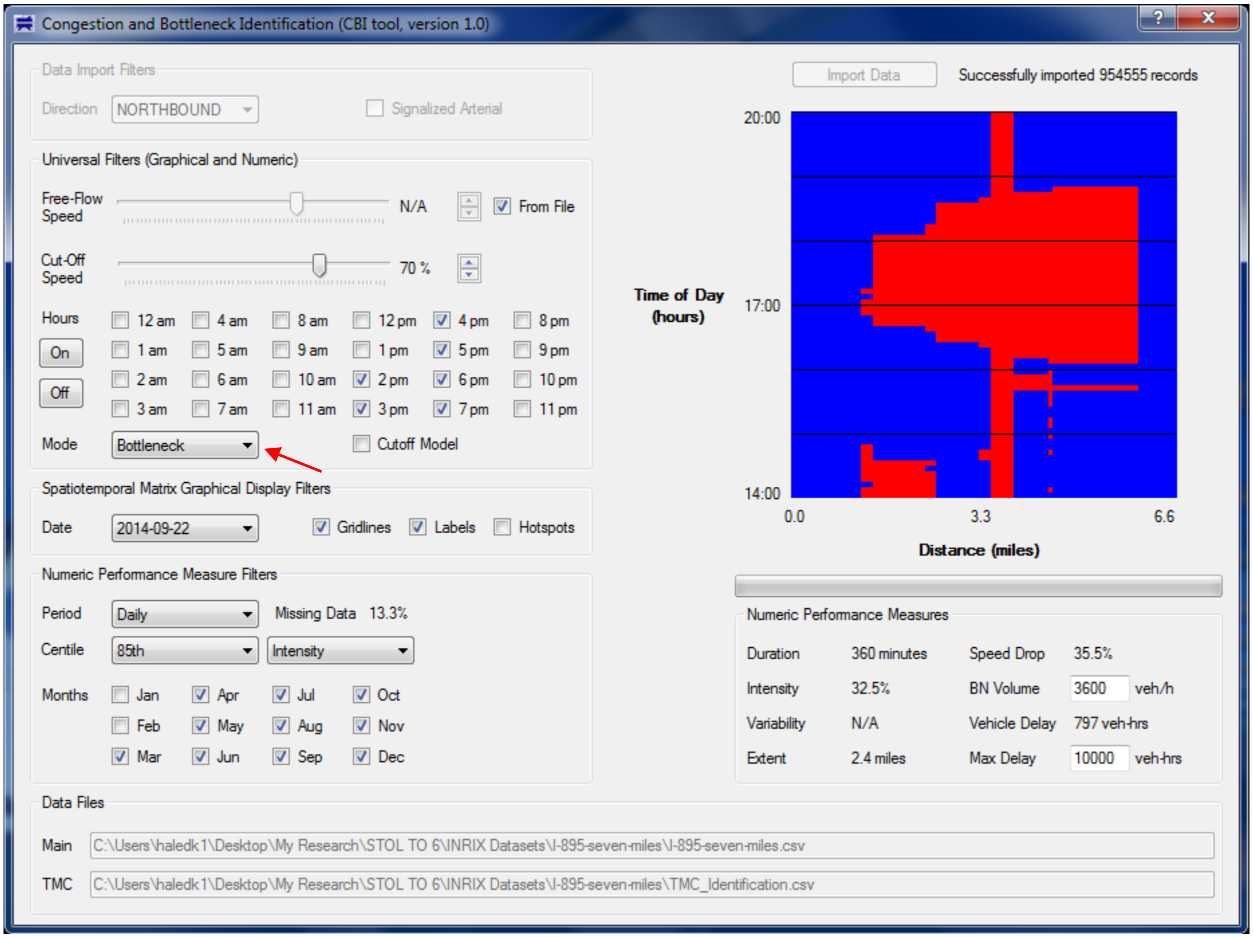
These modes affect how the STM graphical display reflects the chosen analysis. In congestion mode (figure 8), cells are colored yellow when vehicle speeds fall below 50 percent of the free-flow speed. Cells are colored red when vehicle speeds fall below 30 percent of the free-flow speed. All other cells are colored blue, indicating a non-congested state.



Source: FHWA

FIGURE 8. CBI Tool in Congestion Mode.

In bottleneck mode (figure 9), cells are colored red when vehicle speeds fall below the cutoff speed.



Source: FHWA

FIGURE 9. CBI Tool in Bottleneck Mode.

From File Checkbox

The “From File” checkbox uses the INRIX files to apply different speed data to each segment. This checkbox will only be enabled if the INRIX files contain reference speed data. If it is checked, different free-flow speeds and cutoff speeds from the data files will be applied to each segment.

Free-Flow Speed Control

The free-flow speed slider can be used to specify one free-flow speed for the entire analysis. Free-flow speed is only relevant to the congestion mode of analysis. In the bottleneck mode, free-flow speed is irrelevant. Because of this, the free-flow speed slider will be disabled whenever the bottleneck mode is in effect. In addition, the free-flow speed value (displayed to the right of the slider) will be listed as not applicable (N/A) whenever the bottleneck mode is in effect. However, when the "Cutoff Model" box is checked, the free-flow speed slider is always enabled because in the Cutoff Model, cutoff speed is calculated based on free-flow speed.

