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16. Abstract

This report describes the second and final year activities of the project titled "Using Operations-Oriented Performance Measures to Support Freeway Management Systems." Work activities included developing a prototype system architecture for testing the use of performance measures in real-time. Outputs from this effort included operator's screens, a prototype database, and a concept of operations for using the real-time measures. Additional work showcased the application of a multi-criterion screening approach to the selection of competing performance measures.

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OPERATIONS-ORIENTED PERFORMANCE MEASURES FOR FREEWAY MANAGEMENT SYSTEMS: FINAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The researcher in charge of this project was Robert E. Brydia.

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CHAPTER 1:
REVIEW OF YEAR ONE RESEARCH

PROJECT GOALS

Traditionally, one of the standard means for assessing the effectiveness of a strategy is to use the concepts of performance measurement. A common definition for performance measurement is “the use of statistical evidence to determine progress towards specific defined organizational objectives” *(1)*.

In other fields and applications, performance measurement is often used in real-time to evaluate situations such as production line quality. The goal of this project is to examine if performance measurement could be applied in real-time to freeway management. There are two areas of investigation, daily operations and emissions. Year one of the research project examined the background of each area and the potential for utilizing real-time performance measurement.

LEVELS OF OPERATIONAL PERFORMANCE MEASUREMENT

A significant effort in Year One of the project detailed the overall background of performance measurement and where performance measurement can be applied to transportation operations. Figure 1 [adopted from Figure 1-1 of Reference *(2)*] illustrates the levels of application by showing a pyramidal approach to the definition of performance measurement. At the top of the figure is the largest level or area of measurement, the system wide assessment. This level is the most global view of operations and serves a multitude of purposes. This measure may be the information that the public and elected officials receive on a consistent basis, identifying the state of the overall transportation system and the progress the agency is making in operating it in an efficient manner. These types of system wide assessments may be instrumental in focusing funds and personnel on critical priorities.

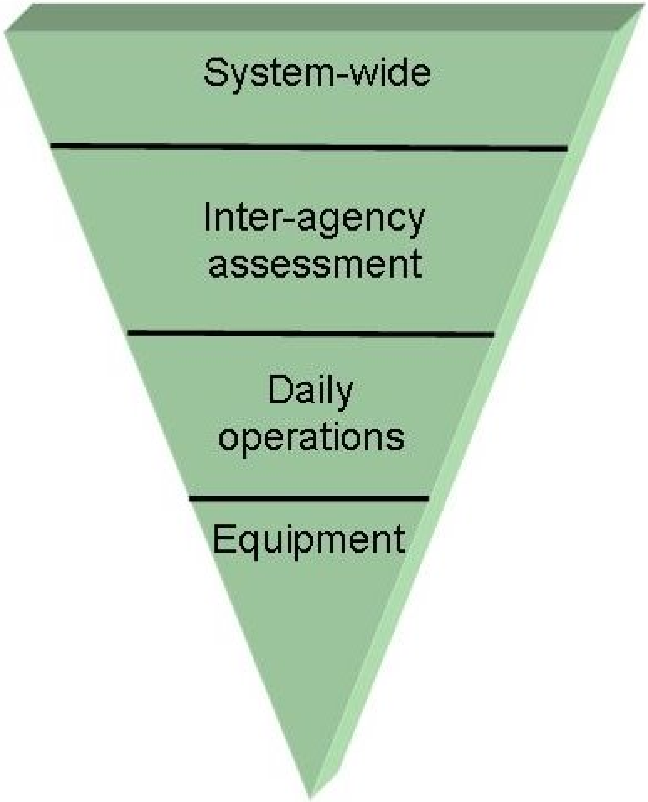


Figure 1. Multilevel Approach to Operational Performance Measures.

The next step down in the pyramid is interagency assessment. Many operational programs, such as incident management, congestion mitigation, air quality, and more, are joint efforts between multiple agencies. The performance measures at this level focus on defining how these programs are working and if the various resources are being used effectively to bring significant improvement to the program. The focus area of these programs is typically smaller than the entire system. Example focus areas may be on a specific corridor or known problem area.

The next level in Figure 1 is daily operations. The focus here is the day-to-day efforts that operators perform in a TMC. On a routine, daily basis, operators determine and execute responses based on inputs and execute strategies to keep traffic flowing. These responses and strategies may be lane shifts, dynamic message sign postings, implementing changes in ramp operations, or more. While the focus area of these actions is typically compressed, i.e., smaller than an entire corridor, the potential impact area is much larger.

At the bottom of the pyramid are those measures that focus specifically on equipment or very discrete elements of the transportation system. Typical applications at this level may include items such as up-time, reliability, integrity of data, or more. Looking at these measures should provide an overview sense of how the data collection, processing, storage, and calculation components of performance measurement are working across the entire extent of transportation operations.

STATE OF THE PRACTICE – OPERATIONS

Prior to the start of the research project, the general perception of the state of the practice in traffic operations was that performance measurement for system wide assessment was employed at some locations. Likewise, some applications were known with regard to the equipment level and the use of measure for response time, downtime, and similar metrics. There were no known applications of real-time operational assessment. While some TMCs may compute a level of service (LOS) or similar measures, for use in an operator display, there were thought to be no formalized actions taken on these values utilizing a systematic process.

In order to quantify the use of performance measurement with TxDOT, a questionnaire was developed and administered to TMCs in Texas to categorize the use of performance measurement across all levels shown in Figure 1. The questionnaire clearly showed that across the state, while performance measurement is understood and appreciated for what it could provide to transportation operations, implementation to date is minimal. This observation was especially true in the arena of daily operations, as there were no respondents utilizing performance measurement for that level.

One of the other findings of the questionnaire was the uncertainty surrounding which measures could be used effectively for real-time operations. There are literally thousands of measures that represent a particular emphasis or strategy or could potentially capture a particular response. It is impossible, however, to implement all of the measures without creating an incomprehensible system of data collection, storage, and analysis techniques. What is, therefore, required is a minimal but comprehensive set of measures that can be used in daily operations to effectively analyze actions and respond appropriately to changes.

The research team performed a literature review to determine what lists of measures have been used external to TxDOT and if there are recommended measures for daily operations. Several sources and lists were examined, but in the end, the list from the National Transportation Operations Coalition (NTOC) was determined to provide the best basis for testing the applicability for real-time use. The NTOC list was originally developed, with support from the Federal Highway Administration, to define approximately 10 measures that could be commonly agreed upon by federal, state, and local transportation officials. As stated in the NTOC final report, these national recommendations were developed to help local traffic administrators with the selection of performance measures and to encourage more national uniformity. The goal is for these performance measures to be used for internal management, external communications, and comparative measurements *(3)*.

The results from NTOC include the following suggestions of performance measures:

- Customer Satisfaction,
- Extent of Congestion – Spatial,
- Extent of Congestion – Temporal,
- Incident Duration,
- Non-Recurring Delay,
- Recurring Delay,
- Speed,
- Throughput – Person,
- Throughput – Vehicle,
- Travel Time – Link,
- Travel Time – Reliability, And
- Travel Time – Trip.

The research team, in conjunction with the project monitoring committee, decided to examine these measures for their application to real-time operations in Year Two efforts of the project.

EMISSIONS PERFORMANCE MEASURES

The first year project report presented an extensive background on air pollution sources and their impacts on human health, focusing on the six most common pollutants designated by the U.S. Environmental Protection Agency (EPA). These pollutants were carbon monoxide (CO), particulate matter (PM), nitrogen dioxide (NO_2), lead (Pb), sulfur dioxide (SO_2), and ozone (O_3). The background also presented the National Ambient Air Quality Standards (NAAQS), air pollution monitoring and measurement, and performance measurement strategies to evaluate changes in emissions from the freeway system. The conclusion from the first year efforts was that few of the available performance measures for emissions are suited for real-time application, and those that are, would need a significant level of monitoring stations to factor out other influences. The report also concluded that it is questionable if the measures could achieve the granularity required for real-time operations in a confined area.

YEAR TWO PROJECT GOALS

Operations

The guiding question behind the Year Two research work was: can the NTOC measures be used to support real-time operations, and how can that be tested? To answer that question, the research team, in conjunction with the project monitoring committee, decided to develop a simulation architecture to build a performance measure display system. Using the real-time data from the simulation would provide constantly changing data for the operator display. The judgment of the capability of using this display to interpret real-time conditions and decide on operational responses would be captured in a concept of operations. Project deliverable P1 is the prototype database structure used in this simulation environment. It is contained in Chapter 3 of this report. Project deliverable P2 is prototype displays for operator interfaces. Numerous examples of these screens are contained in Chapter 4. Project deliverable P3, contained in Chapter 5, is the concept of operations document for using the real-time performance measure from the sample simulation environment.

Emissions

The conclusion of the Year One research pertaining to emissions was that there were no factors really suited for real-time performance measurement at a cost-effective level. For that reason, the Year Two efforts focused on providing a decision-making framework for assisting transportation planners and operators in order to select alternative freeway performance measures based on both qualitative measures, such as understanding, measurability, availability, and importance, and quantitative measures, such as time, cost, accuracy, and reliability.

CHAPTER 2:
REAL-TIME PERFORMANCE MEASUREMENT FOR OPERATIONS

NTOC PERFORMANCE MEASURES

The NTOC report listed 12 performance measures, as shown in Table 1. The table also shows the basis for each performance measure and the judgment of the research team in terms of the measure's capability to be used in real-time. As an example, the measure of 'Customer Satisfaction' is based on perception and the data requirements would be impossible to capture in real-time. This measure is therefore not applicable for real-time usage. On the other hand, a measure such as 'Travel Time-Link', which is based on speed, can be captured in real-time. It is possible that the use of a travel time based performance measure may provide capabilities or information to an operator that is currently not a part of any system.

Table 1. NTOC Performance Measures and Their Basis.

Measure	Basis	Real-Time Usage Capability
Customer Satisfaction	Perception	No
Extent of Congestion-Spatial	Speed	Yes
Extent of Congestion-Temporal	Speed	Yes
Incident Duration	Time	Yes
Non-Recurring Delay	Travel Time	Maybe
Recurring Delay	Travel Time	Maybe
Speed	Speed	Yes
Throughput-Person	Volume	Yes
Throughput-Vehicle	Volume	Yes
Travel Time-Link	Speed	Yes
Travel Time-Reliability	Speed	Yes
Travel Time-Trip	Speed	Yes

It should be noted that the basis for most of the measures in Table 1 are similar, reflecting the common data that are typically available from roadway monitoring implementations across the nation. Many of the measures that are similar, such as the 'throughput' measures, differ only by a multiplicative factor.

MEASURES FOR USE IN REAL-TIME PROTOTYPE TESTING

Of the 12 measures listed in the NTOC report, two were used for testing the real-time application. This testing was a prototype experiment, and the number of measures was kept small to balance the setup needs with the potential information gain. Also, as per the earlier discussion, some of the measures differ only by a multiplicative factor and would not add any knowledge to the research. The research team determined that 'Travel Time-Link' and 'Extent of Congestion-Spatial' would be tested for real-time application. While the basis for both the measures is speed, the extent of congestion measure examines a ratio of speeds and may yield a different basis or interpretation than a pure link travel time.

SYSTEM ARCHITECTURE FOR REAL-TIME TESTING

As in testing measures in any prototype system, the first task was to create a generalized system architecture that would produce the prototype displays and database called for in the project deliverables. The method chosen to meet those needs was to create a small simulation environment that would generate real-time data, perform the necessary calculations for creating the NTOC performance measures, store that information in a database, and then subsequently draw information from the database to generate operator's displays. The main emphasis in this architecture was to generate displays in real-time that would be representative of operator's displays. Figure 2 shows the overall system architecture. Each of the components will be described in additional detail in a subsequent chapter.

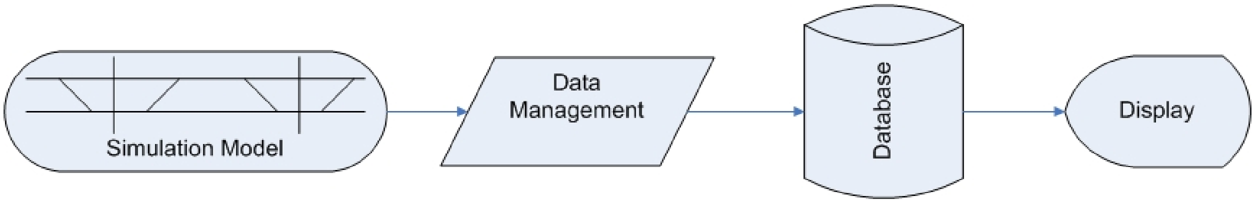


Figure 2. Prototype System Architecture.

- *Simulation Model* – The VISSIM simulation model was used to create the simulation environment and produce 20-second data feeds that emulate traditional detector based roadway implementations.
- *Data Manager* – The data manager receives the 20-second data feeds and manipulates the data as necessary to perform calculations of the performance measures.

- *Data Repository* – The data repository is an Access® database that stores all of the information necessary to feed the operator displays.
- *Displays* – The displays are the visual output of the specific performance measures that can be monitored by an operator in real-time.

CALCULATION METHODOLOGY FOR TRAVEL TIME-LINK

According to the NTOC definitions, the definition of the travel time for a link is the average time required to traverse a section of roadway in a single direction. While the NTOC report is focused on both the planning and historical operations level, the measure can also be examined for real-time purposes.

The travel time of the section is computed as:

$$Travel\,Time_{(section)} = \frac{Length_{(section)}}{Average\ Speed_{(section)}} \qquad \textbf{\textit{Eq. 1}}$$

Where:

Length = length of the section in question

Average Speed = average of all vehicle speeds in the section during the calculation time period

The overall steps to calculating the extent of congestion-temporal measure can be diagrammed in a flowchart as shown in Figure 3. The methodology is very simplistic, as there are no additional calculations beyond the computation of travel time by section. The potential usefulness of this measure will be determined by the operator displays. Additional discussion of these displays will be presented with the results.

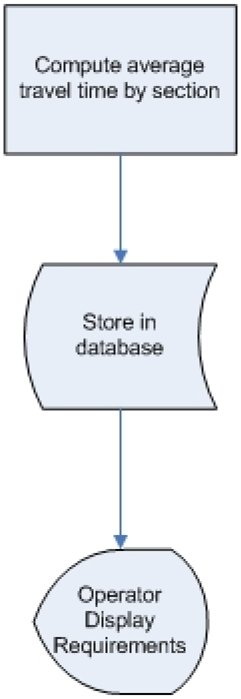


Figure 3. Methodology for Travel Time Performance Measure.

CALCULATION METHODOLOGY FOR EXTENT OF CONGESTION – SPATIAL

According to the NTOC definitions, the definition of the 'Extent of Congestion - Spatial' performance measure is the roadway sections in a pre-defined area that are congested according to a comparison with an unconstrained travel time. For the application to real-time conditions, the methodology looked at each individual section to determine if it was congested.

A section is defined to be congested if:

$$\frac{Travel\,Time_{(section)}}{Travel\,Time_{(unconstrained)}} \geq 1.3 \qquad \textbf{\textit{Eq. 2}}$$

The travel time of the section is computed as:

$$Travel\,Time_{(section)} = \frac{Length_{(section)}}{Average\ Speed_{(section)}} \qquad \textbf{\textit{Eq. 3}}$$

Where:

Length = length of the section in question

Average Speed = average of all vehicle speeds in the section during the calculation time period

The $Travel\ Time_{(unconstrained)}$ of the section is computed as:

$$Travel\,Time_{(unconstrained)} = \frac{Length_{(section)}}{Target\ Speed_{(section)}} \qquad \textbf{\textit{Eq. 4}}$$

Where:

Target Speed = the speed that occurs when vehicles are traveling at speeds established by operations personnel as the desired speed for a given roadway during the prevailing roadway and traffic conditions

The length of the section is a static value that arises from the construction of the simulation environment. The target speed is also a static value, but could be changed by time of day to reflect the anticipated operating characteristics of the roadway in question. A lower target speed might be used during the morning and evening peaks, reflecting the additional traffic that is using the road during those time periods.

The overall steps to calculating the extent of congestion-temporal measure can be diagrammed in a flowchart as shown in Figure 4. As is evident, this flowchart is slightly more complex than the flowchart presented for the travel time performance measure in Figure 3. This increase occurs because the extent of congestion performance measure incorporates a ratio of current to unconstrained travel times by section. The target speed values must be stored in the database along with other items such as section length, and, in addition to calculating the average speed, the methodology must also calculate the travel time ratio. For the purposes of this prototype, the target speeds were not changed throughout the course of the simulation time period. The congestion flag is set according to *Eq. 2* with the resulting value and flag being stored in the database for later use in an operator display.

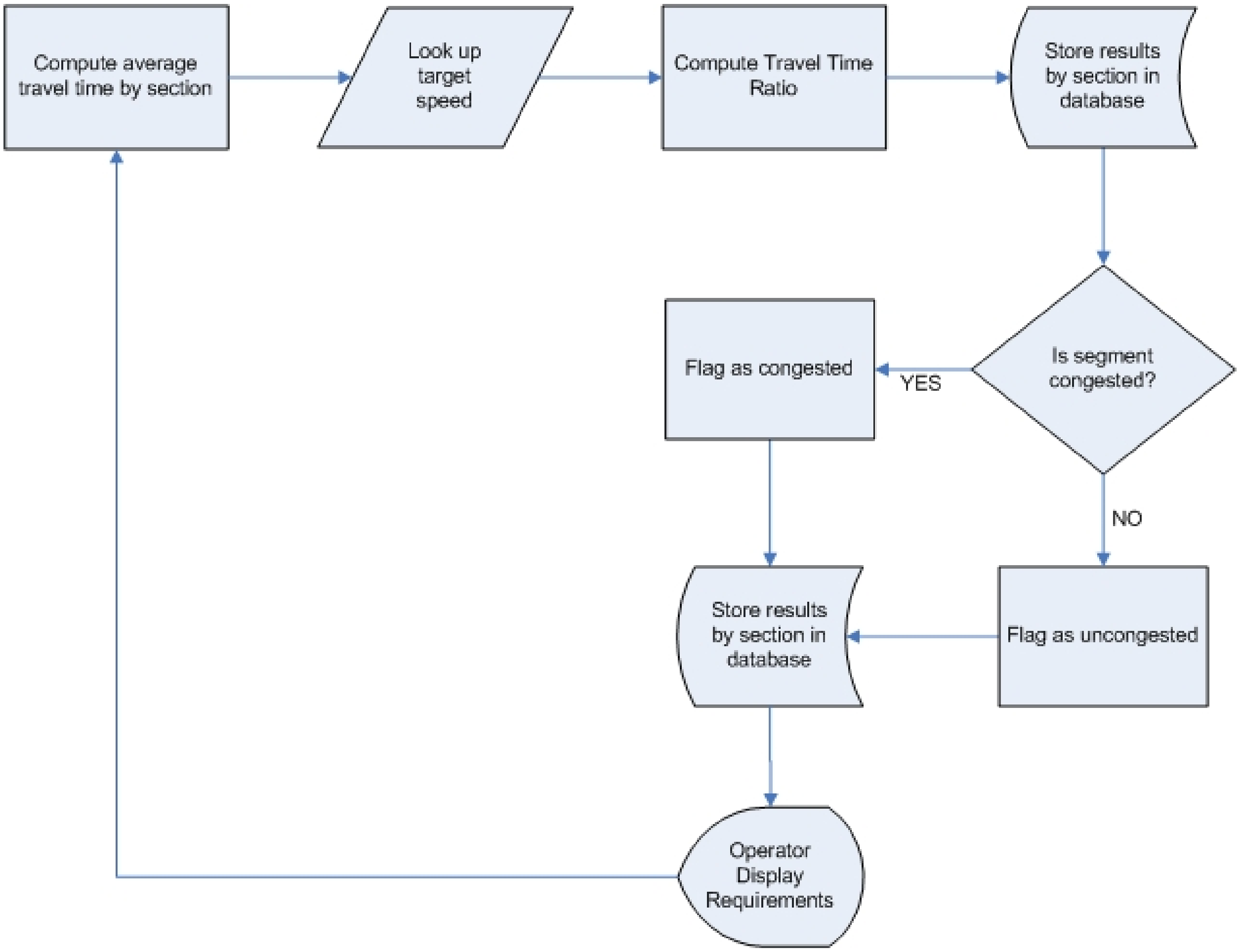
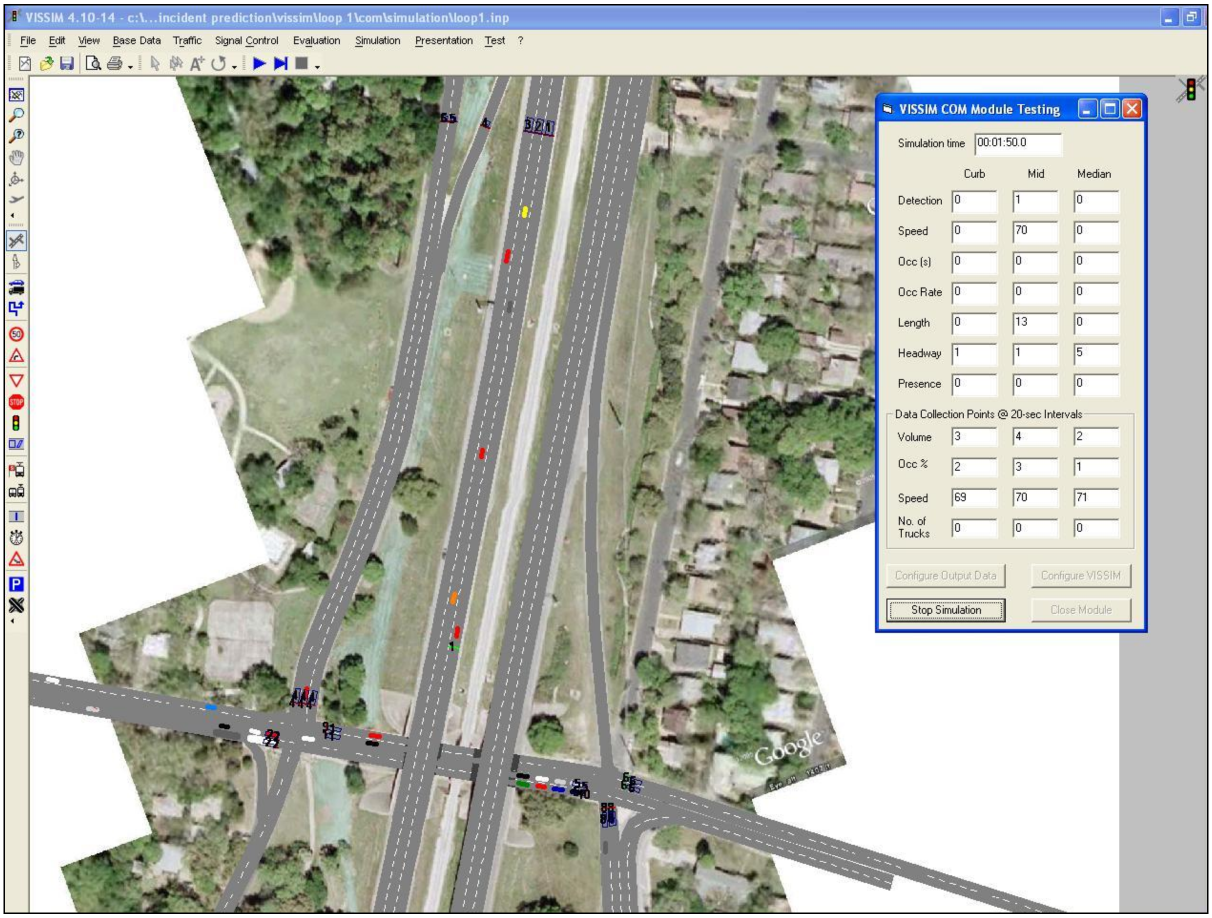


Figure 4. Methodology for Extent of Congestion-Spatial Performance Measure.

CHAPTER 3:
COMPONENTS OF SYSTEM ARCHITECTURE

VISSIM SIMULATION MODEL

The simulation environment utilized for testing performance measures has been used before by research performed for the Texas Department of Transportation (TxDOT) on Project 0-4946, “Dynamic Traffic Flow Modeling for Incident Detection and Short-Term Congestion Prediction.” A seven-mile freeway segment of Loop 1 located in the west of Austin, Texas, from US 183 to Lake Austin Blvd was selected as a simulation test bed. Loop detectors were placed along the simulated network to generate detector observations. The Austin detector mapbook was consulted to ensure that detector placement in the simulated network corresponds with actual locations. The test bed consists of a total of 69 individual inductive loop detectors on various mainline and ramp sections. Figure 5 shows a screen capture of the simulation network.



Simulation time 00:01:50.0

	Curb	Mid	Median
Detection	0	1	0
Speed	0	70	0
Occ (s)	0	0	0
Occ Rate	0	0	0
Length	0	13	0
Headway	1	1	5
Presence	0	0	0

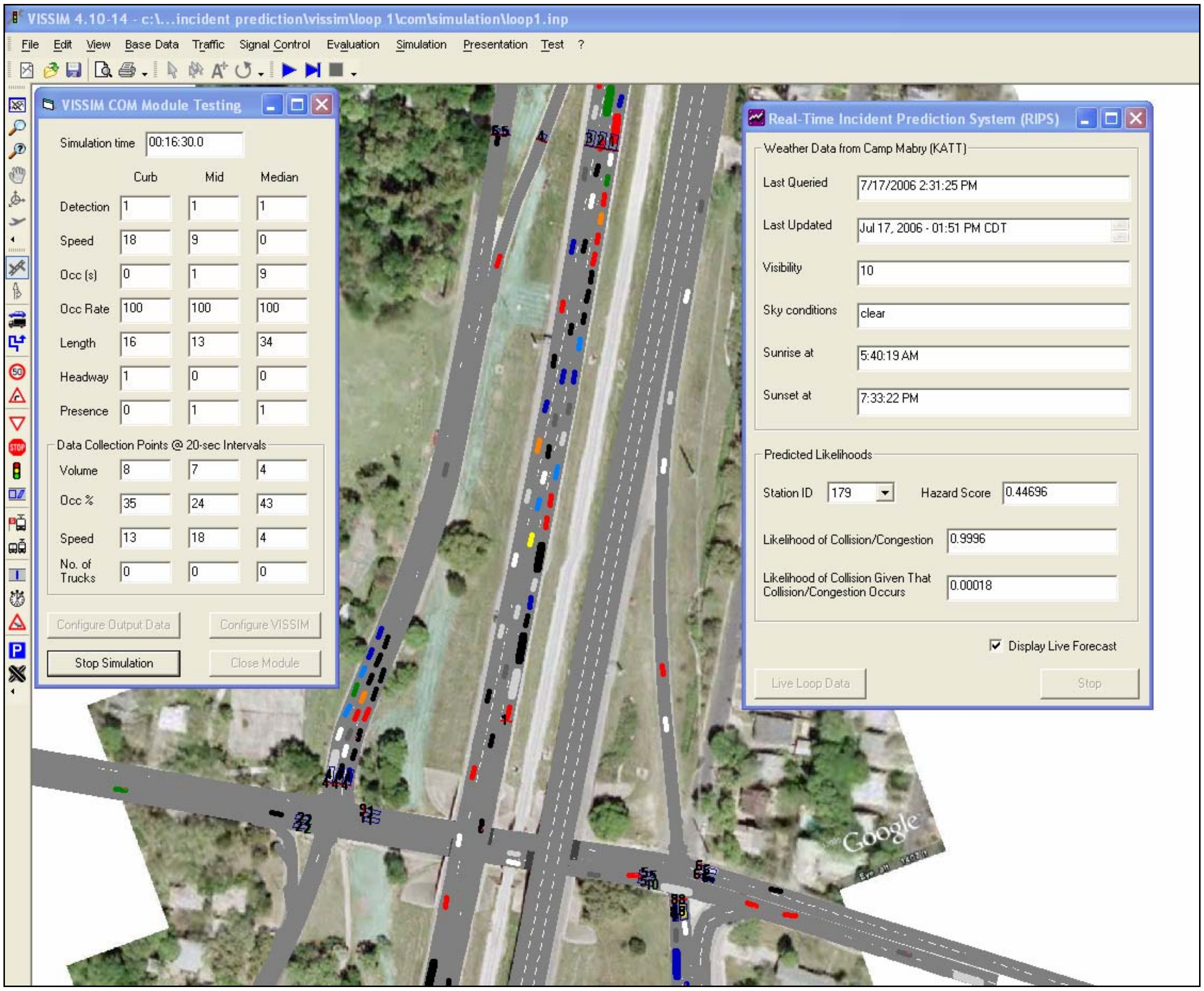
Data Collection Points @ 20-sec Intervals

	Curb	Mid	Median
Volume	3	4	2
Occ %	2	3	1
Speed	69	70	71
No. of Trucks	0	0	0

Figure 5. VISSIM Simulation Network.

