COMMERCIAL REMOTE SENSING & SPATIAL INFORMATION (CRS & SI) TECHNOLOGIES PROGRAM FOR RELIABLE TRANSPORTATION SYSTEMS PLANNING: VOLUME 3 - DECISION SUPPORT TOOLS (DSTs) IMPLEMENTATION AND USER GUIDE

Final Report No. RITARS-12-H-UNCC-3

Prepared for
The Office of the Assistant Secretary for Research and Technology (OST-R)
United States Department of Transportation (USDOT)
### Abstract

This report presents data processing, system functionality and implementation, and user interface of decision support tools (DSTs) to 1) examine spatial variations in the condition of the transportation network based on various performance measures, 2) assess the performance of links along a selected corridor in the transportation network, 3) identify and rank top “N” unreliable links in the transportation network, 4) assess the performance of a link by time-of-the-day and day-of-the-week during a year, 5) retrieve and report performance measures for any further analysis, and, 6) evaluate the effect of an incident on nearby links in the transportation network. The four DSTs are: 1) Reliability Mapping DST; 2) “HeatChart” Visualization DST; 3) Reports DST; and 4) Effect of Incident DST. These DSTs allow practitioners to explore and report performance of links and evaluate the effect of incidents on the transportation network. The outputs from the DSTs can be used to develop performance-based congestion management plans, identification of links (to divert traffic due to an incident) for incident management and re-routing traffic over time, and to assist planners and engineers in their day-to-day activities (mobility and safety improvements). Further, the DSTs also assist transportation system users make reliable route, mode and departure time decisions. Due to the nature of analytical needs and related decisions, it is recommended that DSTs developed and discussed in this report be implemented at regional or local level.

### Key Words

Reliability, Decision Support Tool, DST, Functionality, Implementation, User, Guide

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EXECUTIVE SUMMARY

There has been a paradigm shift in focus from intersection-level to corridor- and area-level analysis and performance measures in recent years. The possibility of capturing dynamic and continuous travel time and/or speed data by responsible governing agencies or obtaining it from private sources such as INRIX, TomTom, HERE, etc. opens many pragmatic avenues to assess reliability of transportation network and make better decisions. Travel time reliability (or index or variability) is considered as the most viable performance measure for corridor-level analysis with potential to be widely used for transportation system planning, project prioritization, and allocation of resources.

Decision support tools (DSTs) are vital to process large datasets, compute performance measures, assess spatial and temporal variations, and rank the links to effectively utilize limited transportation dollars. The outputs from the DSTs can help to develop performance-based congestion management plans, identification of links (to divert traffic due to an incident) for incident management and re-routing traffic over time (say, up to 2 hours after a fatal crash), and to assist planners and engineers in their day-to-day activities (mobility and safety improvements at link- or corridor-level). These DSTs also assist transportation network users make reliable route, mode and departure time decisions.

This report outlines the development and implementation of DSTs that would help practitioners to:

1) examine spatial variations in the condition of the transportation network based on various performance measures,
2) assess the performance of links along a selected corridor in the transportation network,
3) identify and rank top “N” unreliable links in the transportation network,
4) assess the performance of a link by time-of-the-day and day-of-the-week during a year,
5) retrieve and report performance measures data for any further analysis, and,
6) evaluate the effect of an incident on nearby links in the transportation network.

Travel time data for the Charlotte region in the state of North Carolina, for the years 2009 to 2013, comprising about 298 to 2058 links (Traffic Message Channel codes) were used in the development of DSTs. The raw data requested has average travel times for every 1-minute for the entire 5 year period.

The raw data obtained was used to compute various travel time measures. These include: 1) minimum travel time, 2) average travel time, 3) maximum travel time, 4) median travel time, 5) 85th percentile travel time, and 7) 95th percentile travel time (also referred to as planning time - PT). Several factors such as time-of-the-day, day-of-the-week, all weekdays of a year, all weekends of a year and all days were considered in evaluating these travel time measures. From the travel time measures, the reliability measures such as buffer time (BT), buffer time index (BTI), planning time index (PTI), travel time index (TTI), λ skew and λ variance were computed. All the processed information was stored as a single database to be retrieved by the DSTs, as needed, based on input provided by the practitioner.

Four interactive DSTs were developed as a part of this project. They are: 1) Reliability Mapping DST, 2) “HeatChart” Visualization DST, 3) Reports DST, and, 4) Effect of Incident DST. The DSTs are built with analytical and visual capabilities to assess and report condition of the transportation network as well as facilitate practitioner’s need in identifying problems and
prioritizing links for improvements. Due to the nature of analytical needs and related decisions, it is recommended that DSTs developed and discussed in this report be implemented at regional or local level.
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CHAPTER 1: INTRODUCTION

Traffic congestion, in general, reduces the capacity of the roadway and makes the traffic condition unstable. Four-two percent of America’s urban freeways are congested, costing the economy an estimated $101 billion in wasted time and fuel annually (ASCE, 2014). Congestion due to regular commute traffic during morning and evening peak hours is referred to as recurring congestion. It is generally measured in terms of travel time, travel time per mile, travel delay, variation in travel time or volume-to-capacity ratio, and used in long-range transportation planning decisions and project prioritization processes.

One of the major keys to reducing travel time and congestion is regular analysis of traffic flow on major traffic corridors. In conducting the analysis, performance measures are required to evaluate the consistency, dependability and reliability of the roadway for the travelling public. These metrics also help quantify intensity, duration and extent of congestion to develop performance-based congestion management plans.

Incidents during the peak hours further deteriorate operational performance on roads (lead to reduced speed and lessen freedom to maneuver). Traffic congestion due to crashes, inclement weather conditions, mechanical breakdown of vehicles, construction zones and special events is referred to as non-recurring congestion. The effect of an incident on travel time and delay varies based on the type of incident (fatal, severe injury, minor injury or PDO crash or other type of incidents), geometric conditions (number of lanes, divided or undivided road, etc.), existing traffic conditions (peak versus off-peak), the number of lanes closed, and the duration for which the segment is closed.