Cutoff Speed Control

The cutoff speed slider can specify one cutoff speed for the entire analysis. When the "From File" checkbox is turned on, the cutoff speed slider will transform from absolute values into percentages. These percentages, which can differ for each segment, will be applied to free-flow speeds from the INRIX file. Percentage values will be displayed right next to the slider.

Cutoff speed is only relevant to the bottleneck mode of analysis. It is irrelevant in congestion mode. Because of this, the cutoff speed slider will be disabled whenever congestion mode is in effect. In addition, the cutoff speed value (displayed to the right of the slider) will be listed as not applicable (N/A) whenever the congestion mode is in effect.

Cutoff Model Checkbox

The "Cutoff Model" checkbox can be used to calculate cutoff speeds based on free-flow speeds.[(4)] In the original research, cutoff speeds are factored down more as weather (i.e., precipitation) becomes more severe, and/or as visibility becomes more diminished. In one example, the combination of medium rain and a visibility of 6 out of 10 produces a cutoff speed multiplier of 0.75. Thus, if the free-flow speed were 60 mph, cutoff speed would be calculated as 45 mph. In this version of the CBI tool, the cutoff model assumes ideal weather (i.e., clear) and average visibility (i.e., 4 out of 10). This tends to cause free-flow speeds to be multiplied by 0.725 when computing the cutoff speed. Therefore, a free-flow speed of 62 mph would produce a cutoff speed of $62 \times 0.725 = 45$ mph under default conditions.

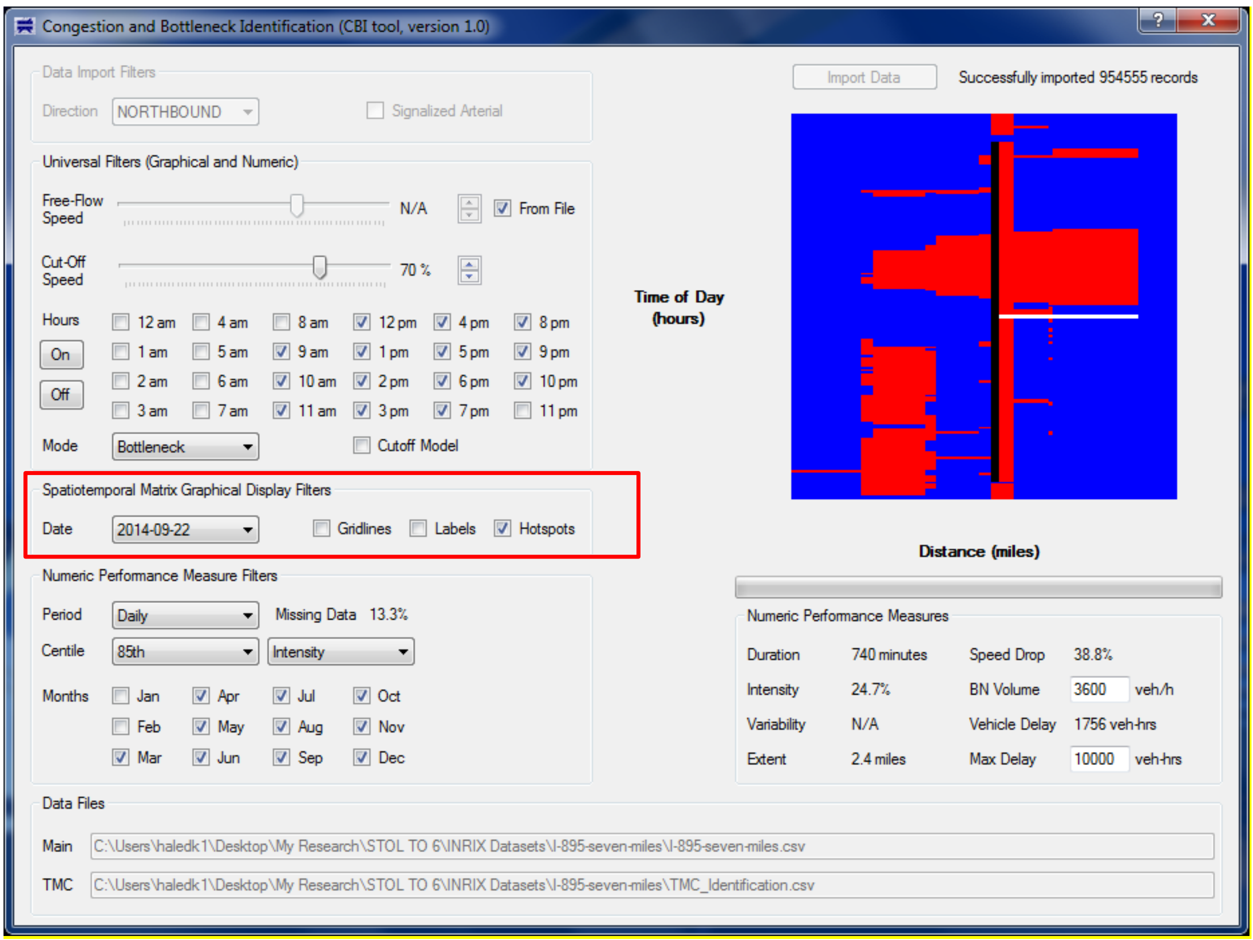
At the outset of a new analysis, it might be helpful to temporarily set cutoff speeds to 75 mph. This should cause the entire analysis box to turn red, because the average speed on urban roadways almost always falls below 75 mph. If any parts of the analysis box remain blue, this could indicate missing data that was not properly measured by INRIX. For example, a recent case study revealed large sectors of missing data in the first seven weeks of the year 2014, along a specific stretch of I–895 in Maryland. In response, January and February were filtered out of the analysis, which then produced more reliable results.