As with most simulation programs, VISSIM works on the concept of links and nodes. The simulation consists of multiple links, each an individual length. Separation into the links was determined by a number of factors, including the presence of ramps and lane additions or drops.

In order to generate congestion during the simulation, a single-lane-block incident was coded in the simulated network using vehicle actuated programming (VAP). This disturbance in the normal traffic flow will illustrate the effects of changes in the traffic flow parameters on the NTOC performance measures. The location, start time, and duration of the incident is all specified and can be modified by the user. For the purposes of the experimental scenario, a test incident scenario was a one-lane-blocked incident that lasted for 10 minutes near the south terminus of the test bed. Figure 6 shows a screen capture of the simulation environment during incident conditions.



Simulation time 00:16:30.0

	Curb	Mid	Median
Detection	1	1	1
Speed	18	9	0
Occ (s)	0	1	9
Occ Rate	100	100	100
Length	16	13	34
Headway	1	0	0
Presence	0	1	1

Data Collection Points @ 20-sec Intervals

	Curb	Mid	Median
Volume	8	7	4
Occ %	35	24	43
Speed	13	18	4
No. of Trucks	0	0	0

Weather Data from Camp Mabry (KATT)

Last Queried 7/17/2006 2:31:25 PM
Last Updated Jul 17, 2006 - 01:51 PM CDT
Visibility 10
Sky conditions clear
Sunrise at 5:40:19 AM
Sunset at 7:33:22 PM

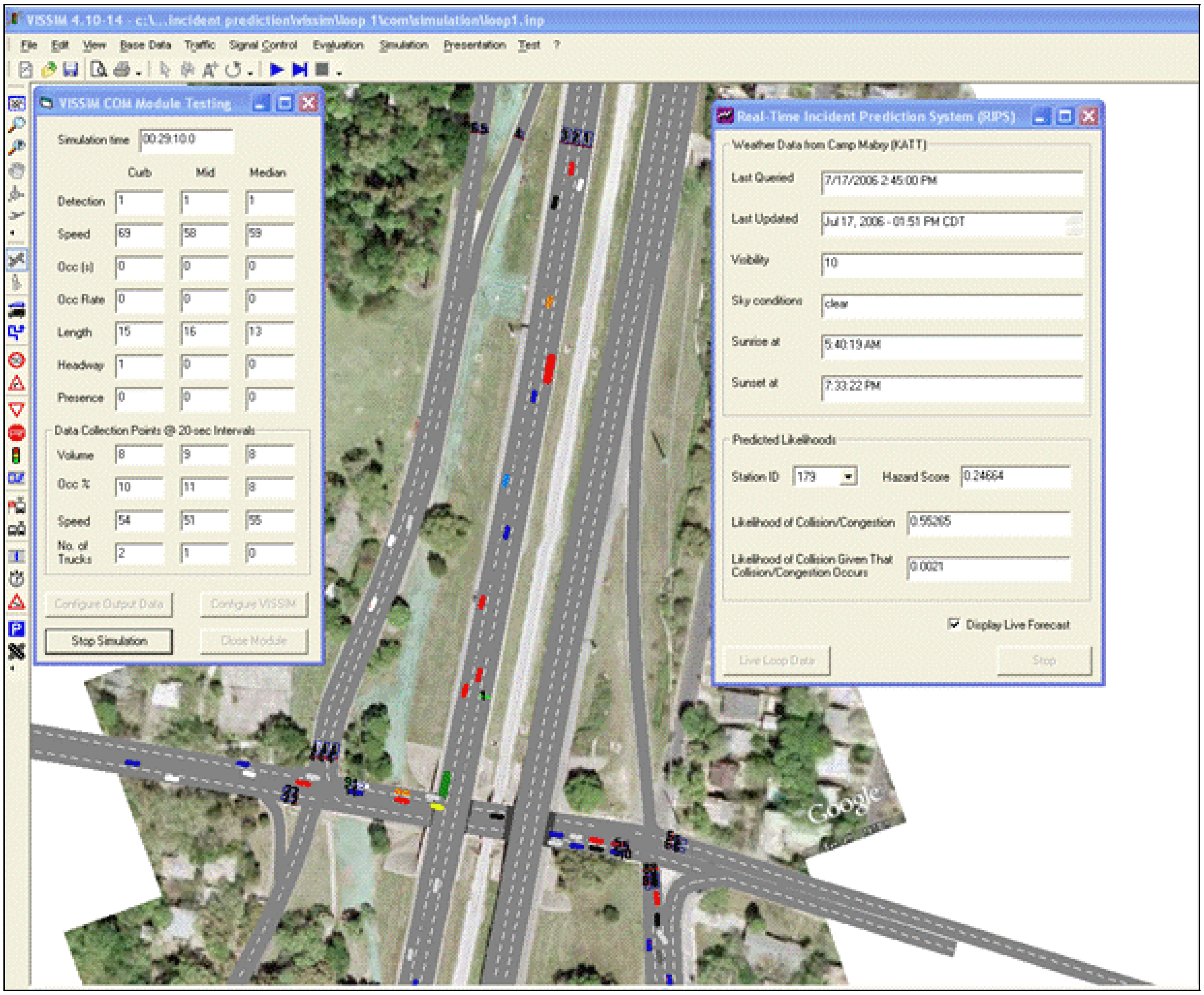
Predicted Likelihoods

Station ID 179
Hazard Score 0.44696
Likelihood of Collision/Congestion 0.9996
Likelihood of Collision Given That Collision/Congestion Occurs 0.00018

☑ Display Live Forecast

Figure 6. VISSIM Simulation Network During Incident Conditions.

Figure 7 shows a screen capture of the simulation environment after the incident has expired and traffic has cleared.



Simulation time 00:29:10.0

	Curb	Mid	Median
Detection	1	1	1
Speed	69	58	59
Occ (s)	0	0	0
Occ Rate	0	0	0
Length	15	16	13
Headway	1	0	0
Presence	0	0	0
Data Collection Points @ 20-sec Intervals			
Volume	8	9	8
Occ %	10	11	8
Speed	54	51	55
No. of Trucks	2	1	0

Weather Data from Camp Mabry (KATT)

Last Queried 7/17/2006 2:45:00 PM
Last Updated Jul 17, 2006 - 01:51 PM CDT
Visibility 10
Sky conditions clear
Sunrise at 5:40:19 AM
Sunset at 7:33:22 PM

Predicted Likelihoods

Station ID 179
Hazard Score 0.24664
Likelihood of Collision/Congestion 0.55265
Likelihood of Collision Given That Collision/Congestion Occurs 0.0021

☑ Display Live Forecast

Figure 7. VISSIM Simulation Network After Incident Clearance.

DATA MANAGEMENT

There are two aspects, or programs, in use within the data management portion of the simulation architecture.

Data Export Program

The first program retrieves the data from the simulation through the use of a custom application developed for the 0-4946 project. The application software was developed using the Visual Basic (VB) programming environment and integrating the VISSIM COM capability through VB's graphical user interface. The VISSIM COM environment is designed for users to control and observe changes in traffic parameters in run-time. The software retrieves the simulated loop detector data from VISSIM and aggregates them into a 20-second data format similar to the Local Control Units (LCUs) in use by TxDOT. These values are output to a data file. Each value is appended to the file so that there is a running history of all values throughout the timeframe of the simulation.

20-Second Data From Simulation Model

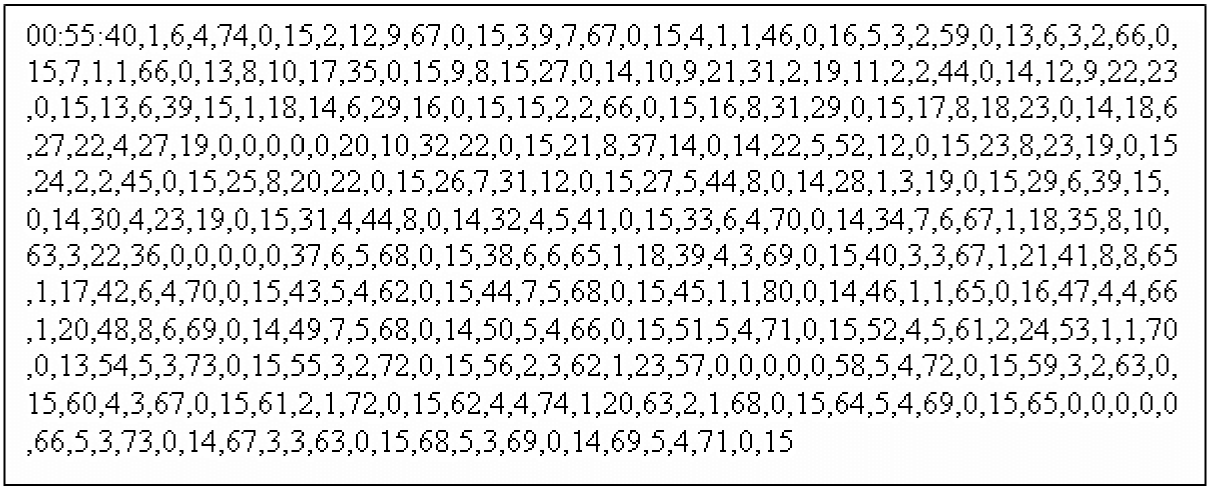
Each 20-second increment contains the following data on a per lane basis:

- Time stamp – expressed in time from the beginning of the simulation, in Hours, Minutes, and Seconds (HHMMSS);
- Detector number – the identification number of the detector to which the following values apply;
- Volume – the total number of vehicles passing over the simulation detector within the past 20 seconds, expressed in vehicles;
- Occupancy – the amount of time the simulation detector was occupied by a vehicle within the past 20 seconds, expressed as a percent;
- Speed – the average of all lane specific speeds of vehicles passing over the simulation detector within the past 20 seconds, expressed in miles per hour;
- Percent trucks – the vehicles in the 20-second vehicle stream that are reported by the simulation as being trucks, expressed as a percentage of the total number of vehicles; and
- Average vehicle length – the average length of all the vehicles passing over the detector in question in the last 20 seconds, expressed in feet.

Data Feed

The data feed from the simulation is created as a comma delimited text string. Each 20-second data string is appended to the end of the open text file during the simulation run, so that the entire data stream of the simulation is recorded for historical purposes. Figure 8 shows an example of the 20-second data stream.

The figure shows an initial entry of 00:55:40, representing the simulation time of 0 Hours, 55 Minutes, and 40 Seconds. Table 2 shows how the data stream can be deciphered, using the comma delimited format and the known sequence of detector number, volume, occupancy, speed, percent trucks, and average vehicle length.



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00:55:40,1,6,4,74,0,15,2,12,9,67,0,15,3,9,7,67,0,15,4,1,1,46,0,16,5,3,2,59,0,13,6,3,2,66,0,
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```

Figure 8. Comma Delimited 20-Second Data Feed from Simulation.

Table 2. Identification of Data Parameters from 20-Second Data File.

Simulation Time	00 Hours, 55 Minutes, 40 Seconds						
Detector number	1	2	3	4	…	68	69
Volume	6	12	9	1	…	5	5
Occupancy	4	9	7	1	…	3	4
Speed	74	67	67	46	…	69	71
Percent trucks	0	0	0	0	…	0	0
Average vehicle length	15	15	15	16	…	14	15

Data Calculation Program – One-Minute Detector Calculations

While each 20-second data string from the simulation is stored in an external text file, the last 15 20-second records are also kept and stored in memory. This shared memory is used by the second data manager program to produce the one-minute detector calculation values. The process of using shared memory is much faster than file access. The shared memory is constantly changed by dropping the oldest 20-second value at the end of the stack and adding in the most current 20-second value at the front of the stack.

Every minute, the last three valid 20-second data feeds from the shared memory are combined into a 1-minute data feed on a per-lane basis. These 1-minute values are then combined into detector station values, which average the values across all lanes in the detector station. This process replicates the procedure used for roadway data implementations within TxDOT.

The 1-minute detector station values that are calculated for use within the simulation environment are:

- Volume – the total number of vehicles passing over the simulation detector within the past 1 minute, expressed in vehicles;
- Average Occupancy – the average amount of time the simulation detector was occupied by a vehicle within the past 1 minute, expressed as a percent;
- Average Speed – the average of all lane specific speeds of vehicles passing over the simulation detector within the past 1 minute, expressed in miles per hour;
- Percent Trucks – the ratio of vehicles in the 1-minute vehicle stream that are reported by the simulation as being trucks, expressed as a percent.

Validity Checks

The processing program for the 20-second data contains some rudimentary validity checking to ensure that data being received are representative of real conditions. This is similar to the validity checks that take place in the TxDOT Advanced Traffic Management System (ATMS) using the LCU and System Control Unit (SCU). Currently, the following validity checks are performed:

1. If Occupancy=0 and Speed=0, and Volume >0 then the data are considered invalid and ignored.
2. If Occupancy=0 and Volume=0 and Speed is >0, then the data are considered valid and ignored.

These basic checks essentially cover the problem of spurious data. While this event is unlikely during a simulation run, such data issues are common in real-world implementations.

Volume

The calculation of volume is a two-step process. Step 1 is to compute the total lane volume in the 1-minute time period as the sum of the individual volumes from the last three valid 20-second data intervals. The 1-minute lane volume calculation can be expressed as:

$$VOLUME_{lane\ (j)} = \sum_{i=1}^{3} VOLUME_{(i)} \qquad \textbf{\textit{Eq. 5}}$$

Where:

$VOLUME_{lane\ (j)}$ = 1-minute volume summary, per lane

$VOLUME_{(i)}$ = 20-second volume count, per lane

i = 20-second count index

j = lane count index.

The detector station volume average is then computed as the average of the 1-minute lane volumes as shown in *Eq. 6*.

$$VOLUME_{station\ (k)} = \frac{\sum_{j=1}^{3} VOLUME_{lane\,(j)}}{n} \qquad \textbf{\textit{Eq. 6}}$$

Where:

$VOLUME_{station\ (k)}$ = 1-minute detector station volume

$VOLUME_{lane\ (j)}$ = 1-minute volume summary, per lane

j = lane count index

k = station count index

n = number of lanes.

Occupancy

The calculation of occupancy is also a two-step process and mirrors the calculations for volume. Step 1 is to compute the average lane occupancy in the 1-minute time period using *Eq. 7*.

$$OCCUPANCY_{lane\ (j)} = \frac{\sum_{i=1}^{3} OCCUPANCY_{(i)}}{3} \qquad \textbf{\textit{Eq. 7}}$$

Where:

$OCCUPANCY_{lane\ (j)}$ = 1-minute occupancy summary, per lane

$OCCUPANCY_{(i)}$ = 20-second occupancy count, per lane

i = 20-second count index

j = lane count index.

The detector station occupancy average is then computed as the average of the 1-minute lane occupancies as shown in *Eq. 8*.

$$OCCUPANCY_{station\ (k)} = \frac{\sum_{j=1}^{3} OCCUPANCY_{lane\ (j)}}{n} \qquad \textbf{\textit{Eq. 8}}$$

Where:

$OCCUPANCY_{station\ (k)}$ = 1-minute detector station occupancy

$OCCUPANCY_{lane\ (j)}$ = 1-minute occupancy average, per lane

j = lane count index

k = station count index

n = number of lanes.

Speed

The calculation of speed as performed by TxDOT field implementations is also a two-step process but it incorporates a weighting by volume. The first step multiplies speed by volume for each of the three, 20-second time periods in the 1-minute calculation period. This is shown in *Eq. 9* and produces a 1-minute volume-weighted speed value for each lane.

$$SPEED_{lane\ (j)} = \sum_{i=1}^{3} SPEED_{(i)} * VOLUME_{(i)} \qquad \textbf{\textit{Eq. 9}}$$

Where:

$SPEED_{lane\ (j)}$ = 1-minute volume weighted speed, per lane

$SPEED_{(i)}$ = 20-second computed speed, per lane

$VOLUME_{(i)}$ = 20-second volume count, per lane

i = 20-second count index

j = lane count index.

The second part of the process then calculates the average weighted speed across the entire station by *Eq. 10*.

$$AVERAGE\ WEIGHTED\ SPEED_{station\ (k)} = \frac{\sum_{j=1}^{3} SPEED_{lane\,(j)}}{\sum_{j=1}^{3} VOLUME_{lane\,(j)}} \qquad \textbf{Eq. 10}$$

Where:

$AVERAGE\ WEIGHTED\ SPEED_{station\ (k)}$ = 1-minute station average speed

$SPEED_{lane\ (j)}$ = 1-minute volume weighted speed, per lane

$VOLUME_{lane\ (j)}$ = 1-minute volume summary, per lane

k = station count index

j = lane count index.

Percent Trucks

The calculation of percent trucks is also performed in a two-step process. Because the simulation environment produces a value of percent trucks, the first step of the calculation is to determine the number of trucks during the 1-minute time period as shown in *Eq. 11*.

$$NUMBER\ OF\ TRUCKS_{lane\ (j)} = \sum_{i=1}^{3} PERCENT\ TRUCKS_{(i)} * VOLUME_{(i)} \qquad \textbf{Eq. 11}$$

Where:

$NUMBER\ OF\ TRUCKS_{lane\ (j)}$ = 1-minute number of trucks, per lane

$PERCENT\ TRUCKS_{(i)}$ = 20-second percent trucks value, per lane

$VOLUME_{(i)}$ = 20-second volume count, per lane

i = 20-second count index

j = lane count index

The calculation of the percentage of trucks across the entire detector station is then performed using *Eq. 12*, which divides the sum of the 1-minute truck values across all lanes by the total volume across all lanes. The detector station percent trucks calculation is performed in this manner to account for uneven volumes during the 20-second time periods, which would skew the final percent trucks number if a simple average were taken.

$$PERCENT\ TRUCKS_{station\ (k)} = \frac{\sum_{j=1}^{3} NUMBER\ OF\ TRUCKS_{lane(j)}}{\sum_{j=1}^{3} VOLUME_{lane(j)}} \qquad \textbf{\textit{Eq. 12}}$$

Where:

$PERCENT\ TRUCKS_{station\ (k)}$ = 1-minute station average speed

$NUMBER\ OF\ TRUCKS_{lane\ (j)}$ = 1-minute sum of the number of trucks, per lane

$VOLUME_{lane\ (j)}$ = 1-minute volume summary, per lane

k = station count index

j = lane count index

DATABASE

Perhaps one of the most critical aspects of testing a real-time performance measurement application to operations is defining a storage medium to use when performing calculations pertaining to the various measures. While using shared memory for the most recent fifteen records of 20-second data works well, the use of shared memory is not practical for storing calculation results over the course of the entire simulation. For both that reason and the additional aspect of keeping an archive of the data produced by the various calculations, the use of an external storage mechanism is an integral component of the system architecture for the prototype performance measures application.

The research team developed the prototype database by looking not only at the calculations required for the two measures tested in the prototype, but by examining a number of calculations required for the NTOC measures that have potential for real-time application. As stated previously, some NTOC measures such as ‘Customer Satisfaction’ are not suitable for real-time use by the nature of the required data collection. In addition to the measures for NTOC, the research team theorized two additional measures, using delay as a substitute for travel time.

Figure 9 assembles the required calculations into one flowchart. The box in the upper-left corner labeled "detector station data" represents the 1-minute data calculated for each detector station. These calculations were detailed in *Eq. 5* through *12*. The second box on the left of the diagram shows the simulation parameters, such as the length of the link and the travel time under free-flow conditions (TT_Free). The box on the right of the diagram shows the output data accumulated across all the calculations made for the NTOC performance measures.

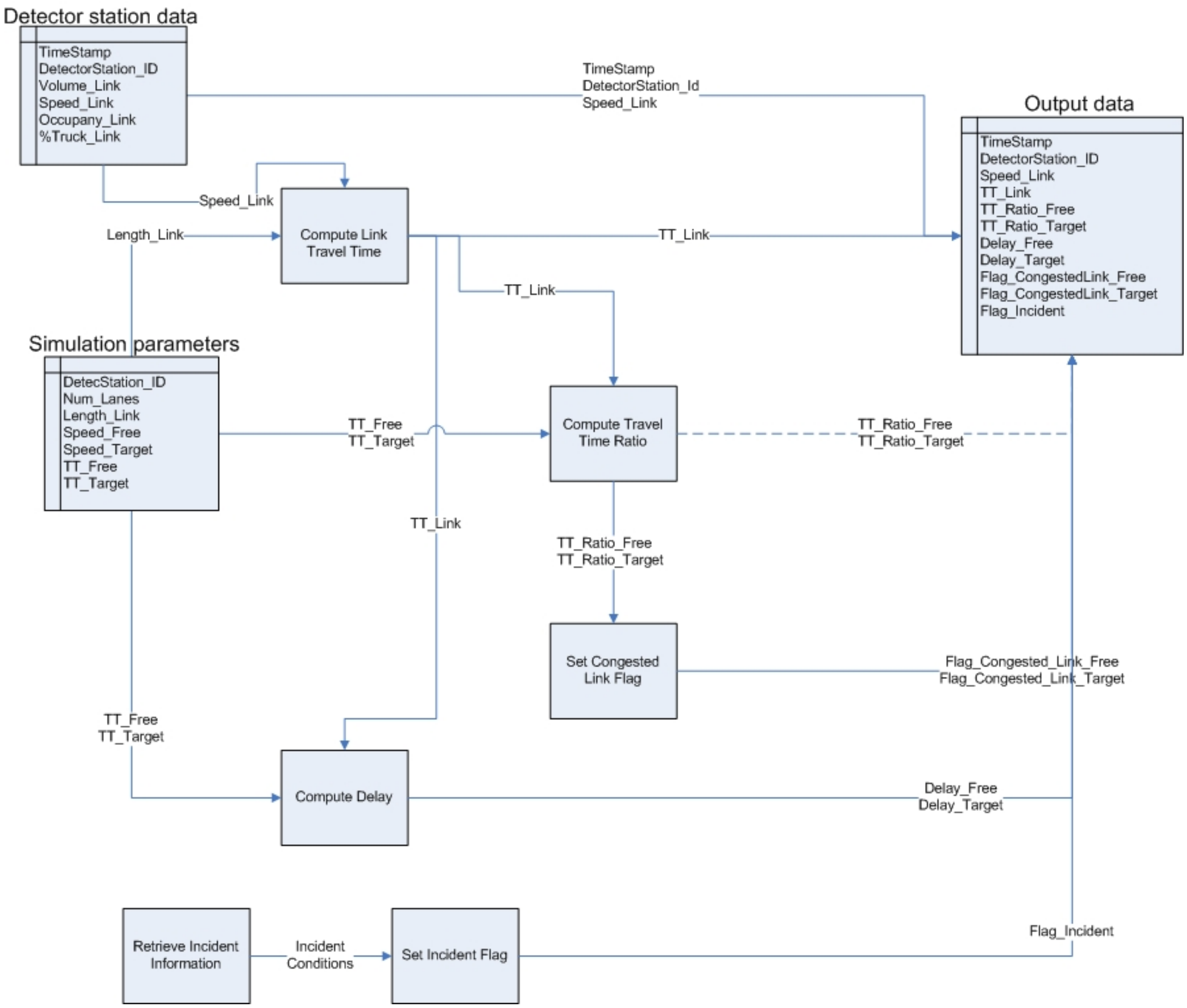


Figure 9. Flowchart of Performance Measure Calculations.

Table 3 details the parameters in Figure 9. The table is organized by abbreviation to match the figure, with additional columns detailing the explanation of the parameter, the type (Input, Calculation, or Output), and the units associated with each item.

Table 3. Parameters Used in Performance Measurement Calculations.

Abbreviation	Explanation	Type	Units
TimeStamp	Time stamp since beginning of simulation	Input/Output	Time (HHMMSS)
DetectorStation_ID	Unique identification number of detector station	Input/Output	Unitless
Num_Lanes	The number of lanes in the detector station	Input	Number of lanes
Length_Link	The length of each link in the simulation	Input	Feet
Speed_Free	Unconstrained (free flow) speed on the link	Input	Miles per hour
Speed_Target	Operator desired speed on the link	Input	Miles per hour
TT_Free	Unconstrained (free flow) travel time on the link	Input/Calculated	Minutes
TT_Target	Operator desired travel time on the link	Input/Calculated	Minutes
Volume_Link	Calculated 1-minute detector station volume	Calculated	Vehicles per hour
Speed_Link	Calculated 1-minute detector station speed	Calculated/Output	Miles per hour
Occupancy_Link	Calculated 1-minute detector station occupancy	Calculated	Unitless
%Truck_Link	Calculated 1-minute detector station percent trucks	Calculated	Unitless
TT_Link	Calculated travel time on link	Calculated/Output	Minutes
TT_Ratio_Free	Calculated travel time ratio on link (current to desired free)	Calculated/Output	Unitless
TT_Ratio_Target	Calculated travel time ratio on link (current to desired target)	Calculated/Output	Unitless
Flag_Congested_Link_Free	Congestion flag for links calculated on basis of TT_Free	Calculated/Output	Unitless
Flag_Congested_Link_Target	Congestion flag for links calculated on basis of TT_Target	Calculated/Output	Unitless
Delay_Free	Calculated link delay based on free flow speed	Calculated/Output	Minutes
Delay_Target	Calculated link delay based on target speed	Calculated/Output	Minutes
Flag_Incident	Congestion flag for presence of incident	Calculated/Output	Unitless

The research team designed the database for the system architecture in Microsoft Access®. Figure 10 shows that the database has three tables. 'DetStation' and 'Detector' contain static information pertaining to the configuration of the scenario in the simulation, while the 'TravelTimeOutput' table contains the results of the performance measure calculations at the 1-minute intervals. Table 4 through Table 6 detail the components of each table in the database.

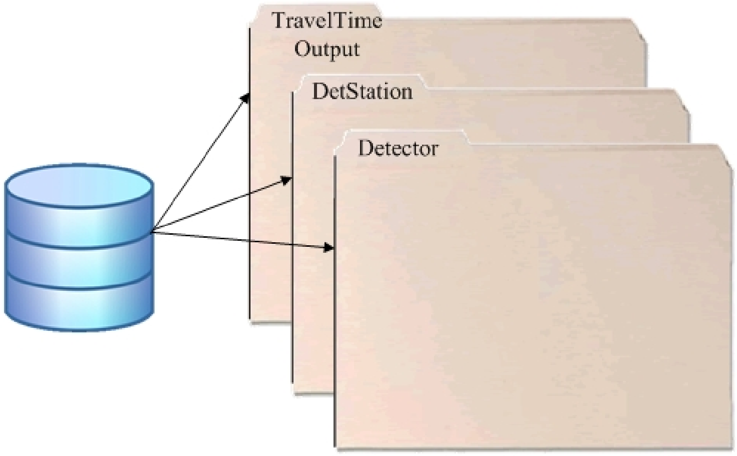


Figure 10. Access Database Used in System Architecture.

Table 4. 'Detector' Table Elements.

Field Name	Field Data Type	Description
Det_station_ID	Integer Number	Detector Station ID
Det_ID	Integer Number	Detector ID

Table 5. 'DetStation' Table Elements.

Field Name	Field Data Type	Description
Det_station_ID	Integer Number	Detector Station ID
Num_dets	Integer Number	Number of lanes at this detector station
Length_link	Double Number	Length of the link represented by the detector station
TT_free_speed	Double Number	Link free speed
TT_target_speed	Double Number	Link target speed
TT_free	Double Number	Link travel time at free speed in hours
TT_free_sec	Double Number	Link travel time at free speed in seconds
TT_free_min	Double Number	Link travel time at free speed in minutes
TT_target	Double Number	Link travel time at target speed in hours
TT_target_sec	Double Number	Link travel time at target speed in seconds
TT_target_min	Double Number	Link travel time at target speed in minutes

Table 6. 'TravelTimeOutput' Table Elements.