Commuter’s reaction to traffic congestion and their acceptable norms tend to vary by the time-of-the-day (peak hour versus off-peak hour) and spatial location (downtown / uptown, urban, suburban and rural areas). As congestion increases, reliability, defined as consistency or dependability in travel times (FHWA, 2012), of travel becomes an increasingly important attribute for users of transportation network. A 1997 survey showed that travel time reliability is one of the most important factor for route choice, making it either the most or second most important reason for choosing primary commute routes (Abdelwahab and Abdel-Aty, 2001). Route-choice laboratory experiments and computer simulations conducted by Avineri and Prashker (2005) indicate that the higher the variance in travel time, the lower is travelers’ sensitivity to travel time differences. In another study, results from preference data collected in Barcelona, Spain showed that travel time reliability is valued on average 2.4 times more than travel time savings (Asensio and Matas, 2008). A large proportion of the unreliability experienced by passengers can be attributed to incident related disruptions (Uniman et al., 2010).

1.1. Need for Decision Support Tools (DSTs)

There has been a paradigm shift in focus from intersection-level to corridor-level analysis and performance measures. Travel time reliability (or index or variability) is considered the most viable performance measure though agencies currently use volume-to-capacity ratio for ranking and prioritization of projects. The possibility of capturing dynamic and continuous travel time and/or speed data by responsible governing agencies or obtaining it from private sources such as INRIX, TomTom, HERE, etc. opens many pragmatic avenues to assess reliability of transportation network and would be an added asset. Several states have Strategic Transportation Planning Offices working to define thresholds (similar to level-of-service criteria) that could be
used for ranking and prioritization of corridor or regional improvement projects based on travel time reliability.

The remotely collected data from private data sources need to be archived, processed, integrated, analyzed, monitored and reported to assess reliability of transportation system through improved transportation planning methodologies. Innovative methods and usable applications with decision support tools (DSTs) will not only add value and enhance business practices adopted by state and local agencies but will also help address congestion-related transportation challenges. These DSTs are critical to develop performance-based congestion management plans and to assist planners and engineers in their day-to-day activities (mobility and safety improvements at link- or corridor-level). Questions such as what is the duration of congestion or if the link is unreliable all the time or only during selected hours of the week plagues practitioners. DSTs to visually examine link performance would help find answers to these questions.

The variation in travel time due to incidents varies by spatial location (as response times vary for downtown/uptown, urban, suburban and rural areas). It is relatively greater during off-peak hours than during peak hours. Fatal and severe injury crashes are relatively high in number during these off-peak hours (could be attributed to low traffic volume and ability to travel at higher speeds apart from other reasons). Under uncertain conditions that lead to non-recurring congestion, commuters are known to exhibit different behaviors such as risk aversion, risk neutrality and risk seeking (Yin and Idea, 2001). There are no widely accepted or commonly used measures or DSTs to assess the possible effect of non-recurring congestion on variation in travel time or traffic delay.

Congestion on a link, in particular due to an incident, could result in travel time variation on upstream or both upstream and downstream links (or vice versa) depending on whether a facility is a divided or undivided roadway. It also depends on traffic conditions and time-of-the-day. Initially after an incident, the effect of an incident on travel time variation decreases as the distance from the subject link increases. This variation could decrease at the incident location but may increase away from the location over time (queue building and dissipation patterns). Mapping and DSTs offer the potential to understand and visualize the effects both spatially and temporally, and manage the transportation network (in particular, to divert traffic on upstream and downstream links during recurring and non-recurring congestion times; re-routing through variable message signs or broadcast media). However, there are no DSTs to examine how the affects vary over time and space from the location of the incident.

Overall, there is a need for DSTs that can assist practitioners find answers to questions such as the following.

1. How does performance of links vary spatially, by the time-of-the-day, day-of-the-week, and year?
2. How could one identify unreliable links on a selected corridor in the transportation network?
3. What are the top “N” congested (unreliable) links in the transportation network for prioritization and allocation of limited resources?
4. How does the reliability of link vary by time-of-the-day and day-of-the-week during a year?
5. What is the effect of an incident on nearby links? How far does it extend and how does it vary over time?
Answers to the above questions not only help understand the effect of recurring and non-recurring congestion components on travel time and traffic delays (to identify appropriate solutions and mitigation strategies) but also serve as a platform to incorporate safety into transportation planning processes.

1.2. Project Objectives
The objectives of this report, therefore, are:

- to develop a framework for travel time data storage, retrieval, analysis and reporting to improve mobility and safety,
- to develop and implement interactive DSTs with analytical and visual capabilities to assess and report the condition of transportation network and facilitate practitioner’s need in identifying and prioritizing transportation projects, and,
- to develop an interactive DST to evaluate the effect of an incident on surrounding links and facilitate practitioners need to manage transportation network by diverting or re-routing traffic through the use variable massage signs.

1.3. Organization of the Report
The remainder of this report is organized as follows. Hardware and software requirements for data processing, development of DSTs, and hosting the DSTs for access by practitioners are discussed in Chapter 2. A discussion on data processing is presented in Chapter 3. A framework of system functionality for implementation is discussed in Chapter 4. The description of how practitioners can use the DSTs to perform various analyses is presented in Chapter 5. Conclusions and directions for future research are presented in Chapter 6.
CHAPTER 2: HARDWARE AND SOFTWARE REQUIREMENTS

The configuration of the system (hardware and software) plays a major role in the ease of data processing, robustness and use of DSTs. This section briefly describes the hardware and software requirements from developer and user perspective for developing and using DSTs similar to those discussed in this report.

2.1. Developer Perspective
The hardware and software requirements for data processing and development of DSTs are described in this section.