Hourly Filters

There are 24 checkboxes; one for each hour of the day. When one of these checkboxes is turned off, that associated hour will be excluded (i.e., filtered out) from all analyses. The On/Off buttons can be used to automatically turn all of the checkboxes on or off. When the CBI tool is first launched, all hours of the day are turned on by default. If someone wished to perform a PM peak analysis, they could click the "Off" button, and then turn on three hourly checkboxes (e.g. 4, 5, and 6 pm). This would be faster than manually turning off 21 checkboxes.

STM GRAPHICAL DISPLAY FEATURES

These options (highlighted area of figure 10) affect the way data are displayed in the STM on the right. The "Date" dropdown menu allows the user to view any day of data from the INRIX files. The three checkboxes to the right display or hide specific features, depending on user preferences. When turned on, the "Gridlines" checkbox shows horizontal hourly gridlines. The "Labels" checkbox shows x-axis (spatial) and y-axis (temporal) labels when checked. The "Hotspots" checkbox shows or hides the maximum bottleneck duration and extent. Hotspots are colored black by default. If a hotspot is narrower than 3 pixels—such that it would be difficult to view on-screen—this hotspot will be colored white and will be expanded to a width of 3 pixels for easier viewing. Figure 10 displays a CBI screen with hotspots turned on, and other STM labels turned off. In this example, the largest bottleneck extent in the analysis box is colored white, whereas the largest bottleneck duration is colored black.



Source: FHWA

FIGURE 10. Example of Displaying Hotspots on the CBI Screen.

NUMERIC PERFORMANCE MEASURES

These data, located on the bottom right of the CBI screen, show different aspects of the bottleneck depending on the filters selected on the left—particularly whether you've selected Daily or Annual in the Period dropdown menu.

Daily Measures

When Daily is selected in the Period dropdown menu, the STM display and the Numeric Performance Measures reflect data for that day only.

- The "Duration" field shows the longest continuous time period during which the segment is congested (i.e., colored red).
- The "Extent" field displays the longest continuous spatial length during which the time interval is congested (i.e., colored red).
- "Intensity" is a two-dimensional performance measure, covering both space and time. This field displays the percentage of the analysis box that is congested (i.e., colored red).
- The "Variability" field is the percentage difference between the chosen day's intensity, and the intensity of the INRIX files' mean (average) day. Variability is thus not applicable (N/A) unless annual results are being displayed.
- The "Speed Drop" field displays the average percentage difference between actual speeds and cutoff speeds, and is only averaged over the congested red area of the analysis box.
- "Missing Data" reports the percentage of missing INRIX data in the chosen day's analysis box. Missing data areas are assumed uncongested (i.e., colored blue) by default.

Vehicle Delay is computed according to the *2013 Most Congested Freeways Report and Methodology*.[6] However instead of using a fixed value of 35 mph, cutoff speeds are obtained from the CBI tool, as described earlier. Bottleneck volumes should be measured immediately downstream of the downstream end of congestion. Users can type the bottleneck volume into the CBI screen. Vehicle Delay is an important performance measure for comparing and ranking bottlenecks, because it captures the effects of both speed drops and volumes.

$$Delay\ on\ each\ TMC\ for\ one\ vehicle\ = \frac{Length\ of\ TMC}{Average\ TMC\ Speed} - \frac{Length\ of\ TMC}{35} \quad (1)$$

$$Delay\ on\ each\ TMC\ (vehicle - hours) = Delay\ on\ each\ TMC\ for\ one\ vehicle \times Bottleneck\ Volume \quad (2)$$

Most of the filters in the Numeric Performance Measure Filters group (bottom left) are not relevant to daily performance measures. They become significant when discussing Annual Measures.

Annual Measures

When the "Period" dropdown menu is changed from "Daily" to "Annual", the program will typically spend a few seconds performing annual analysis calculations.

- Use the “Centile” dropdown menu to determine which percentile data should be described, and the CBI tool will display the data for that day. For example, if the 85th percentile intensity is chosen, the program will automatically display results for whatever day of the year exhibits the 85th percentile worst intensity. This means 85 percent of days in the INRIX dataset will have a lower intensity than that day.
  - The “Date” control will automatically display the correct date of the 85th percentile day.
- There are 12 monthly checkboxes; one for each month of the year. By using these monthly checkboxes, the user can filter out certain months of the year, and perform a seasonal analysis.
  - In the Maryland I–895 case study described earlier, the first 7 weeks of the year 2014 were found to have significant amounts of missing data. January and February were then intentionally filtered out of the annual analysis.
- “Missing Data” reports the percentage of missing data throughout the entire INRIX dataset. Low values of missing data imply higher quality datasets and accurate output measures.