Field Name	Field Data Type	Description
Det_station_ID	Integer Number	Detector Station ID
Length_link	Double Number	Length of the link represented by the detector station
Time_stamp	Text – 11 characters	The 20-second time interval. Time stamp starts at 00:00:00 (HH:MM:SS)
Speed_link	Integer Number	Current 20-second average speed of link
TT_link	Double Number	Link travel time at current 20-second speed in hours
TT_link_sec	Double Number	Link travel time at current 20-second speed in seconds
TT_link_min	Double Number	Link travel time at current 20-second speed in minutes
TT_ratio_free	Double Number	Ratio of the link travel time at current speed to link travel time at free speed
TT_ratio_target	Double Number	Ratio of the link travel time at current speed to link travel time at target speed
Delay_free	Double Number	Difference between link travel time at current speed and link travel time at free speed
Delay_target	Double Number	Difference between link travel time at current speed and link travel time at target speed
Congested_free_link_flag	Yes/No	If TT_ratio_free > 1.3 ➔ link is congested
Congested_target_link_flag	Yes/No	If TT_ratio_target > 1.3 ➔ link is congested
Incident_flag	Yes/No	

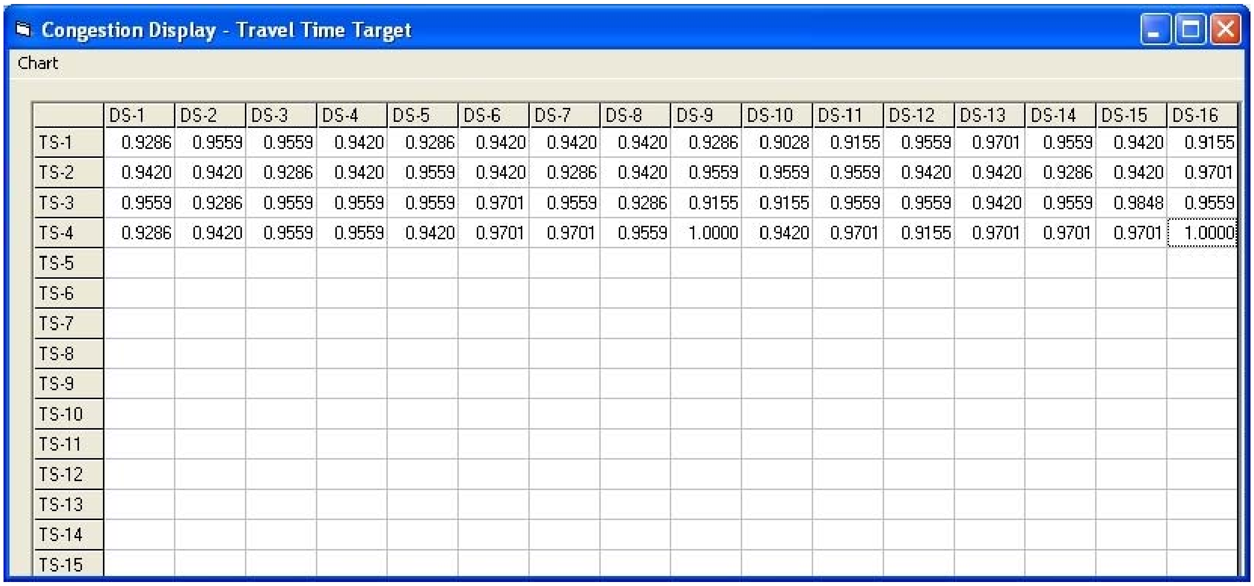
CHAPTER 4:
OPERATOR DISPLAYS

INTRODUCTION TO OPERATOR'S DISPLAYS

One of the deliverables specified for this project was prototype displays of an operator's screen. Combined with the calculation methodology and prototype measures, the operator's screens shown herein can function as a thought-provoking development roadmap for future versions of an operator interface to real-time monitoring. The project team is under no illusion that the displays below are the only acceptable displays. In fact, these displays are meant to illustrate basic principles and show how information can be viewed and used effectively across a wide segment of roadway. No attempt has been made to address the higher-order visual aspects of the screens to make them 'pretty'.

The project proposal called for mock-ups of screens with no functioning code or software components providing the data. As detailed in the Year Two project meetings, the project team took a departure from that philosophy and created a working system as detailed in the previous chapters. Therefore, the following prototype screens are actual screens of a simulation run, being served by real-time data. The project team felt it best to pursue this additional work effort and ensure that the screens being presented were functional and illustrative of the actual information that can be presented for real-time analysis of performance measures.

Each screen presented below utilizes a strip chart concept. Figure 11 illustrates a sample screen. The horizontal axis at the top of the screen is labeled with DS-1, DS-2, etc. These labels represent the detector stations in the simulation. There are 16 total detector stations on the main lanes. The vertical axis represents 1-minute time slices (TS) in the simulation, labeled as TS-1, TS-2, etc. The value within each cell of the strip chart is the specific performance measure calculated at that detector station for that time slice. Note that the time slice labels are static and do not 'roll', i.e., advance, past TS-15. The actual time in the simulation is advancing, as will be evidenced by the changing values of the performance measure in the strip chart cells. The most current time slice values will come in at the bottom of the screen and roll upward as simulation time advances. Future versions of these operator displays would roll the time slice label to represent the physical time of the simulation.

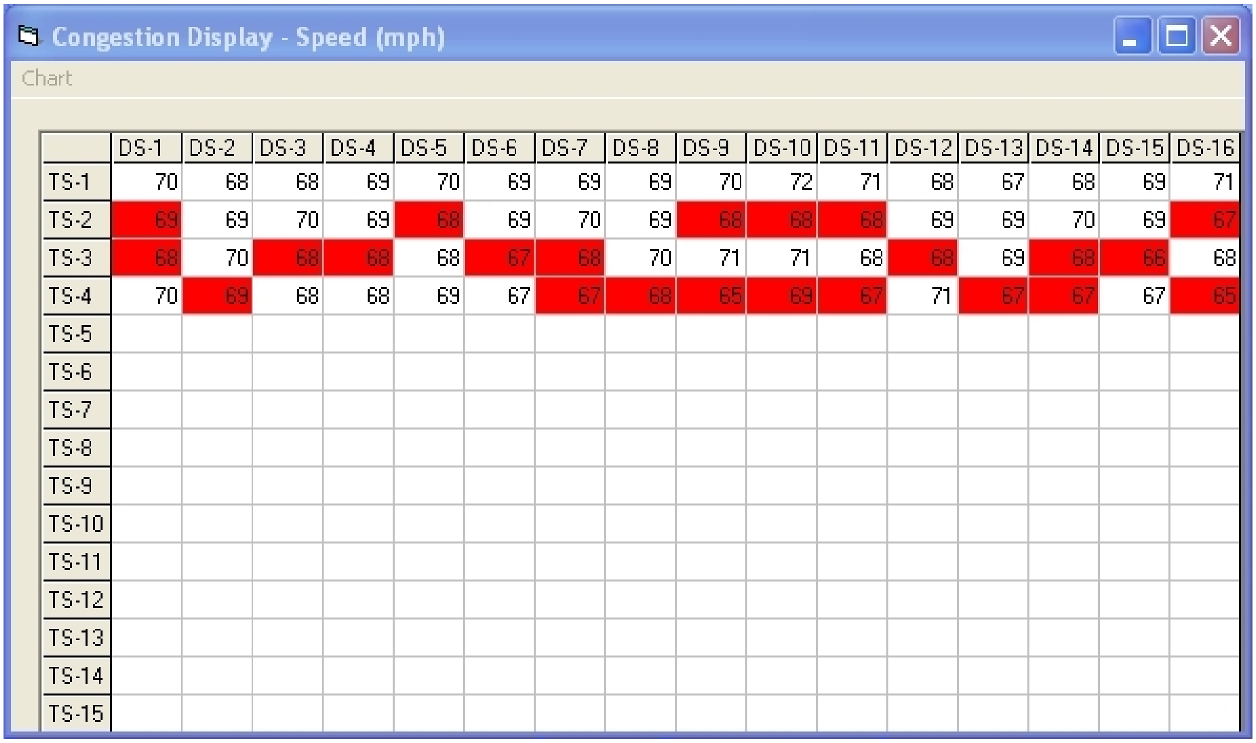


	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9286	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9420	0.9286	0.9028	0.9155	0.9559	0.9701	0.9559	0.9420	0.9155
TS-2	0.9420	0.9420	0.9286	0.9420	0.9559	0.9420	0.9286	0.9420	0.9559	0.9559	0.9559	0.9420	0.9420	0.9286	0.9420	0.9701
TS-3	0.9559	0.9286	0.9559	0.9559	0.9559	0.9701	0.9559	0.9286	0.9155	0.9155	0.9559	0.9559	0.9420	0.9559	0.9848	0.9559
TS-4	0.9286	0.9420	0.9559	0.9559	0.9420	0.9701	0.9701	0.9559	1.0000	0.9420	0.9701	0.9155	0.9701	0.9701	0.9701	1.0000
TS-5																
TS-6																
TS-7																
TS-8																
TS-9																
TS-10																
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

Figure 11. Strip Chart Concept for Operator Displays.

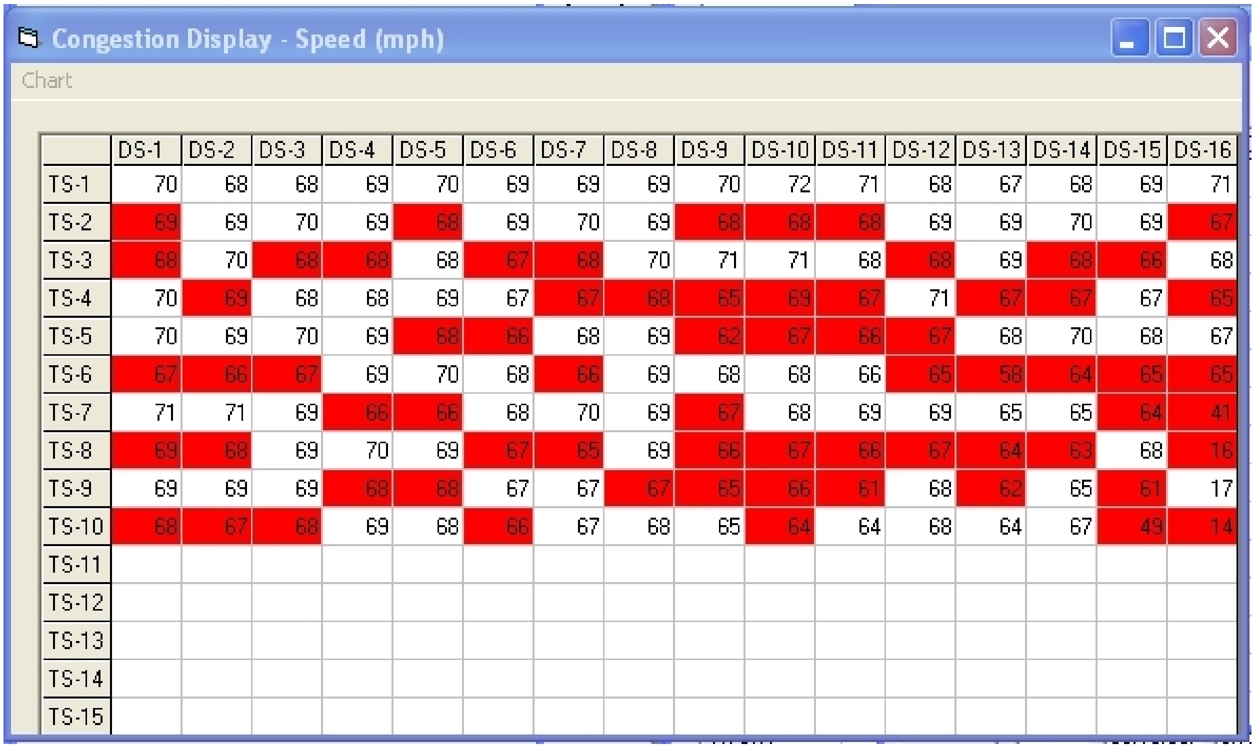
Speed

One of the most basic measures of any roadway condition is speed. The research team built a speed strip chart to help illustrate the concept of how the charts work. Figure 12 through Figure 15 show the strip charts for speed. Red values indicate a decrease in speed in the section



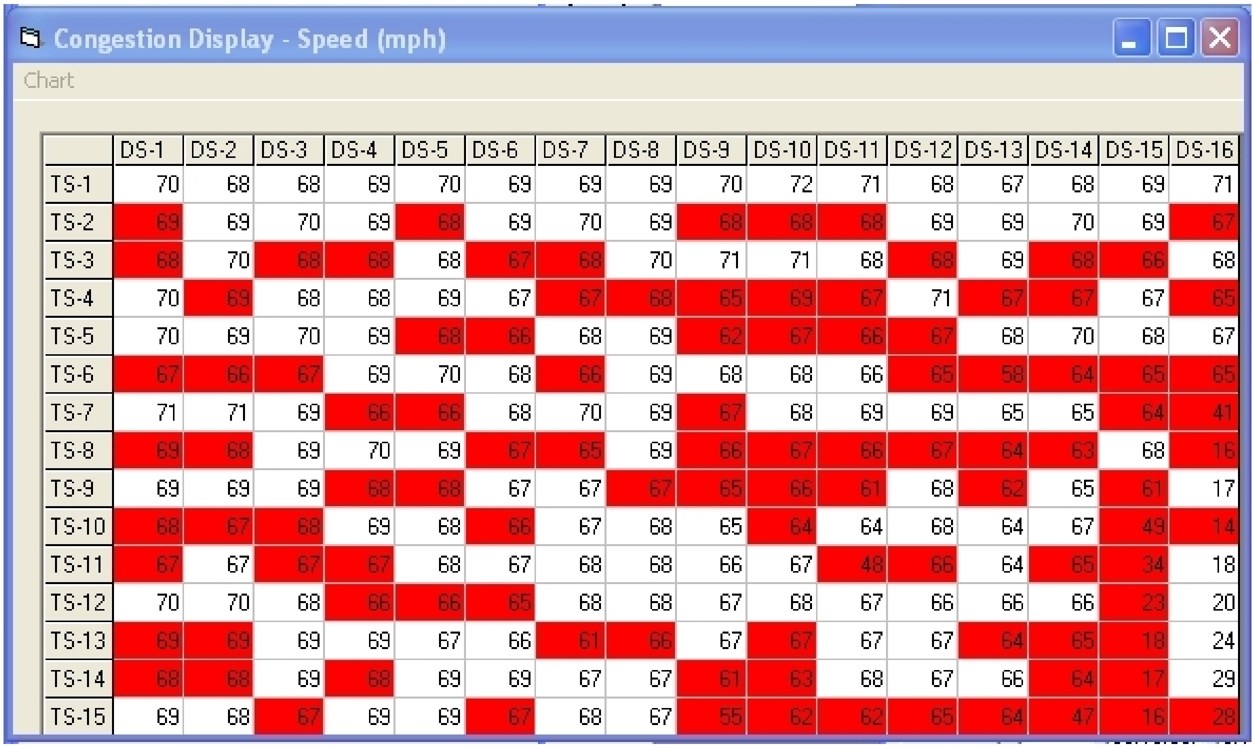
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	70	68	68	69	70	69	69	69	70	72	71	68	67	68	69	71
TS-2	69	69	70	69	68	69	70	69	68	68	68	69	69	70	69	67
TS-3	68	70	68	68	68	67	68	70	71	71	68	68	69	68	66	68
TS-4	70	69	68	68	69	67	67	68	65	69	67	71	67	67	67	65
TS-5																
TS-6																
TS-7																
TS-8																
TS-9																
TS-10																
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

Figure 12. Speed Strip Chart at 4-Minute Simulation Time.



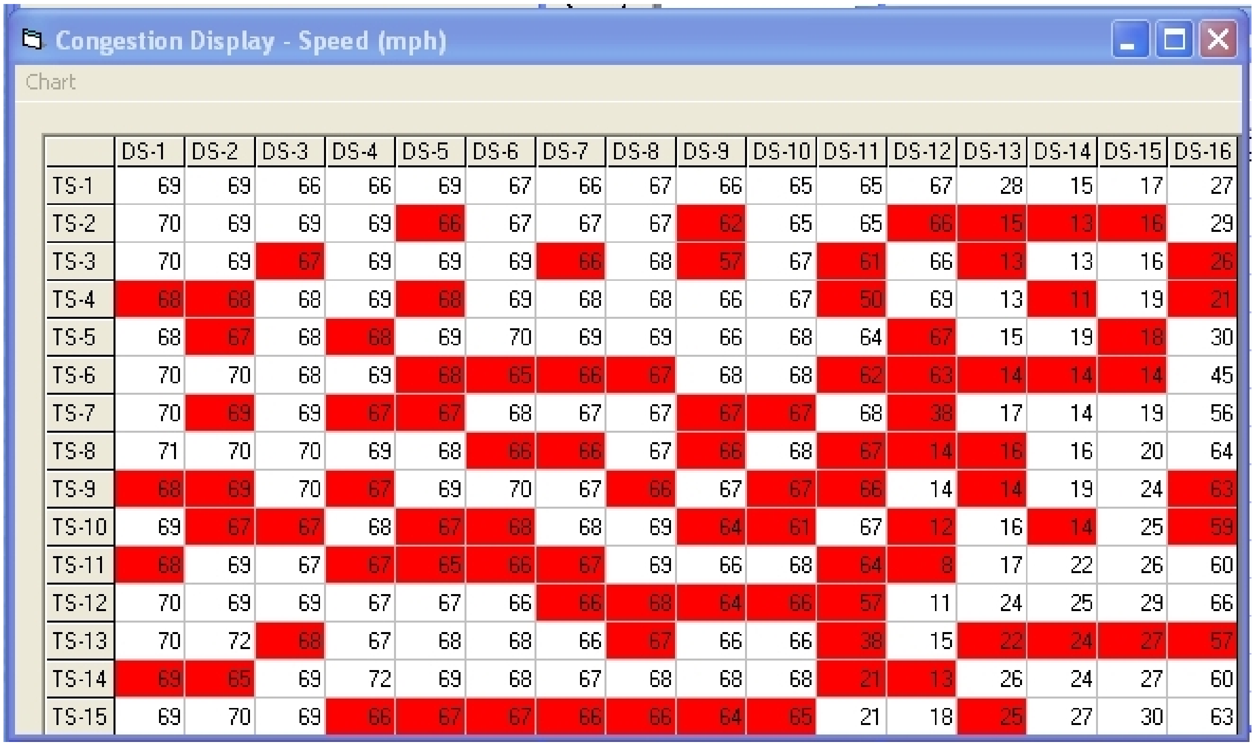
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	70	68	68	69	70	69	69	69	70	72	71	68	67	68	69	71
TS-2	69	69	70	69	68	69	70	69	68	68	68	69	69	70	69	67
TS-3	68	70	68	68	68	67	68	70	71	71	68	68	69	68	66	68
TS-4	70	69	68	68	69	67	67	68	65	69	67	71	67	67	67	65
TS-5	70	69	70	69	68	66	68	69	62	67	66	67	68	70	68	67
TS-6	67	66	67	69	70	68	66	69	68	68	66	65	58	64	65	65
TS-7	71	71	69	66	66	68	70	69	67	68	69	69	65	65	64	41
TS-8	69	68	69	70	69	67	65	69	66	67	66	67	64	63	68	16
TS-9	69	69	69	68	68	67	67	67	65	66	61	68	62	65	61	17
TS-10	68	67	68	69	68	66	67	68	65	64	64	68	64	67	49	14
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

Figure 13. Speed Strip Chart at 10-Minute Simulation Time.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	70	68	68	69	70	69	69	69	70	72	71	68	67	68	69	71
TS-2	69	69	70	69	68	69	70	69	68	68	68	69	69	70	69	67
TS-3	68	70	68	68	68	67	68	70	71	71	68	68	69	68	66	68
TS-4	70	69	68	68	69	67	67	68	65	69	67	71	67	67	67	65
TS-5	70	69	70	69	68	66	68	69	62	67	66	67	68	70	68	67
TS-6	67	66	67	69	70	68	66	69	68	68	66	65	58	64	65	65
TS-7	71	71	69	66	66	68	70	69	67	68	69	69	65	65	64	41
TS-8	69	68	69	70	69	67	65	69	66	67	66	67	64	63	68	16
TS-9	69	69	69	68	68	67	67	67	65	66	61	68	62	65	61	17
TS-10	68	67	68	69	68	66	67	68	65	64	64	68	64	67	49	14
TS-11	67	67	67	67	68	67	68	68	66	67	48	66	64	65	34	18
TS-12	70	70	68	66	66	65	68	68	67	68	67	66	66	66	23	20
TS-13	69	69	69	69	67	66	61	66	67	67	67	67	64	65	18	24
TS-14	68	68	69	68	69	69	67	67	61	63	68	67	66	64	17	29
TS-15	69	68	67	69	69	67	68	67	55	62	62	65	64	47	16	28

Figure 14. Speed Strip Chart at 15-Minute Simulation Time.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	69	69	66	66	69	67	66	67	66	65	65	67	28	15	17	27
TS-2	70	69	69	69	66	67	67	67	62	65	65	66	15	13	16	29
TS-3	70	69	67	69	69	69	66	68	57	67	61	66	13	13	16	26
TS-4	68	68	68	69	68	69	68	68	66	67	50	69	13	11	19	21
TS-5	68	67	68	68	69	70	69	69	66	68	64	67	15	19	18	30
TS-6	70	70	68	69	68	65	66	67	68	68	62	63	14	14	14	45
TS-7	70	69	69	67	67	68	67	67	67	67	68	38	17	14	19	56
TS-8	71	70	70	69	68	66	66	67	66	68	67	14	16	16	20	64
TS-9	68	69	70	67	69	70	67	66	67	67	66	14	14	19	24	63
TS-10	69	67	67	68	67	68	68	69	64	61	67	12	16	14	25	59
TS-11	68	69	67	67	65	66	67	69	66	68	64	8	17	22	26	60
TS-12	70	69	69	67	67	66	66	68	64	66	57	11	24	25	29	66
TS-13	70	72	68	67	68	68	66	67	66	66	38	15	22	24	27	57
TS-14	69	65	69	72	69	68	67	68	68	68	21	13	26	24	27	60
TS-15	69	70	69	66	67	67	66	66	64	65	21	18	25	27	30	63

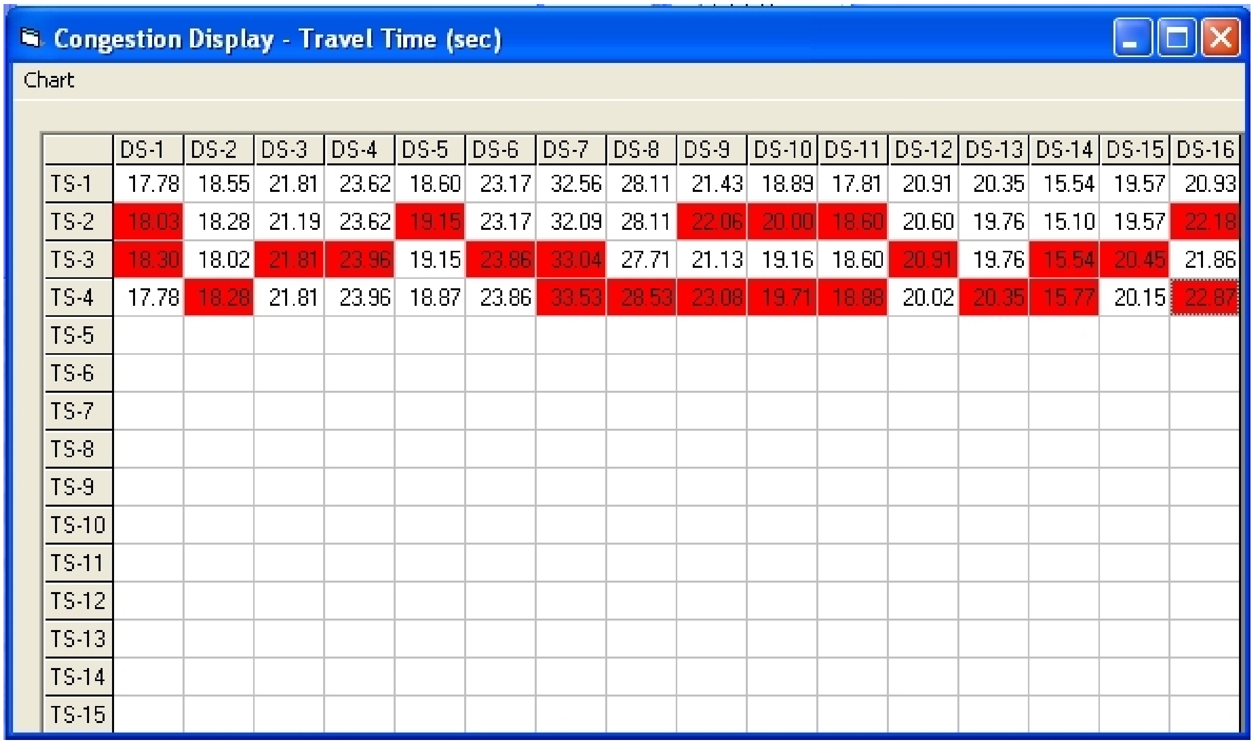
Figure 15. Speed Strip Chart at 20-Minute Simulation Time.

from the previous time slice. By itself, the indications of change in the speed parameter mean very little as they vary continuously in real-time. The highlighting, however, illustrates how the charts work. In practical application, the highlight would likely be restricted from showing unless the speed in a particular section dropped below a target value, such as the “Speed_Target” value from Table 3. This would be an operator-adjusted value.

Travel Time-Link

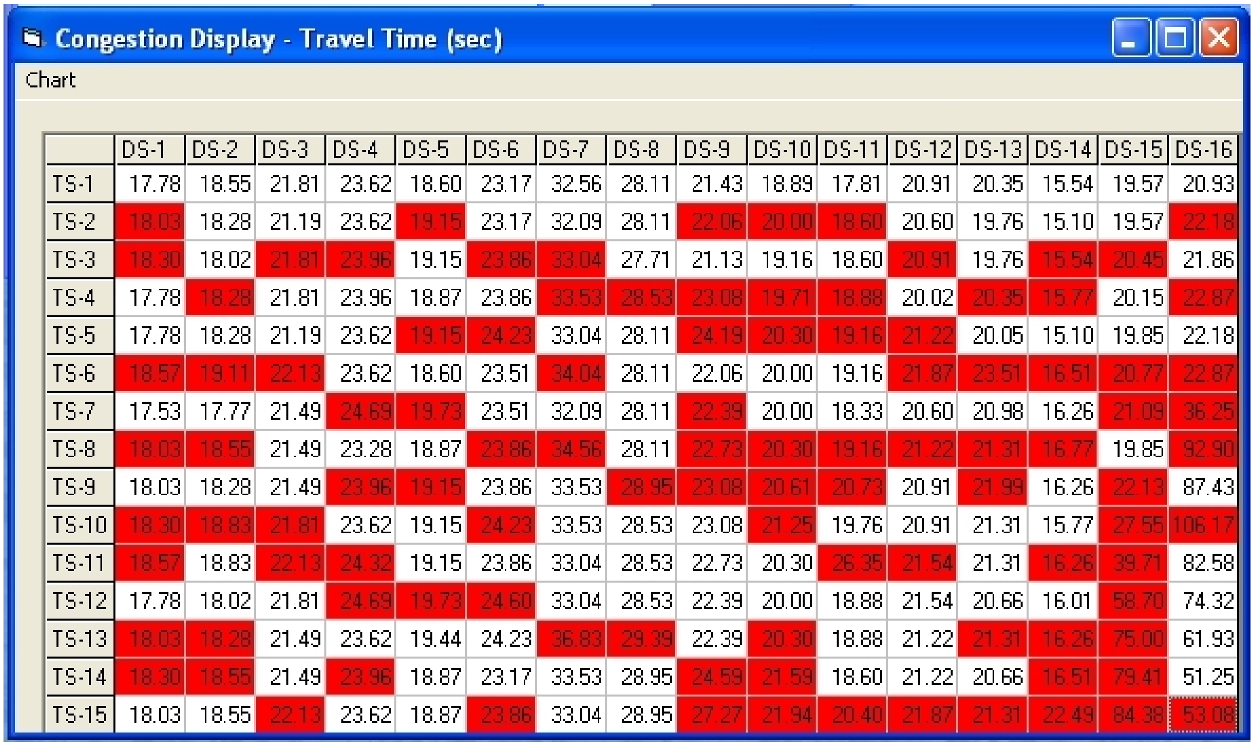
Travel time on a link is one of the measures in the NTOC list that was examined for real-time application. Figure 16 through Figure 18 show the travel time strip charts at a 4-, 15-, and 30-minute simulation time. (Recall that the time slice headings on the vertical axis do not currently roll to reflect simulation time. A quick visual examination will show that the values in the individual cells in the figures are different.)