2.1.1. Hardware Requirements
The basic system configuration used for the development of the DSTs is as follows.

- Windows Server 2012 Operating System
- System Type: 64-bit Operating System, x64-based Processor
- 3.10GHz Processor
- 8 GB 2R×8 RAM
- 4 TB 3G SATA 7.2k 3.5in MDL Hard Drive
- Raid technology & smart array controller

The system configuration was selected based on the total links in the transportation network, number of years of data, its aggregation size (1-minute, 5-minute, 10-minute, etc.), and number of DSTs being developed. Higher configuration systems may be required for faster and robust functioning of the DSTs when larger cities or more detailed data are being considered.

2.1.2. Software Requirements
Most of the software for data processing and development of DSTs require minimum hardware configuration. Based on the expertise of the developer various software are available for processing large datasets and developing DSTs. The software used for data processing and development of the DSTs in this project are summarized as follows.

- Microsoft SQL Server 2014
- Microsoft Visual Studio 2012
- SQL Server Reporting Services 2014
- Microsoft Office Suite
- Apache Tomcat 7.0
- Eclipse 1.4.0

2.2. User’s Perspective
For a user to access the DSTs, a system with very minimum configuration where Java is installed to run Java based applications is required. For best results, it is recommended using Firefox or Chrome as Internet browsers. The output can be stored as Microsoft Excel spreadsheet files, in Adobe Acrobat format or as a web-based table (xml). The user should have Microsoft Office Suite and Adobe Acrobat installed to open any downloaded files.
CHAPTER 3: DATA PROCESSING

DSTs are applications based on data that assist practitioners in making decisions. Programs are written to provide practitioners with specific functions in an easy-to-use package. Visualization techniques are typically adopted, where appropriate, for easy understanding of spatial and temporal variations in travel time based performance measures.

3.1. Raw Data

Data is the backbone for the different DSTs developed as a part of this project. INRIX (INRIX, 2014) travel time data for Charlotte region in the state of North Carolina, for the years 2009 to 2013, was used in the development and illustration of working of the DSTs. The INRIX data was downloaded from RITIS website in a raw unprocessed format. The raw data file has Traffic Message Channel (TMC) code (tmc_code), time-stamp (measurement_tstamp), speed (speed), average speed (average_speed), reference speed (reference_speed), travel time (travel_time_minutes) and score (confidence_score). Each field in the raw data file is briefly described below (INRIX, 2013).

1. Traffic Message Channel (TMC) - defines section identity of the roadway segment.
2. Speed - current estimated space mean speed for the roadway segment in miles per hour.
3. Average speed - historical average mean speed for the roadway segment for that hour-of-the-day and day-of-the-week in miles per hour.
4. Reference speed - calculated “free flow” mean speed for roadway segment in miles per hour. It is the 85th percentile point of the observed speeds on that segment.
5. Travel time - current estimated travel time it takes to traverse the roadway segment in minutes.
6. Score - an indicator of data type (30 indicates real-time data; 20 indicates real-time data across multiple segments; 10 indicates historical data).

The data requested has average travel times for every 1-minute for the entire 5 year period. Figure 1 shows the snapshot of the raw data downloaded from INRIX.
3.2. Processed Data and Final Database

The data was then processed to remove null values and other miscalculated values. The data processing and mining was performed using Microsoft SQL Server 2012. A data dictionary was developed to explain all data elements in the processed database.

As the objective of the project was to establish and develop DSTs that provide visual information of travel time and other performance measures of a given link, data tools and query applications were developed to compute various travel time measures such as 1) minimum travel time, 2) average travel time, 3) maximum travel time, 4) median travel time, 5) 85th percentile travel time, and 7) 95th percentile travel time (also referred to as planning time - PT). Several factors such as time-of-the-day, day-of-the-week, all weekdays of a year, all weekends of a year and all days were considered in evaluating these travel time measures. This database was used to compute performance measures that helps evaluate the link-level reliability. The reliability measures that were computed include buffer time (BT), buffer time index (BTI), planning time index (PTI), travel time index (TTI), λ skew and λ variance. Each of these measures are described briefly next.

1) Buffer time (BT): It is the difference of 95th percentile travel time and the average travel time. It represents the required additional time for an on time performance (Lomax et al., 2004).

\[
\text{Buffer time (BT)} = TT_{95} - TT_{Ave} \quad \text{Eq. 3.1}
\]
2) Buffer time index (BTI): It is the ratio of difference of 95th percentile travel time and the average travel time to the average travel time (Lomax et al., 2004).

\[
\text{Buffer time index (BTI)} = \frac{TT_{95} - TT_{Avg}}{TT_{Avg}} \times 100
\]

Eq. 3.2

3) Planning time index (PTI): It is the ratio of 95th percentile travel time and the free flow travel time or 15th percentile time (Sisiopiku and Islam, 2012).

\[
\text{Planning time index (PTI)} = \frac{TT_{95}}{TT_{free\ flow}}
\]

Eq. 3.3

4) Travel time index (TTI): It is the ratio of average travel time to the free flow travel time (Lyman and Bertini, 2008).

\[
\text{Travel time index (TTI)} = \frac{TT_{Ave}}{TT_{free\ flow}}
\]

Eq. 3.4

5) \( \lambda \) skew: It is the ratio of difference in 90th percentile and 50th percentile travel times to the differences in 50th percentile and 10th percentile travel times (van Lint et al., 2004).

\[
\lambda \text{ skew} = \frac{TT_{90} - TT_{50}}{TT_{50} - TT_{10}}
\]

Eq. 3.5

6) \( \lambda \) variance: It is the ratio of difference between 90th percentile and 10th percentile to the 50th percentile travel time (Bogers et al., 2008).

\[
\lambda \text{ variance} = \frac{TT_{90} - TT_{10}}{TT_{50}}
\]

Eq. 3.6

The computed reliability measures were added to the application database so that it could be accessed by the various DSTs developed as a part of this project.