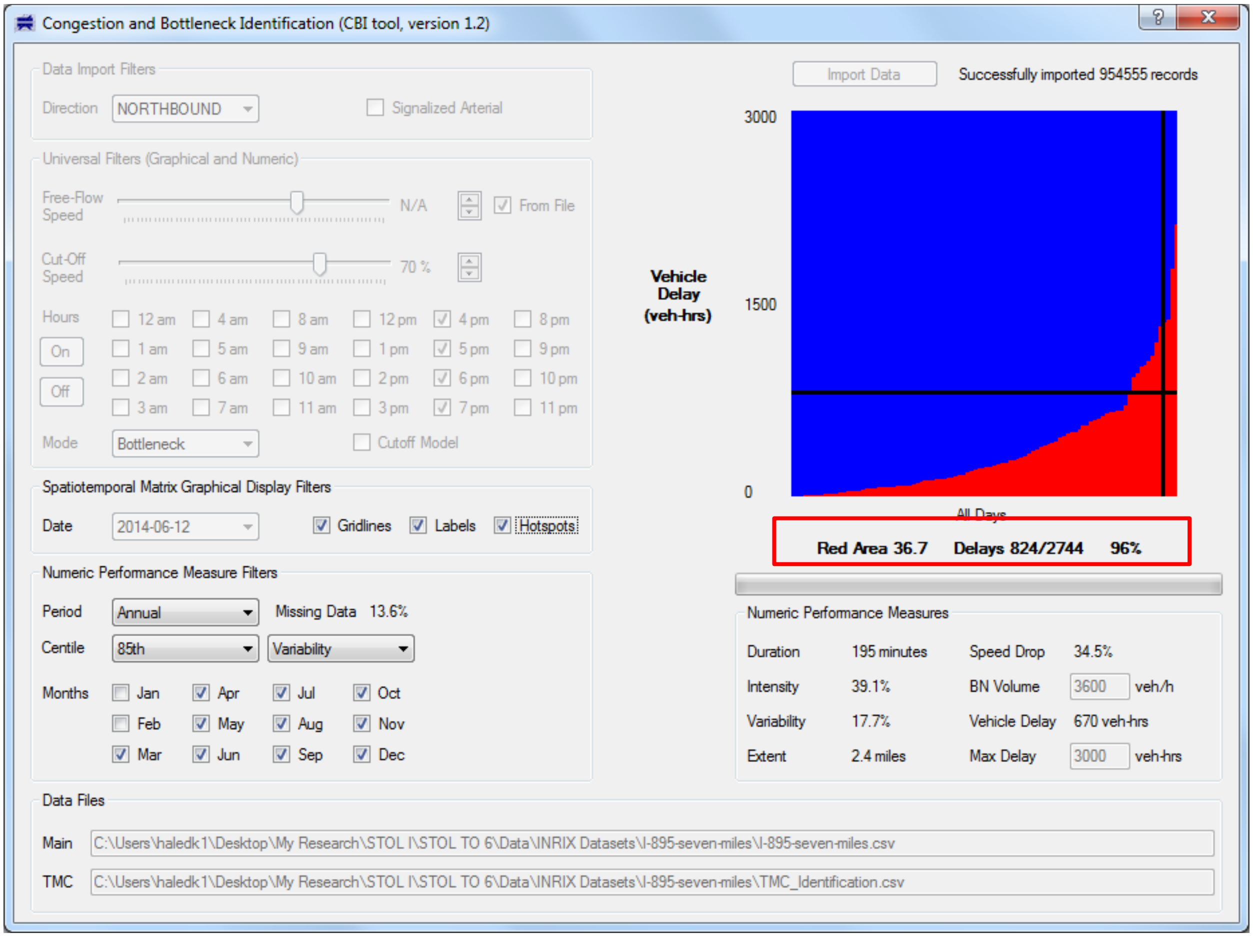
When “Period” is set to “Annual,” many of the program controls will be disabled. This prevents inconvenient 5–10 second recalculation delays that would occur while trying to change cutoff speeds, or peak periods. To regain access to the full set of controls, simply switch the “Period” control back to “Daily,” make necessary changes to the filters, and switch back to “Annual.”

Reliability Measures

When the “Period” control is set to “Annual,” and when the “Centile” control is set to “Variability,” the program switches into a special reliability modeling mode. Figure 11 illustrates an example of this reliability modeling mode.

The Spatiotemporal Traffic Matrix (STM) has been converted into an Annual Reliability Matrix (ARM). The x-axis now contains all days of the year, and reflects percentile worst days of the year. The y-axis now denotes vehicle-hours of delay; this maximum value is obtained from the “Max Delay” entry, near the bottom right-hand corner of the screen.

The ARM displays all daily delays of the year in ascending order, with the lowest-delay day on the far left, and the highest-delay day on the far right. (Note: When in reliability modeling mode, the CBI tool sorts data according to vehicle delay. Therefore, the value of variability will not be consistent with centile, as one would normally expect.)