The perceived usefulness of real-time monitoring of travel time on a link is mixed. On one hand, the strip charts provide an immediate and up-to-date assessment of roadway conditions that are important to a traveler. These strip charts prove that the concept of monitoring the NTOC measure in real-time is indeed possible.



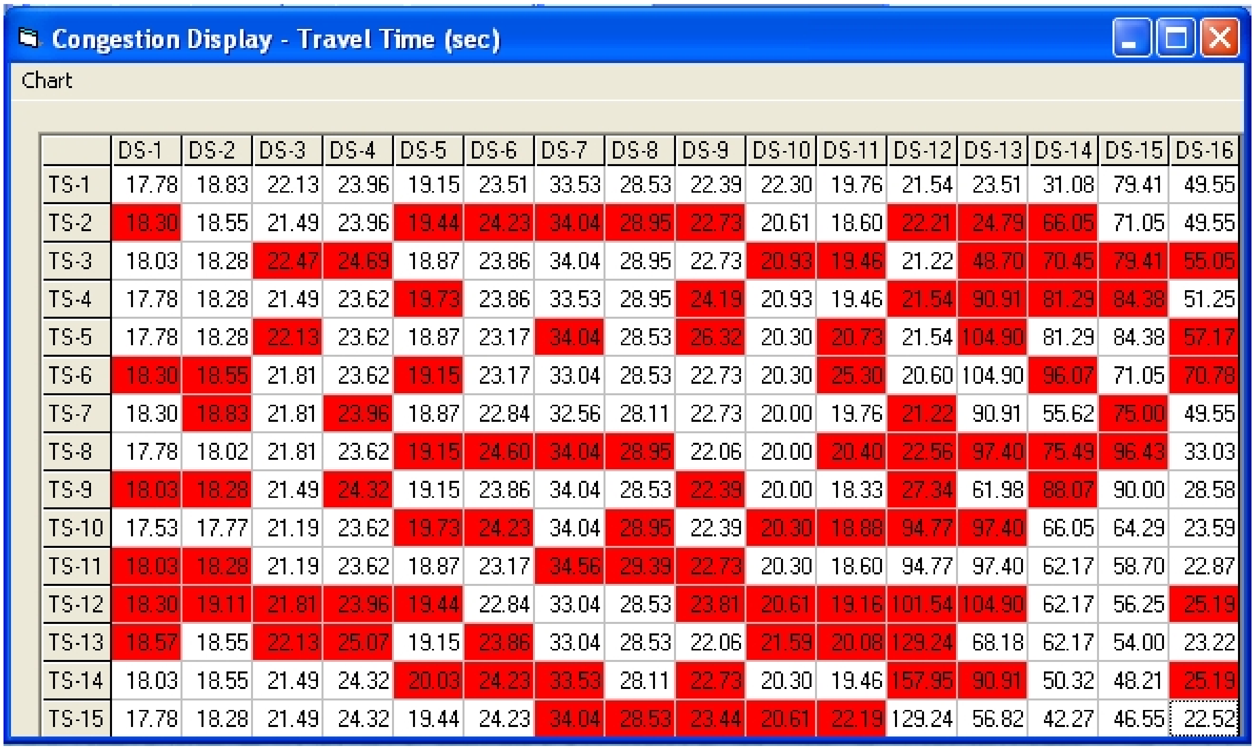
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	17.78	18.55	21.81	23.62	18.60	23.17	32.56	28.11	21.43	18.89	17.81	20.91	20.35	15.54	19.57	20.93
TS-2	18.03	18.28	21.19	23.62	19.15	23.17	32.09	28.11	22.06	20.00	18.60	20.60	19.76	15.10	19.57	22.18
TS-3	18.30	18.02	21.81	23.96	19.15	23.86	33.04	27.71	21.13	19.16	18.60	20.91	19.76	15.54	20.45	21.86
TS-4	17.78	18.28	21.81	23.96	18.87	23.86	33.53	28.53	23.08	19.71	18.88	20.02	20.35	15.77	20.15	22.87
TS-5																
TS-6																
TS-7																
TS-8																
TS-9																
TS-10																
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

Figure 16. Travel Time-Link Strip Chart at 4-Minute Simulation Time.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	17.78	18.55	21.81	23.62	18.60	23.17	32.56	28.11	21.43	18.89	17.81	20.91	20.35	15.54	19.57	20.93
TS-2	18.03	18.28	21.19	23.62	19.15	23.17	32.09	28.11	22.06	20.00	18.60	20.60	19.76	15.10	19.57	22.18
TS-3	18.30	18.02	21.81	23.96	19.15	23.86	33.04	27.71	21.13	19.16	18.60	20.91	19.76	15.54	20.45	21.86
TS-4	17.78	18.28	21.81	23.96	18.87	23.86	33.53	28.53	23.08	19.71	18.88	20.02	20.35	15.77	20.15	22.87
TS-5	17.78	18.28	21.19	23.62	19.15	24.23	33.04	28.11	24.19	20.30	19.16	21.22	20.05	15.10	19.85	22.18
TS-6	18.57	19.11	22.13	23.62	18.60	23.51	34.04	28.11	22.06	20.00	19.16	21.87	23.51	16.51	20.77	22.87
TS-7	17.53	17.77	21.49	24.69	19.73	23.51	32.09	28.11	22.39	20.00	18.33	20.60	20.98	16.26	21.09	36.25
TS-8	18.03	18.55	21.49	23.28	18.87	23.86	34.56	28.11	22.73	20.30	19.16	21.22	21.31	16.77	19.85	92.90
TS-9	18.03	18.28	21.49	23.96	19.15	23.86	33.53	28.95	23.08	20.61	20.73	20.91	21.99	16.26	22.13	87.43
TS-10	18.30	18.83	21.81	23.62	19.15	24.23	33.53	28.53	23.08	21.25	19.76	20.91	21.31	15.77	27.55	106.17
TS-11	18.57	18.83	22.13	24.32	19.15	23.86	33.04	28.53	22.73	20.30	26.35	21.54	21.31	16.26	39.71	82.58
TS-12	17.78	18.02	21.81	24.69	19.73	24.60	33.04	28.53	22.39	20.00	18.88	21.54	20.66	16.01	58.70	74.32
TS-13	18.03	18.28	21.49	23.62	19.44	24.23	36.83	29.39	22.39	20.30	18.88	21.22	21.31	16.26	75.00	61.93
TS-14	18.30	18.55	21.49	23.96	18.87	23.17	33.53	28.95	24.59	21.59	18.60	21.22	20.66	16.51	79.41	51.25
TS-15	18.03	18.55	22.13	23.62	18.87	23.86	33.04	28.95	27.27	21.94	20.40	21.87	21.31	22.49	84.38	53.08

Figure 17. Travel Time-Link Strip Chart at 15-Minute Simulation Time.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	17.78	18.83	22.13	23.96	19.15	23.51	33.53	28.53	22.39	22.30	19.76	21.54	23.51	31.08	79.41	49.55
TS-2	18.30	18.55	21.49	23.96	19.44	24.23	34.04	28.95	22.73	20.61	18.60	22.21	24.79	66.05	71.05	49.55
TS-3	18.03	18.28	22.47	24.69	18.87	23.86	34.04	28.95	22.73	20.93	19.46	21.22	48.70	70.45	79.41	55.05
TS-4	17.78	18.28	21.49	23.62	19.73	23.86	33.53	28.95	24.19	20.93	19.46	21.54	90.91	81.29	84.38	51.25
TS-5	17.78	18.28	22.13	23.62	18.87	23.17	34.04	28.53	26.32	20.30	20.73	21.54	104.90	81.29	84.38	57.17
TS-6	18.30	18.55	21.81	23.62	19.15	23.17	33.04	28.53	22.73	20.30	25.30	20.60	104.90	96.07	71.05	70.78
TS-7	18.30	18.83	21.81	23.96	18.87	22.84	32.56	28.11	22.73	20.00	19.76	21.22	90.91	55.62	75.00	49.55
TS-8	17.78	18.02	21.81	23.62	19.15	24.60	34.04	28.95	22.06	20.00	20.40	22.56	97.40	75.49	96.43	33.03
TS-9	18.03	18.28	21.49	24.32	19.15	23.86	34.04	28.53	22.39	20.00	18.33	27.34	61.98	88.07	90.00	28.58
TS-10	17.53	17.77	21.19	23.62	19.73	24.23	34.04	28.95	22.39	20.30	18.88	94.77	97.40	66.05	64.29	23.59
TS-11	18.03	18.28	21.19	23.62	18.87	23.17	34.56	29.39	22.73	20.30	18.60	94.77	97.40	62.17	58.70	22.87
TS-12	18.30	19.11	21.81	23.96	19.44	22.84	33.04	28.53	23.81	20.61	19.16	101.54	104.90	62.17	56.25	25.19
TS-13	18.57	18.55	22.13	25.07	19.15	23.86	33.04	28.53	22.06	21.59	20.08	129.24	68.18	62.17	54.00	23.22
TS-14	18.03	18.55	21.49	24.32	20.03	24.23	33.53	28.11	22.73	20.30	19.46	157.95	90.91	50.32	48.21	25.19
TS-15	17.78	18.28	21.49	24.32	19.44	24.23	34.04	28.53	23.44	20.61	22.19	129.24	56.82	42.27	46.55	22.52

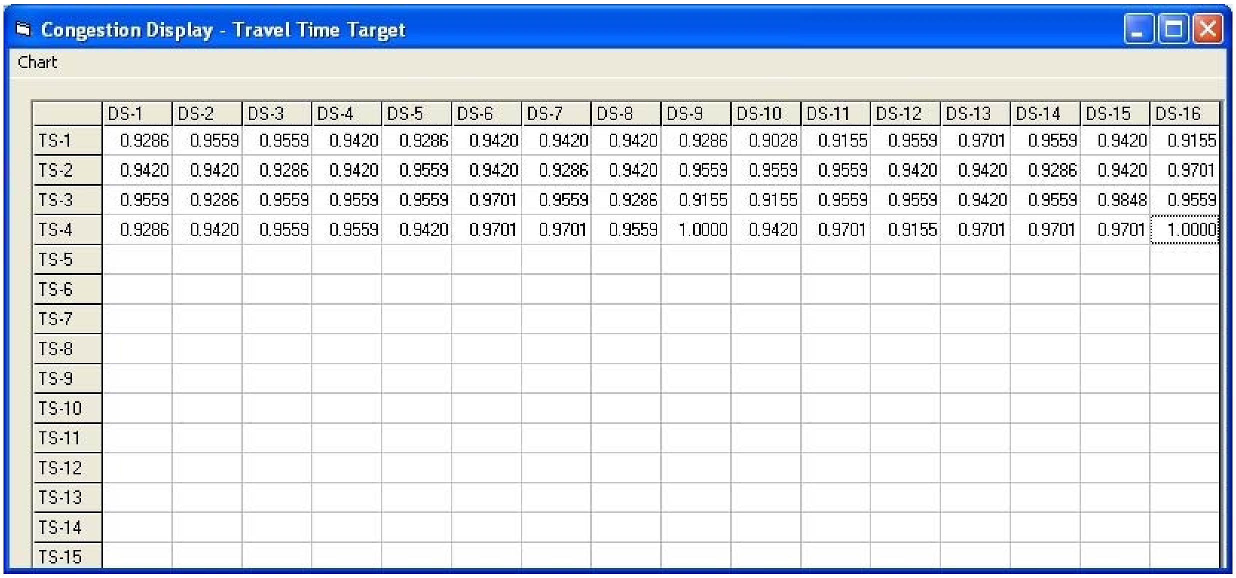
Figure 18. Travel Time-Link Strip Chart at 30-Minute Simulation Time.

However, the concern with travel time monitoring is the same as with speed. Even a slight change in travel time introduces a flag to color the cell red. For a practical application, the alert should only come on when the travel time drops below a specified value, such as the 'TT_Target' value in Table 3. Ideally, this parameter would be specified by time of day and by detector station, and would act as a yardstick to measure against the current travel time across the detector station.

Extent of Congestion – Spatial

The research team felt that the NTOC measures developed to examine the extent of congestion also held significant potential to identify when and where an incident or traffic disruption starts, as well as showing the affect across the rest of the system. Because the measure utilizes a ratio of current travel time to a desired travel time, instead of an absolute value, the measure should be less susceptible to slight changes and yet still be reactive to significant changes in the conditions. The strip charts illustrated in Figure 19 through Figure 25 use the 'TT_Target' as the denominator in the calculation of the ratio.

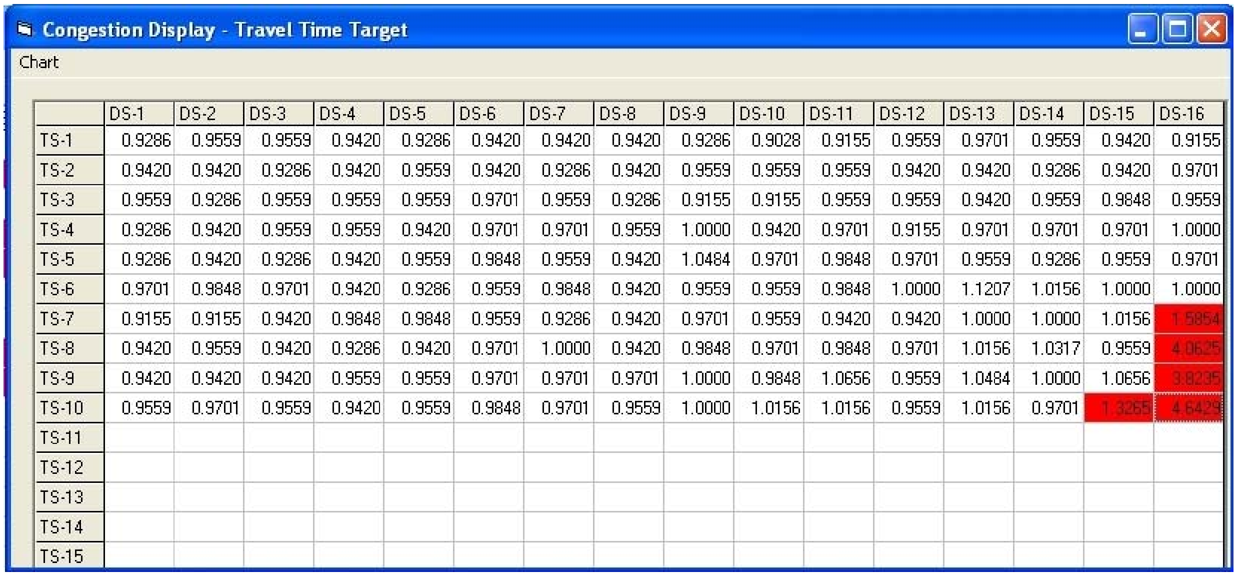
At the 4-minute timeframe (Figure 19), the strip chart shows no problems across the entire range of detector stations in the simulation. While this is primarily because the simulation is loading traffic into the scenario, this represents a free flow condition in real life. Some of the travel time ratios, such as detector station 1 at time slice 4, show a value less than 1, indicating that the current speed is exceeding the target speed set by the operator.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9286	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9420	0.9286	0.9028	0.9155	0.9559	0.9701	0.9559	0.9420	0.9155
TS-2	0.9420	0.9420	0.9286	0.9420	0.9559	0.9420	0.9286	0.9420	0.9559	0.9559	0.9559	0.9420	0.9420	0.9286	0.9420	0.9701
TS-3	0.9559	0.9286	0.9559	0.9559	0.9559	0.9701	0.9559	0.9286	0.9155	0.9155	0.9559	0.9559	0.9420	0.9559	0.9848	0.9559
TS-4	0.9286	0.9420	0.9559	0.9559	0.9420	0.9701	0.9701	0.9559	1.0000	0.9420	0.9701	0.9155	0.9701	0.9701	0.9701	1.0000
TS-5																
TS-6																
TS-7																
TS-8																
TS-9																
TS-10																
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

Figure 19. Target Travel Time Ratio Strip Chart at 4-Minute Simulation Time.

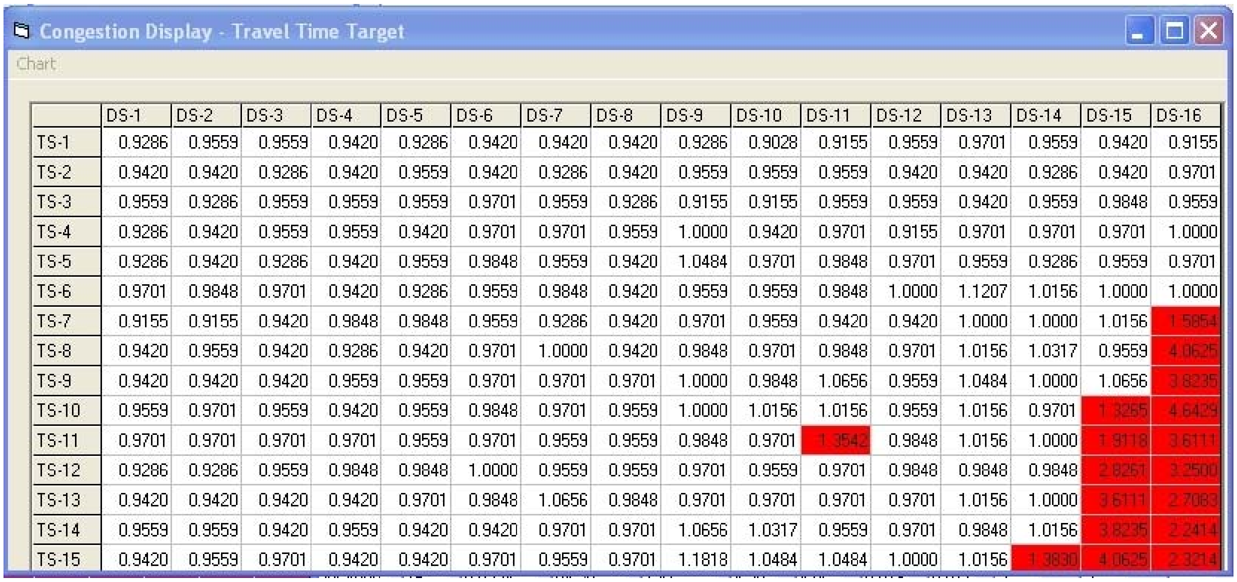
Figure 20 shows the situation where the travel time ratio is beginning to increase. Based on the rapid rise of the travel time ratio in the 7- to 8-minute time slice, the assumption would be that an incident or some other disruption to normal traffic flow has occurred.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9286	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9420	0.9286	0.9028	0.9155	0.9559	0.9701	0.9559	0.9420	0.9155
TS-2	0.9420	0.9420	0.9286	0.9420	0.9559	0.9420	0.9286	0.9420	0.9559	0.9559	0.9559	0.9420	0.9420	0.9286	0.9420	0.9701
TS-3	0.9559	0.9286	0.9559	0.9559	0.9559	0.9701	0.9559	0.9286	0.9155	0.9155	0.9559	0.9559	0.9420	0.9559	0.9848	0.9559
TS-4	0.9286	0.9420	0.9559	0.9559	0.9420	0.9701	0.9701	0.9559	1.0000	0.9420	0.9701	0.9155	0.9701	0.9701	0.9701	1.0000
TS-5	0.9286	0.9420	0.9286	0.9420	0.9559	0.9848	0.9559	0.9420	1.0484	0.9701	0.9848	0.9701	0.9559	0.9286	0.9559	0.9701
TS-6	0.9701	0.9848	0.9701	0.9420	0.9286	0.9559	0.9848	0.9420	0.9559	0.9559	0.9848	1.0000	1.1207	1.0156	1.0000	1.0000
TS-7	0.9155	0.9155	0.9420	0.9848	0.9848	0.9559	0.9286	0.9420	0.9701	0.9559	0.9420	0.9420	1.0000	1.0000	1.0156	1.5854
TS-8	0.9420	0.9559	0.9420	0.9286	0.9420	0.9701	1.0000	0.9420	0.9848	0.9701	0.9848	0.9701	1.0156	1.0317	0.9559	4.0625
TS-9	0.9420	0.9420	0.9420	0.9559	0.9559	0.9701	0.9701	0.9701	1.0000	0.9848	1.0656	0.9559	1.0484	1.0000	1.0656	3.8235
TS-10	0.9559	0.9701	0.9559	0.9420	0.9559	0.9848	0.9701	0.9559	1.0000	1.0156	1.0156	0.9559	1.0156	0.9701	1.3265	4.6429
TS-11																
TS-12																
TS-13																
TS-14																
TS-15																

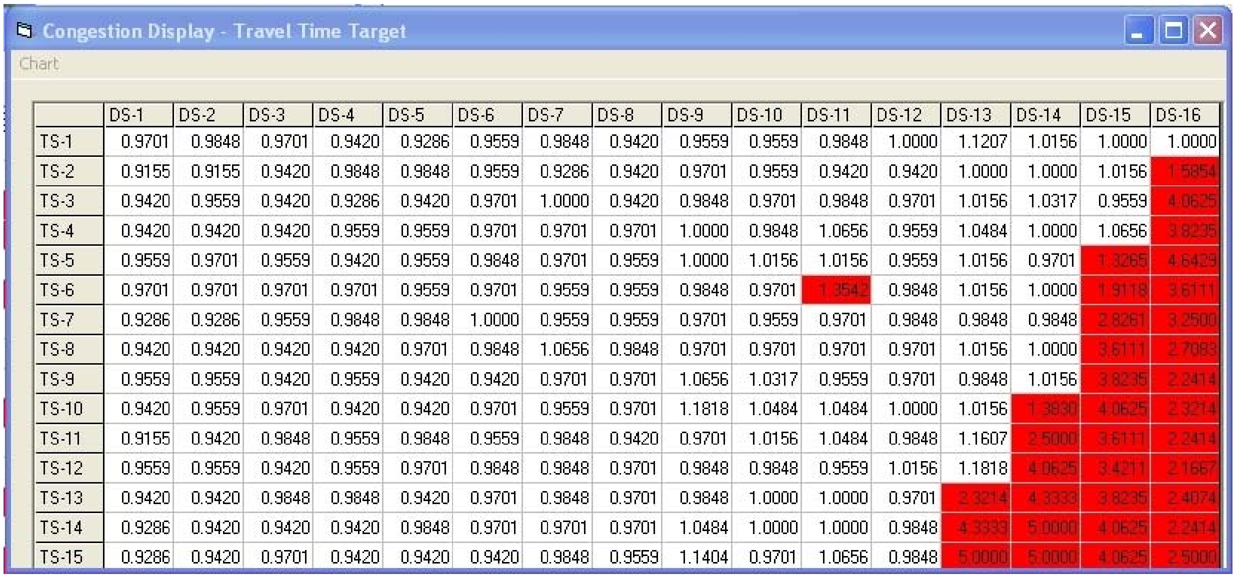
Figure 20. Target Travel Time Ratio Strip Chart at 10-Minute Simulation Time.

Looking at Figure 21, the effect of the incident can be seen as spreading, both temporally and spatially, as other detector stations are now showing an increase in the travel time ratio. The same holds true for Figure 22 at the 20-minute simulation time mark.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9286	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9420	0.9286	0.9028	0.9155	0.9559	0.9701	0.9559	0.9420	0.9155
TS-2	0.9420	0.9420	0.9286	0.9420	0.9559	0.9420	0.9286	0.9420	0.9559	0.9559	0.9559	0.9420	0.9420	0.9286	0.9420	0.9701
TS-3	0.9559	0.9286	0.9559	0.9559	0.9559	0.9701	0.9559	0.9286	0.9155	0.9155	0.9559	0.9559	0.9420	0.9559	0.9848	0.9559
TS-4	0.9286	0.9420	0.9559	0.9559	0.9420	0.9701	0.9701	0.9559	1.0000	0.9420	0.9701	0.9155	0.9701	0.9701	0.9701	1.0000
TS-5	0.9286	0.9420	0.9286	0.9420	0.9559	0.9848	0.9559	0.9420	1.0484	0.9701	0.9848	0.9701	0.9559	0.9286	0.9559	0.9701
TS-6	0.9701	0.9848	0.9701	0.9420	0.9286	0.9559	0.9848	0.9420	0.9559	0.9559	0.9848	1.0000	1.1207	1.0156	1.0000	1.0000
TS-7	0.9155	0.9155	0.9420	0.9848	0.9848	0.9559	0.9286	0.9420	0.9701	0.9559	0.9420	0.9420	1.0000	1.0000	1.0156	1.5854
TS-8	0.9420	0.9559	0.9420	0.9286	0.9420	0.9701	1.0000	0.9420	0.9848	0.9701	0.9848	0.9701	1.0156	1.0317	0.9559	4.0625
TS-9	0.9420	0.9420	0.9420	0.9559	0.9559	0.9701	0.9701	0.9701	1.0000	0.9848	1.0656	0.9559	1.0484	1.0000	1.0656	3.8235
TS-10	0.9559	0.9701	0.9559	0.9420	0.9559	0.9848	0.9701	0.9559	1.0000	1.0156	1.0156	0.9559	1.0156	0.9701	1.3265	4.6429
TS-11	0.9701	0.9701	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9848	0.9701	1.3542	0.9848	1.0156	1.0000	1.9118	3.6111
TS-12	0.9286	0.9286	0.9559	0.9848	0.9848	1.0000	0.9559	0.9559	0.9701	0.9559	0.9701	0.9848	0.9848	0.9848	2.8261	3.2500
TS-13	0.9420	0.9420	0.9420	0.9420	0.9701	0.9848	1.0656	0.9848	0.9701	0.9701	0.9701	0.9701	1.0156	1.0000	3.6111	2.7083
TS-14	0.9559	0.9559	0.9420	0.9559	0.9420	0.9420	0.9701	0.9701	1.0656	1.0317	0.9559	0.9701	0.9848	1.0156	3.8235	2.2414
TS-15	0.9420	0.9559	0.9701	0.9420	0.9420	0.9701	0.9559	0.9701	1.1818	1.0484	1.0484	1.0000	1.0156	1.3830	4.0625	2.3214

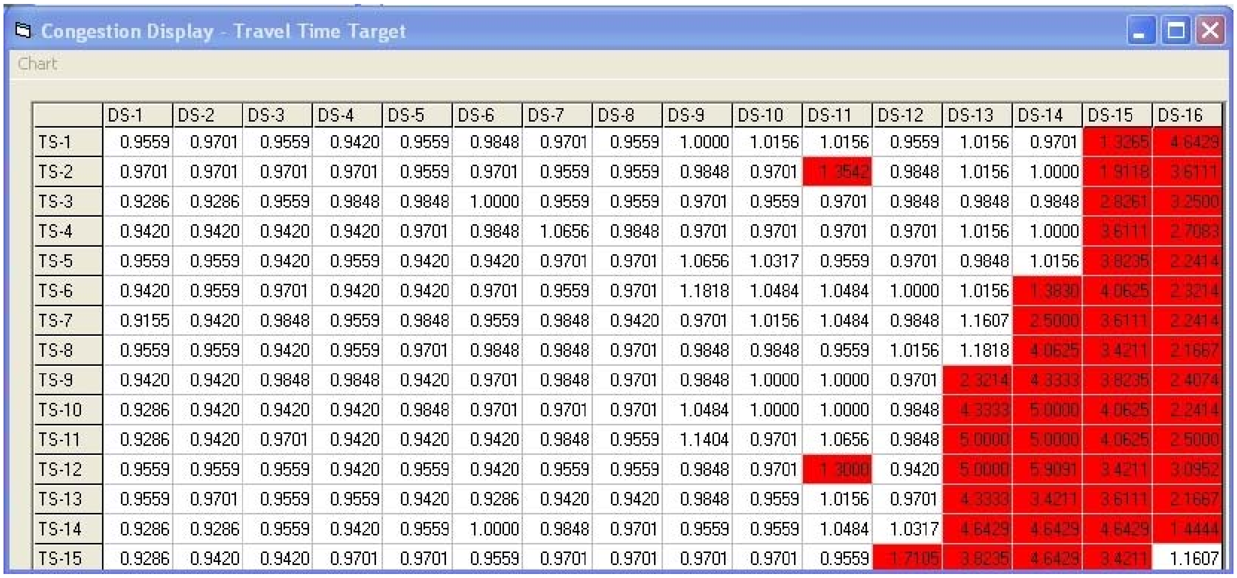
Figure 21. Target Travel Time Ratio Strip Chart at 15-Minute Simulation Time.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9701	0.9848	0.9701	0.9420	0.9286	0.9559	0.9848	0.9420	0.9559	0.9559	0.9848	1.0000	1.1207	1.0156	1.0000	1.0000
TS-2	0.9155	0.9155	0.9420	0.9848	0.9848	0.9559	0.9286	0.9420	0.9701	0.9559	0.9420	0.9420	1.0000	1.0000	1.0156	1.5854
TS-3	0.9420	0.9559	0.9420	0.9286	0.9420	0.9701	1.0000	0.9420	0.9848	0.9701	0.9848	0.9701	1.0156	1.0317	0.9559	4.0625
TS-4	0.9420	0.9420	0.9420	0.9559	0.9559	0.9701	0.9701	0.9701	1.0000	0.9848	1.0656	0.9559	1.0484	1.0000	1.0656	3.8235
TS-5	0.9559	0.9701	0.9559	0.9420	0.9559	0.9848	0.9701	0.9559	1.0000	1.0156	1.0156	0.9559	1.0156	0.9701	1.3265	4.6429
TS-6	0.9701	0.9701	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9848	0.9701	1.3542	0.9848	1.0156	1.0000	1.9118	3.6111
TS-7	0.9286	0.9286	0.9559	0.9848	0.9848	1.0000	0.9559	0.9559	0.9701	0.9559	0.9701	0.9848	0.9848	0.9848	2.8261	3.2500
TS-8	0.9420	0.9420	0.9420	0.9420	0.9701	0.9848	1.0656	0.9848	0.9701	0.9701	0.9701	0.9701	1.0156	1.0000	3.6111	2.7083
TS-9	0.9559	0.9559	0.9420	0.9559	0.9420	0.9420	0.9701	0.9701	1.0656	1.0317	0.9559	0.9701	0.9848	1.0156	3.8235	2.2414
TS-10	0.9420	0.9559	0.9701	0.9420	0.9420	0.9701	0.9559	0.9701	1.1818	1.0484	1.0484	1.0000	1.0156	1.3830	4.0625	2.3214
TS-11	0.9155	0.9420	0.9848	0.9559	0.9848	0.9559	0.9848	0.9420	0.9701	1.0156	1.0484	0.9848	1.1607	2.5000	3.6111	2.2414
TS-12	0.9559	0.9559	0.9420	0.9559	0.9701	0.9848	0.9848	0.9701	0.9848	0.9848	0.9559	1.0156	1.1818	4.0625	3.4211	2.1667
TS-13	0.9420	0.9420	0.9848	0.9848	0.9420	0.9701	0.9848	0.9701	0.9848	1.0000	1.0000	0.9701	2.3214	4.3333	3.8235	2.4074
TS-14	0.9286	0.9420	0.9420	0.9420	0.9848	0.9701	0.9701	0.9701	1.0484	1.0000	1.0000	0.9848	4.3333	5.0000	4.0625	2.2414
TS-15	0.9286	0.9420	0.9701	0.9420	0.9420	0.9420	0.9848	0.9559	1.1404	0.9701	1.0656	0.9848	5.0000	5.0000	4.0625	2.5000

Figure 22. Target Travel Time Ratio Strip Chart at 20-Minute Simulation Time.