The final database has travel time and reliability measures for each link based on time-of-the-day and day-of-the-week. The database also has route or street name and TMC codes with “from-to” coordinates. Figure 2 shows the snapshot of the processed data using Microsoft SQL Server.

3.3. Data Size

Table 1 shows the number of rows and raw data size downloaded and size after processing the data for the development of DSTs. The data size increases with an increase in the number of TMC’s considered and data aggregation intervals (aggregated to 15-minutes, 30-minutes, or 1-hour etc.).

Table 2 shows the comparison of reliability measures computed by aggregating 1-minute interval travel time to 30-minutes and 1-hour for 4-links on I-85 corridor. From Table 2, the minimum travel times, average travel times and 85th percentile travel times computed for two 30-minute intervals (05:00 PM - 05:30 PM and 5:30 PM - 06:00 PM) and for 1-hour interval (05:00 PM - 06:00 PM) do not vary and are almost equal. However, 95th percentile travel times and reliability measures (BTI, PTI, TTI and \( \lambda \) variance) are observed to be different. Therefore, at a
macro-level, travel times during an hour, average travel times and free-flow travel times do not vary and are same as the aggregate for that particular hour. However, the reliability of the links varies for every smaller interval and is different when compared to the reliability computed as an aggregate for that hour.

High processing times and low system performance was observed because of large data size in evaluating travel time measures for the transportation network at 15-minute and 30-minute intervals. Therefore, travel times measures are computed by aggregating 1-minute travel time data to every 1-hour (time-of-the-day) in this study. However, in case of the DST to evaluate the effect of an incident, a 15-minute interval data is required. Therefore, the raw data was also consolidated to every 15-minute interval along with one-hour intervals that was used for developing other DSTs.

![Figure 2: Snapshot of Processed Data using Microsoft SQL Server](image)

<table>
<thead>
<tr>
<th>Year</th>
<th>#TMCs</th>
<th># of Rows (1-minute)</th>
<th># of Rows (1-hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>296</td>
<td>155,577,600</td>
<td>78,624</td>
</tr>
<tr>
<td>2010</td>
<td>311</td>
<td>163,461,600</td>
<td>86,184</td>
</tr>
<tr>
<td>2011</td>
<td>1,972</td>
<td>1,036,483,200</td>
<td>389,256</td>
</tr>
<tr>
<td>2012</td>
<td>1,705</td>
<td>896,148,000</td>
<td>320,712</td>
</tr>
<tr>
<td>2013</td>
<td>2,049</td>
<td>1,076,954,400</td>
<td>344,232</td>
</tr>
</tbody>
</table>

2009-2012 raw data size is equal to 130GB. 2013 raw data size is equal to 65GB.
Table 2: Comparison of Travel Time Measures Computed at 30-minute and 1-hour Intervals

<table>
<thead>
<tr>
<th>TMC Code</th>
<th>Time-of-the-Day</th>
<th>Travel Times</th>
<th>BTI</th>
<th>PTI</th>
<th>TTI</th>
<th>Gamma-Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>125-04642</td>
<td>05:00PM-05:30PM</td>
<td>0.31</td>
<td>0.37</td>
<td>0.58</td>
<td>0.34</td>
<td>0.36</td>
</tr>
<tr>
<td>125-04642</td>
<td>05:30PM-06:00PM</td>
<td>0.32</td>
<td>0.39</td>
<td>0.63</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>125-04643</td>
<td>05:00PM-05:30PM</td>
<td>0.59</td>
<td>0.71</td>
<td>1.08</td>
<td>0.66</td>
<td>0.70</td>
</tr>
<tr>
<td>125-04643</td>
<td>05:30PM-06:00PM</td>
<td>0.62</td>
<td>0.74</td>
<td>1.19</td>
<td>0.68</td>
<td>0.71</td>
</tr>
<tr>
<td>125-04644</td>
<td>05:00PM-05:30PM</td>
<td>0.72</td>
<td>0.89</td>
<td>7.71</td>
<td>0.76</td>
<td>0.79</td>
</tr>
<tr>
<td>125-04644</td>
<td>05:30PM-06:00PM</td>
<td>0.72</td>
<td>0.91</td>
<td>7.71</td>
<td>0.77</td>
<td>0.81</td>
</tr>
<tr>
<td>125-04645</td>
<td>05:00PM-05:30PM</td>
<td>0.79</td>
<td>1.09</td>
<td>9.90</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>125-04645</td>
<td>05:30PM-06:00PM</td>
<td>0.79</td>
<td>1.17</td>
<td>11.88</td>
<td>0.86</td>
<td>0.91</td>
</tr>
<tr>
<td>125-04645</td>
<td>05:00PM-06:00PM</td>
<td>0.79</td>
<td>1.13</td>
<td>11.88</td>
<td>0.85</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Note 1: Min, Avg, Max, 15th Percentile, 50th Percentile, 85th Percentile, and 95th Percentile are minimum, average, maximum, 15th percentile, 50th percentile, 85th percentile, and 95th percentile (or PT) travel times, respectively.

Note 2: BTI, PTI and TTI are buffer time index, planning time index, and travel time index.

Note 3: Gamma-Var is $\lambda$ variance.
CHAPTER 4: SYSTEM FUNCTIONALITY AND IMPLEMENTATION

To facilitate easy access and use of DSTs, this project relied on web-based data driven applications. The practitioner could use their computer or mobile device with connection to the internet and an internet browser to typically access the DSTs. The basic system functionality of the DSTs for implementation is outlined using figures 3 and 4. Figure 3 outlines the functionality of geospatial based DSTs, while Figure 4 outlines the functionality of non-geospatial based DSTs. The functionality of the DSTs involves the following steps.