Source: FHWA

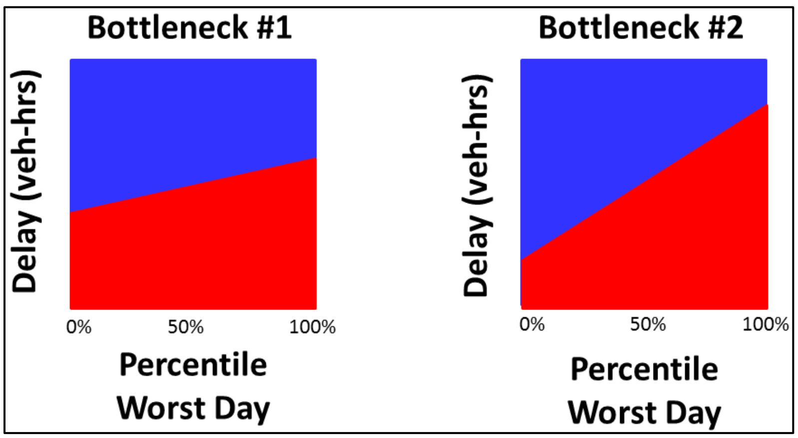
FIGURE 11. Example of the Annual Reliability Matrix (ARM).

ARM-based performance measures are displayed below the ARM (see the red box in figure 11):

- The first value is the total Red Area, which is the total amount of delay that occurred throughout the year.
- The first delay value represents a delay level below which 85 percent of the ARM's red area exists.
    - This value is the one used to create the horizontal black line if the "Hotspots" checkbox is turned on.
- The second delay value (after the "/") is the maximum delay point that occurred throughout the year.
- The fourth value is a percentile day, to the right of which 85 percent of the ARM's red area exists.

Interpreting ARM Displays

The ARM and associated numeric measures are believed to be effective tools for comparing and ranking traffic bottlenecks. These performance measures convey both the annual intensity and variability of traffic congestion. Some performance measures in the industry convey annual intensity, while ignoring annual variability and reliability. For example, figure 12 demonstrates a comparison of two hypothetical ARMs. The amount of red area is essentially equal for both bottlenecks. By some industry standards, these two bottlenecks would be considered equivalent priorities. However, bottleneck #2 (on the right) should be ranked as the higher priority, because more time would be needed to ensure an on-time arrival.



Source: FHWA

FIGURE 12. Example Comparison of Annual Intensity and Reliability.

The 85th percentile delay level appears to be more effective for comparing bottlenecks than 85th percentile delay. This is because the computation explicitly reflects a summation of delay values throughout the year, whereas the percentile delay simply needs to be larger than a portion of other days' delays. This relationship of 85th percentile delay level to 85th percentile delay is similar to the relationship of mean to median. The 85th percentile delay level explicitly reflects 85 percent of the red area. The 85th percentile delay simply says that 85 percent of the days had a lower delay. The 100th percentile delay level is helpful for additional context, but this only reveals which bottleneck experiences the highest-delay day of the year.

The 85th percentile delay level appears to be more effective than the 50th percentile delay level, because the 50th percentile delay level focuses on 50 percent of the best days of the year. The 85th percentile delay level provides a reasonable number for focusing on some of the worst days of the year, without over-emphasizing a small number of absolute worst days. Because of this, the value is always an 85th percentile value, regardless of what is selected in the "Centile" control. By contrast, the standard D.I.V.E. performance measures (i.e., Duration, Intensity, Variability, Extent) all use the chosen percentile from the "Centile" control.

Further Discussion of Vehicle Delay, Intensity, and Speed Drop

Vehicle delay, intensity, and speed drop are primary measures of traffic performance within the CBI tool. However, their values can sometimes be non-intuitive in comparison with one another. For example, if a given day of the year has the highest intensity and the highest speed drop, one might expect that same day to have the highest vehicle delay (indeed, the tool allows easy jumping from the 100th percentile Vehicle Delay day to the 100th percentile Intensity day). Despite this, some analyses have relatively low vehicle delay on a day having both the highest intensity and the highest speed drop. How is this possible?

The delay equation (shown earlier in the Daily Measures section) shows that the delay for each individual vehicle is essentially set equal to that vehicle's actual travel time (e.g., 20 seconds) minus cutoff speed travel time (e.g., 15 seconds). This is consistent with traditional definitions of vehicle delay, in which free-flow travel times are subtracted from actual travel times. Speed drop in the CBI is only averaged over the congested red area; its value is not diluted by the percentage of uncongested blue area. Intensity is simply the proportion of the analysis box that is congested. Thus, the calculations of these measures are relatively straightforward, and are simply defined.

A deeper investigation of these calculations reveals that the relationship between vehicle delay and speed drop is exponential instead of linear. In other words, doubling the speed drop could quadruple or quintuple the resulting amount of vehicle delay. Consequentially, a day experiencing severe speed drops within 25 percent of the analysis box could potentially produce more vehicle delay than a day experiencing mild speed drops within 50 percent of the analysis box. For more clarification, a simple example calculation is shown next.

Example Calculation of Vehicle Delay and Speed Drop

This example assumes a total of five TMC segments, and assumes that each TMC segment is one mile in length. The analysis time period is 8:00 am through 8:15 am. The cutoff speed is 47 mph on each segment. Average vehicle speeds (in units of mph) on all five TMC segments are listed below.