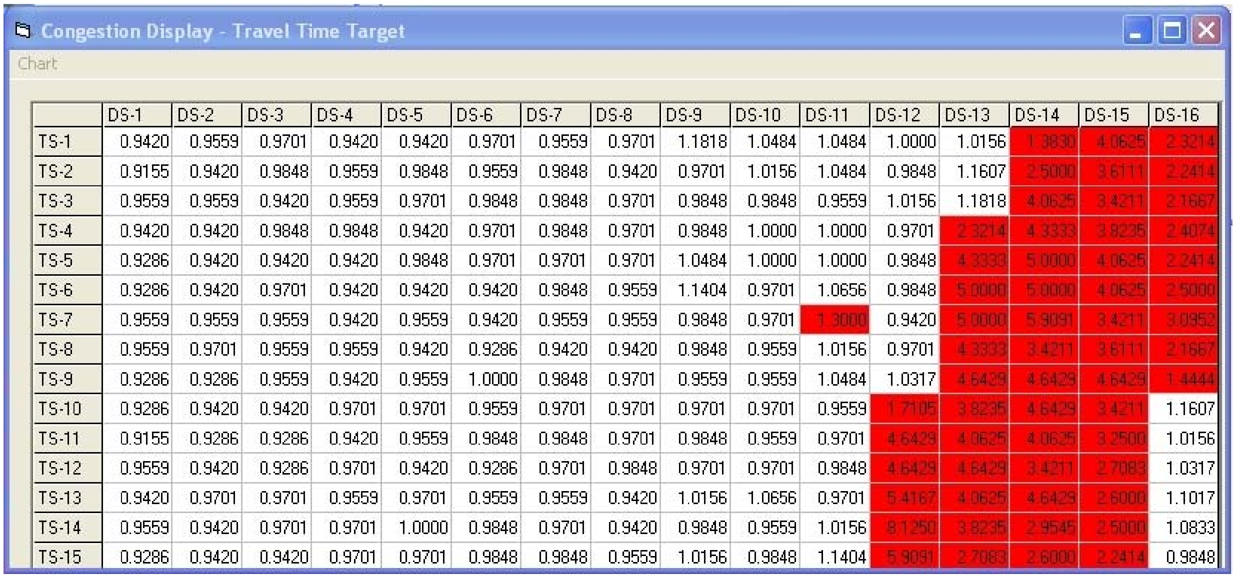
Figure 23, at Detector Station 16, shows a decrease in the travel time ratio. This is the first decrease seen since the incident started. If this trend continues, it can be interpreted as the clearing effects becoming noticeable after the incident is removed. Note that this strip chart does not indicate the exact point in time when the incident was cleared. In fact, in the simulation scenario, the incident took place from 5 to 15 minutes, so this process picked up the effects of the incident within approximately 2 minutes of the start. After the incident ended, at 15 minutes, the first clearing effects are noticeable approximately 10 minutes later.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9559	0.9701	0.9559	0.9420	0.9559	0.9848	0.9701	0.9559	1.0000	1.0156	1.0156	0.9559	1.0156	0.9701	1.3265	4.6429
TS-2	0.9701	0.9701	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9848	0.9701	1.3542	0.9848	1.0156	1.0000	1.9118	3.6111
TS-3	0.9286	0.9286	0.9559	0.9848	0.9848	1.0000	0.9559	0.9559	0.9701	0.9559	0.9701	0.9848	0.9848	0.9848	2.8261	3.2500
TS-4	0.9420	0.9420	0.9420	0.9420	0.9701	0.9848	1.0656	0.9848	0.9701	0.9701	0.9701	0.9701	1.0156	1.0000	3.6111	2.7083
TS-5	0.9559	0.9559	0.9420	0.9559	0.9420	0.9420	0.9701	0.9701	1.0656	1.0317	0.9559	0.9701	0.9848	1.0156	3.8235	2.2414
TS-6	0.9420	0.9559	0.9701	0.9420	0.9420	0.9701	0.9559	0.9701	1.1818	1.0484	1.0484	1.0000	1.0156	1.3830	4.0625	2.3214
TS-7	0.9155	0.9420	0.9848	0.9559	0.9848	0.9559	0.9848	0.9420	0.9701	1.0156	1.0484	0.9848	1.1607	2.5000	3.6111	2.2414
TS-8	0.9559	0.9559	0.9420	0.9559	0.9701	0.9848	0.9848	0.9701	0.9848	0.9848	0.9559	1.0156	1.1818	4.0625	3.4211	2.1667
TS-9	0.9420	0.9420	0.9848	0.9848	0.9420	0.9701	0.9848	0.9701	0.9848	1.0000	1.0000	0.9701	2.3214	4.3333	3.8235	2.4074
TS-10	0.9286	0.9420	0.9420	0.9420	0.9848	0.9701	0.9701	0.9701	1.0484	1.0000	1.0000	0.9848	4.3333	5.0000	4.0625	2.2414
TS-11	0.9286	0.9420	0.9701	0.9420	0.9420	0.9420	0.9848	0.9559	1.1404	0.9701	1.0656	0.9848	5.0000	5.0000	4.0625	2.5000
TS-12	0.9559	0.9559	0.9559	0.9420	0.9559	0.9420	0.9559	0.9559	0.9848	0.9701	1.3000	0.9420	5.0000	5.9091	3.4211	3.0952
TS-13	0.9559	0.9701	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9848	0.9559	1.0156	0.9701	4.3333	3.4211	3.6111	2.1667
TS-14	0.9286	0.9286	0.9559	0.9420	0.9559	1.0000	0.9848	0.9701	0.9559	0.9559	1.0484	1.0317	4.6429	4.6429	4.6429	1.4444
TS-15	0.9286	0.9420	0.9420	0.9701	0.9701	0.9559	0.9701	0.9701	0.9701	0.9701	0.9559	1.7105	3.8235	4.6429	3.4211	1.1607

Figure 23. Target Travel Time Ratio Strip Chart at 25-Minute Simulation Time.

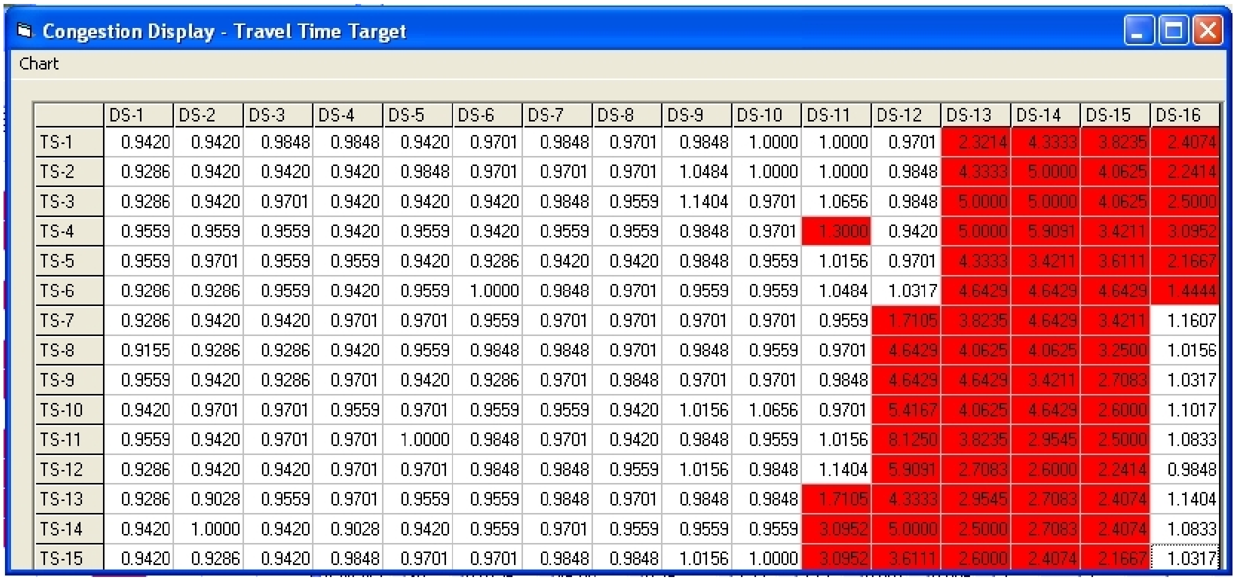
The clearing effects continue in Figure 24. Currently, only the area directly around the incident is clearing. There is currently no spatial component to the clearance.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9420	0.9559	0.9701	0.9420	0.9420	0.9701	0.9559	0.9701	1.1818	1.0484	1.0484	1.0000	1.0156	1.3830	4.0625	2.3214
TS-2	0.9155	0.9420	0.9848	0.9559	0.9848	0.9559	0.9848	0.9420	0.9701	1.0156	1.0484	0.9848	1.1607	2.5000	3.6111	2.2414
TS-3	0.9559	0.9559	0.9420	0.9559	0.9701	0.9848	0.9848	0.9701	0.9848	0.9848	0.9559	1.0156	1.1818	4.0625	3.4211	2.1667
TS-4	0.9420	0.9420	0.9848	0.9848	0.9420	0.9701	0.9848	0.9701	0.9848	1.0000	1.0000	0.9701	2.3214	4.3333	3.8235	2.4074
TS-5	0.9286	0.9420	0.9420	0.9420	0.9848	0.9701	0.9701	0.9701	1.0484	1.0000	1.0000	0.9848	4.3333	5.0000	4.0625	2.2414
TS-6	0.9286	0.9420	0.9701	0.9420	0.9420	0.9420	0.9848	0.9559	1.1404	0.9701	1.0656	0.9848	5.0000	5.0000	4.0625	2.5000
TS-7	0.9559	0.9559	0.9559	0.9420	0.9559	0.9420	0.9559	0.9559	0.9848	0.9701	1.3000	0.9420	5.0000	5.9091	3.4211	3.0952
TS-8	0.9559	0.9701	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9848	0.9559	1.0156	0.9701	4.3333	3.4211	3.6111	2.1667
TS-9	0.9286	0.9286	0.9559	0.9420	0.9559	1.0000	0.9848	0.9701	0.9559	0.9559	1.0484	1.0317	4.6429	4.6429	4.6429	1.4444
TS-10	0.9286	0.9420	0.9420	0.9701	0.9701	0.9559	0.9701	0.9701	0.9701	0.9701	0.9559	1.7105	3.8235	4.6429	3.4211	1.1607
TS-11	0.9155	0.9286	0.9286	0.9420	0.9559	0.9848	0.9848	0.9701	0.9848	0.9559	0.9701	4.6429	4.0625	4.0625	3.2500	1.0156
TS-12	0.9559	0.9420	0.9286	0.9701	0.9420	0.9286	0.9701	0.9848	0.9701	0.9701	0.9848	4.6429	4.6429	3.4211	2.7083	1.0317
TS-13	0.9420	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9420	1.0156	1.0656	0.9701	5.4167	4.0625	4.6429	2.6000	1.1017
TS-14	0.9559	0.9420	0.9701	0.9701	1.0000	0.9848	0.9701	0.9420	0.9848	0.9559	1.0156	8.1250	3.8235	2.9545	2.5000	1.0833
TS-15	0.9286	0.9420	0.9420	0.9701	0.9701	0.9848	0.9848	0.9559	1.0156	0.9848	1.1404	5.9091	2.7083	2.6000	2.2414	0.9848

Figure 24. Target Travel Time Ratio Strip Chart at 30-Minute Simulation Time.

Figure 25 shows both the shock wave from the incident and the clearance of the incident continuing to migrate temporally and spatially.



	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9420	0.9420	0.9848	0.9848	0.9420	0.9701	0.9848	0.9701	0.9848	1.0000	1.0000	0.9701	2.3214	4.3333	3.8235	2.4074
TS-2	0.9286	0.9420	0.9420	0.9420	0.9848	0.9701	0.9701	0.9701	1.0484	1.0000	1.0000	0.9848	4.3333	5.0000	4.0625	2.2414
TS-3	0.9286	0.9420	0.9701	0.9420	0.9420	0.9420	0.9848	0.9559	1.1404	0.9701	1.0656	0.9848	5.0000	5.0000	4.0625	2.5000
TS-4	0.9559	0.9559	0.9559	0.9420	0.9559	0.9420	0.9559	0.9559	0.9848	0.9701	1.3000	0.9420	5.0000	5.9091	3.4211	3.0952
TS-5	0.9559	0.9701	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9848	0.9559	1.0156	0.9701	4.3333	3.4211	3.6111	2.1667
TS-6	0.9286	0.9286	0.9559	0.9420	0.9559	1.0000	0.9848	0.9701	0.9559	0.9559	1.0484	1.0317	4.6429	4.6429	4.6429	1.4444
TS-7	0.9286	0.9420	0.9420	0.9701	0.9701	0.9559	0.9701	0.9701	0.9701	0.9701	0.9559	1.7105	3.8235	4.6429	3.4211	1.1607
TS-8	0.9155	0.9286	0.9286	0.9420	0.9559	0.9848	0.9848	0.9701	0.9848	0.9559	0.9701	4.6429	4.0625	4.0625	3.2500	1.0156
TS-9	0.9559	0.9420	0.9286	0.9701	0.9420	0.9286	0.9701	0.9848	0.9701	0.9701	0.9848	4.6429	4.6429	3.4211	2.7083	1.0317
TS-10	0.9420	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9420	1.0156	1.0656	0.9701	5.4167	4.0625	4.6429	2.6000	1.1017
TS-11	0.9559	0.9420	0.9701	0.9701	1.0000	0.9848	0.9701	0.9420	0.9848	0.9559	1.0156	8.1250	3.8235	2.9545	2.5000	1.0833
TS-12	0.9286	0.9420	0.9420	0.9701	0.9701	0.9848	0.9848	0.9559	1.0156	0.9848	1.1404	5.9091	2.7083	2.6000	2.2414	0.9848
TS-13	0.9286	0.9028	0.9559	0.9701	0.9559	0.9559	0.9848	0.9701	0.9848	0.9848	1.7105	4.3333	2.9545	2.7083	2.4074	1.1404
TS-14	0.9420	1.0000	0.9420	0.9028	0.9420	0.9559	0.9701	0.9559	0.9559	0.9559	3.0952	5.0000	2.5000	2.7083	2.4074	1.0833
TS-15	0.9420	0.9286	0.9420	0.9848	0.9701	0.9701	0.9848	0.9848	1.0156	1.0000	3.0952	3.6111	2.6000	2.4074	2.1667	1.0317

Figure 25. Target Travel Time Ratio Strip Chart at 35-Minute Simulation Time.

These figures show that the incident was picked up within the same 2- to 3-minute timeframe of the existing TxDOT incident detection algorithm based on loop occupancy. Since the calculations on the raw data from the simulation are the same, this correspondence is not surprising. What is different, however, is that the use of this performance measure and the strip charts combine to give a powerful view to the spreading shock wave from the incident itself. This could allow operators to determine how far upstream a response should be carried, a process that currently only takes place by visual surveillance with cameras.

SUMMARY

The prototype operator displays emphasize several points. First, the use of the NTOC performance measures in real-time can, in fact, provide an understanding of roadway conditions and serve as a baseline to visually communicate that information, on both a temporal and spatial basis. Second, while the initial results are promising, a modification to the NTOC methodology would be necessary for some measures, such as a straight comparison of speed or travel time. Without a comparison baseline, the normal volatility in these parameters would render them somewhat useless for identifying abnormal conditions. Finally, additional efforts are necessary to determine the sensitivity of the measures to variations in traffic levels, changes in the ratio value used, etc. Additionally, a determination of the sensitivity of the travel time ratio performance measure should be made if the target travel time values change by time of day, as determined by an operator.

CHAPTER 5:
CONCEPT OF OPERATIONS

BACKGROUND

A comprehensive Concept of Operations (COO) document typically addresses the Who, What, When, Where, Why, and How aspects of a system. The COO is intended to reach a wide audience. Generally, the level of detail is balanced between being general enough for stakeholders external to the implementation, with enough information to provide the basis for specific requirements for system implementation. The typical components of a COO might include:

- scope,
- references,
- operational description,
- operational needs,
- system overview,
- support environment, and
- operational scenarios.

While the above components are typical, it should be understood that the COO is not a one-size-fits-all document. COOs and the elements they contain are expected to be tailored to the unique aspects of the system under discussion.

COO FOR REAL-TIME PERFORMANCE MEASURE: 'EXTENT OF CONGESTION-SPATIAL'

Within the research of this project, speed, travel time, and the spatial extent of congestion were tested as potential performance measures for real-time usage. Speed and travel time may show future usage, although a real-time implementation would have to move beyond the NTOC definitions and incorporate some type of comparison to historical, or set values, in order to remove the alerts that result from the normal volatility in traffic. The spatial extent of congestion, however, showed significant potential for real-time usage direct from the NTOC recommendations. A COO will be developed for the usage of this performance measure.

Because this COO is being developed as a stand-alone document, it is more generic and does not include the components of the support environment or specific operational scenarios.

COO COMPONENTS

Each of the components of the COO applicable to the extent of congestion are detailed below.

Scope

Description

This is a concept of operations document for using the performance measure entitled "Extent of Congestion-Spatial" in real-time, by TMC operators as a supplemental tool for detecting and managing roadway incidents.

Purpose

Transportation Management Centers (TMCs) play an active role in monitoring traffic flow and responding to incidents in the traffic stream. Typical responses may include alerts to emergency services (EMS) and/or modification of information provided to other motorists to help reduce speed, effect lane changes, effect diversions, and/or create additional awareness of the incident.

The use of real-time performance measures may be a supplemental tool that operators in a TMC can use in support of incident management. Real-time performance analysis can assist with detection of an incident, determining the location of an incident, determining the extent of the incident's effect, and the timeframe of the incident's effects.

Audience

The intended audience for this COO is operators in a TMC who would use it in support of traffic monitoring and incident management activities.

References

The reference for the 'Extent of Congestion-Spatial' performance measure is the "National Transportation Operations Coalition (NTOC) Performance Measurement Initiative. Final Report."*(3)*.

Operational Description

Figure 26 shows the operational diagram for the extent of congestion-spatial performance measure. The process starts with the automated reception of data from standard roadway deployments that bring back speed, volume, and occupancy information. This information is then pre-processed, prior to operator viewing, to determine the current travel time ratio as per the NTOC reference. This information is then displayed as a corridor strip chart for operator review.

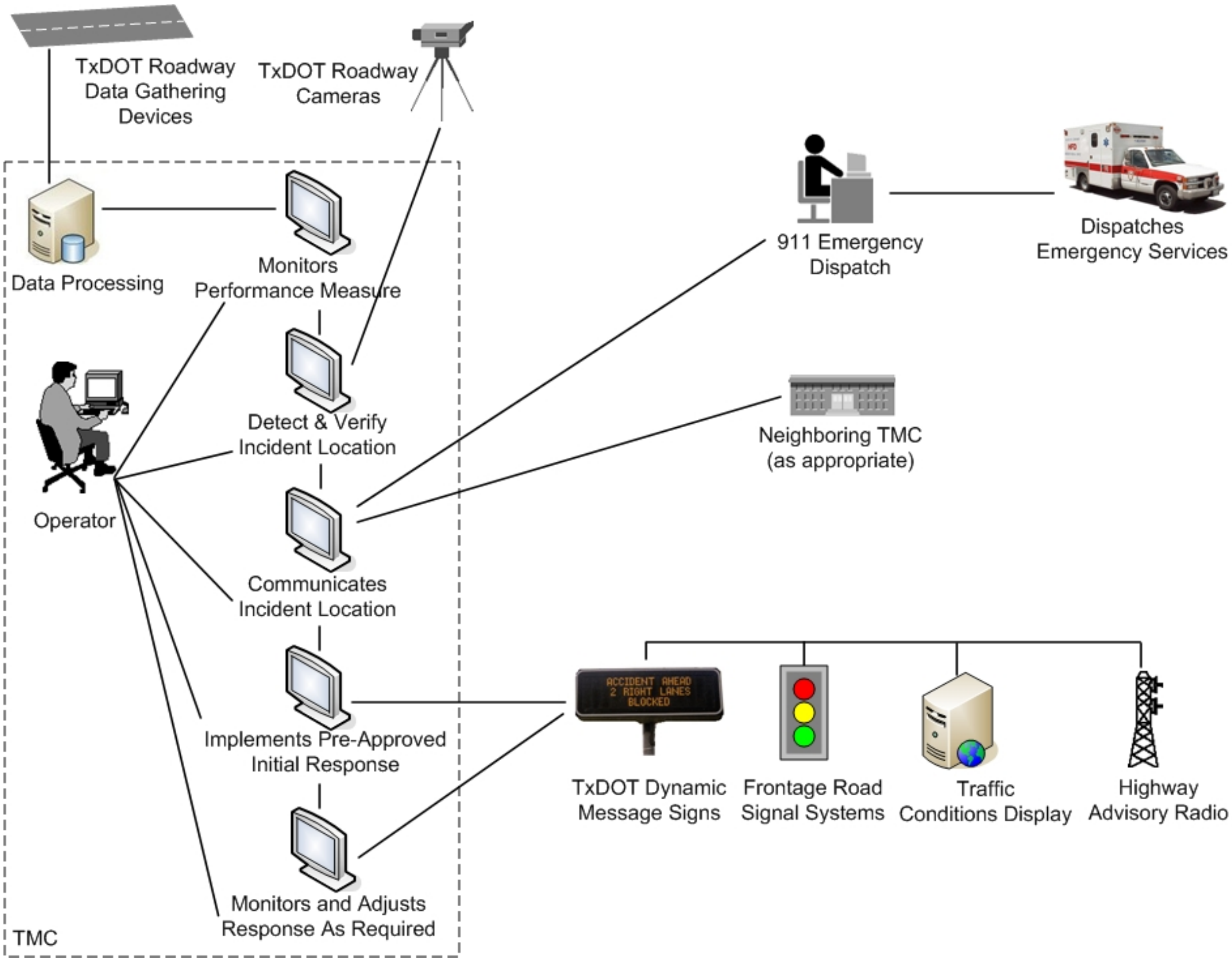


Figure 26. Operational Diagram for Performance Monitoring.

When an incident is presumed (as an example, refer to Figure 19 through Figure 25), the operator would typically verify the incident with appropriate surveillance cameras. The primary action following confirmation would be to alert emergency services, if necessary. A communication may also be sent to neighboring TMCs, depending on the location, type, and expected duration of the incident.

Following notification, the TMC operator would assess what actions and/or information can and should be presented to the traveling public pertaining to the incident. Options for actions may include alerting motorists via dynamic message signs, highway advisory radio, the traffic conditions display, and media. The operator may also alter ramp and or frontage road signal operations, as appropriate, to allow for better diversion patterns. Throughout the duration of the incident, the operator will continue to monitor and adjust the traffic response plan, as appropriate.

Operational Needs

Incorporation of real-time performance monitoring using the ‘Extent of Congestion-Spatial’ measure, supplements the available information for effectively managing the roadway, particularly during incidents. Implemented as a corridor view, the performance measure provides a comprehensive, data-driven, data-responsive, real-time assessment of the incident’s impacts beyond the visual scope of looking at surveillance cameras. To implement this measure, the following general needs are noted:

- pre-processing capability for roadway data,
- information processing capability for processed data,
- ability to access and control roadway surveillance capabilities,
- real-time information updates to TMC operators,
- ability to communicate incident location and associated information to emergency services and/or other TMCs, and
- ability to control roadway infrastructure.

System Overview

System Scope

The scope of the real-time performance measurement system can be system wide, although the view into the data should be performed at a corridor level.

System Users

The users of this real-time performance measuring capability are TMC operators.

Interfaces

Externally, the system must interface to the data communications feed from roadway sensors. Internally, the pre-processing component must interface to the information displays viewable by TMC operators.

Capabilities

The system should have the capability to display the 'Extent of Congestion-Spatial' performance measure in real-time on a corridor basis. Expected minimal output is a strip chart format with spatial measurements on the horizontal axis and temporal measurements on the vertical axis. Temporal components should roll vertically, with at least a 15-minute display being visible at all times. The strip chart interface should place the current value of the performance measure within each cell (intersection of time and spatial component). Cells should be color coded for a visual alert if the value of the previous time slice within the same spatial component is less than the value of the current time slice. Example strip charts can be seen in Figure 19 through Figure 25.