1. The practitioner opens a web browser to access the DST and send a request with selected input parameters.
2. The web browser then passes on the request to a server hosted by the developer of the DST.
3. On receiving the request, the server reads the input parameters and then accesses the database developed to retrieve the data based on the selected input parameters.
4. In case of geospatial based DST (Figure 3), it sends the output from the previous step to MapQuest Server and generates a map. Connection to MapQuest Server is not needed in case of the non-geospatial based DST.
5. The web server receives the final output from MapQuest or generates the final output in case of non-geospatial based DST and sends it to the web browser.
6. The practitioner’s web browser then displays the map, chart, or table and also supports other necessary interactions (example, change input parameter to re-generate outputs).

**Figure 3: Flowchart Illustrating Working of Geospatial based DST**

**Figure 4: Flowchart Illustrating Working of Non-geospatial based DST**

A detailed description of architecture for each of the four DSTs developed is described in the following sections.

**4.1. Reliability Map DST**

The reliability map DST uses MapQuest map to spatially represent the selected performance measure over the transportation network for the study area. This DST has been designed in a way
that is easy for the practitioner to use, understand and interact with the map. This DST retrieves data from the database and represents it over the map based on the selected input parameters. Figure 5 shows the flowchart describing the architecture of reliability mapping DST at system perspective.

The year, day-of-the-week, time-of-the day, factor (reliability performance measure) and filter (all links in the transportation network, selected route in the transportation network through the use of a dropdown menu or top ‘N’ unreliable links) are provided as input through the web interface. The data relevant to the selected input parameters are then retrieved from the database. The data retrieved will have all the travel time and performance measure information for each TMC code along with their respective “from-to” coordinates. This “from-to” coordinate information is used to spatially represent the output (performance measure) based on the selected input parameters on a MapQuest map. Each link (TMC code) is color coded based on their performance measure values (plus or minus 1 and 2 standard deviations from average) and is represented in the form of a legend. The information related to each TMC code is stored on the tooltip which is displayed with a red marker that is placed on each TMC code. A single click on the red marker will pop-up information on the tooltip with all the information related to the respective TMC code. To download the data displayed on the map, a click on the download button at the bottom of the page will save the data retrieved from the database into a Microsoft Excel spreadsheet. Also, a link is provided on the tooltip to view the “HeatChart”. On clicking it, the visualization of performance measure by day-of-the-week and time-of-the-day based on data for the entire year for the selected TMC code is displayed.

4.2. “HeatChart” Visualization DST
The “HeatChart” visualization DST shows the selected reliability performance measure of a link as a heat chart with time-of-the-day and day-of-the-week data spanning an entire year. It can be accessed by either using the “Visualization” tab or through the tooltip information for a selected link (as mentioned in the previous section). Through visual inspection, one can identify the most unreliable day-of-the-week and time-of-the-day in a year for the selected link. The heat chart also provides an assessment of the “duration of congestion or lack of reliability”. Figure 6 shows the flowchart describing the architecture of “HeatChart” visualization DST at system perspective.

The year, link (TMC code), and the factor (reliability performance measure) are provided as input parameters through the web interface. The DST checks for the validity of the input parameters. If valid, the data relevant to the selected input parameters will then be retrieved from the database. The data retrieved will have all the travel time and performance measure information for the selected TMC code. This information is represented in the form of “HeatChart”.

The heat chart consists of seven concentric circles each representing a day-of-the-week. These concentric circles are further divided into 24 parts radially from the center, each representing time-of-the-day (hour). Each block of the heat chart is color coded based on data for the entire year. The higher reliability values are represented with lighter color, while dark color blocks indicate highly unreliable times of the day during a day-of-the-week. When the mouse is hovered over a block (representing a particular time-of-the-day and day-of-the-week) on the heat chart, the respective reliability performance measure for the hovered block is displayed.
Figure 5: Architecture of Reliability Mapping DST from System Perspective
4.3. Reports DST
The reports DST uses SQL Server’s Reporting Services (SSRS) to generate a report based on selected options such as year, TMC code, time-of-the-day and day-of-the-week. It can be accessed by using the “Reports” tab of the application. Figure 7 shows the flowchart describing the architecture of reports DST at system perspective.

The year, day-of-the-week, time-of-the day and the TMC code are provided as input parameters through the web interface. The SSRS retrieves all the relevant data from the database. The DST is built such that it can retrieve data even for multiple input parameters. The data
retrieved is then represented in the form of a report. The right side of each column header will have an up and down arrows to sort the data retrieved. The DST also provides an option to save the output in the selected format (xml, pdf, or xlsx).

4.4. Effect of Incident DST

The effect of incident DST shows the effect on an incident (crash) on the surrounding links of the transportation network. It uses MapQuest map to spatially represent the effect of an incident over time and space. Figure 8 shows the flowchart describing the architecture of effect of incident DST at system perspective.

The severity of an incident (crash information in the database), day-of-the-week and time-of-the-day are provided as input parameters through the web interface. Based on the input parameters, this DST retrieves all the roadway links with selected crash severity. The parameters such as road name and the radius from the incident (1-mile, 2-mile, 3-mile, 4-mile and 5-mile) are then selected from the dropdown menu. The location of the incident will be extracted from the incident database and is shown on the MapQuest map as a marker. A single mouse click on the marker opens the tooltip with the information related to the incident. Also, a link is provided on the tooltip to show the effect of the incident on the surrounding links within the selected radius. On clicking it, the DST retrieves average travel time variations for every 15-minute intervals on all the links around the given radius from the location of the incident for 30 minutes before the time of incident to 2 hours after the time of incident.
The travel time variation on a link is computed as the percentage increase in the travel time during the incident with respect to average travel time on the same link without an incident (same time-of-the-day and day-of-the-week). In the data retrieved, each link in the transportation network is uniquely identified by its respective TMC code. It then plots each TMC code on the MapQuest using “from-to” coordinates. Each link is color coded based on the percentage...
variation of travel times. A red marker is placed on each TMC code where all the related information for the TMC code is stored.