Day One: 42, 42, 42, 42, 42
Day Two: 46, 46, 26, 46, 46
Day Three: 40, 40, 40, 40, 40

This example illustrates that, even though days one and two have the same average speed drop, the severe speed drop on day two of segment 3 produces a much higher vehicle delay on day two compared to day one. Furthermore, even though day three has a higher average speed drop than day two, the severe speed drop on day two of segment 3 again produces a higher vehicle delay on day two, compared to day three.

Average speed drop on day one = average speed drop ÷ cutoff speed
= (5+5+5+5+5) ÷ 5 ÷ 47
= 10.6%

Average speed drop on day two = average speed drop ÷ cutoff speed
= (1+1+21+1+1) ÷ 5 ÷ 47
= 10.6%

Average speed drop on day three = average speed drop ÷ cutoff speed
= (7+7+7+7+7) ÷ 5 ÷ 47
= 14.9%

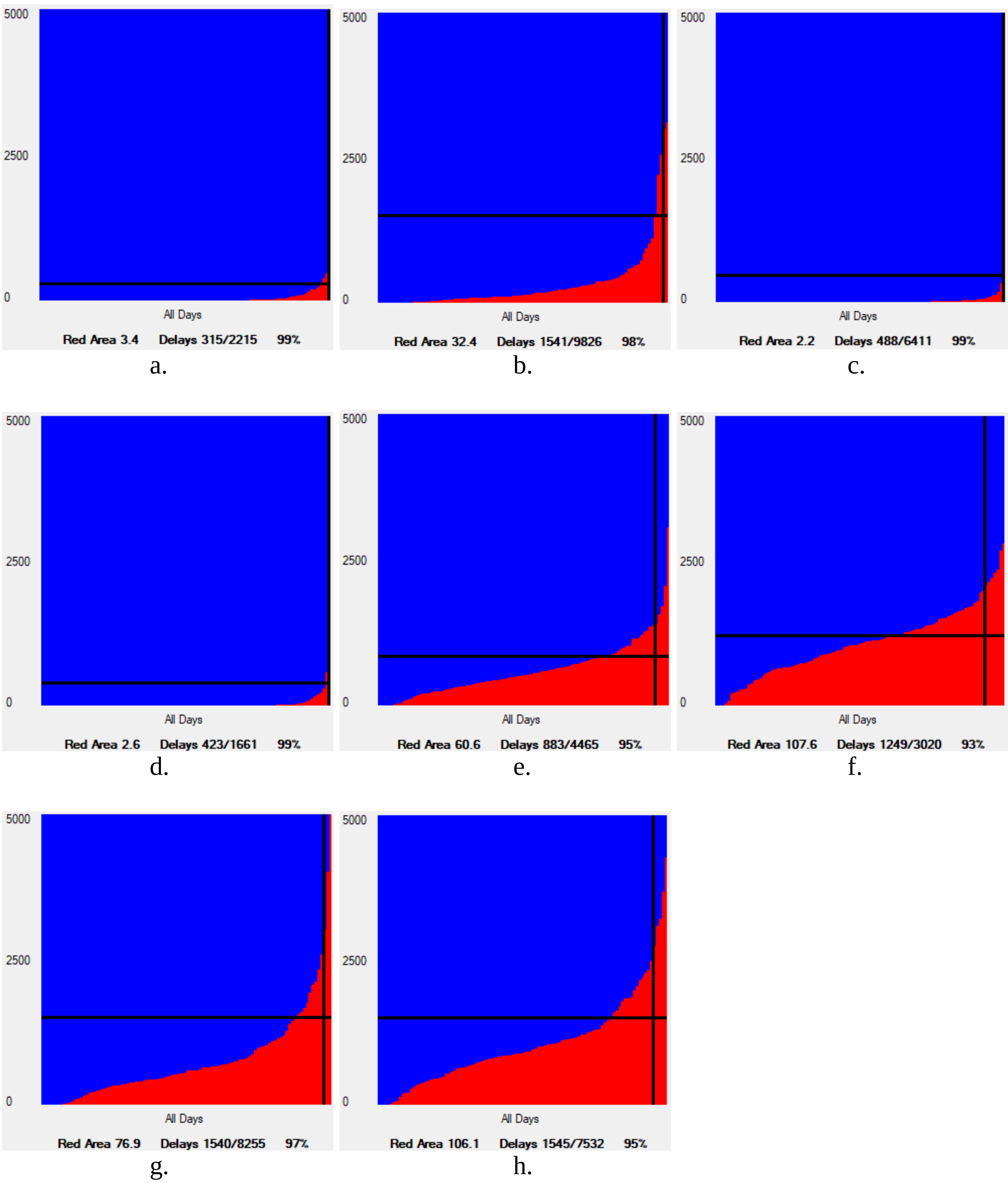
Vehicle delay on day one = ∑((actual travel time – free-flow travel time) × bottleneck volume)
= 5 × ((1/42 – 1/47) × 4400)
= 55.7 vehicle-hours

Vehicle delay on day two = ∑((actual travel time – free-flow travel time) × bottleneck volume)
= 4 × ((1/46 – 1/47) × 4400) + 1 × ((1/26 – 1/47) × 4400)
= 83.8 vehicle-hours

Vehicle delay on day three = ∑((actual TT – free-flow travel time) × bottleneck volume)
= 5 × ((1/40 – 1/47) × 4400)
= 81.9 vehicle-hours

CASE STUDY OF COMPARING AND RANKING BOTTLENECKS

Figure 13 illustrates a case study comparison of eight real-world bottleneck locations.