Completed COO

The complete COO is shown in Table 7.

Table 7. Concept of Operations Document for Extent of Congestion-Spatial Performance Measure.

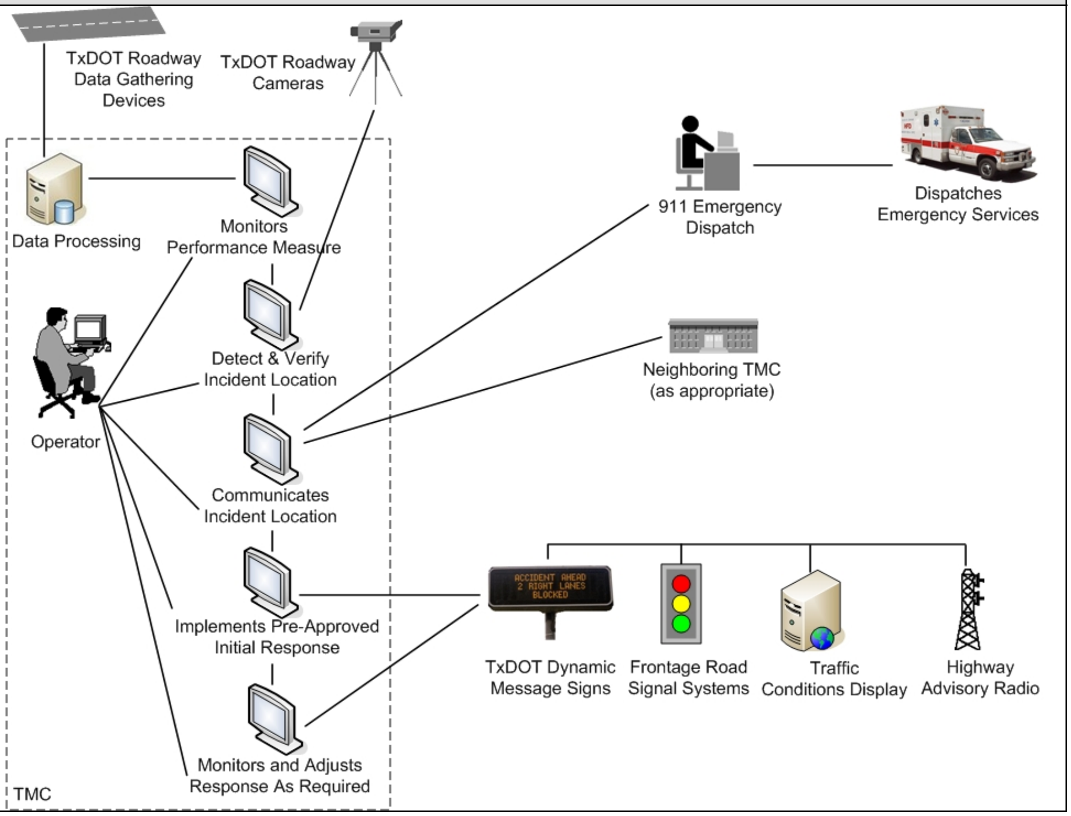
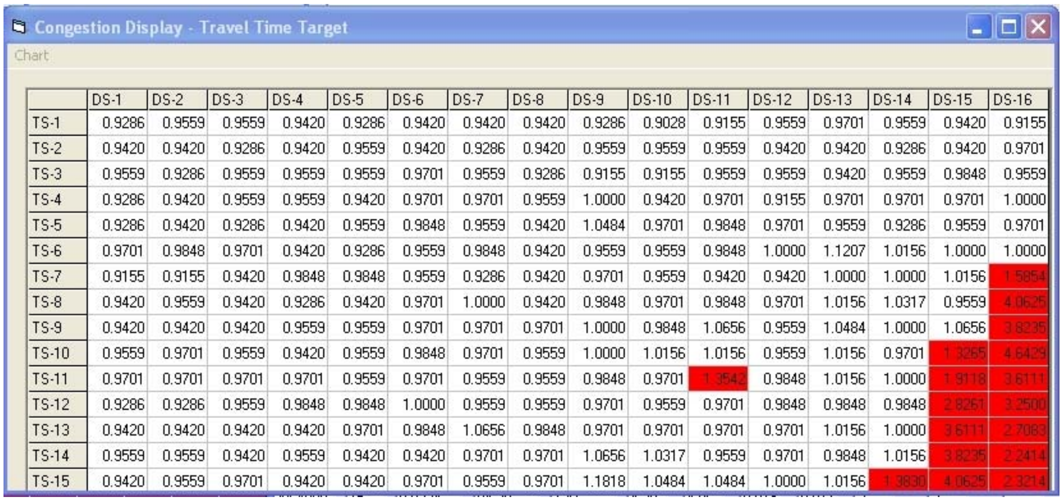
SCOPE	
Description:	This is a concept of operations document for using the performance measure entitled "Extent of Congestion-Spatial:" in real-time, by TMC operators as a supplemental tool for detecting and managing roadway incidents.
Purpose:	Transportation Management Centers (TMCs) play an active role in monitoring traffic flow and responding to incidents in the traffic stream. Typical responses may include alerts to emergency services (EMS) and/or modification of information provided to other motorists to help reduce speed, effect lane changes, effect diversions, and/or create additional awareness of the incident. The use of real-time performance measures may be a supplemental tool that operators in a TMC can use in support of incident management. Real-time performance analysis can assist with detection of an incident, determining the location of an incident, determining the extent of the incident's effect and the timeframe of the incident's effects.
Audience:	TMC operators are responsible for traffic monitoring and incident management.
REFERENCES	
	National Transportation Operations Coalition (NTOC) Performance Measurement Initiative. Final Report. July 2005. http://www.ntoctalks.com/ntoc/ntoc_final_report.pdf
OPERATIONAL DESCRIPTION	
	

Table 7. Concept of Operations Document for
Extent of Congestion-Spatial Performance Measure (continued).

OPERATIONAL DESCRIPTION (continued)	
	The operational diagram shows that the process starts with the automated reception of data from standard roadway deployments that bring back speed, volume, and occupancy information. This information is then pre-processed, prior to operator viewing, to determine the current travel time ratio as per the NTOC reference. This information is then displayed as a corridor strip chart for operator review. When an incident is presumed (as an example refer to Figure 19 through Figure 25), the operator would typically verify the incident with appropriate surveillance cameras. The primary action following confirmation would be to alert emergency services, if necessary. A communication may also be sent to neighboring TMCs, depending on the location, type, and expected duration of the incident. Following notification, the TMC operator would assess what actions and/or information can and should be presented to the traveling public pertaining to the incident. Options for actions may include alerting motorists via dynamic message signs, highway advisory radio, the traffic conditions display, and media. The operator may also alter ramp and/or frontage road signal operations, as appropriate, to allow for better diversion patterns. Throughout the duration of the incident, the operator will continue to monitor and adjust the traffic response plan, as appropriate.
OPERATIONAL NEEDS	
	Incorporation of real-time performance monitoring using the 'Extent of Congestion-Spatial' measure, supplements the available information for effectively managing the roadway, particularly during incidents. Implemented as a corridor view, the performance measure provides a comprehensive, data-driven, data-responsive, real-time assessment of the incident's impacts beyond the visual scope of looking at surveillance cameras. To implement this measure, the following general needs are noted: • pre-processing capability for roadway data, • information processing capability for processed data, • ability to access and control roadway surveillance capabilities, • real-time information updates to TMC operators, • ability to communicate incident location and associated information to emergency services and/or other TMCs, and • ability to control roadway infrastructure.
SYSTEM OVERVIEW	
Scope	The scope of the real-time performance measurement system can be system wide, although the view into the data should be performed at a corridor level.
Users	The users of this real-time performance measuring capability are TMC operators.

Table 7. Concept of Operations Document for Extent of Congestion-Spatial Performance Measure (continued).

SYSTEM OVERVIEW (continued)	
Interfaces	Externally, the system must interface to the data communications feed from roadway sensors. Internally, the pre-processing component must interface to the information displays viewable by TMC operators.
Capabilities	The system should have the capability to display the 'Extent of Congestion-Spatial' performance measure in real-time on a corridor basis. Expected minimal output is a strip chart format with spatial measurements on the horizontal axis and temporal measurements on the vertical axis. Temporal components should roll vertically, with at least a 15-minute display being visible at all times. The strip chart interface should place the current value of the performance measure within each cell (intersection of time and spatial component). Cells should be color coded for a visual alert if the value of the previous time slice within the same spatial component is less than the value of the current time slice. An example strip chart can be seen below. 

	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7	DS-8	DS-9	DS-10	DS-11	DS-12	DS-13	DS-14	DS-15	DS-16
TS-1	0.9286	0.9559	0.9559	0.9420	0.9286	0.9420	0.9420	0.9420	0.9286	0.9028	0.9155	0.9559	0.9701	0.9559	0.9420	0.9155
TS-2	0.9420	0.9420	0.9286	0.9420	0.9559	0.9420	0.9286	0.9420	0.9559	0.9559	0.9559	0.9420	0.9420	0.9286	0.9420	0.9701
TS-3	0.9559	0.9286	0.9559	0.9559	0.9559	0.9701	0.9559	0.9286	0.9155	0.9155	0.9559	0.9559	0.9420	0.9559	0.9848	0.9559
TS-4	0.9286	0.9420	0.9559	0.9559	0.9420	0.9701	0.9701	0.9559	1.0000	0.9420	0.9701	0.9155	0.9701	0.9701	0.9701	1.0000
TS-5	0.9286	0.9420	0.9286	0.9420	0.9559	0.9848	0.9559	0.9420	1.0484	0.9701	0.9848	0.9701	0.9559	0.9286	0.9559	0.9701
TS-6	0.9701	0.9848	0.9701	0.9420	0.9286	0.9559	0.9848	0.9420	0.9559	0.9559	0.9848	1.0000	1.1207	1.0156	1.0000	1.0000
TS-7	0.9155	0.9155	0.9420	0.9848	0.9848	0.9559	0.9286	0.9420	0.9701	0.9559	0.9420	0.9420	1.0000	1.0000	1.0156	1.5854
TS-8	0.9420	0.9559	0.9420	0.9286	0.9420	0.9701	1.0000	0.9420	0.9848	0.9701	0.9848	0.9701	1.0156	1.0317	0.9559	4.0625
TS-9	0.9420	0.9420	0.9420	0.9559	0.9559	0.9701	0.9701	0.9701	1.0000	0.9848	1.0656	0.9559	1.0484	1.0000	1.0656	3.8235
TS-10	0.9559	0.9701	0.9559	0.9420	0.9559	0.9848	0.9701	0.9559	1.0000	1.0156	1.0156	0.9559	1.0156	0.9701	1.3265	4.6429
TS-11	0.9701	0.9701	0.9701	0.9701	0.9559	0.9701	0.9559	0.9559	0.9848	0.9701	1.3542	0.9848	1.0156	1.0000	1.9118	3.6111
TS-12	0.9286	0.9286	0.9559	0.9848	0.9848	1.0000	0.9559	0.9559	0.9701	0.9559	0.9701	0.9848	0.9848	0.9848	2.8261	3.2500
TS-13	0.9420	0.9420	0.9420	0.9420	0.9701	0.9848	1.0656	0.9848	0.9701	0.9701	0.9701	0.9701	1.0156	1.0000	3.6111	2.7083
TS-14	0.9559	0.9559	0.9420	0.9559	0.9420	0.9420	0.9701	0.9701	1.0656	1.0317	0.9559	0.9701	0.9848	1.0156	3.8235	2.2414
TS-15	0.9420	0.9559	0.9701	0.9420	0.9420	0.9701	0.9559	0.9701	1.1818	1.0484	1.0484	1.0000	1.0156	1.3830	4.0625	2.3214

CHAPTER 6:
USING A MULTI-CRITERION APPROACH TO SELECT PERFORMANCE MEASURES

Selecting freeway performance measures is an especially complex and difficult process that requires considering the different aspects influencing freeway operations. Furthermore, construction funds, labor, and materials are becoming increasingly scarce, which reduces the possibility of decreasing congestion problems by increasing capacity *(4)*. Thus, traffic operations management plays an important role in alleviating traffic congestion, improving safety, and improving mobility in existing freeway systems. Operations management strategies used for freeway systems include traffic incident detection, traveler information systems, managed lanes, ramp management, etc. In order to evaluate freeway performance before and after any of these operational strategies are applied, measures of effectiveness (MOEs), such as density, speed, and volume *(5)* and the travel time index *(6)*, are utilized. The quality of these performance measures depends on the equipment and data collection techniques used.

Transportation planners must determine whether equipment and data collection techniques should be provided in specific locations or exclusively when incidents occur; some equipment can provide performance measure data without additional investment. For example, existing loop detectors can provide spot speeds at specific locations, which enable a planner to track improvements at a particular location. Recently, NCHRP Synthesis 311 *(1)* has developed a scoring approach to assess the strengths and weakness of performance measures. The qualitative criteria that are used for evaluating the performance measures include clarity and simplicity, descriptive and predictive ability, analysis capacity, accuracy and precision, and flexibility. These criteria may do a good job assessing performance measure quality in a general sense; however, they do not provide a strong approach for identifying preferred performance measures based on specific local characteristics, such as the reliability and accuracy of different data collection strategies for the same performance measure. In addition, when choosing a particular performance measure, there will likely be costs associated with either collecting the data necessary for generating the performance measure in the first place or on-going operational costs associated with tracking and maintaining the performance measure data itself. At a local level for specific constraints and conditions, the decision-making criteria should include commensurate quantitative criteria because decision-makers are unlikely to arrive at the preferred alternative when using only general assessments of qualitative criteria.

This report provides a decision-making framework for assisting transportation planners and operators in selecting alternative freeway performance measures based on both qualitative, such as understanding, measurability, availability, and importance, and quantitative measures, such as time, cost, accuracy, and reliability. This research considers the scoring of qualitative criteria in NCHRP 311 *(1)* as a potential starting point for selecting among alternative performance measures where the decision-makers can decide whether to consider or reject a performance measure based on its score for qualitative criteria; the decision makers can establish minimum performance thresholds for the qualitative criteria, and all alternative performance measures that fail to meet or exceed these thresholds for all criteria will be excluded from further consideration. The remaining candidate performance measures still must be evaluated for the local characteristics using quantitative criteria. Decision-makers may establish similar performance thresholds for the quantitative criteria and use them for screening as well. After all screening is complete, the authors propose using a multi-criteria decision model (MCDM), such as Simple Additive Weighting (SAW) and ELECTRE III, to combine quantitative criteria for evaluating the performance measures. A MCDM ranks the alternatives for the decision-makers to make their final selection. The approach that this report proposes improves on existing techniques by adding a screening stage and integrating quantitative criteria that can handle local characteristics. These improvements make the approach viable for local decision-makers who must choose freeway operational performance measures under constrained conditions, such as budget or personnel. In the following chapters, the proposed methodology is discussed in detail and presented with an example of its application.

CHAPTER 7:
DEVELOPING PERFORMANCE MEASURES

Before the discussion of how to assess performance measures, one must first understand how performance measures are developed. One possible use of performance measures is in the assessment of freeway operational strategies. Planners can use a top-down methodology where the type of performance measures may be established at the highest level to assess the program goals, which may not be easily measurable; then at the next lower level, either output or outcome measures may be used to evaluate the program objectives; at the next lower level, output measures are commonly used to assess the immediate impacts of policies or projects. At the lowest level, input measures are generally used to assess the program resources. The use of program targets may be integrated into this process to provide ongoing monitoring and assistance with future improvement decisions. Figure 27 is an example of a transit system improvement that shows the impacts at each level.

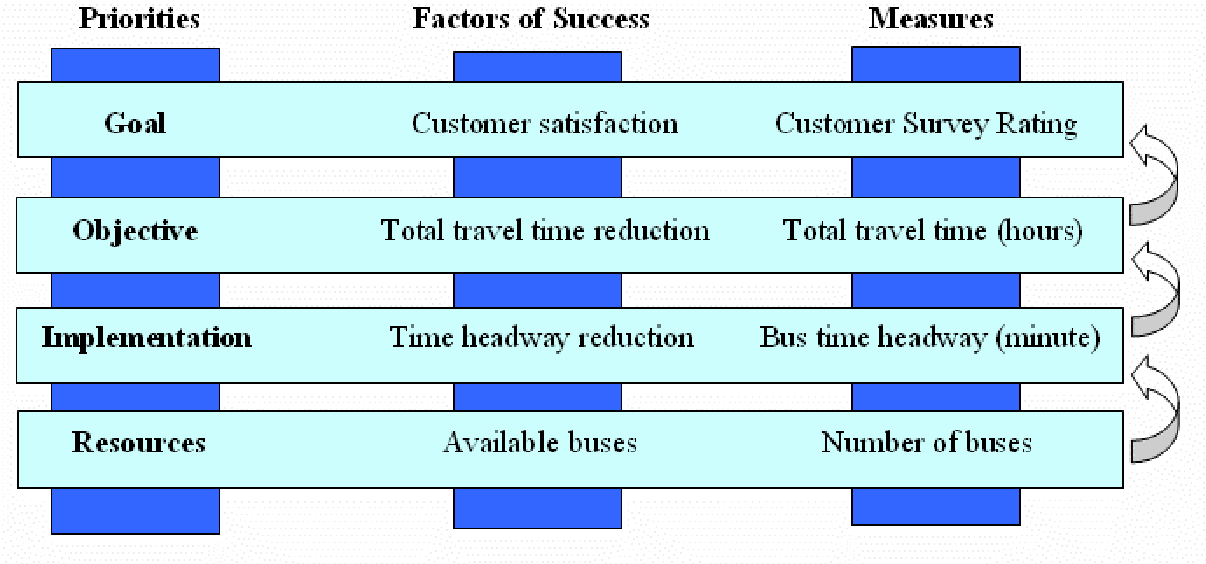


Figure 27. Multilevel Structure for Performance Measures.

The top-down methodology can be utilized in multilevel operations to assess freeway performance from systemwide to a particular area as shown in Figure 28. According to Brydia et al. *(7)*, the application of performance measurement in freeway operations can incorporate multiple scales or levels based on the number of agencies using the performance measures. At the top level, systemwide, the measures are used to assess a global view of operations. In the next lower level, called the interagency level, many agencies will share resources in order to improve their operational programs, such as incident management and air quality. The third level, daily operations, focuses on Transportation Management Center operations, such as lane shifts, dynamic messages, signal timing, and ramp metering. TMC operators may use these measures to assess their programs and strategies. At the bottom level, the measures are used to assess equipment or discrete elements of the transportation system, such as equipment reliability. Since the performance measures can be used in multiple scales, good performance measures should be able to assess the freeway performance in multiple scales also. For example, performance measures used to assess at the systemwide level should also apply at the interagency level. In addition, performance measures for equipment should be used to evaluate potential performance measures for daily operation.

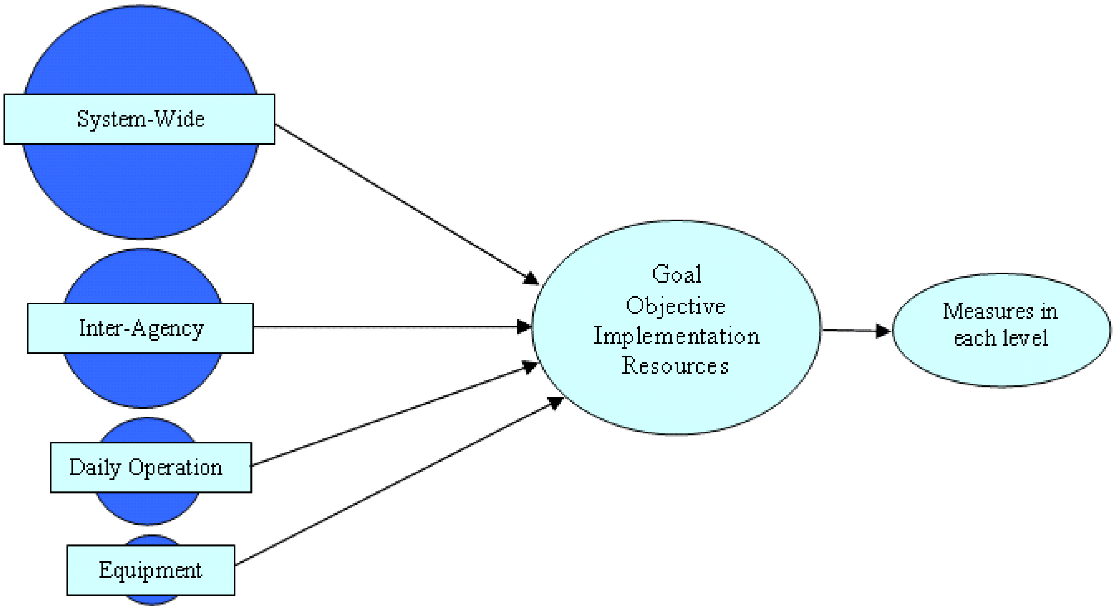


Figure 28. Multilevel Operation Approach.

Since performance measurement has been used in many fields, there is no single methodology or exact rule for selecting specific measures. In addition, criteria for selecting appropriate performance measures should be decided by the people who are involved in the performance measurement program, such as those who collect and use the data or experts who understand the strengths and limitations of each performance measure. Good performance measures in general should focus on the goals and objectives of the program whose performance is to be assessed. They should be simple, easy to understand for everyone, able to respond to the changes in the system, inexpensive to obtain, organizationally acceptable, credible, timely, comparable, compatible, customer focused, consistent, measurable, available, balanced, valuable, and practical *(7, 8, 9)*. The following chapters provide a framework for weighing performance measures to choose the optimal measure for the application.

CHAPTER 8:
PERFORMANCE MEASURE CREATION AND SELECTION METHODOLOGY

The five steps developed in this methodology focus on the roles of decision makers and coordinators in creating and screening performance measures. The decision makers are defined as the individuals responsible for using the performance measures for evaluating freeway operational strategies, while the coordinators are defined as individuals who assist the decision makers by guiding the process and conducting any necessary analysis during the performance measure selection process. Figure 29 shows the methodology.

STEP 1: ESTABLISH THE "DECISION STATEMENT"

Specifying the proper "decision statement" is a crucial step for the decision makers because it can determine if the solution meets the desired goal. In addition, the established decision statement will lead the solutions to be "simple versus complex" or "broad versus narrow." For example, a decision statement: "select a strategy to reduce traffic congestion on a freeway" will provide a solution of only the one best strategy. However, if the decision statement is changed to "select strategies to reduce traffic congestion on a freeway," this may lead to the consideration of various strategies, which minimize traffic congestion on a freeway. The roles of decision makers and coordinators involved in this step are:

- Decision makers have to clarify the objective by identifying a problem and establishing a decision statement in order to scope the problem's boundary and feasible solutions. A problem can cause various challenges, for example, traffic congestion may lead to environmental externalities, such as air pollution. Thus, decision makers should focus on the main cause of the problem rather than the outcomes of the problem.
- Coordinators should ensure that the results of the discussion will lead to the main cause of the problem. They should provide useful information, which includes traffic condition data, travel behavior, on-road activities, etc.

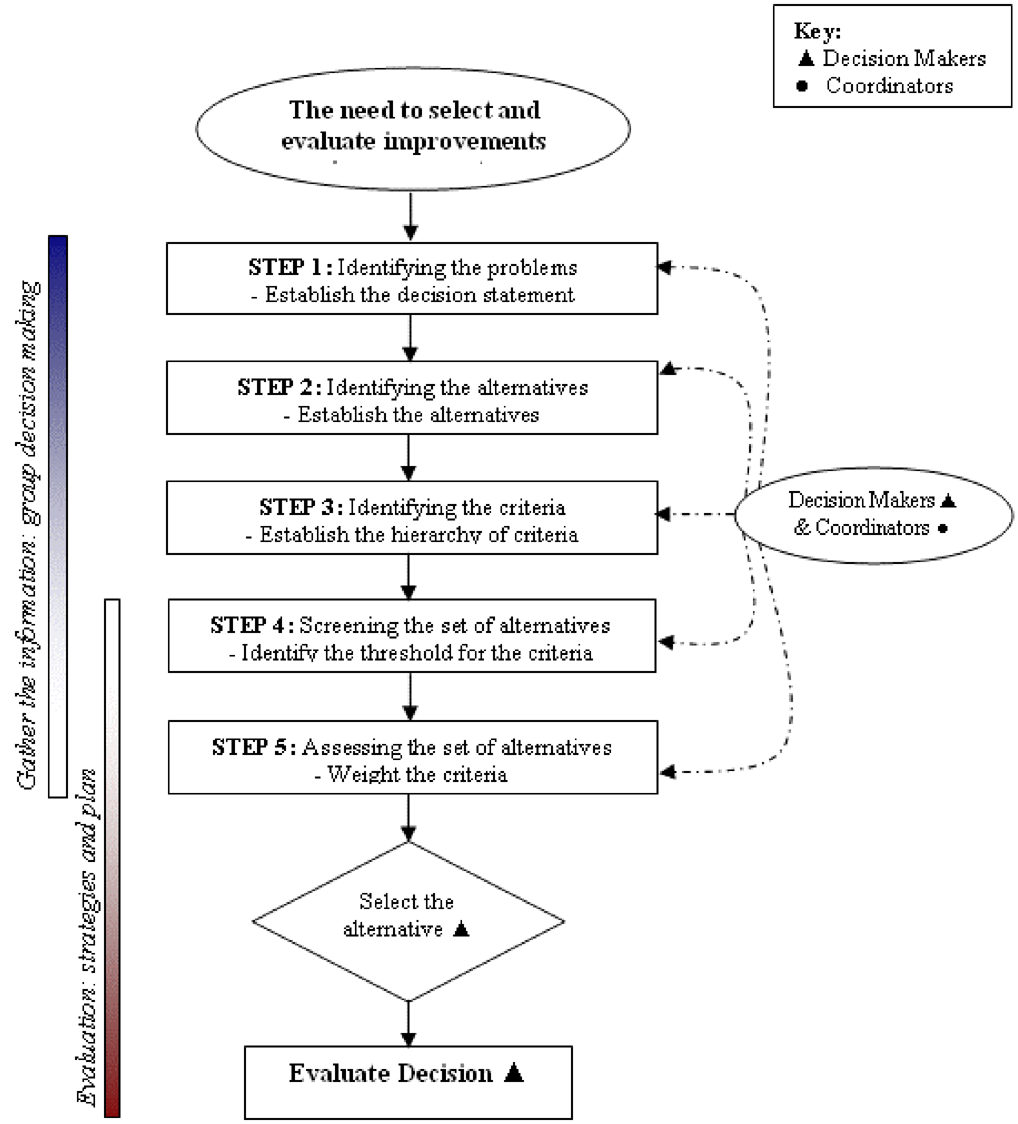


Figure 29. Decision-Making Process.

STEP 2: IDENTIFY THE "SET OF ALTERNATIVES OR SOLUTIONS"

Once a decision statement is identified, the decision makers must clearly understand the program goals and performance measures. They must establish the possible alternatives or solutions based on the decision statement described in Step 1. The roles of the decision makers and coordinators involved in this step are:

- Decision makers must establish the feasible alternatives or solutions.
- Coordinators should provide any additional information as needed. The useful information will enhance decision makers' viewpoints in the selection of feasible

alternatives or solutions. To accomplish this, coordinators may conduct a survey for the decision makers that may include the following questions:

- What are the objectives of the program?
- What are the current operational performance measures used in the program?
- What operational performance measures do you expect to be applied in the future?
- The purpose of providing the program objectives is to make sure that the decision makers consider these objectives when generating possible alternatives.