By default, the DST shows the travel time variation of nearby links in the transportation network at a time 15-minutes before the incident. The DST is provided with clickable buttons to navigate through previous and next 15-minute intervals to visualize the effect of incident on the nearby links in the transportation network (over time) for the next two hours. Figure 9 illustrates the working of the effect of incident DST.

Figure 9: Data Processing and Computing Travel Time Variation Due to an Incident
CHAPTER 5: USER INTERFACE

Four interactive DSTs were developed as a part of this project. They are: 1) Reliability Mapping DST, 2) “HeatChart” Visualization DST, 3) Reports DST, and, 4) Effect of Incident DST. The DSTs are built with analytical and visual capabilities to assess and report condition of the transportation network as well as facilitate practitioner’s need in identifying and prioritizing links for improvements.

The following sections describe how the DSTs developed can answer each of the following questions.

1. How does performance of links vary spatially, by the time-of-the-day, day-of-the-week, and year?
2. How could one identify unreliable links on a selected corridor in the transportation network?
3. What are the top “N” congested (unreliable) links in the transportation network for prioritization and allocation of limited resources?
4. How does the reliability of link vary by time-of-the-day and day-of-the-week during a year?
5. What is the effect of an incident on the surrounding links? How far does it extend and how does it vary over time?

5.1. Reliability Mapping DST
This DST has the ability to spatially depict reliability of selected link or links on a map. It can also be used to identify top ‘N’ unreliable links or sections (visually) in the transportation system. Figure 10 describes the architecture of the reliability mapping DST from user perspective. Some of the basic features of the reliability mapping DST are the ability 1) to zoom in and zoom out of the map to visualize the information at macroscopic and microscopic levels, 2) to zoom in and view information on the tooltip provided for each link in the map, and, 3) to query data and visualize data based on the search filters such as year, day-of-the-week, time-of-the-day, and reliability performance measure.

![Figure 10: Architecture of Reliability Mapping DST from User Perspective](image-url)
5.1.1. Assessing the Condition of Transportation Network

Delays in the transportation system are caused because of insufficient capacity in the system to handle the demand. These delays could be highly fluctuating (inconsistent) based on time-of-the-day and day-of-the-week, especially on highways and freeways. It is very important for planners to evaluate reliability of each link in the transportation network and assess the condition of transportation system. The reliability mapping DST developed helps assess the condition of transportation system through spatial representation of reliability of each link by time-of-the-day and day-of-the-week for each selected year. Spatial representation of reliability of the transportation network helps planners easily compare the performance of two links and identify the unreliable segments in the transportation network during the selected time-of-the-day and day-of-the-week. In case of any need to further analyze the data based on the selected input parameters, practitioners can download the processed data for all links with all performance measures (not just the selected factor or performance measure) into a Microsoft Excel spreadsheet. The following steps describe how to use the reliability mapping DST to assess the condition of transportation network.

**Step 1:** Select year, day-of-the-week, time-of-the-day and the factor / performance measure (Planning Time Index - PTI, Buffer Time Index - BTI, Travel Time Index - TTI, $\lambda$ variance - Gamma Var, or Average Travel Time - Travel Time) as shown in the Figure 11.

![Figure 11: Snapshot of Reliability Mapping DST - Selecting the Input Parameters](image)

**Step 2:** Select “All Links” to spatially represent reliability of all the links in the transportation network.

**Step 3:** Submit request to view link level reliability of the entire transportation network as shown in Figure 12. From Figure 12, based on the color one can easily identify the most unreliable and reliable links in the entire transportation network for the selected time-of-the-day and day-of-the-week. In the figure, the links with black and red color are highly unreliable, whereas links that are color coded with green are reliable links.
Step 4: Click on the “yellow marker”, which is located at the beginning of each link (TMC code) on the map. A pop-up will appear with details of the selected link (as can be seen in Figure 13).

Step 5: Click on the “Download All the Information into Excel” link which is located below the map to download all the data related to the selected parameters into a Microsoft Excel spreadsheet as shown in the Figure 14.
5.1.2. Assessing the Condition of a Selected Corridor

Planners and engineers quite often are interested in evaluating the performance of a particular corridor rather than the entire transportation network. The reliability mapping DST developed also helps evaluate the performance of a selected corridor and identify unreliable links along the corridor. In case of any need to further analyze the data related to the corridor and selected input parameters, practitioners can download the processed data with all performance measures into a Microsoft Excel spreadsheet. The following steps describe how to use the reliability mapping DST to assess the condition of a corridor.

**Step 1:** Select year, day-of-the-week, time-of-the-day and the factor / performance measure (Planning Time Index - PTI, Buffer Time Index - BTI, Travel Time Index - TTI, $\lambda$ variance - Gamma Var, and Average Travel Time – Travel Time) as shown in the Figure 11.

**Step 2:** Select a particular roadway (say, I-85) from the dropdown list to spatially represent its performance.

**Step 3:** Submit the request to view performance measure of a particular roadway as shown in Figure 15. From Figure 15, one can easily identify the most unreliable links (color coded with black) on I-85 corridor and suggest necessary improvements. Similarly, as mentioned in the legend, the green color links tends to be more reliable than any other links on the I-85 corridor.
Figure 15: Snapshot of Reliability Mapping DST - Displaying Performance Measure for a Selected Corridor (I-85)

**Step 4:** Click on the “yellow marker”, which is located at the beginning of each link (TMC code) on the map. A pop-up will appear with details of the selected link (similar to one in Figure 13).

**Step 5:** Click on the “Download All the Information into Excel” link which is located below the map to download all the data related to the selected input parameters into a Microsoft Excel spreadsheet as shown in the Figure 14.