Source: FHWA

FIGURE 13. Example Comparison and Ranking of Bottlenecks

The steps for producing these eight diagrams were as follows:

ARM Diagram Generation Steps

Open INRIX dataset. When the CBI tool is first launched, open the folder where the Readings and TMC Identification CSV files are located. Open both files.

Select analysis direction. In the Data Import Filters group box (upper right-hand corner of the screen), select the direction of travel that will be analyzed.

Import data. Click on the Import Data button at the top of the screen, to import the data inside the Readings and TMC Identification files. A typical INRIX dataset has hundreds of thousands of data records, so the data import process may take several seconds on the computer. To show progress, a label on the upper right-hand corner of the screen will say "Imported 0.1 million records", "Imported 0.2 million records", "Imported 0.3 million records", etc.

Select free-flow speed and cutoff speed. In this case study, the "From File" checkbox was turned on for all eight bottleneck evaluations. This allows unique free-flow speeds to be imported from the INRIX dataset for each roadway segment. After this, the "Cutoff Speed" percentage was set to 73 percent for all eight bottleneck evaluations, consistent with the clear-weather multiplier recommended by Elhenawy et al.(4)

Select hours of the day to be analyzed. First, the "Off" button was clicked to turn off all 24 hourly checkboxes. Then, a few hourly checkboxes were turned on, to fully encapsulate the anticipated congestion hours. Some of the eight case study analyses focused on the PM peak direction, while others were focused on the AM peak. However, the exact checkboxes turned on in each case varied according to local congestion patterns. In other words, some AM peak analyses lasted from 6–8 am, others lasted from 7–10 am, etc.

Enter a bottleneck volume. As stated earlier in this guide, bottleneck volumes represent the flow rate immediately downstream of the downstream end of congestion. These flow rates may be measured in the field, obtained from a traffic analysis tool, or perhaps obtained from other sources. Therefore, in this case study, each of the eight bottleneck locations had a unique value entered for the bottleneck volume, in the lower right part of the screen.

Enter a maximum delay. This part is tricky because the maximum delay value producing the best ARM display cannot really be known until after the ARM is generated. In fact, for apples-to-apples ARM comparisons, maximum delay should be equal for all locations being compared. Therefore, after all eight ARMs were reviewed for all eight sites, it was decided that a maximum delay of 5000 vehicle-hours would adequately display the annual delay within all eight. Arriving at this value required a bit of trial and error, but it didn't take long.

Switch to an annual period. After the above settings were complete, the Period dropdown menu (lower left-hand part of the screen) was changed from "Daily" to "Annual." At this point the tool takes a few seconds of calculation time, but a progress bar on the right side of the screen is designed to make it obvious how much time remains.

Switch to variability. In the dropdown box that lets one choose between Duration, Intensity, Variability, Extent, and Vehicle Delay, choosing “Variability” while the “Period” is set to “Annual” will invoke the ARM diagram.

Turn on the Hotspots checkbox. When the ARM diagram is visible, turning on the Hotspots checkbox will make the tool draw a horizontal line below which 85 percent of the red area (i.e., annual delay) resides.

Process of Comparison

The ARM diagram and three associated numeric measures can now be used for direct, apples-to-apples comparisons and rankings. It is believed that a multivariate approach (i.e., based on multiple measures) provides a more robust process of comparison than a univariate approach (i.e., based on a single measure). The following case study narrative may help to illustrate why.