STEP 3: ESTABLISH THE "SET OF CRITERIA USED FOR ASSESSING PERFORMANCE MEASURE BASED ON EQUIPMENT AND DATA COLLECTION TECHNIQUES ON FREEWAY SYSTEMS"

Once the set of feasible alternatives is generated in Step 2, the set of constraints for assessing the feasible alternatives should be established. The set of constraints may include qualitative and quantitative criteria. The qualitative criteria will be used to determine the possibility of assessing the performance measures, and they may include measurability, comprehension, and availability. The quantitative criteria may include budget constraints or limitations of equipment and data collection techniques. The roles of the decision makers and coordinators involved in this step are:

- Decision makers have to identify the "set of constraints" for assessing the quality of the freeway performance measures in the next step. They should indicate the critical criteria.
- Coordinators should provide any additional information, especially information that enhances the decision makers' criteria selection, as needed. The information should include the limitations of the feasible alternatives provided in the previous step. The possible decision maker questions include:
    - What are the current performance measures used in the program at the system wide, interagency, daily operation, or equipment level?
    - What factors affect the use of those performance measures?

The coordinators may propose some potential criteria, which provide decision makers a starting point. Then, the decision makers must choose to accept or reject these proposed criteria, or provide alternate criteria. This process assists the decision makers' criteria selection. An example of a questionnaire is illustrated in Figure 30; however, the complete questionnaire is provided in Appendix A. Note that in Figure 30 blank spaces are available, indicating the availability of decision makers to include their own criteria.

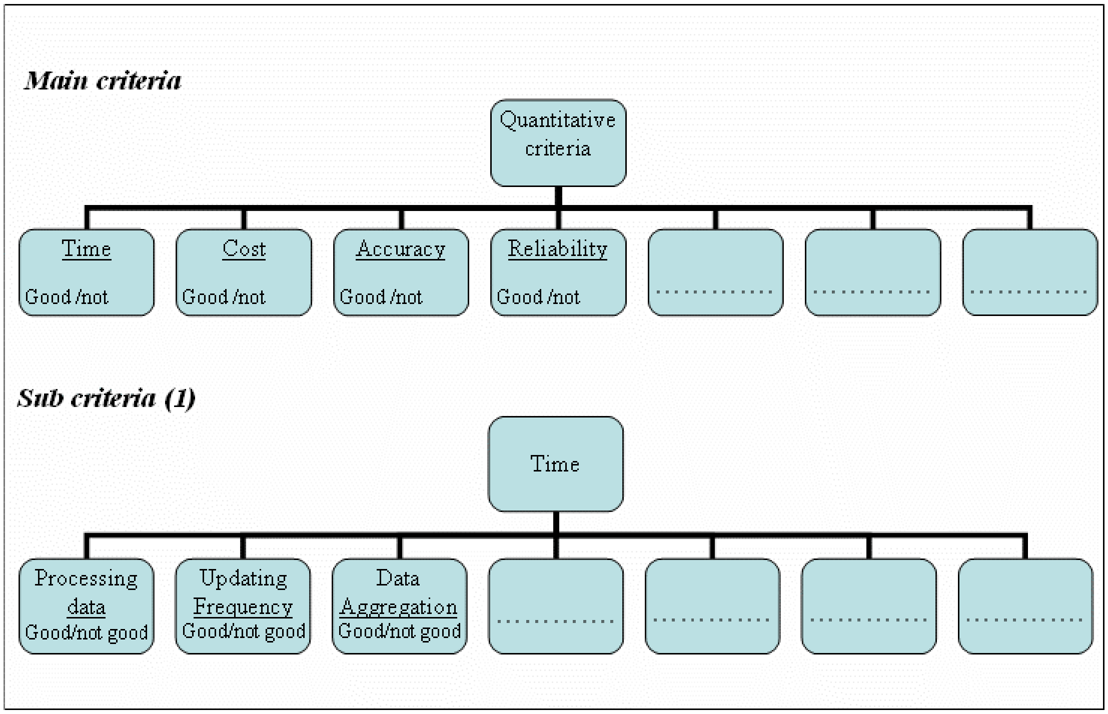


Figure 30. The Hierarchy of Criteria for Performance Measures.

Within Steps 2 and 3, various techniques, such as brainstorming, nominal group technique (NGT), surveys, or the Delphi method may be used to generate feasible alternatives and their criteria. Coordinators need to select the proper technique for the particular situation because each technique has its own advantages and limitations. For example, according to Ababutain *(10)*, the objective of brainstorming is to generate all possible ideas in order to enhance the possibility of reaching ideal solutions. Thus, the final results may generate an unlimited number of solutions; however, the limitation of brainstorming occurs when some members of the group have strong opinions, which lead the other members to quickly reach an agreement without a complete discussion. Thus, the results may not include other potentially better solutions. Unlike the brainstorming technique, the NGT uses a questionnaire survey to allow decision makers to communicate in writing, which can avoid preliminary arguments. However, surveys that allow face-to-face and phone interviews may create conforming influences and decrease the possibility of generating ideas freely. Because the selection of freeway operational strategies decision uses experts who are directly involved with the freeway management system, the researchers selected the Delphi method. According to Dalkey and Helmer *(11)*, coordinators will select the respondents from a group of experts that will be asked intensive questions with controlled opinion feedback. Disagreements among the experts will develop successive iterations until the various opinions yield to a widely acceptable view. The process ends at this point. The success of this method depends on experts' knowledge, experiences, and viewpoints that can reflect the true value of whatever they judge. For example, constructing a new freeway can provide both advantages and disadvantages depending on the experts' viewpoints. A new freeway can reduce traffic congestion; however, it can induce new vehicles to use it and increase on-road emissions.

STEP 4: SCREENING THE "SET OF ALTERNATIVES OR SOLUTIONS IN STEP 2"

Quality is better than quantity. More performance measures do not mean that they will provide a better assessment of the program. Thus, Step 4 provides an approach for screening the alternatives that are identified in Step 2. The processes include grouping the performance measures, defining the direct or proxy performance measures, setting the constraints, and eliminating performance measures based on minimum assessment levels established by the decision makers.

Step 4.1: Grouping the Alternatives that Convey the Same Meaning

In order to avoid using redundant performance measures, the performance measures that convey the same meaning must be grouped. For example, when planners consider the human health impacts due to traffic congestion, the Air Quality Index (AQI) used in the United States and the Air Quality Health Index (AQHI) used in European countries are indicators for assessing ambient air quality, which affects human health. However, both indices convey the same meaning; to be practical, decision makers should select either AQI or AQHI, but not both. The coordinators must clearly understand the definition of the alternatives obtained in Step 2 before they group them.

Step 4.2: Defining Direct or Proxy Performance Measures

Ideally, decision makers should consider direct performance measures before resorting to proxy performance measures. Good performance measures should be a direct consequence of activities. For example, if the desired result is minimizing traffic congestion, traffic volume should be a good performance measure (direct consequence). A proxy measure, such as vehicle registration, may sometimes be used in the absence of suitable performance measures due to time, budget constraints, or data unavailability. Unfortunately, a proxy measure may not provide a good result because it relies on strong correlation between the factors. The coordinators have to define the performance measures in Step 4.1 as either direct or proxy measures.

Step 4.3: Setting the Constraints for Screening the Alternatives

Qualitative criteria and quantitative criteria will be used to screen the feasible performance measures in the next step. Both qualitative and quantitative criteria established in Step 3 may have either a minimum or maximum acceptable value for each criterion, which represents the threshold that the performance measures must reach. The decision makers have to establish the set of constraints and their thresholds.

Step 4.4: Eliminating the Alternatives by Aspects

As developed in NCHRP Synthesis 311 *(1)*, Table 8 details a scoring approach to assess the strengths and weakness of various measures based on the qualitative criteria and sub-criteria.

Table 8. Criteria Performance Measures.

Criteria	Sub-Criteria
Clarity and simplicity	The measure is simple to present, analyze, and interpret The measure is unambiguous The measure's units are well defined and quantifiable The measure has professional credibility Technical and nontechnical audiences understand the measure
Descriptive and predictive ability	The measure describes existing conditions The measure can be used to identify problems The measure can be used to predict change and forecast condition The measure reflects changes in traffic flow conditions only
Analysis capability	The measure can be calculated easily The measure can be calculated with existing field data There are techniques available to estimate the measure The results are easy to analyze The measure achieves consistent results
Accuracy and precision	The accuracy level of the estimation techniques is acceptable The measure is sensitive to significant changes in assumptions The precision of the measure is consistent with planning applications The precision of the measure is consistent with an operation analysis
Flexibility	The measure applies to multiple modes The measure is meaningful at varying scales and settings

The performance measures that meet a sub-criteria requirement will be given a score of +1; otherwise they will be given a score of 0. Using this scoring approach, the significance of the clarity and simplicity issues can be explained by its score (5/20); scores for the descriptive and predictive ability, analysis capability, accuracy and precision, and flexibility issues are (4/20), (5/20), (4/20), and (2/20), respectively. Take note that some rankings are based on 4 sub-criteria while others are based on 5. The performance measures that received a minimum score of 15 out of 20 are considered in practice. The performance measures in the NCHRP 311 that pass the minimum score of 15 out of 20 are listed in Table 9.

These criteria and sub-criteria can be used for assessing performance measure quality and identify an initial set for consideration. However, in practice, decision makers may consider the significance of each issue differently. For example, the score for flexibility may be higher than (2/20). In addition, this method does not provide a minimum value cut-off based on quantitative criteria. Decision makers may have specific local characteristics that must be achieved, such as minimum percentage of reliability and accuracy of performance measures based on the different data collection strategies.

Table 9. Performance Measures Scores.

Performance Measure	Overall Score	Clarity and Simplicity (out of 5)	Descriptive and Predictive Capability (out of 5)	Analysis Capability (out of 4)	Accuracy and Precision (out of 4)	Flexibility (out of 2)
Air quality impacts	16	5	3	3	3	2
Bridge condition	16	5	4	4	3	0
Delay caused by incidents	17	5	2	4	4	2
Delay recurring	20	5	5	4	4	2
Delay total	20	5	5	4	4	2
Density (vehicles per hour per lane)	19	5	5	4	4	1
Density (vehicles per lane-mile)	18	5	4	4	4	1
Duration of congestion	19	4	5	4	4	2
Evacuation clearance time	15	5	3	3	3	1
Incident response time	17	5	3	4	4	1
Incidents (fatal) per million vehicle-miles	17	5	3	4	4	1
Incidents (injury) per million vehicle-miles	16	5	3	3	4	1
Incidents (number of crashes or stopped vehicles)	17	5	3	4	4	1
Incidents (property damage only) per million vehicle-miles	16	5	3	3	4	1
Level of service	17	5	4	3	4	1
Number of miles operating in desired speed range	19	5	5	4	4	1
Pavement condition	18	5	4	4	4	1
Percent of ITS equipment	17	5	3	4	4	1
Percent of travel congested	15	3	3	3	4	2
Person-miles traveled	20	5	5	4	4	2
Queuing of traffic (frequency)	18	5	5	4	4	0
Queuing of traffic (length)	18	5	5	4	4	0
Rail crossing incidents	17	5	3	4	4	1
Response time to weather-related incidents	15	4	2	4	4	1
Response times to incidents	15	4	2	4	4	1
Speed	20	5	5	4	4	2
Toll revenue	16	5	3	3	3	2
Traffic volume	19	5	5	4	4	1
Travel time	19	5	5	4	4	1
Travel time predictability	18	5	5	3	4	1
Travel time reliability	15	3	3	4	4	1
Vehicle-miles traveled	19	5	5	4	4	1
Vehicle occupancy (persons per vehicle)	18	5	3	4	4	2
Volume/capacity ratio	19	5	5	3	4	2

Unlike the scoring approach in NCHRP 311, the proposed methodology provides thresholds for both qualitative and quantitative criteria. Once the set of constraints is established in Step 4.3, the alternatives that do not meet the standard criteria thresholds are eliminated. The criteria presented in this paper are assumed to be critical for selecting the performance measures. If any performance measures fail to meet one minimum criterion threshold, they will be rejected. This report suggests some initial qualitative and quantitative criteria and their thresholds. The survey should be provided to the decision makers to establish the supplemental criteria and their thresholds next; the complete questionnaire is provided in the Appendix to this report.

Coordinators have to screen the alternatives using qualitative and quantitative criteria using the thresholds provided in Step 4.3. The qualitative criteria used in this report include:

- *Comprehension* – performance measures should be understandable at any managerial level without defining the terminology.
- *Measurability* – performance measures should be measurable.
- *Availability* – performance measures should be readily available.
- *Comparability* – performance measures should be comparable with other agencies.
- *Importance* – performance measures should be useful to the public.

The quantitative criteria suggested in this report include:

- *Time* – includes data aggregation time, data processing time, and updating data frequency time.
- *Cost* – includes capital costs, operational costs, and maintenance costs.
- *Accuracy* – includes data processing accuracy, instrumental accuracy, data aggregation accuracy, and human accuracy.
- *Reliability* – includes the failure of field equipment, communication, and database.

AN EXAMPLE OF SCREENING “THE SET OF ALTERNATIVES OR SOLUTIONS” IN STEP 4

The NTOC report *(3)* recommends performance measures for local administrators to be used for internal management, external communications, and comparative measurements as follows: customer satisfaction, extent of congestion-spatial, extent of congestion-temporal, incident duration, recurring and non-recurring delay, speed, throughput-person, throughput-vehicle, travel-link, travel reliability, and travel trip. Assume that the traffic management center

(TMC) or third level in Figure 28 will use speed as one of the alternative performance measures for a freeway system. The screening approach outlined in Step 4 should be applied as follows.

Step 4.1: Grouping The Alternatives That Convey The Same Meaning

Speed can be divided into two groups: spot speed and space mean speed. Spot speed is described as an instantaneous speed measured at a specific location, while space mean speed is an average travel speed over a distance. The equipment and techniques used for collecting spot and space mean speed data are:

- *Spot speed* - gun radar, loop detector, microwave sensor, video sensor, infrared sensor, and acoustic sensor.
- *Space mean speed* - test vehicle (floating car) technique, license plate matching technique, video matching technique, ITS probe vehicle technique, time lapse photography, and toll tag matching technique.

Step 4.2: Defining Direct or Proxy Performance Measures

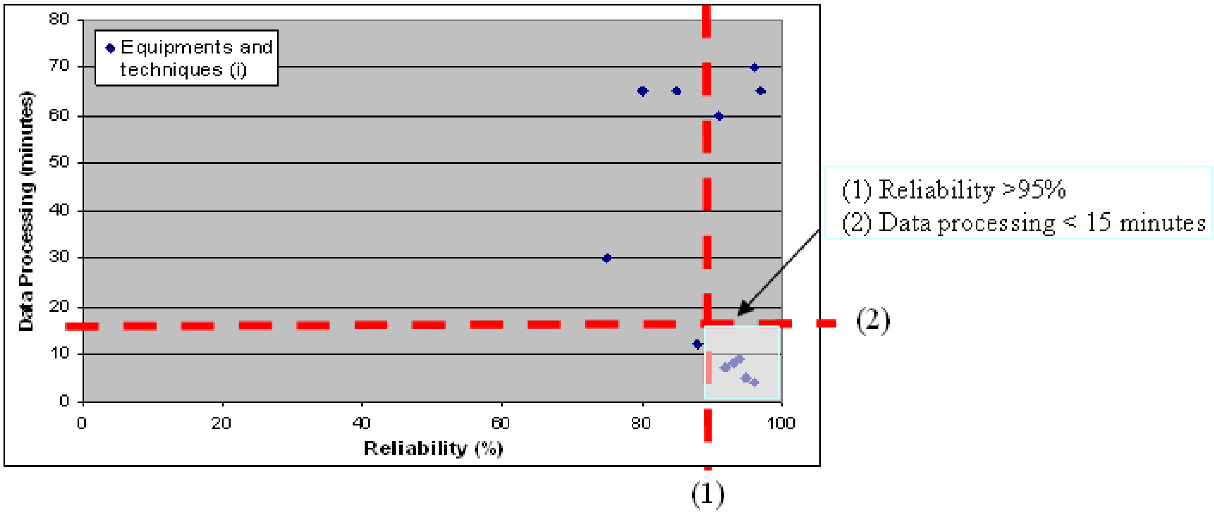
Both spot speed and space mean speed are defined as direct performance measures.

Step 4.3: Setting the Constraints for Screening the Alternatives

When considering qualitative criteria, speed should be an appropriate performance measure, which can be understood by most people; moreover, it is measurable because speed data can be collected using a variety of data collection techniques. Lastly, it can be compared between agencies and is useful for the general public. When considering quantitative criteria, the study proposes that decision makers use the accuracy, reliability, and data processing time as constraining criteria. The data collection for accuracy and reliability should be higher than 95 percent and 85 percent, respectively; data processing should be less than 15 minutes.

Step 4.4: Eliminating the Alternatives by Aspects

In the absence of valid data, the accuracy constraint is omitted, so decision makers will consider the data collection strategies that have reliability above 95 percent and data processing less than 15 minutes. Figure 31 illustrates the results when screening criteria by minimum performance thresholds. The alternatives that do not meet some specified standard are eliminated until the remaining alternatives, which pass all constraints, fall in the shaded area.



(1) Reliability >95%
(2) Data processing < 15 minutes

Figure 31. Graphic Presentation of Reliability and Data Processing Time.

STEP 5: ASSESSING THE "SET OF ALTERNATIVES FROM STEP 4"

Once the decision makers screen the performance measures in Step 4 to determine the feasible alternatives, multi-criteria decision making (MCDM) models, which allow decision makers to evaluate the tradeoffs among the various criteria, are applied in this step. MCDM models require decision makers to establish the weights of each criterion. Numerous techniques are used for assigning the criteria weights, such as presumption of equal weights, ranking system, ratio system, basic pair-wise analysis, hundred point system, and swing weight approach *(12)*. Each technique has its own advantages and limitations. For example, "presumption of equal weights" may be first assumed when decision makers are not ready to assign the criteria weights; however, equal weights rarely exist in the final set of weights. In addition, a ranking system is a simple method, which requires less effort from decision makers, but the results from the ranking method are only ordinal, which limits the validity of most mathematical operations related to them. One simple technique, applied in this methodology, is called the "one hundred point system." In this technique, decision makers are given 100 points to distribute amongst the criteria. The points allocated to a criterion directly give its percentage weight. The advantages of this method are its straightforward concept and its ability to provide data that can be evaluated using a ratio scale. However, this strength leads to a concern about the validity of the results that the coordinator must address through a series of verification questions that verify if the final result matches the decision-makers' intentions. Specifically, the decision maker must agree with the ratio scale implications of their weights. The roles of the decision makers and coordinators involved in this step are:

- Decision makers have to establish the criteria weights through one of the weighting techniques described above. MCDM models will be used to assess those alternatives in the final decision-making process.
- Coordinators have to provide additional questions to assess the consistency of the results of the weighting technique used. For example, within the “one hundred point system” approach, decision makers must understand the comparisons and ratios between the criteria.

CHAPTER 9:
MULTI-CRITERIA DECISION-MAKING MODELS

Selecting performance measures is usually based on more than one criterion. Using a MCDM approach allows decision makers to analyze complex decision problems with usually conflictive and opposite points of view. Additionally, this type of analysis can be used to evaluate performance measures when their attributes are not valued in monetary terms *(12)*. According to Polatidis et al. *(13)*, there are two main families of MCDM models: utility function-based models and outranking methods. The utility function-based models include Multi-Attribute Utility Theory (MAUT) *(14)*, Analytic Hierarchy Process (AHP) *(15)*, and Simple Additive Weighting (SAW). Outranking methods include the ELECTRE families *(16, 17)*, PROMETHEE I and II methods *(18)*, and Regime Method Analysis *(19)*. Some models, such as Stochastic Multiobjective Acceptability Analysis (SMAA) *(20)*, Novel Approach to Imprecise Assessment and Decision Environment (NAIDA) *(21)*, and Flag Model *(22)*, do not fit into either of these broad families.

All MCDM models can provide the ranking of alternatives, but none of them can be described to fit decision problems completely. For example, SAW uses a simple utility function model, which requires high quality of data (using real data or actual scores); however, decision makers may only require a ranking of the alternatives rather than their actual scores. Unlike the SAW model, AHP's use of pairwise comparisons allows decision makers to establish the ranking of alternatives when actual information is unavailable; unfortunately, within the AHP approach, decision makers may have a difficult time making all of the necessary comparisons. The concordance methods do not require decision makers to weight the importance of one criterion against the others. This method may provide only a partial ranking and preferred options rather than one best option. The selected MCDM methods should fit the complexity of problems, availability of data, and weighting technique. The authors provide an application of the SAW and ELECTRE III methods, which are assumed to fit with the available data and decision problems.

EXAMPLE USING "MCDM MODELS"

Following Steps 1 through 4, the authors assume that the decision makers decide to use speed as a performance measure to assess the freeway performance at the implementation level. Decision makers are asked to define the criteria and weights to assess the data collection strategies. Assuming a weighting technique is used to obtain the weight for each criterion and sub-criterion shown in Figure 32, the three main criteria are composed of cost, accuracy, and reliability, weighted by 65, 20, and 15 percent, respectively.

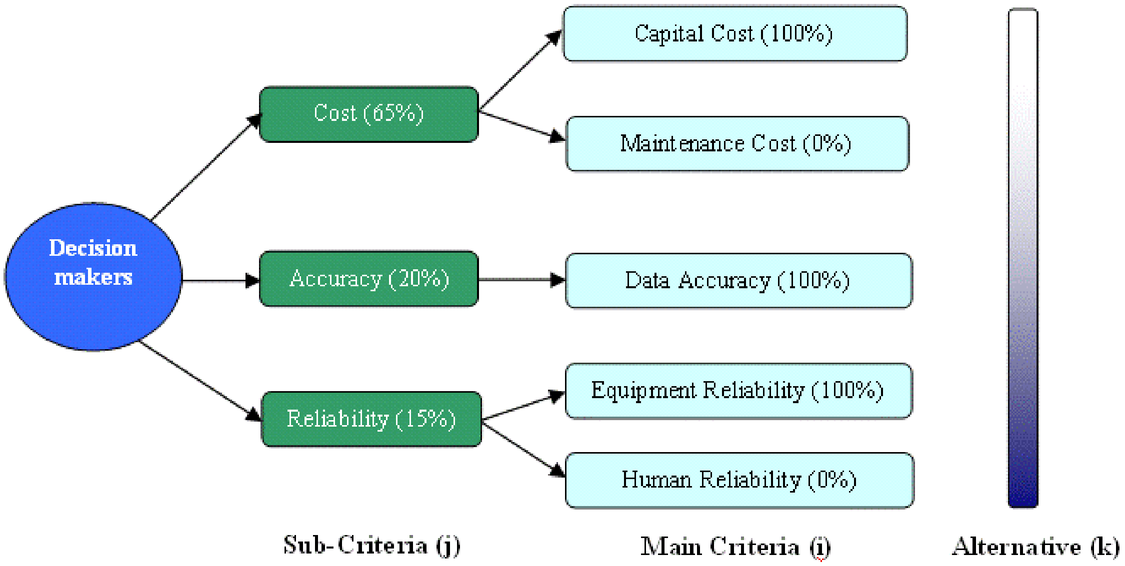


Figure 32. Weighting Criteria and Sub-criteria.

Five sub-criteria are considered; however, the authors assume that decision makers are not concerned about the maintenance cost and human reliability criteria and assign them a zero for their weight.

Based on the screening of alternatives in Step 4, the six remaining alternatives are loop detector, microwave sensor, video sensor, infrared sensor, acoustic sensor, and ITS probe vehicle. In order to assess each alternative with various quantitative criteria, the following formulas, called the ideal point concept, can be used for criteria normalization:

$$C_{ijk} = \frac{x_{ijk} - \min x_{ijk}}{\max x_{ijk} - \min x_{ijk}}$$ ***Eq. 13***

$$C_{ijk} = \frac{\max x_{ijk} - x_{ijk}}{\max x_{ijk} - \min x_{ijk}}$$ ***Eq. 14***

Where:

x_{ijk} is the score of alternative k with respect to criteria i on sub-criteria j,

C_{ijk} indicates the benefit of performance measure.

After normalization, all criteria are positive criteria where a higher C_{ijk} is preferred. Within the ideal point concept, the quantitative data are converted into a comparable unit between "0 and 1" where "0" is the lowest utility value. The use of *Eq. 13* and *Eq. 14* depend on the variable x_{ijk}. If an increase of x_{ijk} leads to improvement, then *Eq. 13* is used; otherwise, *Eq. 14* is applied. For example, if x_{ijk} is travel time, an alternative that leads to the increase of travel time will be unfavorable and *Eq. 13* is used. *Eq. 13* and *Eq. 14* are applied in this example and the scaling values are shown in Table 10, which is used for the SAW and ELECTRE III methods.

SAW METHOD

In Figure 32, the decision hierarchies are composed of two levels: main criteria (level *i*) and sub-criteria (level *j*). The form of an additive utility function in the upper level (*i*) is:

$$V_{tot} = \sum_{i=1}^{n} w_{ik} U_{jk}$$ ***Eq. 15***

Where:

V_{tot} is the overall valuation for alternative k; w_{ik} is the weight assigned to criterion i for alternative k; U_{jk} is the utility in the lower level j for alternative k; and n is the number of criteria. The utility function in the lower level is calculated as follows:

$$U_{jk} = \sum_{j=1}^{m} w'_{jk} C_{ijk}$$ ***Eq. 16***

Where:

U_{jk} is the utility in the lower level *j* for alternative *k*; *m* is the number of sub-criteria of criterion *j*; w'_{jk} is the weight assigned to sub-criterion *j*; C_{ijk} is the scaling value calculated from *Eq. 13* or *Eq. 14*. The final decision is based on the result from the overall valuation in *Eq. 15*.

Table 10. Scaling Value for the Alternatives.

Sub-Criteria	Loop Detector	Microwave Sensor	Video Sensor	Infrared Sensor	Acoustic Sensor	ITS Probe Vehicle
Capital Cost ($)	14,400	13,000	13,000	20,000	5,600	100,000
Data Accuracy (%)	95	95	95	90	90	90
Equipment Reliability (%)	95	95	95	95	92.5	96
Scaling the sub-criteria using Eq. 13 and Eq. 14.						
Data Accuracy	0.91	0.92	0.92	0.85	1.00	0.00
Equipments Reliability	1.00	1.00	1.00	0.00	0.00	0.00
Capital Cost	0.71	0.71	0.71	0.71	0.00	1.00

ELECTRE III METHOD

The ELECTRE III method uses the concept of a concordance and discordance index to obtain alternative rankings. A concordance index $C_j(a,b)$ for any pair of alternatives implies that alternative *a* is at least as good as alternative *b*. Then, the concordance index is calculated as follows:

$$C_j(a,b) = \sum_{j=1}^{n} w_j c(a,b)$$ ***Eq. 17***

Where:

w_j is the relative importance of the different criteria.

$c(a,b)$ is the local concordance index.

$$\begin{cases} 1, \text{ if } g_j(a) + q_j \geq g_j(b) \\ 0, \text{ if } g_j(a) + p_j \leq q_j(b)\text{; otherwise} \end{cases} \qquad \textbf{\textit{Eq. 18}}$$

$$C_j\,(a,b) = 0, \text{ if } g_j(a) + p_j \leq q_j(b)\text{; otherwise} \qquad \textbf{\textit{Eq. 19}}$$

$$\frac{g_j(a) - g_j(b) + p_j}{p_j - q_j} \qquad \textbf{\textit{Eq. 20}}$$

The discordance index is used to model the magnitude of the lack of compensation between the criteria by using a veto threshold v_j (constant threshold). A discordance index $d_j(a,b)$ for each pair of alternatives implies no alternative *a* is better than alternative *b*. Then, the discordance index is calculated as follows:

$$D_j(a,b) = \begin{cases} 0, \text{ if } g_j(a) + p_j \geq g_j(b)\ ; \\ 1, \text{ if } g_j(a) + v_j \leq g_j(b)\text{; otherwise} \\ \dfrac{g_j(b) - g_j(b) - p_j}{v_j - p_j} \end{cases} \qquad \textbf{\textit{Eq. 21}}$$

The discordance indices of different criteria are not aggregated using the criteria weights because each criterion is evaluated for discordance individually. The degree of outranking or credibility index is defined as follows:

$$S(a,b) = \begin{cases} C(a,b), \text{ if } D_j(a,b) \leq C(a,b), \forall_j\ \text{; otherwise} \\ C(a,b) \displaystyle\prod_{j \in J(a,b)} \frac{1 - D_j(a,b)}{1 - C_j(a,b)} \end{cases} \qquad \textbf{\textit{Eq. 22}}$$

Where: $J(a,b)$ is a set of criteria for which $D_j(a,b) > C(a,b)$

The credibility index is used to assess the tradeoff between alternatives *a* and *b*. Alternative *a* will outrank alternative *b* when $S(a,b)$ is greater than a minimum 'threshold' value, λ, which is usually set at approximately 0.85. Then, a positive score *+1* will be given to alternative *a*. In contrast, a negative score *-1* will be given to alternative *b* being outranked. The final ranking will be established based on the total score through the process of descending and ascending distillation. More explanation of ELECTRE III can be found in Rogers et al. *(12)*.