5.1.3. Identifying Top “N” Unreliable Links in the Transportation Network

A delay due to a single highly unreliable link in the transportation network can propagate to the nearby links in the transportation network. Identifying the top unreliable links in the transportation network will help reduce the overall delays and also help agencies and practitioners to prioritize and allocate limited available transportation dollars. The reliability mapping DST helps identify top “N” (10, 25 or 50) unreliable links in the transportation network for the selected year, time-of-the-day and day-of-the-week. In case of any need to further analyze the data related to the top “N” unreliable links in the transportation network, practitioners can download the processed data for all unreliable links with all performance measures for the selected criteria into a Microsoft Excel spreadsheet. The following steps describe how to use the reliability mapping DST to identify top “N” unreliable links in the transportation network.

**Step 1:** Select year, day-of-the-week, time-of-the-day and the factor / performance measure (Planning Time Index - PTI, Buffer Time Index - BTI, Travel Time Index - TTI, λ variance - Gamma Var , and Average Travel Time – Travel Time) as shown in the Figure 11.

**Step 2:** Select top ’10’, ’25’ or ‘50’ unreliable links from the options provided.

**Step 3:** Submit request to view top “N” unreliable links (say, 50) in the transportation network as shown in Figure 16. The figure shows all the top 50 unreliable links in the transportation network...
during Tuesdays from 4 PM - 5 PM making it very easy to identify links or section to prioritize resources and implement transportation improvement projects.

Figure 16: Snapshot of Reliability Mapping DST - Top ‘50’ Unreliable Links

**Step 4:** Click on the “yellow marker”, which is located at the beginning of each link (TMC code) on the map. A pop-up will appear with details of the selected link (similar to one in Figure 13).

**Step 5:** Click on the “Download All the Information into Excel” link which is located below the map to download all the data related to the selected input parameters into a Microsoft Excel spreadsheet as shown in the Figure 14.

### 5.2. “HeatChart” Visualization DST

This DST summarizes performance measure of the selected link, for all days of week and times of day using data for the entire year, as a circular heat chart. The heat chart allows the end user to identify the most unreliable day-of-the-week and time-of-the-day in a year for the TMC code. It also provides a visual summary of total unreliability duration for a given link for every day-of-the-week. Figure 17 describes the architecture of the “HeatChart” visualization DST from user perspective.

**Figure 17: Architecture of “HeatChart” Visualization DST from User Perspective**

#### 5.2.1. Assessing the Performance of a Link by Time-of-the-Day and Day-of-the-Week

The previous section described how to identify unreliable links in the transportation network or on a corridor and to identify top “N” unreliable links for a selected time-of-the-day and day-of-the-week.
the-week. However, it is very important to evaluate how the performance measure of the link varies by time-of-the-day and day-of-the-week during a year i.e., to evaluate if the link is unreliable only during peak hours or to assess during which times-of-the-day and day-of-the-week’s the link is unreliable. The following steps describe how to use the “HeatChart” visualization DST to assess the performance of a link by time-of-the-day and day-of-the-week during a year.

**Step 1:** Select the year, TMC code and the factor / performance measure (Planning Time Index - PTI, Buffer Time Index - BTI, Travel Time Index - TTI, λ variance - Gamma Var, and Average Travel Time – Travel Time) as shown in Figure 18.

![Figure 18: Snapshot of “HeatChart” Visualization DST - Selecting the Input Parameters](image)

**Step 2:** Submit request to view the heat chart for the link as shown in Figure 19. The figure shows that the given link is unreliable during weekdays continuously from morning 8 AM till 6 PM in the evening. Similarly, the duration of unreliability for any other link in the transportation network can be accessed from the developed heat chart based on selected input parameters.
5.3. Reports DST

This DST allows the practitioner to download all the relevant travel times and reliability performance measures data for multiple years, TMC codes and days of the week into a Microsoft Excel spreadsheet. The data downloaded can be used for any further analysis or inclusion as part of project reports. Figure 20 describes the architecture of the reports DST from user perspective.

5.3.1. Retrieve and Report Performance Measures Data

Currently, most of the transportation agencies use travel time estimates from Bureau of Public Roads equation or other sources in travel demand modeling process due to the unavailability of travel time performance measures data for most of the links in the transportation network. The availability of performance measures data by time-of-the-day and day-of-the-week for the transportation network opens avenues to use this information to calibrate and improve accuracy of travel demand models. The reports DST developed can help download the performance measures data for selected year or multiple years, selected time-of-the-day (peak hours) or multiple times of the day and for select day-of-the-week or multiple days of the week, for all the links in the transportation network or selected links. The following steps describe how to use the reports DST to download the performance measures by time-of-the-day and day-of-the-week.
Step 1: Select the year(s), day-of-the-week and TMC codes as shown in Figure 21.

![Figure 21: Snapshot of Reports DST - Selecting the Input Parameters](image)

Step 2: Submit request to view the relevant travel times and performance measures data as shown in Figure 22.

![Figure 22: Snapshot of Output of Reports DST](image)

Step 3: Click on the download button to download the data in required format as shown in Figure 23.
5.4. Effect of Incident DST

This DST shows an incident and its effect on nearby links based on percentage difference in link travel times. The travel time variation can be observed over space and time. Figure 24 describes the architecture of the effect of incident DST from user perspective. All the basic features of the reliability mapping DST such as zoom in/out feature, information on tooltip and search filters were also incorporated for the effect of incident DST.