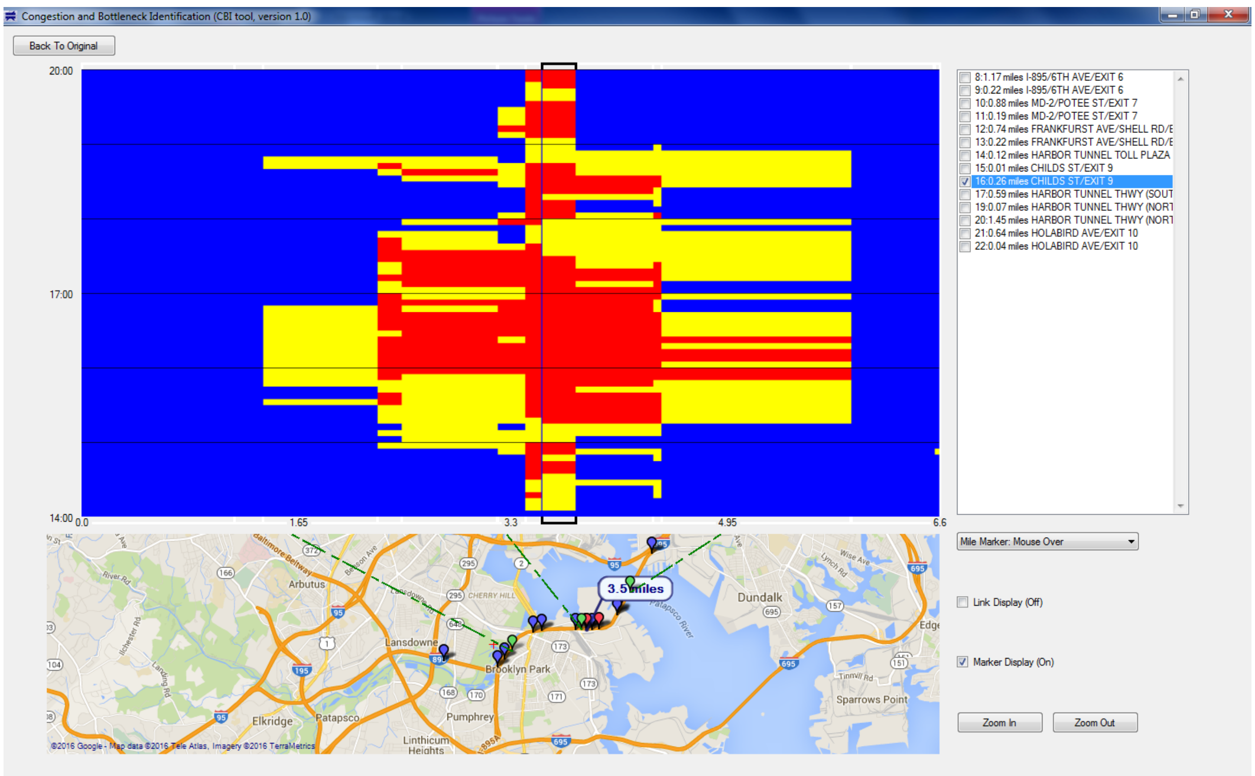
Overall annual delay is probably the best performance measure to begin the comparison, for this reason: If one bottleneck has significantly more overall annual delay than a second bottleneck, it almost certainly offers less travel-time reliability than the second bottleneck. However, if two bottlenecks have similar values of overall annual delay, the 85th percentile delay level should be an effective tiebreaker for indicating which bottleneck exhibits superior reliability. Finally, the 100th percentile delay level should clarify the results in some situations.

In this particular case study, figures 13f and 13h would be ranked as the worst bottlenecks according to their total red areas of 107.6 and 106.1, respectively. However, it seems that the difference between 107.6 and 106.1 is not enough to confidently assert that 13f is the worst bottleneck in terms of reliability. In fact, the bottleneck shown in figure 13h has a much higher 85th percentile delay level (1545 veh-hours) than the bottleneck shown in figure 13f (1249 veh-hours). Indeed, the bottleneck ARM in figure 13h appears to have a steeper annual slope than the bottleneck ARM in figure 13f. Therefore, the bottleneck in figure 13h appears to be the worst bottleneck in terms of annual reliability. Next, according to the total red area, figures 13e and 13g are the next worst bottlenecks. Although the total red area of 13g (76.9) appears to be significantly higher than that of 13e (60.6), the 85th percentile red area of 13g (1540) is also much greater than that of 13e (883). Therefore, 13g is worse than 13e.

It is interesting to note that if the 85th percentile delay level were used as a univariate measure for ranking bottlenecks, figures 13g (1540 veh-hours) and 13g (1545 veh-hours) would have graded out as equal bottlenecks. However, because figure 13h has much more total annual delay (106.1) than figure 13g (76.9), 13h is demonstrably less reliable. Similarly, if the 85th percentile delay level were used as a univariate measure, figures 13g (1540 veh-hours) and 13b (1545 veh-hours) also would have graded out equally; but because 13g has much more total annual delay (76.9 versus 32.4), 13g is demonstrably less reliable. The question becomes, how could figures 13g and 13b have such unequal total annual delays while having similar 85th percentile delay levels? This implies that figure 13b must have had one or two extremely bad days to skew the results. Indeed, the worst day at 13b (9826 veh-hours) was the worst delay day among all eight bottlenecks. Thus, the final rankings would be figures 13h (worst), 13f, 13g, 13e, 13b, 13a, 13d, and 13c (best).

GOOGLE MAPS FEATURE

The STM takes up a small portion of the screen in the CBI tool. Therefore, a feature was added to automatically generate a much larger version of the STM. In addition, Google Maps is used to automatically generate a map underneath this larger version of the STM. Figure 14 illustrates this feature.



Source: FHWA (Original map: ©2017 Google).[7]

FIGURE 14. Google Maps Feature in the CBI Tool.

This feature requires internet access, which allows the CBI tool to automatically download data from Google Maps. In order to launch the Google Maps view, simply click somewhere inside the STM analysis cube. GPS coordinates within the INRIX file(s) are used to automatically obtain the appropriate map, so the feature is very easy to use, and requires no data entry by the user. This feature cannot be launched when the CBI tool is in the special reliability modeling mode (i.e., when an ARM diagram is displayed on screen). Instead, the Google Maps feature can only be launched when the CBI tool is in the standard mode (i.e., when an STM diagram is displayed on screen).

ACKNOWLEDGMENTS

Figure 2 was reprinted with permission from the 2010 Highway Capacity Manual, Fifth Edition by the National Academy of Sciences, Courtesy of the National Academies Press, Washington, DC.

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