Roy et al. *(16)* describes the value of the preference threshold (*p*) and indifference threshold (*q*), which is set as the margins of uncertainty, error, or imprecision. The *p* and *q* thresholds can be defined by the decision makers' opinions. The *p* threshold is related to the positive attitude that a decision-maker may have for a particular criterion's score. In addition, the *q* threshold is the point where decision makers perceive a difference between alternatives *(23)*. The veto threshold (*v*) can be set against the hypothesis that alternative *a* will usually be better than *b*. Due to the fact that sometimes alternative *a* may be worse, or alternative *b* outperforms alternative *a*, the veto threshold (*v*) always is set greater than the *p* threshold. However, the estimation of the veto threshold is difficult and many studies, in practice, often avoid using it. As a result, the credibility index for each pair of alternatives is assumed to be equal to the concordance index *(16)*.

This example avoids the use of the veto threshold. The decision makers perceive the value of the *p* and *q* threshold as follows:

- *Capital Cost* – This is an important criterion with the maximum weight because it relates directly to the availability of types of equipment, techniques, etc. Thus, the *q* threshold is set to a "small" value ($q = 0.15$), while the preference threshold is set twice as large ($p = 0.30$).
- *Data Accuracy* and *Equipment Reliability* – This relates to the quality of information obtained. However, current technologies lead to only slight differences in equipment accuracy and reliability. Thus, the *q* threshold is set to a "large" value ($q = 0.25$), while the preference threshold is set twice as large, $p = 0.50$.

ANALYSIS OF RESULT

The full ranking of alternatives using the SAW model based on the scaling data (Table 10) and weighting criteria (Figure 32) are analyzed. From this analysis, the microwave and video sensors appear to be the best alternative with the same highest score (0.91) for the SAW method. Loop detector, infrared sensor, acoustic sensor, and ITS probe vehicle trail behind in that order. The ELECTRE III model is utilized to assess the same alternatives and the microwave and video sensors are again the best alternatives at the highest level; however, the loop detector is also one of the top alternatives (Figure 33).

The rank order for the two techniques is very similar; however, ELECTRE III does not provide a score for the alternatives as SAW does. This difference between the two techniques is critical for the decision-makers and coordinators to consider. Recall specifically, the earlier discussion regarding the decision statement in Step 1; the choices made at this stage will likely determine the appropriate technique to apply in Step 5. The core concept behind the difference in the two techniques is ELECTRE III's assumption that small differences between alternatives are indistinguishable from one another due to inherent uncertainties in the decision-making process. As seen in Figure 33, the alternatives that share the same rank in ELECTRE III all have very similar scores in the SAW technique.

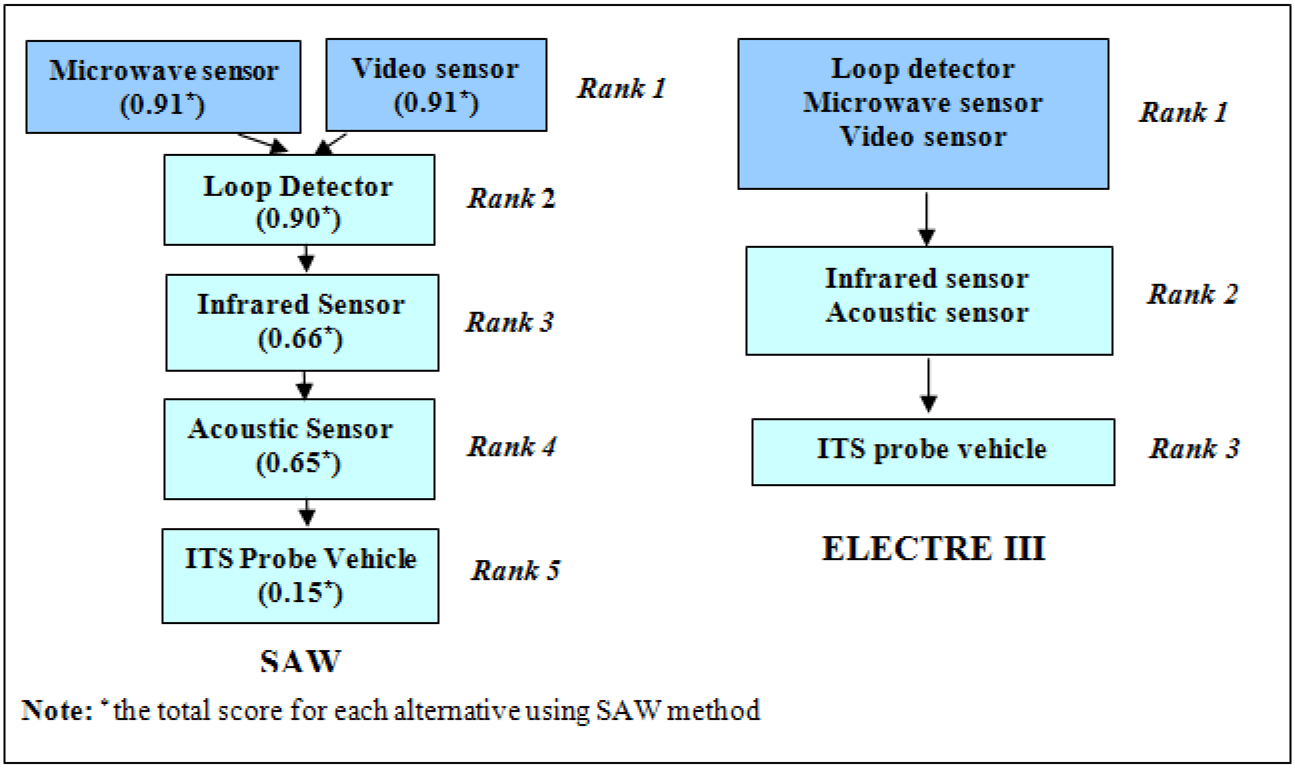


Figure 33. Ranking of Alternatives by using SAW and ELECTRE III Method.

CHAPTER 10:
CONCLUSIONS AND DISCUSSION

OPERATIONS

The research performed within the scope of this project provided the groundwork feasibility test of using performance measures in real-time. Year One efforts indicated that real-time performance measurement is not being done. An examination of two thrust areas, operations and emissions, concluded that the operations area was a viable avenue to continue development of a real-time performance monitoring capability. The emissions area was not found to be viable for development of a real-time, narrowly focused monitoring architecture.

In Year Two, a prototype real-time performance monitoring system was developed. The development of this prototype system encompassed the creation of a system architecture, assessment of potential measures, simulation based testing of real-time measures, assessment of results and future viability, prototype interfaces and data storage capabilities, and a concept of operations to guide future development or implementation.

The prototype interfaces (operator displays) emphasize several points. First, the use of the NTOC performance measures in real-time can, in fact, provide an understanding of roadway conditions and serve as a baseline to visually communicate that information, on both a temporal and spatial basis. Second, while the initial results are promising, a modification to the NTOC methodology would be necessary for some measures, such as a straight comparison of speed or travel time. Without a comparison baseline, the normal volatility in these parameters would render them somewhat useless for identifying abnormal conditions. Finally, additional efforts are necessary to determine the sensitivity of the measures to variations in traffic levels, changes in the ratio value used, etc. Additionally, a determination of the sensitivity of the travel time ratio performance measure should be made if the target travel time values change by time of day, as determined by an operator.

MULTI-CRITERION SELECTION

The selection framework detailed in this report improves on earlier research by facilitating the constrained selection of freeway operational performance measures. The process allows decision makers to generate candidate solutions and criteria before using both qualitative and quantitative performance thresholds, and reduce the possibilities to a set of feasible alternatives. The use of MCDMs provides an opportunity for the decision makers to evaluate the tradeoffs across the different criteria. The decision makers must select the appropriate weighting techniques or MCDMs based on the complexity of their problem or the required results because each technique and MCDM has both strengths and limitations. The proposed criteria and application framework provides the guidelines for future applications by TxDOT. The successful implementation of the proposed methodology requires complete and engaged participation from the decision makers.

Implementation of this research will use actual decision maker input to generate realistic criteria and their weights. Additionally, decision maker input is required to establish the proper performance thresholds. Testing the process with decision maker participation will facilitate revision of the framework to fully meet TxDOT needs. After using this framework for selecting operational freeway performance measures, it can be modified so that it is able to evaluate different operational strategies and recommend alternatives for selection. This future improvement is critical for the selection of operational alternatives in real-time based on their associated performance measures.

CHAPTER 11: REFERENCES

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APPENDIX
MULTI-CRITERIA SELECTION MODEL QUESTIONNAIRE

SURVEY DOCUMENT

This appendix contains a survey document distributed to the project monitoring committee during the course of the research to help define both the qualitative and quantitative aspects of the multi-criterion selection model formulation.

Overview of assessing performance measures by quantitative and qualitative criteria

Quantitative and qualitative criteria are used to assess the quality of performance measures. Figure A-1 illustrates the hierarchic criterion for selecting performance measures. Time, cost, accuracy and reliability constraints are used as quantitative criteria which are quantifiable, whereas qualitative criteria include understanding, measurability; availability, comparability, and importance (see Figure A-1). The definition of each criterion is described in Table A-1.

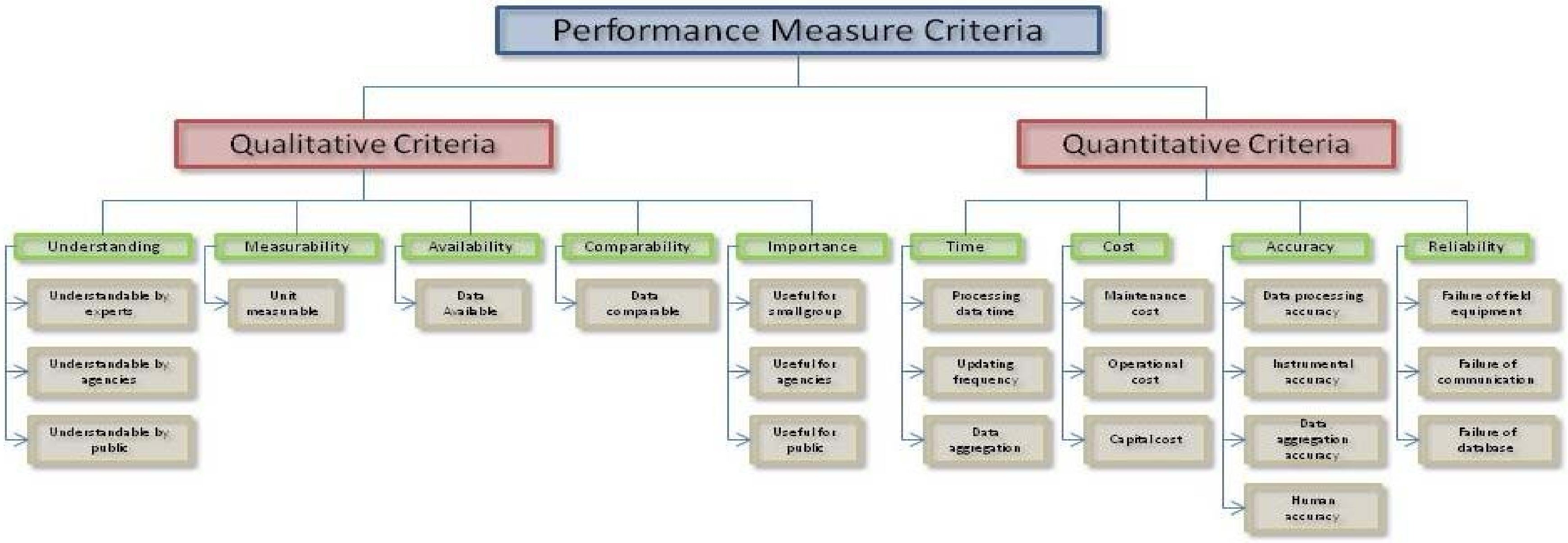

Figure A-1. Hierarchic criterion for selecting performance measures.

Table A-1. Description of quantitative and qualitative criteria.

Main-criteria	Sub-criteria	Description
Time	Data aggregation time	is the time duration required to gather the appropriate amount of data
	The processing data time	is the time required to calculate the performance measures after the operational center received all information.
	Updating frequency time	is the time between real-time updates of the performance measures (Data aggregation time plus time for transferring the data from fields to operation center).
Cost	Capital costs	are one time total costs being expensed to collect the data necessary to calculate the performance measure. Capital costs include costs of land, buildings, construction, and equipment.
	Operational costs	are costs related to operation of organization and equipment.
	Maintenance costs	are costs of labor and parts to perform repairs. Maintenance costs may also be required to maintain the equipment and data.
Accuracy	Data processing accuracy	is the quality of value being estimated or calculated by computable systems compared with the actual value estimated by reliable computable systems.
	Instrumental accuracy	is the quality of value being measured by field equipment compared with the actual value measured by reliable instrument.
	Data aggregation accuracy	is the quality of value being gathered by computers or humans compared with the actual value gathered by reliable approach.
	Human accuracy	is the quality of value being processed by humans compared with the actual value processed by reliable approach.
Reliability	Failure of field equipment	is the percentage of time the field equipment does not function properly in routine circumstances or in unexpected conditions.
	Failure of communication	is the percentage of time the communication system does not function properly in routine circumstances or in unexpected conditions.
	Failure of database	is the percentage of time the database system does not function properly in routine circumstances or in unexpected conditions.
Understanding	Level 1	understandable by only experts (no need to define the terminology)
	Level 2	understandable by agencies or organization (people in agencies or organization that work in the program understand the measures without defining the terminology)
	Level 3	understandable by public (most people understand it without defining the terminology) **Note:** Good performance measure should be understandable at any level without defining the terminology.

Table A-1. (Cont.) Description of quantitative and qualitative criteria.

Main-criteria	Sub-criteria	Description
Measurability	Level 1	Immeasurable
	Level 2	Measurable **Note:** Good performance measure should be measurable.
Availability	Level 1	Data unavailable
	Level 2	Data available **Note:** Good performance measure should be readily available as a direct performance measure.
Comparability	Level 1	Incomparable with other agencies or standards
	Level 2	Comparable with other agencies or standards **Note:** Good performance measure should be comparable with other agencies.
Importance	Level 1	Useful for a small group
	Level 2	Useful for agencies or organizations
	Level 3	Useful for public **Note:** Good performance measure should be useful for public.

Example of question on screening criteria

1. Do you think that screening criteria being provided are acceptable and suitable for assessing freeway operation?

   Yes ___

   NO ___

Please, suggest the minimum and maximum value for screening criteria in Table A-2 below:

Table A-2. The perception of decision makers' criteria threshold.

Criteria	Criteria	Threshold
Time (seconds)	Maximum data aggregation time	
	Maximum processing data time	
	Maximum updating frequency time	
Cost ($)	Maximum capital cost	
	Maximum operation cost	
	Maximum maintenance cost	
Accuracy (%)	Minimum % accuracy of data processing	
	Minimum % accuracy of instrument	
	Minimum % accuracy of data aggregation process	
	Minimum % accuracy of human interface	
Reliability (%)	Minimum % reliability of equipment	
	Minimum % reliability of communication system	
	Minimum % reliability of database system	

If the answer is “No”, please suggest and explain other screening criteria including the minimum or maximum threshold which should be added.

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Example of question on assessing performance measures by quantitative and qualitative criteria

2. Do you think that criteria for selecting performance measures should include qualitative criteria?

   Yes ___

   NO ___

If the answer is "No", please skip to question (4).

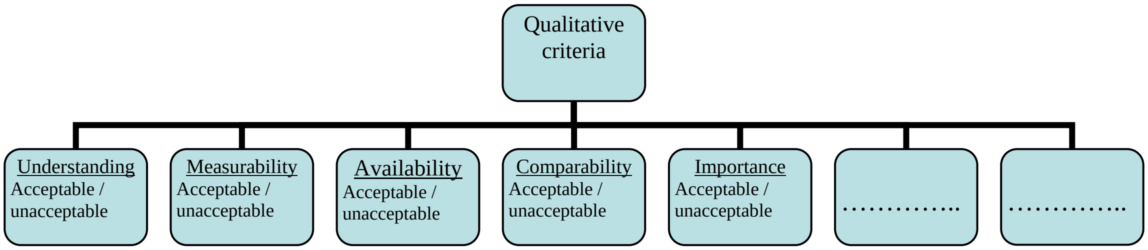
3. Do you think that qualitative criteria listed in Table A-1 are acceptable and suitable to assess the performance measure for freeway operation?

   Yes ___

   NO ___

   If the answer is "No", please suggest other criteria which should be added (fill out in blank box) or omitted (circle).

Main criteria



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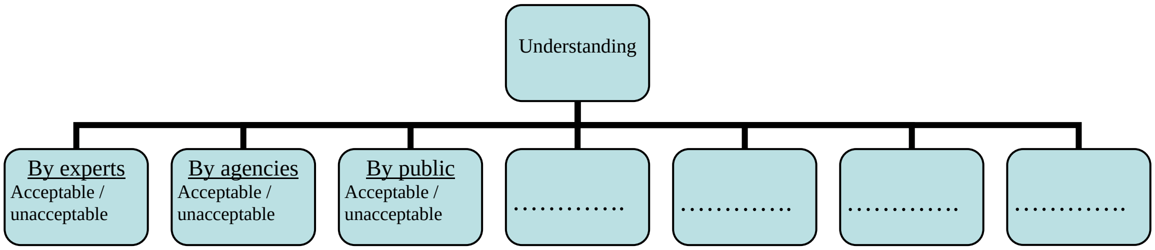
Sub criteria



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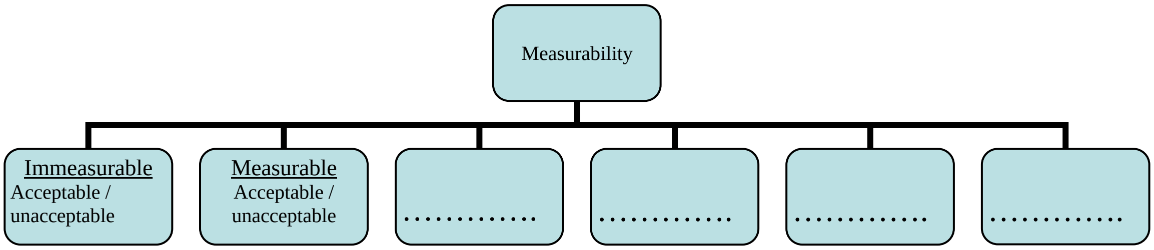

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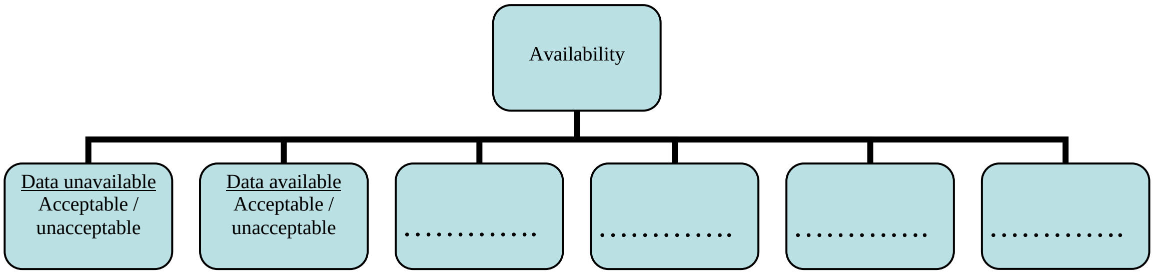

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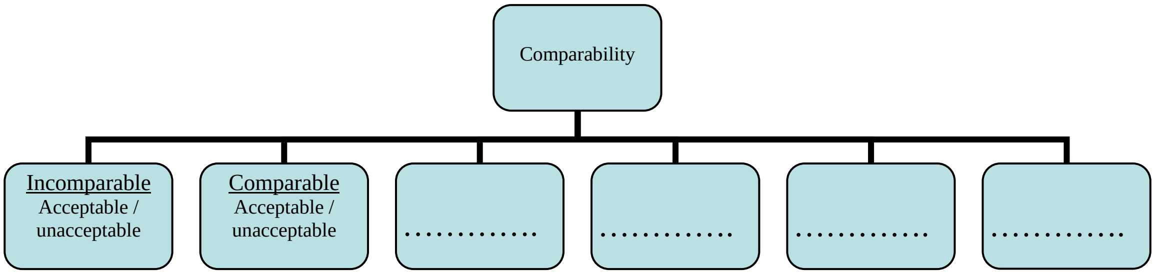

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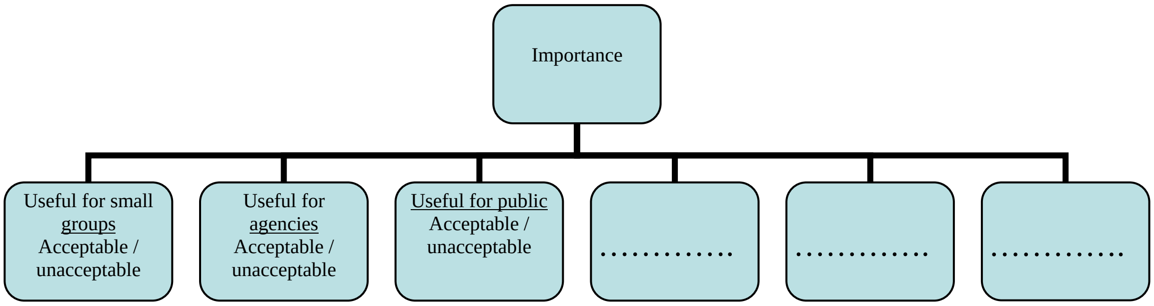

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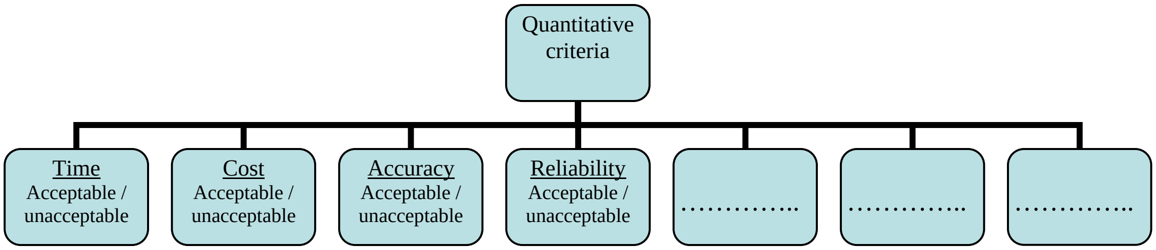
4. Do you think that quantitative criteria listed above are acceptable and suitable to assess the performance measure for freeway operation?

   Yes ___

   NO ___

   If the answer is "No", please suggest other criteria which should be added (fill out in blank box) or omitted (circle).

Main criteria



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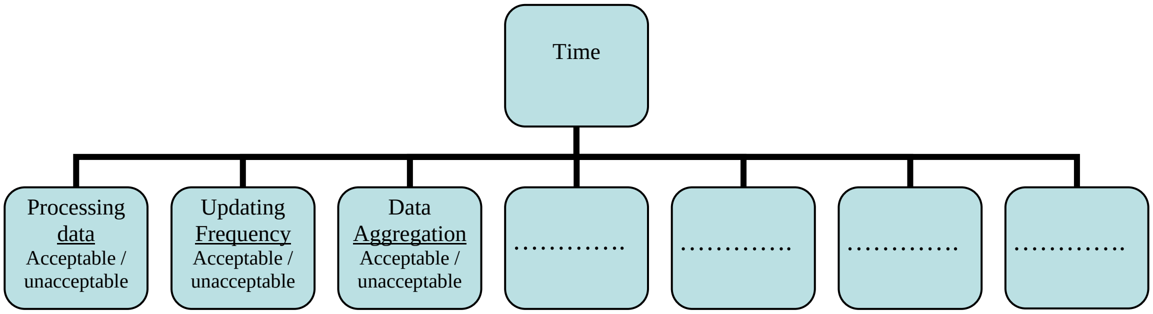
Sub criteria



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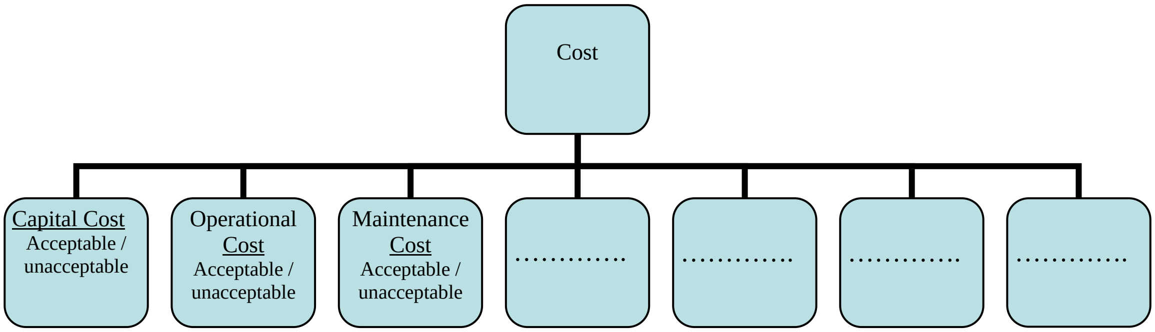

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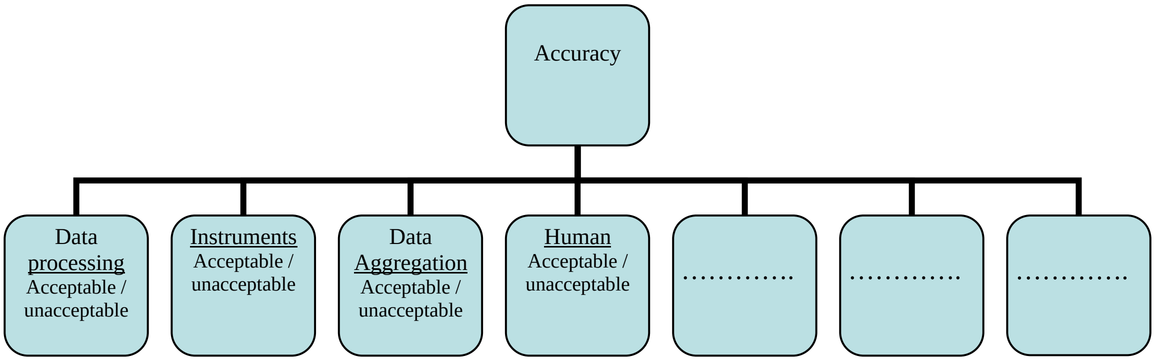

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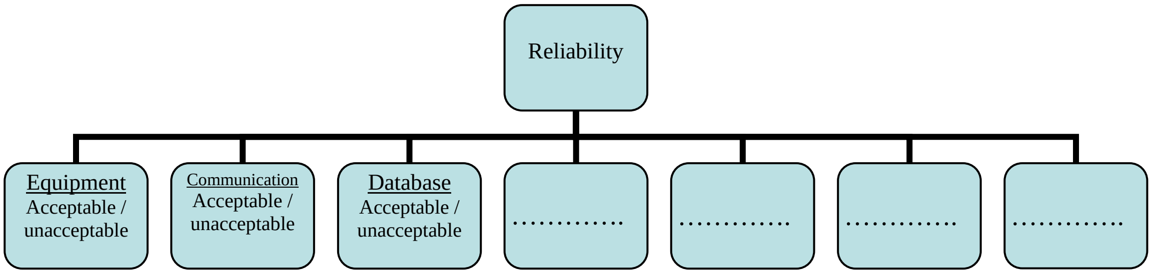

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