5.4.1. Evaluate the Effect of Incident on Surrounding Links

Most of the non-recurring congestion in the transportation system is due to incidents. The effect of an incident on nearby links in the transportation network could vary by the time at which the incident occurred, its severity, spatial location and network characteristics. To identify effective
countermeasures (detouring, provide information through dynamic message signs, or media), a thorough understanding of the effect of an incident on the transportation network is essential. The effect of incident DST developed helps evaluate the effect of an incident by severity, time-of-the-day and day-of-the-week on nearby links. It is computed as the percentage increase in the travel time due to an incident when compared to the travel time without incident (same time-of-the-day and day-of-the-week). The output from the DST quantifies and spatially represents the effect of an incident (in terms of delays caused due to an incident). This information helps planners effectively make decisions and provide users with most reliable information regarding the delays due to an incident. It will also help identify all the nearby links in the transportation network (radius from the incident) that are affected due to the incident. The DST quantifies delays for every 15-minute interval, 30 minutes before the incident to 2 hours after the incident. This will help evaluate the total incident clearance time for an incident based on its severity, incident time and day-of-the-week. The following steps describe how to use the effect of incident DST to assess the condition of transportation network.

**Step 1:** Select severity of crash, day-of-the-week, time-of-the-day, street name and radius around the crash as shown in Figure 25. To show all the crashes of a given severity, once the crash severity is selected, by selecting “All Days” in the day-of-the-week dropdown, the tools shows all times of the day at which the selected severity of crashes have occurred. By selecting a particular time-of-the-day and street name, all crashes related to the selected severity that have occurred on that street during the selected time-of-the-day from 2009 to 2013 will be shown spatially on the map. This way the tool developed shows all the crashes by severity that have occurred during 2009-2013 on the selected street. However, one has to select time-of-the-day at which the crashes have occurred (shown in the dropdown of time-of-the-day option) since the effect of a crash on the nearby links vary based on the time at which the crash has occurred.

![Figure 25: Snapshot of Effect of Incident DST - Selecting the Input Parameters](image)

**Step 2:** Submit request to view the incident location spatially as shown in Figure 26.
Step 3: To view all the information about the selected incident, click on the incident location. A tooltip with all the information relevant to the incident will be shown (Figure 26).

![Figure 26: Snapshot of Incident Location and Tooltip Information](image)

Step 4: Click on the “View Effect of Incident” link provided on the tooltip to examine the effect of crash on nearby links within the selected radius. The DST then shows the percentage difference in travel time on links within the selected radius at the time of crash. The percent difference in travel time is based on travel time during the period with crash and travel time during the same day-of-the-week / time-of-the-day without crash. Figure 27 shows the effect of an incident on nearby links at the time of incident.

![Figure 27: Snapshot of Effect of Incident at the Time of Incident](image)

Step 5: The Prev 15-min and Next 15-min buttons will help the end user observe the percentage difference in travel time similarly over the 2-hour period. Figure 28 shows the effect of incident
30 minutes after the time of crash. From Figure 27 and Figure 28, 30 minutes after the crash, the travel time of the adjacent links to crash location increased from 20% to 40%. Similarly, travel time variations on the surrounding links and their extent can be easily evaluated for any given crash using the DST developed.

Figure 28: Snapshot of Effect of Incident 30 Minutes after the Time of Incident
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This project report presents four interactive DSTs with analytical and visual capabilities to assist practitioners make decisions pertaining to transportation system. They are: 1) Reliability Mapping DST, 2) “HeatChart” Visualization DST, 3) Reports DST, and 4) Effect of Incident DST. These DSTs help practitioners perform the following.

1) Assess the condition of the transportation network based on various performance measures
2) Assess the condition of a given corridor in the transportation network
3) Identify top “N” unreliable links in the transportation network
4) Assess the performance of a link by time-of-the-day and day-of-the-week during a year
5) Retrieve and report performance measures data for any further analysis
6) Evaluate the effect of incidents on the surrounding links in the transportation network

Each DST performs a dedicated function to easily navigate through different features of the overall application. The two geospatial based DSTs (reliability mapping DST and effect of incident DST) use MapQuest map to spatially represent the selected performance measure. The “HeatChart” visualization DST generates a heat chart, while the reports DST retrieves data and generates output through the SQL Server Reporting Services.

The geospatial based reliability mapping DST developed has seamless transition from macroscopic level (transportation network-level) to details at a microscopic level (link-level). The macroscopic level details help assist decision-makers and practitioners in transportation planning and development of performance-based congestion management plans. The microscopic level details help engineers in identifying site-specific solutions and improvements. This DST also helps identify top ‘N’ (10, 25 and 50) unreliable links in the transportation network for prioritization and allocation of resources.

The “HeatChart” visualization DST helps visualize performance measure of the selected link by time-of-the-day and day-of-the-week during a year. This DST helps identify critical unreliable time periods by day-of-the-week in that year. The practitioner will be able to visualize the intensity and duration of performance measure by time-of-the-day to plan and improve mobility as well as safety.

The reports DST retrieves, disseminates and reports travel times and reliability measures by time-of-the-day and day-of-the-week for selected years. The practitioners can generate reports and store them in their local storage devices to use it for any other purpose of their interest. For example, the outputs from the DSTs developed can be used in the travel demand modeling process to better calibrate and enhance accuracy of the outputs generated through the process.

The effect of incident DST shows the effect of an incident over time and space. This DST helps identify critical links to divert traffic due to an incident - incident management and re-routing traffic.

Overall, the DSTs developed and implemented such as those as a part of this project are expected to add value and enhance business practices adopted by state and local agencies. These DSTs also assist transportation network users make reliable route, mode and departure time decisions. Emergency response units can use the information to select reliable paths to provide timely services. FedEx, USPS, UPS, etc. can use the information to avoid unreliable paths and deliver goods on time.
Availability of travel time data for all links (major as well as minor roads) in the transportation network will certainly add value and enhance the DSTs. Also, integrating at a system level with other components such as weather data, traffic counts, event planning, incidents such as mechanical breakdown of vehicles, and construction activities will improve and enhance the effectiveness of DSTs in making transportation related decisions.

Transportation planning, project prioritization and ranking decisions are typically made at regional or local level. Considering the nature of these decisions, it is recommended that DSTs developed and discussed in this report be implemented at regional or local level.
REFERENCES